Vrije Universiteit Brussel

An interdisciplinary study on novelty regulation to produce radical change

- The novelty model: regulation by the self-organization of exaptation and serendipity
- The meta-model: from the multiple features of innovation to Agile-Enterprise Innovation Planning
- Proof-of-concept: educational experiments, participating in a venturing ecosystem and designing a systematic innovation system

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Abstract

This PhD thesis is an interdisciplinary investigation of how the creation of novelty can be regulated. Novelty is a general concept describing the evolutionary emergence of things that did not exist before, while integrating more specific ideas like adaptation, exaptation, creativity, invention and innovation. The controlled production of novelty must construct radically new things out of existing constraints, and thus overcome the conservation law that is inherent in most phenomena. A general solution to this paradox is proposed in the form of an abstract novelty model. It shows how novelty can bootstrap itself by means of a network of feedback loops interacting via a central workspace that mediates between system and environment. This abstract model is then mapped onto four more concrete models, showing how novelty emerges in four different domains: individual cognition, evolution of science and technology, strategic management of organizations, and management of socio-technological innovation. A meta-model then shows how these different applications can be mapped onto each other through a grid of conversion patterns. This suggests two methodologies for implementing the new insights: Carbureted Action Research, which proposes a development path for the phase transition that characterizes the emergence of a socio-technological ecosystem; and the Agile-Enterprise Innovation Planning architecture, which makes such radical innovation more manageable by stimulating the spinning-off of supporting ecosystems. To validate these methodologies, concrete applications in three domains are investigated: an experiment with project-based educational systems, a case study of an open-source software development ecosystem, and a design for an "Interversity", i.e. Internet-based university of the future. The resulting observations provide a proof of concept that the proposed novelty theory is applicable in practice.

Executive summary

This PhD thesis is an interdisciplinary investigation, inspired by evolutionary and cybernetic theories, of how the creation of novelty can be regulated. Novelty is what did not exist before, but emerges into existence. Novelty is an abstract concept that binds together more concrete ideas like creativity, discovery, invention and innovation, while clarifying the differences between natural and artificial evolution.

Natural evolution produces *relative* novelty through *adaptation*. Artificial evolution produces *absolute* novelty through *exaptation*, i.e. the utilization of a structure for a function other than that for which it was developed through environmental selection. Technology is an example of absolute novelty, but so are proteins and feelings. In contrast to the relative novelty that evolves gradually through adaptation, *radical* novelty is the result of a *phase transition* in which a new type of system emerges. Radical and absolute novelties cannot be explained by mere gradual adaptation: they require a mechanism of novelty production.

Models of such a mechanism have been proposed in different domains, including cognition, science and technology studies, and strategic management of innovation. The present work generalizes and synthesizes several of these models in the form of an abstract novelty model. This abstract model is then mapped onto more concrete models in six different application domains: sailing against the wind, knowledge creation, environmental enrichment, strategy management, agile development, and systematic innovation.

The essence of the abstract model is that it shows how the process can overcome the *conservation* law that is inherent in most phenomena, and which basically states that something cannot be created out of nothing. For example, sailing against the wind seems to contradict the law of conservation of momentum, according to which you cannot convert momentum moving in one direction (the one in which the wind blows) to momentum for moving in the opposite direction (the one to which the ship is heading). In the case of knowledge creation, the novelty producing process must overcome the conservative bias inherent in the fact that all problem solving is based on existing knowledge. In the case of strategic management, the existing organization imposes constraints that make it difficult to create a truly novel organization.

Thus, the controlled production of novelty is inherently paradoxical, as it must use existing resources to create radically new ones. The novelty model proposes a general solution to this conundrum by showing how novelty can bootstrap itself out of existing elements by means of a system of feedback loops interacting via a workspace.

This theoretical model is then applied as a conceptual tool to support organizational and technological innovation. It does so by proposing two general methodologies:

Agile-Enterprise Innovation Planning (ÆIP) and *Carbureted Action Research* (CAR). To validate these methodologies, concrete applications in three domains are investigated: an experiment with project-based educational systems, a case study of an open-source software development ecosystem, and a design for an "Interversity", i.e. Internet-based university of the future. With these different validations, this PhD thesis provides a proof of concept that the proposed novelty theory and its methodology to support systematic innovation are applicable to the real world.

After a general introduction to the problem domain, the thesis begins with a chapter that uses an agent-based simulation and a number of illustrative examples of technologically supported cognition to examine how intelligence can be amplified. We thus investigate the mechanisms behind exaptation and the serendipitous discovery of new functions. The research draws our attention to how important the enrichment of the environment is for augmenting the intelligence of agents acting in that environment.

A deeper understanding of the mechanism for intelligence amplification is required, motivating the development of the novelty theory. From the study of cognition we move to fundamental studies of complex evolution, including the self-organization of dissipative structures and the origin of life. This helps us to understand how the evolutionary mechanism overcomes conservation—i.e. how it produces novelty—by using a *workspace*. By default, the workspace is the medium for agents to work in. By giving the concept "workspace" a more general meaning, we can use it to better understand how environmental conditions can amplify intelligence.

In the next chapter, the general novelty model is introduced as a bootstrapping mechanism on a workspace that can produce novelty more effectively. The workspace is subjected to four processes, called "novelty anchors", that feed in and out of it: *internalizing*, *externalizing*, *directing* and *evolving*. The workspace is the central medium of operation. It is connected via the anchors to two other mediums: the *environment* (external) and the *system* (internal). The artificial evolution of the workspace develops both the system core (e.g. internal memory) and the environmental enrichment. This produces a constructive co-evolution between system and environment.

To make the abstract novelty model more concrete, we apply it to the case of individual cognition. Here, we show how knowledge is created in a coherent way, which is why this application is called the Cohering model. Modeling knowledge and mastering action describe the two aspects of the co-evolution process between system and environment. Modeling is the process that develops the system core on the basis of the novelty (i.e. knowledge) that emerges in the workspace. Mastering is the complementary process that implements the novelty by enriching the environment. Advanced cases of modeling and mastering bring us to the need for studying scientific and technological development.

From Science and Technology Studies (STS) we learn how constructs in the social fabric can mobilize elements of the world, thus bringing together resources that

were initially distributed around the globe into one socio-technological ecosystem. This makes these resources more accessible for study and use. In his study of mobilization, the STS scholar Bruno Latour has analyzed the novelty production more explicitly. This inspires us to formulate a second concrete implementation of the abstract novelty model, which maps onto Latour's model of mobilization. This new model, the Eventuating model, describes the modeling of workspaces and the mastering of scarcity. By means of historical examples, it is shown how phase transitions in socio-technological ecosystems can revolutionize the whole social fabric.

The phase transition characterizing innovation becomes a central issue in Strategy Management Studies (SMS). First, we consider another application of the novelty model, called the Strategizing model, which examines the value that organizations create. Studies of organizations in SMS have led to the development of a framework that describes the dynamic capabilities of an organization. The dynamic capabilities framework becomes another application of the novelty model, called the Strategizing model. It investigates how modeling and mastering apply to organizations. Different types of innovation are situated in the different stages of the phase transition, thus giving us a broader view of the process of innovation.

Innovation requires project management and methods for designing solutions in a complex adaptive environment. This brings us to another application of the novelty model, called the Establishing model, which helps us to produce effective project management for innovation. With this last application we are ready to formulate a meta-model, which integrates the four previous models (Cohering, Eventuating, Strategizing and Establishing). This meta-model allows us to investigate the phase transition more systematically, by focusing on conversion patterns (e.g. the conversion from implicit knowledge to explicit knowledge). Each of the novelty models has its own conversion patterns. Together, these conversion patterns define the Agile-Enterprise Innovation Planning (ÆIP) grid. The ÆIP grid is a form of *descriptive* knowledge, i.e. it explains how innovation happens. For practical applications, we also need *prescriptive* knowledge that would tell us how to produce innovation.

The prescriptive model, which is called *Carbureted Action Research* (CAR), proposes two co-development paths that envelop the innovation during the phase transition. The final part of the CAR model is the ÆIP architecture, which is an Enterprise Architecture that shows how supporting socio-technological ecosystems can be spun off from the main innovation. The ÆIP architecture is intended to make radical innovation more manageable. To make the ÆIP architecture more concrete, three different validations are elaborated. The first validation uses controlled experiments in education. The second one is based on participation research in an open-source community. The last one is more theoretical, proposing an operational model for the ÆIP architecture in the context of universities.

The controlled experiments focus on project-oriented education about software tools. In the agile education experiment, we investigate how to teach when the

subject is evolving so quickly that the content is outdated by the end of the education period—a phenomenon characteristic of Internet-based software development. The solution is to focus more on the methods than on the content and to shift from education as *knowledge transfer* from teacher to student to education as teacher-supervised *knowledge creation* by the students. However, the bottleneck for agile education is the need for close supervision, which requires a low student-to-teacher ratio.

In the scalable education experiment, complementing teacher supervision with peer evaluation widens this bottleneck. This in principle allows the education system to scale up to a much larger number of students for the same number of teachers. Evaluation of students' work by other students requires us to develop a framework of methods and software tools to ensure a sufficient quality of results (e.g. by motivating students to make a fair number of contributions and by minimizing the effect of poor or biased evaluations).

In these teaching experiments, students are asked to develop a prototype application of a software tool for doing Internet-supported business—ideally in order to create a spin-off company. This shows how, in the ÆIP architecture, education can be an interface between academic research and a concrete development ecosystem outside the university.

By participating in an actual software development project, namely the Drupal open-source content management system, we obtain a deeper insight in the concrete dynamics of self-organizing innovation. We observe an interesting business ecosystem emerging through a variety of capital investments. By interviewing the entrepreneurs in the ecosystem, we get a more detailed view of how innovation happens in practice. This provides us with a better understanding of the natural development of an innovative ecosystem, which we need for the ÆIP architecture.

The last challenge for the ÆIP architecture is to create an operational model that combines the insights of the other validations to design a system that can spin off innovation ecosystems. The envisaged system is a self-organizing and distributed university, called the *Interversity*, where project-oriented, research-based education is central. The focus is on the development of ecosystems that support the research within the university, but also provide a wider service to society. As such, the Interversity would rest on the same three pillars as the traditional university (research, education and public service), but with much stronger synergy between these pillars. The goal of the operational model is to provide a proof of concept for the ÆIP architecture, and in particular propose a direction for future research on the subject.

The concluding chapter summarizes the main principles of the novelty theory developed in this dissertation, together with its potential applications in supporting innovation. It is followed by an extensive glossary in which the most important new concepts discussed in this work are briefly defined.

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1 Introduction

-- Fortune favors the prepared mind --

(Louis Pasteur 1854)

The forecast of half a century ago envisioned our present society to have flying cars and androids. These technologies are still considered futuristic, while existing technologies, like GPS and social media, were not even imagined. This experience has made people very suspicious about forecasting. We must face it: *we are blind to the future*. We need to question whether the blindness is inevitable or a consequence of our lack of knowledge. The common belief that innovation implies luck would make the blindness inevitable. With plain luck one would expect a random distribution, but what is observed is concentrations or "hubs": cultural hubs, scientific hubs, technological hubs, etc. Concentrations indicate a hidden order and suggest that we lack knowledge. A research challenge exists to understand that hidden order.

The main problem with forecasting is that agents use their own experience to do it. However, what is emerging in society is often in strong contrast to the knowledge of the agent. It is the paradox of novelty. Novelty is what is fundamentally new. The novelty of knowledge is reached by learning. Learning is based on our knowledge and acting, which is based on experience. What is fundamentally new is not covered by knowledge and emerged from the feedback of our actions. Novelty hides in the shadows of the agent's experience.

Heylighen (2010) describes novelty as being the difference between prospects and mystery. Prospects are the ability to foresee opportunities and threats, while mystery is the possibility of achieving an as yet absent prospect. Novelty is when that mystery dissolves and becomes new knowledge. The problem of forecasting has to do with the mystery of novelty. The past experience alone cannot construct the novelty of knowledge. It requires unfamiliar action creating new experiences. Heylighen (Ibid) describes it as the horizon of knowledge. A horizon is a constraint that prevents us from seeing our surroundings. We do not know what is behind the horizon. What is behind the horizon is a mystery and it may contain novelty. It requires action to reach a new position at which point what was hidden becomes visible. The research on mystery has so far been conceptual. This limits our abilities to truly understand the dynamics of novelty regulation.

Regulation has many meanings. It is defined here as the ability to use input to direct action and requires knowledge. Novelty regulation may appear to be an oxymoron. Novelty regulation is a way to resolve the mystery, to master the unfamiliar actions and to model new knowledge. The paradox of novelty is that mastering and

modeling require knowledge, while knowledge creates a bias and therefore is in contradiction to novelty. How do we regulate novelty? A complicated feedback mechanism is required that I call the novelty model (details are in Chapter 4). In innovation studies, this regulation is called "creative destruction". The term creative destruction has gained a particular meaning (details in Section 6.1.1). Novelty regulation is in many ways a more technical concept where the broader meaning of creative destruction gets lost. The research of this PhD focuses on all forms of novelty regulation, and is not only about knowledge creation and innovation. It is about a fundamental insight of how regulation is possible and how a paradoxical mechanism can overcome conservation. For example, sailing against the wind can be expressed as a novelty regulation mechanism that overcomes the conservation of momentum (details in Section 4.1.6). In the case of sailing against the wind, the relationship between novelty regulation and creative destruction is lost.

The use of novelty regulation is particular relevant for developers, such as scientists or engineers. Mysteries relate to understanding the world and starts a process that eventually results in the development of artifacts that penetrate this new world. Rittel and Webber (1973) describe how some mysteries create wicked problems for developers. They compare how developers deal with problems with the wicked or devious action of taming aggressive animals (e.g. lion). It requires time to build trust with the creature and once that trust is built, the tamer gains higher status as the master of such dangerous creatures.

Heylighen (2010) describes such mastery by referring to "the hero's journey" as described by Campbell (1949). The hero is first called to action, undergoes a road of trials and finally reaps a reward. Developers dealing with novelty encounter an aggressive, although conceptual, creature that attacks our world view, disrupts it and breaks it down. It is a creative destruction process and it shows how the developer is only partly in control. Often the developer is compelled by the insight and feels an urge to take on the challenge. This is the call to action. It requires time to build the appropriate tools to domesticate the unfamiliar new world. In that process, developers shape reality, which is the road of trials. The reward at the end is to be understood as a bootstrapping solution. Bootstrapping refers to a recursive relationship created first by a different process. Bootstrapping can be defined as follows:

> **Bootstrapping:** Two "things" A and B can be said to stand in a bootstrapping relationship if A is used to develop, support or improve B, while B is used to develop, support or improve A. In other words, both B and A emerge into existence from a co-evolution of prior, less defined "things".

A simple case of bootstrapping is the chicken or the egg problem where it is unclear which one came first. It is an incorrect statement since both emerge into existence by a co-evolution process. In a same way the knowledge and the world are developed in a co-evolution. The knowledge has not only changed, but the environment has also changed with many new kinds of artifacts. The concept of mastery and wicked problems are known primarily on design studies and the

related innovation management to support development. Concepts like mystery and modeling are part of the development around an action ontology that can help us to understand our increasingly complex and adaptive world (Francis Heylighen 2011). Ontological studies are conceptual and stand in strong contrast to innovation management studies, which are pragmatic. While the former is unable to validate the concepts by applying use, the latter is unable to manage radical challenges due to the lack of a theoretical foundation.

The gap between innovation practice and ontological theories requires a science of innovation. The goal of a science of innovation is to have a stronger theory that can result in experiments and profoundly shape our reality through radical changes. Such an ambitious challenge is far too great to give any conclusive results with a PhD. The goal of this PhD is to show the opportunity for a science of innovation by creating a proof-of-concept with the research on novelty regulation. An approachable way to move from conceptual development to more testable development can be reached by agent simulation based on the ontology. In our case, the simulations involve a setup of prospect and mystery for an agent that can change its environment. The experiments give us insight on the dynamics of novelty regulation and development of the novelty model (details in Section 2.1.1). The simulation is the start of the research, not the end. After the simulation, the challenge is to use the insight to support actual innovation.

The novelty model brings us to more abstract theory about intelligence that dissolves the boundaries between agents and its environment. Interestingly enough, such insights emerge from going deeper into the embodied & embedded studies of intelligence and recognize how an agent's cognitive abilities extends into the environment (Clark 1998). Other cognitive studies help us to understand the relevance of the environment for intelligence. An example are the studies on environmental enrichment that show how mice in a cage with toys are smarter than mice in a dull cage (Renner & Rosenzweig 1987). These studies on individual intelligence align well with the studies on collective intelligence that emphasizes the role of the environment for the cognitive ability of the system (see Section 2.3). Most cognitive studies that show the actual dynamic of intelligence are often done with experiments on less intelligent animals or on human disabilities. For a science of innovation it will require the exploration of intelligence beyond normal capabilities.

Ashby (1956) describes advanced intelligence as intelligence amplification. He argues that intelligence, like physical power, can be amplified. Advancements in information technology can help us to understand the concept of intelligence amplification. Agent simulations only give us insight into the feedback dynamics. To understand environmental enrichment and intelligence amplification requires us to work with people and their messy reality, not just software simulations. It is a shift away from building (software) agents to building support for the coordination of agents (real people). The amplifications for one individual agent are rare and limited by our understanding of intelligence as well as our ability to rewire the coordination of information for an individual. More opportunities are seen to

improve coordination between people, which means amplification of collective intelligence, in particular to support innovation.

At any time the many different innovations are connected like a network, showing how development in one area spreads to other areas creating a truly fascinating enrichment. For example, you cannot disconnect the innovation around electricity from the other innovations happening during this second industrial revolution. At first, this complexity may appear as an inevitable obstacle for any development. However, by considering the development of a process of domestication – meaning that you shape reality by changing it – such complexity can become an opportunity. This opportunity relates to environmental enrichment. While the capabilities of environmental enrichment were demonstrated with experiments using mice, the practice of environmental enrichment can be much more clearly recognized in the history of our social fabric.

The environmental enrichment in our social fabric results in making novelties more approachable, like transforming a rare event into an omnipresent event. The transformation of events is a very different application of novelty regulation, which stands in strong contrast to knowledge creation. For example, during the second industrial revolution electricity was rare. Only some people with considerable knowledge about electricity could have it. Electricity first had to be generated in more stable qualities in order to become more approachable. Improvement of our ability to interact with this new entity is reached by creating artifacts that allow the measuring of electricity and transforming it in several ways. Electricity is eventually institutionalized. It is produced by power centrals, delivered into households by electrical grids and used by the masses for a broad range of electrical tools.

If we wanted to simulate something as rich as the evolution of electricity by agent simulations, it would require decades of development without any certainty that such development would give us more insight into the mechanism of novelty regulation. In other words, agent simulation allows us to test part of the ontology and can be a stepping stone. However, the real test is by embracing real people in real settings and creating solutions to actual problems. The constructive nature of development makes it hard to stick to simulations. For example, electricity needs to become abundant before the computer can emerge. Computers need to become abundant before the Internet can emerge and our current enriched social media have only become possible by availability of the Internet. Social media is now a foundation for new development around collective intelligence. We can mimic some of these constructions with simulations, but it would not validate the novelty regulation profoundly.

The constructive nature of development is more commonly studied by biological evolution as the self-organizing nature of succession (species and ecosystems). It shows how pioneers conquer the barren landscapes and create the conditions for more complex biological systems to gain a foothold. The study of self-organizing evolution of creativity and innovation has been studied less and forms part of the gap that requires investigation. Biological studies are also the domain where

development by domestication is most advanced. Domestication, by plants and animals, is the ability to replace natural evolution with a social evolution. Other species, in a similar manner to humans domesticate, e.g. ants also grow farms and maintain cattle. By investigating the biological evolution, the dynamics required to understand novelty regulation can be improved. The real test is to make the insights useful for the support of innovation.

The concept of domestication can also be recognized in technological development. With the development around wicked problems and the problems of developing in complex adaptive environments, an approach similar to domestication was required. The concept of agile management was developed in order to describe the adaptive and interactive way for development, comparable to how domestication has been applied in biology. The concept has emerged through software development and has resulted in a definition of the agile manifesto (Beck et al. 2001). The agile management studies are pragmatic and show no relationship to evolutionary studies. Some confusion may arise since domestication can also mean the ability to create households. This has been adopted by scholars in technology development (Pantzar 1997; Morley 2003; Berker et al. 2006). These studies do not consider the rich knowledge obtained from evolutionary studies on domestication.

Domestication is but one of many evolutionary terms that are essential to understand the dynamics of novelty regulation. Another essential concept is "exaptation" which shows consensus between both the biological and technological studies. Exaptation is the utilization of a structure or feature for a function other than that for which it was developed through natural selection. The concept of exaptation originated in Gould's (1982, 1991) studies of biological evolution. For example, the first feathers were unable to allow birds to fly. They have evolved for some other reason (e.g. keeping warm) and get exapted later in evolution for flying. The non-linear development shows how exaptation creates wicked problems, which explains why exaptive evolution has not been investigated as much as adaptive evolution. Exaptation has proved to be useful to describe biological evolution. The concept is even more useful to describe the non-linear dynamics of innovation.

Niche construction is a concept in biological evolution that has become, with studies on exaptations, a way to describe technological evolution (Andriani & Cohen 2013). These studies can help us to approach the earlier mentioned hubs. Mokyr (2000) elaborates how many historical cases of science and technology are developed by exaptation. Dew et al. (2004) show how important this mechanism is for entrepreneurs today. The studies on exaptation are descriptive, by investigating specific cases. The agent simulations show how the novelty regulation can produce exaptation. The simulations show how to produce exaptations in the form of creativity and to absorb serendipitous events by observation. Serendipity occurs with events that have useful, but unexpected, benefits for the agent. It is exaptation and serendipity that the novelty model is able to regulate.

Exaptation and serendipity are also important concepts to describe the environmental enrichment of the social fabric. The exaptation happens frequently

with a solution that emerges in one domain and gets used for other domains. The serendipity arises from rare events that challenge the existing social fabric, including its ontology. For example, to solve a problem for mining, Torricelli used mercury because of its great density and in the process the barometer got discovered. This created an important conceptual insight for the later development of steam power. In recent innovation studies, it is seen how exaptation and serendipity become issues for management and the ability to create such a management goes beyond the current agile management applications. In fact, recent studies on agile management have been describing an implementation of the novelty model (see Section 7.1.1).

Exaptation and serendipity can result in inventions for an individual. Inventions are not yet innovations. Inventions can exist long before they turn into innovations. The difference between invention and innovation is the effect on the social fabric. Many inventions stayed dormant for a long time before they become essential components of the social fabric. For example, Mokyr (1990) demonstrate this with the case for ancient mills, like horse mills and water mills. During the classic period not much innovation was recognized. Innovation returned during the Middle Ages, when milling was used for many purposes and the windmill was developed. Understanding inventions are mostly recognized in the domain of Science and Technology Studies (STS) that focus on the enrichment of the social fabric. Innovation is more of a focus in Strategy Management Studies (SMS) where it is investigated as part of the competitive advantages for organizations.

Organization is another essential component to understand. It is as important for knowledge creation as it is for the enrichment of the social fabric. Let's first consider an example of knowledge creation. To know how riding a bike works, you need to master it. Having a bike does not give a person the ability to ride it. By mastering, a rudimentary example of an organization is reached that is shaped only inside one's head and is described as knowledge. For more sophisticated operations in our social fabric, the organization is recognized as institutionalization (e.g. around electricity). Between organizing in one person's head and organization of the social fabric, a whole scale of organizations exist that is central to innovation. Such organizations are agents in our social fabric but they are not that fabric. They are companies, governances, socio-cultural organizations, etc. These social organizations have the ability to shape reality.

Organizations show many of the dynamics we would associate with an individual, like mastering and modeling. For example, Latour (1999) notes that airlines fly and not airplanes. In other words, the technology is not enough; you need people and many other resources, the legal framework, operational processes, the public's approval, etc. The social organizations are created to bind this all together. As organizations mature, it becomes clear how their ability to act becomes less dependent on the smart entrepreneurs that started the organization and more dependent on the operational processes that can shape the people in the organization. Organizations have the ability to shape reality, which is another

implementation of novelty regulation next to knowledge creation, environmental enrichment and agile management.

Each novelty regulation is about overcoming a paradoxical conservation. For knowledge creation the conservation is the bias of experience, which is paradoxical since learning happens in experience. For developing enrichment, the conservation is the existence of an event, which is paradoxical by the required succession (e.g. chicken or egg problem). The paradox of agile management is to create a good management strategy when the developer changes the reality during development. The paradox of shaping reality is that organization inherently creates limitations, while such order enables leverage and extends prior abilities.

All of the paradoxes have a similar core and require a similar novelty regulation mechanism. One exceptional case of the mechanism strips away all extra complications, but pays the price by losing the relation to innovation. The case is sailing against the wind and the paradox revolves around the conservation of momentum. The sailing against the wind shows the mechanism of novelty regulation most clearly. I therefore examined sailing against the wind before creating the in-depth description of the novelty model (see Section 4.1.6). It is this theory on novelty that should demonstrate the opportunities for a science of innovation.

A scale transition is recognized when one novelty regulation becomes more central than the other. Take the example of electricity again. First, very smart individuals, being the developers, create the foundation. When it is institutionalized, it can involve millions of people who have no clue how the whole works. This transition arises from a smooth increase in organization. These social organizations show considerable diversity and the environment is also enriched by artifact that does not have agency itself, but amplifies that of other agents, like technology. Considering all of the added complexity, it may be astonishing that in the process electricity has actually become easier to access. In order to understand what happens requires additional insights into how evolutionary dynamics deal with increased complexity by meta-system transitions (Turchin 1995; Heylighen 2004b). An ancient and well-known meta-system transition in evolution is the shift from single-cell organism to multi-cell organisms.

Evolution is an ongoing process. An interesting meta-system for the novelty research relates to such ongoing transitions by cognition and the hybrid relation between human and machines. Starting from innovative hubs a meta-system transition is recognized that makes the innovation go global. Related to the current innovations around information technology and the Internet a particular meta-system transition gets described as the Global Brain. (F. Heylighen 2011a) expresses the rising awareness around the topic as follows:

> This concept of a cognitive system at the planetary level has been proposed by many different authors under different names: planetary brain, world brain, global mind, noosphere, social brain, Metaman [Stock, 1993], super-organism [Heylighen, 2007c], super-being [Turchin, 1977], and collective consciousness are some of the roughly equivalent

> synonyms. ... The term "global brain" seems to have been first used by Russell [1995]. The first people to have made the connection between this concept and the emerging Internet may well be Mayer-Kress [1995] and de Rosnay [2000]. Heylighen and Bollen [1996], and Goertzel [2001] appear to be the first researchers to have proposed concrete applications.

The social fabric is an artificial system showing on-going meta-system transitions. In this macro-evolution, smaller phase transition gets recognized. It can be compared to the dynamics of the sea where larger tides exist showing how wave after wave transform the tides. In a same way, the macro-evolution of the social fabric has smaller waves that show a constructive process. A phase transition is the moment when matter changes form, e.g. from solid to liquid. The system goes from one stable phase, across a chaotic instable phase, to become a different stable organization with different properties. The transition is mostly recognized when it is breaking down the existing system and replacing it with a new system. The breakdown is, in fact, the central stage of the phase transition. In order to truly understand the dynamics, it requires us to understand what came before and what happens after the breakdown.

In this PhD the phase transition is described by five stages: premature, incubation, growth, maturity and enrichment. During each stage a different state and a scale are recognized. The local development, where only a few people with extensive expertise are able to approach the novelty and create inventions, is the premature stage of the phase transition. The novelty is then fragile and only appears as rare events requiring specific conditions. It is during the premature stage that knowledge creation is most essential. The incubation phase is about the embodiment of the novelty by developing artifacts and creating environmental enrichment. It is something that happens with groups of entrepreneurial people. The novelty becomes very strong by the creation of organization during the growth phase and shows the breakdown of the old social fabric in favor for a new one. During the maturity phase the scale shifts again, now to inter-organizational structures like chains and sectors. The maturity relates to a huge cost reduction for the operation of the novelty, making the novelty become even more embedded in the social fabric. It is, however, only with the enrichment phase that the novelty becomes truly ambient and global by automatization. The enrichment phase creates a constructive foundation where new phase transition can be built upon.

Rogers (2010) describes a diffusion of customers for innovation. The division seems more generally applicable and can also be used to describe the division of innovation. The diffusion has the shape of a normal distribution and can at least explain the population increase in the commonly applied S-curve of innovation. The S-curve is another way to describe the normal distribution by considering the total distribution instead of the relative. Different types of innovation described by management studies can be related to different phases of the S-curve. These relationships are only introduced to demonstrate the opportunity for a science of innovation. More research is required by innovation scholars to verify if the description that is created is sound. This task is not pursued in this PhD. A different kind of validation is explored that is more in line with my academic training, which

is the validation of experiments. To reach this goal, a very ambitious plan has been developed to demonstrate how the phase transition becomes manageable by an enterprise system.

Enterprise architecture contains people, information, technology, and other operational aspects of organizations (Giachetti 2011). The enterprise architectures currently being built are complex systems, but often not very agile. Some scholars mention the concept of Agile-Enterprises (see Section 7.2.1), however, no profound development of the concept has been completed. The lack of progress relates to the absence of a good theoretical foundation. Based on the theory created by the novelty research, this PhD develops Agile-Enterprises Innovation Planning (ÆIP) as a way to become more serious about building enterprise architectures to support innovation by intelligence amplification. To validate ÆIP, several experiments were conducted that eventually resulted in the planning of a large-scale ÆIP implementation.

1.1 Chapter overview

Part I starts with Chapter 2 by investigating exaptation and continues with an examination of how it affects our understanding of intelligence. It shows how individual intelligence can be better understood and how collective intelligence can be synthesized. This goes beyond the more commonly recognized aggregation of collective intelligence. The study shows how limited our understanding is about such dynamics, while the opportunities to solve problems with such a mechanism is thrilling. In order to better understand the dynamics of novelty regulation, Chapter 3 investigates evolutionary studies to find a grounding. It results in a much stronger definition of our theory. This becomes the basis for Chapter 4 that creates the theory of the novelty research and describes the details of the novelty model, with examples of knowledge creation. It contains the dynamics and structures of novelty regulation in a more formal way. This information is utilized in the subsequent chapters for the other novelty models. The novelty model to study intelligence is about insights which I have named the Cohering model.

Part II discusses different domains and the resulting implementation of a novelty model. Each chapter is clearly divided into two parts. The first part is about the novelty model recognized in the domain, while the second part is about the phase transition. Chapter 5 begins with Science and Technology Studies (STS) analyses and how events become more approachable by enrichment. For that reason, I named it the Eventuating model. The second part of Chapter 5 considers the evolution of the social fabric and shows how different environments create different types of mediation. It is a way to investigate the hubs that naturally created a phase transition.

Chapter 6 focuses on Strategy Management Studies (SMS) and the capabilities of venturing organizations. The novelty model that builds from capabilities is called the Strategizing model. The second part considers more details on different

mediations, connecting the different innovation concepts to the phase transitions. Chapter 7 is about agile management. It begins with a debate about action research versus design research. Because the domain is about methods to direct action, the novelty model is now named Establishing. Establishing is a meso-level model, creating an interesting recursion between all the previous models and connecting all the novelty models to a meta-model. The recursion leads to 20 conversion patterns for the phase transition, which make up the ÆIP grid.

While Part I and Part II end with a design, part III starts with a design for the validation. The CAR method contains three types of validation: experimenting, participating and designing. Chapter 8 describes the design pattern for the different types of validation which are applied in the following chapters. Chapter 9 contains two types of educational experiments. The first is called agile education which shifts the educational task from knowledge transfer to knowledge creation. The second is called scalable education. It demonstrates how agile education can become massive by more structure for collective intelligence.

Chapter 10 provides details on a specific development ecosystem that has an interesting balance between community interest and business interest. The circumstantial constraints show how in this ecosystem, innovation is self-organization by the artifact that have enriched the ecosystem and the agents that inhabit the ecosystem. The emergence of the self-organizing innovation is an event that developed between 2005 and 2010. In 2010, I interviewed the entrepreneurs who were involved. The entrepreneurs were not aware of the dynamics that took place, showing that the development is mediated more by the ecosystem than by the agents. It also demonstrates how innovation can self-organize.

The last chapter involves the design of next generation universities named an Interversity. Two types of Interversities get developed that show how the research can continue. One type of Interversity is about developing more massive tasks. Education is currently undergoing this type of a process. It is also shown how research and public service can undergo such a transformation. The other type of Interversity is about institutionalizing radical change by the design of an ÆIP architecture that shows how to spinoff ecosystems. Where the first type of Interversity is an emerging trend, the latter requires a much more developed science of innovation. With these designs, this PhD shows how the proof-of-concept can be used to plan more advanced research goals.

1.1.1 Research questions Part I: a foundation with the novelty theory

Each chapter works on a research question. In Part I, those research questions build up to the novelty theory. The most important problem that we are facing is an understanding of intelligence. Therefore, the first question to work on is:

> ***Research Question I.1:*** *What is the mechanism behind exaptation and can it help us to understand intelligence?*

Chapter 2 begins with agent simulation to introduce the basic mechanism of novelty regulation by creative exaptations and serendipitous observations. The cognitive investigation continues by considering how brain plasticity allows for the development of artifacts that overcome disabilities. The investigation of artifacts shows how to extend intelligence. It creates an argument of how technology enables intelligence amplification. The examples given show that intelligence amplification is reachable by a hybrid relationship between people and technology. It is a process of distributing a problem over a crowd of cognitive agents and using moderators to filter the flow for the most intelligent contributions. The cognitive study introduces some important concepts like flow, environmental enrichment and workspace. I consider these design concepts for cognitive abilities. Chapter 3 attempts to find a grounding in those important design concepts by examining evolutionary studies. The research question now becomes:

> ***Research Question I.2:*** *Can a foundation be built for novelty research by integrating design into studies on evolution and if so in what way?*

The investigation starts with examining self-organization by physical system and continues with more advanced structures. It evaluates the studies of the origin of life and the very complicated biochemical mechanisms and artifacts. Even physical system workspaces can get recognized, which show how sensory input is given to a workspace to create patterns and motoric response. The sensory-motoric nature of workspaces is central to understanding how systems gain autonomy. The evolutionary studies add several important mechanisms and concepts, create a rich enough terminology to begin building a theory of novelty. It allows us to work on the research question for Chapter 4:

> ***Research Question I.3:*** *How can the novelty research be articulated as a system and cybernetic theory and how can it be expressed more formally?*

The chapter works on the research question by first creating a system-and-cybernetic description of the dynamics recognized in previous chapters. It extends the evolutionary cybernetic research of Heylighen (1992). In the second part of the chapter, the novelty model and its feedback is more formally described. It allows a more refined understanding of the dynamics created by the novelty model. To demonstrate the general nature of the novelty model, the case of sailing against the wind is considered first. It should prepare the reader for what is to come in Part II when different novelty models are examined.

1.1.2 Research questions Part II: the meta-model for innovation

While Part I focuses on the application of novelty for knowledge creation, we should not lose sight that what made the novelty research central is the recognition of the same feedback mechanism in different domains. With the exception of sailing against the wind, all the models have some relationship to innovation. The novelty model in Science and Technology Studies (STS) showed the similarities and demonstrated how the novelty model can be implemented in a very different setting.

The Cohering model worked on creative exaptations and serendipitous observations. The Eventuating model shows how exaptation and serendipity occurs in science and technology where everything revolves around events that develop the social fabric. The research question becomes:

> ***Research Question II.1:*** *How does the social fabric produce novelty and how does this relate to the evolution of science and technology?*

During the first section of Chapter 5 several quotations by scholars in STS are presented to elaborate on what the Eventuating model does and how the scholars already described the model. The model is slightly refined so that it is more generally applicable to the development of the social fabric and not only for the scientific development. The second part is trickier since it tries to describe the general dynamics of a macroevolution. It is, however, necessary to provide such a description in order to introduce the constructive development of the social fabric by phase transitions and to focus on the contemporary state of Internet innovation. What makes it difficult is that innovation to some extent always happens naturally and shows a hybrid relation to evolution in general. The macroevolution introduces some of the mediators required for innovation and shows how they have initially emerged. These mediators become more central in Chapter 6 on Strategy Management Studies (SMS) where the research question becomes:

> ***Research Question II.2:*** *How can we apply the novelty research to understand innovations made by organizations?*

The first part of Chapter 6 describes how SMS develops a way to approach a complex adaptive environment. The focus is on values and the creation of an organization that can develop innovations. Organizations have capabilities, and with the capability frameworks another novelty model gets recognized. The domain has worked less clearly on novelty research. Some general quotes are presented to show how novelty regulation correlates to creative destruction and competitive advantage. To complete the picture, some cases are created, based on recent innovations, to illustrate how organizations evolve by value exaptation and serendipitous values.

The organizational studies in SMS are limited to a description of the capabilities where the development is the natural effect of the organizational structure. The concept of correcting a process required yet another domain and also another novelty model, which now relates to agile management as a validation method. The first part of Chapter 7 elaborates on the Establishing model and how it has been developed by a debate between the two methods of action research versus design research. To combine this model with the insights of the previous chapters a research question arises:

> ***Research Question II.3:*** *How can we apply the novelty model as the foundation for the Agile-Enterprise Innovation Planning?*

While Enterprise Planning is known for classic applications, the challenge is to make such large structures agile and applicable to the complex adaptive nature of

innovation. The debate between action research and design research has resulted in the development of a general Establishing model, but fails to provide the details. The difficulty is that the Establishing is a meso-level model that combines all of the novelty models into one meta-model. In other words, the other models become the mediums for the Establishing model. To demonstrate this, I describe conversion patterns that show how the Establishing model was implicitly present during the other novelty regulations and how a focus on establishing can lift each of the novelty models to new heights. Knowledge creation shows the most development where the first four conversion patterns are already described by Nonaka (1995). By the recursion a whole grid for ÆIP can be made of 20 conversion patterns, which are developed in the second part of Chapter 7.

1.1.3 Research questions Part III: ways of validating the research

The ÆIP grid gives us insight into the complexity of the meta-model, but raises questions about how it can help us to develop support for innovation. This requires Chapter 8 to investigate the method for validation:

> ***Research Question III.1***: *How can the novelty research be demonstrated and validated in a setting with actual people?*

Chapter 8 describes the design of the Carbureted Action Research (CAR) that develops around the catalyst of the phase transition. The ÆIP grid shows how most conversion patterns are the side effects of other novelty models, which creates a need to have a different separation for the validation. Three dynamics are identified for CAR that require three different validations. The first validation is to demonstrate the complex knowledge creation and involves education experiments. The second validation is to understand ecosystem dynamics involving participation research. The last validation is the design for systematically creating the first two dynamics and creates what is called the ÆIP architecture. Once the general design of the validation is described, details are created during the actual validation. Each validation creates different research questions. For the education experiments the research question becomes:

> ***Research Question III.2***: *What insights can experiments in academic education give us on Agile-Enterprise architectures?*

To answer the question, experiments investigated agile education. They revolved around the question of how we can teach if the content is out of date by the end of the course. The setting is to make education deal with complex adaptive environments. The solution is to create a project-oriented education, which creates a high demand for tutoring. To make such a solution possible an experiment on scalable education is developed that supports the tutoring by enterprise architecture. Consistent with the educational experiment, the participatory research of Chapter 10 has been developed around the questions:

> ***Research Question III.3***: *What insights can participation research give us about self-organizing innovation in development ecosystems?*

By participation it was recognized how a business ecosystem had emerged from a software development project that showed open innovation. By interviewing entrepreneurs it becomes clear how the innovation is actually self-organizing by the exaptation of artifacts, created for developers, used by entrepreneurs for their serendipitous effects. The relevance of working with a rich ecosystem and understanding the circumstantial constraints that result in particular dynamics give us the required insight to continue the ÆIP research. To advance the research requires larger scale experiments in the fittest environments. This leads to the concept of next generation universities and how ÆIP architecture can be a design for it. In Chapter 11 it results in the research question:

> **Research Question III.4***: How can we apply our research to design enterprise architectures for next generation universities?*

Universities are historically seen as places of universal knowledge. Because of information overload and the acceleration of innovation, the concept of universal knowledge is becoming an illusion. Even the largest universities today only have some of the knowledge. Chapter 11 is called the Interversity as a proposal on how universities may change. It draws the attention to "what is between us" (from the Latin "inter", like in Internet, interact, interdependent, etc.). Universities today are built on three pillars: education, research and public service. To achieve an Interversity, the pillars need to be addressed in a complex adaptive manner. I suggest two such approaches: the open Interversity is about making academic education and research massive and the integrated Interversity is about the spinning of ecosystems that have the capabilities to produce radical change.

2 Investigating Intelligence Amplification

2.1 Research on exaptation

The research starts as an Artificial Intelligence (AI) experiment focusing on the internal regulation required for one agent to show exaptation. The first subsection goes into the details of the research by developing simulations. While developing simulations have been useful in getting a basic insight on the regulation of exaptation, it is not the appropriate way to continue the research. To continue the research it is better to work with real people and actual intelligence where technology is used to support intelligence.

The second subsection considers different cases to understand the shift to real people. The first cases are technologies used in the application of brain plasticity to overcome disabilities. It is then extended to cases where technologies support brain enhancement, observing what is called Intelligence Amplification (IA). The technology development involving brain plasticity contributes to the theory building around novelty regulation. The insight is used to understand how technology can influence intelligence.

A shift is required from technology supporting intelligence amplification in individuals, to ICT supporting innovation by collective intelligence. The cases of intelligence amplification show that the technology is not high-tech. In some cases, it is even hard to describe the artifacts as technology. All cases show how technology transforms the sensory-motoric experience so that the individual can work with the appropriate cognitive processes to perform actions. Learning is going to be a particular challenge. Education adds more of the required concepts, like flow and scaffolds. The last subsection is considered to be a special case of educational innovation, combining the Intelligence Amplification into a collective setup. The case demonstrates that synthesizing collective intelligence creates a more systematic solution for intelligence amplification in the case that collective intelligence is available.

2.1.1 Exaptation by simulations with software agents

Simulating exaptation is a study on the regulation of higher-level cognition, which is different than low-level cognition. The higher-level cognition requires reasoning. It was more common with the classic AI on general intelligence and has been lost in specialized AI approaches using algorithms for lower-level cognition (FRANKLIN 2006,GOERTZEL & PENNACHIN 2007). Because no earlier use of software agents for research on exaptation was known, it was decided to use an agile software development method to explore this higher-level cognition(Kiemen 2003, 2006). Another, unrelated study of exaptation by software agents, is done by Villani et al. (2007).

My own investigation demonstrates how the agile management could be used to deal with uncertainty in AI research. In the first subsection, I introduce the iterations and explain how the first iterations create the complex adaptive environment as a pre-condition for the main simulation. In a second subsection, I describe how serendipity allows the agent to develop its knowledge base and to eventually create exaptation. In the last subsection, I consider how this experiment has created the focus of the research on novelty regulation and how it forces us to abandon agent simulations in favor of working with real people.

2.1.1.1 Complex adaptive simulation environment

We used the common software modeling method "abstraction first" to begin the research. The approach starts with abstract descriptions. The next iterations replace those abstractions with more elaborate structures and functions. The method tries to take into account the improvements by the other AI developers without making their research focus take over the required development. A strict order is followed to remove the abstractions of earlier iterations based on how they affect the dynamics to study exaptation, eventually resulting in not integrating the other AI development. In the last subsection, I explain the reason for abandoning this path.

In total, seven iterations were created by three simulations (Table 3.1). The first two explorative simulations were created to make the complex adaptive landscape, which was the pre-condition for investigating exaptation. After the second simulation, it was considered sufficiently complex adaptive to create a case for simulating exaptation. The simulation mimics how an ape uses a stone to open nuts. Five iterations were created before the simulation reached a satisfying understanding of the regulation behind exaptation. The first iteration was still about creating a complex adaptive landscape, using a method of reverse engineering to create objects in the simulation. It uses the distribution of values to create objects, which adds variety and ambiguity to the simulation.

Table 3.1 The seven iteration of the exaptation experiment

Iterations	What	How
Room simulation	Adaptive actions	Move-landscapes
Key simulation	Goal oriented actions	State-spaces agents
Nuts simulation		
1 Ambiguity	Increased variety	Values by distribution
2 Process flow	Actions take time	Process stack
3 Exaptation (logical)	Knowledge creativity	Process recombination
4 Novelty regulation	Complex feedback system	Parallel processing & workspaces
5 Serendipity	Complex embodiment	Relative perception & spillover processes

The interesting work starts with iteration two which is focused on improving the knowledge base of the agent. With the room simulation, moving was a process that requires time to execute and conditions to be verify during the execution. The key simulation adds more actions, controlled by the memory of the agent. The actions were simpler and got identified as a problem for research on exaptation. With iteration two, a design was implemented that made all actions become processes like moving. Even the reasoning of the agent is a process. In the simulation, the reasoning happens several times faster than the physical processes. This allows the reasoning to regulate the physical processes. Each process is represented in the knowledge base of the agent. The process description has five variables: do, get, at, on and with. Two variables are conceptual tags relevant for the regulation. The variable 'do' is the name of a particular action and 'get' is the anticipated outcome of the process. The other variables 'at, 'on' and 'with' are the conditions required for executing the process. These variables can have the agent as the default value. The agent would start with a usable knowledge base for the initial environment. The starting knowledge of the agent is as follows:

- do: view get: identifyObject
- do: move get: newPosition
- do: pickup get: Object at: Object
- do: eat get: stopHunger on: nutmeat

From the agent's need, to stop the hunger, an internal reasoning is resolving the pre-conditions to execute the process 'eat'. This triggers a cascade of required processes to reach its goal. The variable 'on' and 'with' could only get executed if the agents had those objects in its possession (and the agent always has itself in possession). If this condition is not met, the agent adds two processes: 'view' to identify the required object in the environment and 'pickup' to possess the object. Note how the 'pickup' process has an upper capital for both 'get' and 'at'. This was used to indicate a variable (inspired by logical programming). This means that 'Object' could actually be anything. The 'pickup' process shifts the problem of having the object to being close to the object. This brings us to the variable 'at', indicating a condition that a process can only get executed if the agent is close to a particular object (and the agent is always close to itself). If the condition is not met, the process 'move' is required.

The next step is to apply these rules. To stop the hunger the 'on: nutmeat' needs to become concrete, adding 'view' and 'pickup'. The process 'view' has only default conditions and can get executed directly. By the view process the agent identifies object-342 as nutmeat that it wants. Now the agent needs to pick up the object, what requires moving to the object. So once the agent starts moving it internally has the following process stack:

1. do: move get: object-342 (being executed, condition not yet reached)
2. do: pickup get: object-342 at: object-342 (pending, waiting for move)
    - do: view get: identifyObject (object-342, executed)
3. do: eat get: stopHunger on: object-342 (pending, waiting for pickup)

It is necessary to provide some insight on the software architecture behind this description. This requires some understanding of object-oriented programming. In object-oriented programming, everything is an object, what makes 'process' a virtual object of the simulation containing the five variables and some methods. When the 'process' object gets the method-call 'execute', it transforms the variable 'get', being a name, to a method-call, which is then sent to the object linked to the variable 'on' and 'with'. For example, in the case of 'view' the variable 'on' is the agent itself. The 'agent' object had a method 'view' that sends a method-call 'beingViewed' to all objects in the environment. All objects have the method 'beingViewed' that returns a set of variables. Together with the distance, the agent uses these variables to create a selection. In this case, it selected object-342.

The software architecture creates the framework for different simulations. The framework contains abstract objects, agents and processes. For example, in the simulation above, only 'eat' is a process unique to the current 'nuts' simulation. It was implemented by extending the general 'agent' object to an object called 'ape'. This technique was not needed for all objects. For example, the 'process' object contains general dynamics that are well developed and did not require extensions. Because the 'process' object transforms a name into a method, those methods had to exist in the object getting the method-call. In the 'agent' object, some general methods like 'move', 'view' and 'pickup' were already implemented. While in the 'ape' object, the method 'eat' was implemented. The framework hides common structures and functions. It creates, by bundling concrete extension, clarity for the researcher.

I'm not again going into great detail to describe how other structures and functions are coded. The next section focuses on how the simulation allows new knowledge to emerge from the actions of the agent. To elaborate the growth of the knowledge, the order of the iteration is mixed up. The focus of our research that is to get a simulation on exaptation, enforced a test that triggered a cascade of adjustments by the next iterations. Only with iteration five did we consider the experiment on exaptation to be acceptable. It is therefore necessary to elaborate on the outcome.

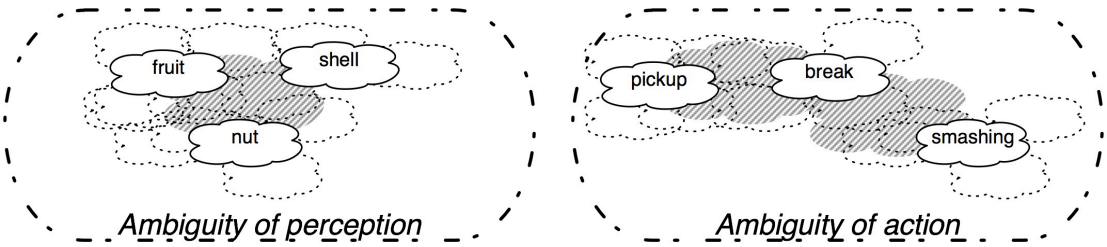
2.1.1.2 Serendipity in flow leading to exaptation

To get to an acceptable flow, ambiguity became essential. Only one object existed that represented hybrid states between the nutshell and nutmeat. The object in the simulation had a variable representing the percentage of the shell around the nutmeat, as the example in Figure 2.1 illustrates. At the start, the agent only searches for nutmeat, which are the objects having 0% shell. The agent eats the nutmeat, which changes the landscape.

Figure 2.1 Examples of the interpretation of the 'shell' value in the simulation. Left, the object has 0% shell, in the middle between 25% - 75% shell and on the right 100% shell.

Iteration five improves the simulation by considering the complex embodiment of the objects in the simulations, creating ambiguity in perception and action. Depending on the percentage of the shell the object could get perceived as nutmeat. Of course, the more open the shell the more likely that the agent is going for that object. Objects below 20% shell would just get picked up like the open nutmeat. With a shell between 20% and 40% the shell would linger and fall off early during the pickup. Between 40% and 60% the agent begins to nip the nutmeat out of the shell and by 75% shell the agent needs to peel off the shell. By simply going for the most open nuts, the agents have to adapt to small perturbations to the process, what can be learned by simple sensory-motoric corrections. The description shows how a simple adaptation process arises for each action, while over time the action has become very different. This part of the simulation shows the relevance of circumstantial conditions in the environment, making serendipitous effects emerge. For both perception and acting the ambiguity is enabling the change. For the simulation the overlap between the perceptions and the actions were illustrated as gray zones between the concepts (Figure 2.2).

Figure 2.2 The overlap between perceptual concepts on the one hand and processes on the other hand in the simulation creating ambiguity.

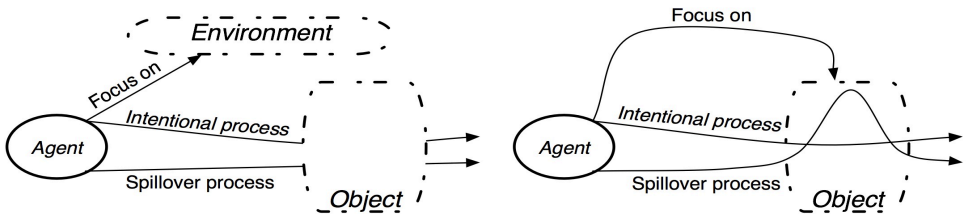


A richer description of the process allows the agent to observe the spillover effects of its actions. In the simulation a simpler solution was used, although it was still developed enough to be the interpretation of the dynamics of the richest description. Consider the situation of the code. In the simulation, the execution of 'pickup', by a method-call to object-342, creates a chance, relative to the percentage of shell, that object-342 executes a process that reduces the value of the shell. In the simulation, this happened by object-342 creating a 'process' object and calling the method 'execute' on it:

- do: break (get: nutmeat) on: nut

The variable 'get' is between breakages as it is what the agent uses to label the outcome of the process. It is not really part of the process itself. The spillover process requires observation. Only in the case where the agent was focusing on the object could it perceive the spillover process in action. It is expected that, in reality, many side effects can happen around action and most are ignored. The agent is able to identify serendipity. How this happened is part of the architecture of novelty regulation. It requires a decoupling of internal processes from external processes, as demonstrated in Section 2.2.4. It is now best to just accept that the agent can identify serendipity and stay focused on the simulation at hand. The serendipitous observation in the simulation is that picking up also creates breaking and breaking the nut gives you nutmeat. For the simulation, the spillover was presented as a wave that initially was hidden from the intentional process, but observable. The wave stays hidden if the agent is not focused on the object (Figure 2.3).

Figure 2.3 Creation of spillover processes by the ambiguity of perception and action

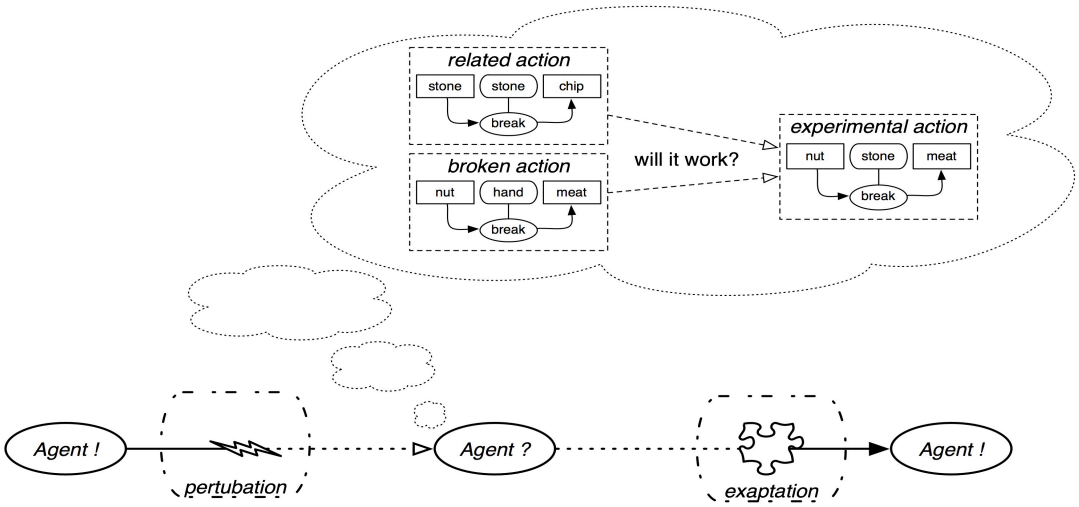


In case the agent did make the serendipitous observation, it had now a second way to get nutmeat, by breaking nuts. This creates a significant change allowing close nuts to become considered. More closed nuts would create a distinct sound of breaking. This is less the case with the chestnuts in Figure 2.1, so consider hazelnuts and walnuts. This sound is relatively related to rock fall, which is the process of one rock falling and smashing into another. The first such rock fall would get ignored. It now links to existing knowledge and becomes a serendipitous observation. Allowing the agent to add:

- do: break (get: chip) on: stone with: stone

It is important to note that this is the only process where 'with' is used. It is a simple description, to indicate that two objects are involved to create the process. At first, the observation has no effect on the activity of the agent. While the agent tries breaking the hardest nuts a breakdown occurs, as the agent does not have the force to break the object by hand. The breakdown creates an inconsistency with 'get'. In the simulation, other such inconsistencies were possible, like the agent picking up a nut, initially perceived as nutmeat, but where the chances were bad and the breaking did not occur. In case no more knowledge exists, the situation is confusing and it restarts the whole reasoning. In the case of breaking, more experience was built resulting in an exploration of alternatives. Focusing on the most recent changes, like the sound and force of breaking, the exploration creates alternatives by a recombination of knowledge, as illustrated in Figure 2.4.

Figure 2.4 The exaptation by the recombination of existing actions.



The creative process is always an exaptation and this recombined action is an experimental process. The exaptation of breaking replaces the default (the agent) by a stone. It does not always need to be a perturbation triggering the need for exaptation. It could also come from an insight, under pressure, being bored, etc. In general, it is considered to be a challenge. The challenge would lead to an experimental process that has to be tried before it is considered valuable. After executing the experimental process, the agent gets positive feedback that a stone can indeed break the hard nuts and the agent adds the process description:

- do: break get: nutmeat on: nut with: stone

The simulation created a very basic case of exaptation. Problems with the experimental process can result in a cascade of changes, making the agent create a whole new body of knowledge. In fact, it is what happened to our research itself. Iteration three of the simulation was by pressure to get some effect of exaptation in the simulation experiment results in the adjustments for two more iterations before it became an acceptable solution. It is in a way funny, since the research on regulating novelty was created by … regulating novelty. This effect was recognized after the simulation research and got used to bootstrap the research on novelty, like using the insight of the theory to develop an improved methodology.

2.1.1.3 Basics of novelty regulation

Iteration four makes the simple reasoning of the agent become a complex feedback system. Table 3.1 indicates how parallel processes and workspaces were the solution. A short introduction is given in this chapter, while Chapter 4 takes a in-depth look at the complex feedback system. The parallel processes get implemented twice. The easiest implementation is the reasoning being a process many times faster than the physical process, what allows the adaptation to small perturbations. The tricky implementation is how parallel processing makes simple rules become higher-level cognition. To elaborate on this, I need to present some more detail on

cognition. The dynamics are described in Section 2.2.4. The parallel processes require a workspace. In the former, the workspace is the environment, in the latter, it is a special memory. It is the workspace that allows the serendipitous observations. The parallel processes take it up in the reasoning and when it creates any relation to existing knowledge it becomes noticed. The relevance and details of workspaces require insights on collective intelligence. Sections 2.3.2 and 2.3.3 gives more detailed insight on workspaces.

The last iteration was not the end of the simulation research, but no concrete next simulation was built. One exploration, to improve the simulation, was to remove the abstraction that mimics the sensory-motoric part. Actual sound and actual movement would make the sensory-motoric part concrete. This would require a shift to robotics instead of software agents. The investigation concluded that the research in robotics is still a long way removed from the requirements needed for the complex adaptive dynamics of the simulation. Development could be started to narrow the gap, but it would change our actions from research on exaptation to building complex adaptive robotics. Because the exaptation is our focus, an alternative path was taken to continue the research.

The simulation did create the basic understanding on how knowledge can be created by action. In the simulation, the actions are directed externally to the environment, making the simulation about mastering. In addition, internally directed actions can be created to improve the knowledge base. This is described in this PhD dissertation as modeling. Modeling allows for knowledge to become defined abstractly, like the 'pickup' process. Indeed, if we look at babies, we can see them create, by trial and error, an understanding of what object can be picked up and how.

A second path of investigations by agent simulations explored how to replace the abstraction of knowledge. In the simulation the knowledge is essential, but how it got built stayed abstract. Investigating how to build knowledge from experience implies more refined simulations on modeling, also using the social aspect of creating knowledge. Interestingly, it creates the same problems as the simulations for advanced mastering, although the field of application was radically different. To create good cases of modeling, the simulation needs to develop as a multi-agent simulation, since modeling is entwined with linguistic activities and social activities. A huge increase of complex adaptive dynamics is again needed for simulations. It is now related to multi-agent modeling and complex knowledge.

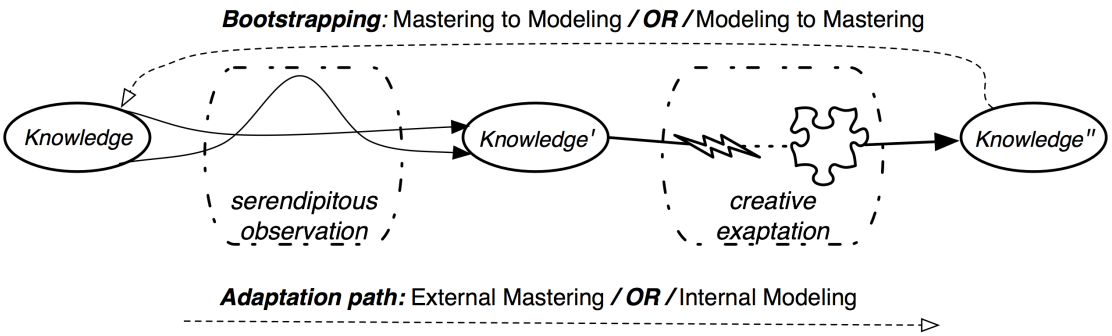
By the exploration of advanced simulations, the insight was discovered that both mastering and modeling occurred by the same process. The difference is an internal or external orientation. The simulation showed the external orientation. Imagine a complex knowledge structure and an agent reasoning about the knowledge to create abstractions. The serendipitous patterns in the knowledge triggers the development. The agent uses those patterns to create abstract concepts. By default, concepts are links between sensory-motoric experiences. Therefore, concepts linked to concepts are actually creating an exaptation. It is expected that the first abstractions may not

be well designed. Mastering is used to get additional insights on how this can be improved.

Consider how mastering happens with the repetition of the process 'eat'. The repetition creates an adaptation path, allowing small adaptive steps, making 'pickup' transform to 'breaking'. For modeling, reflection creates a similar repetitive adaptation path that could make the eventual abstractions become very different from the initial abstraction. For example, many good ideas have first been metaphors that then create whole bodies of knowledge.

The similarity between modeling and mastering led to my focus on one feedback mechanism that can be applied both internally and externally. The adaptation path is through the many small iterations a continuous process, with the exceptional discontinuous events of serendipitous observations and creative exaptations. The whole system becomes fully capable of creating knowledge by a bootstrapping process between mastering and modeling. Figure 2.5 gives a visual description of the whole process.

Figure 2.5 The bootstrapping process combing serendipity, exaptation and adaptations.



Consider that most of the iterations created for the investigation of exaptation are also about the pre-conditions of the complex adaptive systems (environment, agents, objects and processes). Simulations are intended to simplify reality in order to examine a particular aspect. For our simulation, it was necessary to gain an insight inot the regulation behind exaptation. This was answered on iteration four and improved with iteration five. What is now needed to continue the research is not a simplified reality, but a niche to grow and continue what was found with the simulations. The niche is to support real people in the development of innovation. It does require some investigation before it becomes clear how the research can continue.

2.1.2 Technology exaptation for cognition

The research shifted to real people and their technology. It is, however, still the same research on novelty regulation. A point of entry is found by considering the breakdown of normal cognitive abilities. In support of disabilities, brain plasticity turns out a way of recreating cognitive abilities by exaptation. First, some cases of

creative exaptation around brain plasticity are given. In subsequent cases, I also consider the relation to serendipitous observations. The final cases show how the mechanism is used for Intelligence Amplification.

2.1.2.1 MirrorBox artefact

The MirrorBox is a proven therapy for phantom limb pain (Ramachandran & Rogers-Ramachandran 1996). People with phantom limb pain feel pain in an amputated limb. The MirrorBox therapy works by re-creating a visual presence of the amputated limb (Figure 3.10). The patient is asked to do some exercise with both hands. Of course, the patient is aware that the hand does not exist. In a way this therapy is, therefore, the reverse of the placebo effect. While the patient is aware of the artificial setting, it does result in the relaxation of connections in the brain. In a way perception was exapted to stimulate particular traumatized neurons that no longer had a relation to the embodiment.

Figure 3.10 An example of the MirrorBox for a missing arm.

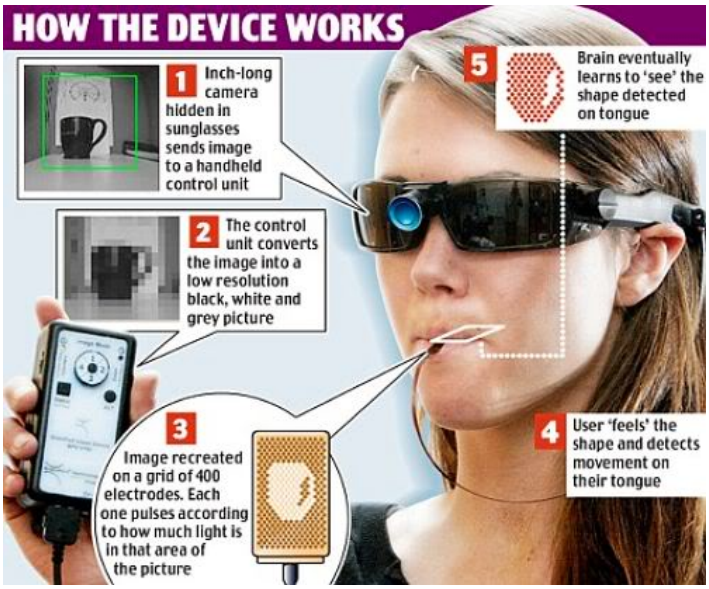
2.1.2.2 BrainPort artefact

A new therapy allows people who have become blind to see with their tongue. This is achieved by providing a camera that can transform the perceptual stimuli to touch, the so-called BrainPort (Figure 3.11). This simple tool allows blind people to catch a ball after only a 15 minute exercise (Danilov & Tyler 2005). During the interviews, the blind people express that they “see” the ball. Similar to the MirrorBox, we are not in any position to judge the patients in their experience. Therefore, our prejudice about 'seeing' is wrong, not their experience.

This case demonstrates how our touch can be exapted for seeing. In a way, we may not need eyes to see, but eyes are probably the best interface for seeing. This only works for people how became blind. For people that were born blind, the required

internal abstraction (indeed by modeling) has not formed, which is the precondition for the BrainPort to work.

Figure 3.11 BrainPort makes blind people see with their tongue



2.1.2.3 Sensory-motoric coupling artifacts

Both MirrorBox and the BrainPort compensate for the broken sensor-motoric coupling of cognition by re-routing it to other sensor-motoric coupling in a natural way. Other cases exist where the rerouting does not happen in the brain itself, but by the design of the solution. For example, Neurofeedback has become a proven therapy for epileptic (Sterman & Friar 1972) and ADHD patients (Masterpasqua & Healey 2003). Neurofeedback visualizes the brain waves, which brings the state of our brain into the sensory range. The rerouting then happens by external means. The therapy helps ADHD patients to learn to focus and epileptic patients to learn to relax by the visualization of their brain state.

A non-therapeutic tool that brings unmonitored variables into the sensory range is the tactile flight suit (Schrope 2001), which is used to help a pilot operate a helicopter. The suit allows inexperienced pilots to perform difficult tasks like holding the helicopter in a stationary hovering (Clark 2008, p 36). The suit creates a puff-induced vibrating sensation that translates the helicopter's movement. The suit makes a pilot "feel" the helicopter and experience the helicopter as an extension of their body. The tactile flight suit case is one of the rare examples where actual intelligence amplification is recognized for individuals that goes beyond the disability problem.

2.1.2.4 Insights for novelty regulation

In most cases, the technology was not high-tech. All cases do relate to sensory-motoric coupling. The cases of disabilities show intelligence recapturing by exaptation with other sensory-motoric coupling. The study creates a focus for designing fit interfaces and transforming information to become digestible by our sensors. Sensory-motoric coupling allows the exploration of cause and effect, which creates the knowledge and intelligence. Allowing our most developed sensors to deal with problems can create Intelligence Amplification. Recognizing this makes us look at many of our activities in a different way. This includes creating maps, working on a blackboard, etc. We use highly evolved perception to amplify our reasoning. In fact, it is in the cognitive studies known as extended cognition (see more in Section 2.2.3).

Each tool that is discussed requires extensive research. For example, it takes a profound understanding of cognition to even consider the artifacts. The invasive nature of the artifacts on people also requires strong regulation of the research. While the cases create insights and allow for theoretical development, they are not suited for validating the novelty research in the limited time of a PhD. To examine novelty regulation more directly requires a move to collective intelligence.

2.1.3 **Education and the design of collective intelligence**

In order to evaluate the collective intelligence of a highly intelligent agent requires us to start with educational research that introduces some of the fundamental concepts like flow and instructional scaffolds. These concepts are elaborated before considering the actual cases. The cases draw the attention to environmental enrichment. The concept of environmental enrichment is mentioned without proper definition. This is discussed in Section 2.3.2.1. The environmental enrichment brings us from education to an exaptation of game-like structures, now called gamification. This stimulates the self-organization of education by environmental enrichment. In the last subsection, a case shows how education is the proper place for the kind of intelligence amplification that can help us to validate the novelty research. That case is the key to understanding how collective intelligence can amplify individual intelligence.

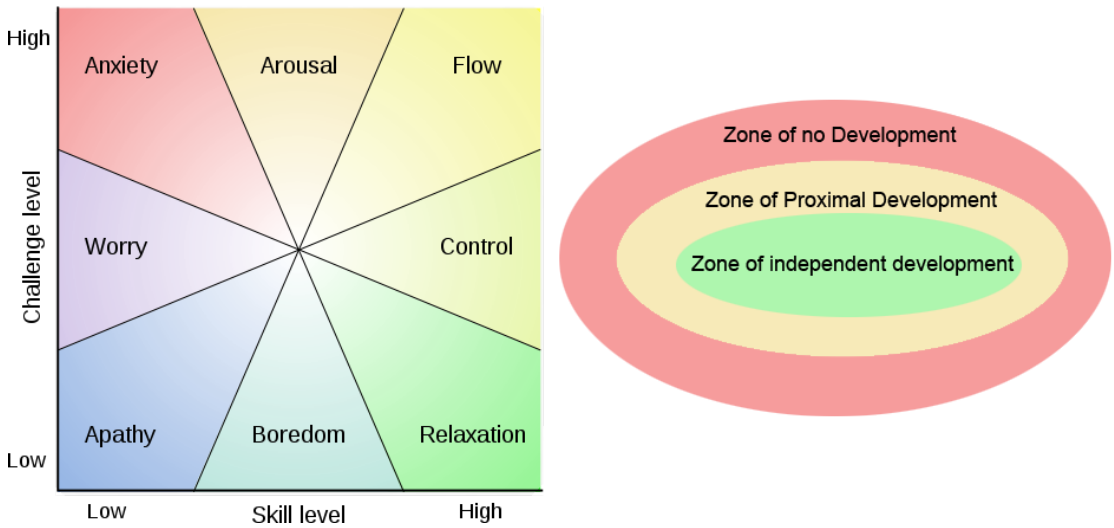
2.1.3.1 Flow and Zone of Proximal Development

Csikszentmihalyi (1988; 1992) introduced the concept flow as a psychological state of mind created by two variables: challenge of the task and the skills of a person. The psychological states are shown in the left part of Figure 3.11. Flow is a particular state of mind with high challenge levels as well as high skill levels. The state of flow is not easily reached, but mediation can facilitate the entrance to a Zone of Proximal Development (ZPD), in which flow becomes common. Vygotsky (1987) studies ZPD between independent learning and a zone that simply cannot be

reached even with assistance. In the right side of Figure 3.12, I used colors to indicate the state of each zone in relation to the psychological state of mind. Independent learning is considered a state of relaxation. In the case that an independent development results in a state of flow, I consider it circumstantial. This means that the environment is the actual mediator and so it is ZPD. The ZPD is the state fit for flow, reachable by the proper design. The zone of no development results in anxiety.

With an understanding of Flow and ZPD, the need for well-designed mediations becomes our focus. Mediation can have many forms. It could even be virtual, like simple guidelines and metaphors. Mediation can come from people, like a teacher or peers. Mediation can even come from organizational structures and enrichment in the environment. Mediation, which is needed to understand innovation, will be discussed in four chapters (Chapters 4-7).

Figure 3.12 Left the emotional relation to challenge and skills, right the ZPD



The challenge of getting people in a state of flow is universal and very approachable from my software engineering background. It is going to require more than software development to create well-designed interfaces that can stimulate the state of flow. It is an organizational study of systems where software is only part of the puzzle. This PhD creates educational experiments (see Chapter 9) where software tools are an essential part of the system. It requires considerably more insight to show exactly how education can be used for the development of innovation. For now, I will keep it as an introduction.

2.1.3.2 Instructional scaffolding

Instructional scaffolding for learning was first introduced by Bruner to describe children's oral language acquisition (Wood et al. 1976). In such cases, very basic instructional supports are used like particular articulations (e.g. articulating

"mama" over and over). Children's books are a simple example of instructional scaffold. Depending on the age, a book has a particular structure designed to help that age group appropriate the story and language in the book.

Scaffolds are supported structures during construction. The concept of scaffolding could at first be misleading. However, closer examination shows how fitting the term is. It is primarily used to indicate a temporal structure. However, temporal is relative. For the customer, the scaffold is a temporal entity. For the constructor, it is a reusable tool. Instructional scaffolding are similarly temporal for the student and reusable for the teacher.

Instructional scaffoldings are stepping stones for learning. In many stages of education, it allows students to first learn the basics and then move on to advanced usages. Notice that Intelligence Amplification, bringing an unmonitored variable into sensory range, is reached by creating scaffolds. Not just instructional scaffolds, but scaffold as a more general concept will be central to this PhD for the support of innovation.

Scaffolding is a way to facilitate mediation. Teachers are scaffolds for students, providing personal coaching, giving verbal support to written instructions, using the blackboard to build the process, etc. In more recent work, Clay (2005) illustrates how this seemingly trivial relationship between teacher and students reinforces the student's cognitive development. Piaget (1928) shows that students learn more from their peers than from authorities. Peers create psychological scaffolds. For example, students have the same level of understanding, which can help to use the proper articulation. Other students also gain confidence to reach a similar level as they consider themselves more equal to other students than to a teacher. Such dynamics are useful for an experiment on synthesizing collective intelligence by a peer-learning system (see section 9.3).

2.1.3.3 SOLE case by guided self-organizing

Mitra (2003) remarks that the place on earth where education is most needed is the place where it is mostly absent. He, therefore, designed a project called "hole in the wall" which replaces the teacher by technology. The technology is not very advanced but it does create the required environmental enrichment to make education more self-organizing. The technology for the experiment was a simple computer that was connected to the Internet. The experiments started in urban slums and rural India, where the computers were installed in a solid wall (see Figure 3.13). It was found that children, in the absence of any teacher or instruction, were capable of learning how to use a computer for themselves. The initial experiment envisioned the Self-Organizing Learning Environments (SOLE) case (Mitra & Quiroga 2012). SOLE demonstrates that the essential environmental enrichment required to stimulate education is nothing more than a workspace.

Figure 3.13 children in slums self-educating in group with use of the Internet

With a workspace, it becomes possible to create a guided self-organization. The guidance results from the mediation of both the technology and the peers. As shown in Figure 3.13, it is a group of people collaborating in the same workspace. While the workspace allows for the learning to happen, the group can stimulate each other to do so and makes the learning go faster by knowledge sharing. At the moment, I only mention that the workspace allows for the learning to happen. The way that this works is an intriguing dynamic that is explored with the novelty regulation in Chapter 4. The focus in this chapter is on understanding intelligence amplification.

2.1.3.4 KidsCam artefact

All previous cases have created a context of intelligence amplification. The next case is the turning point that shows how individual intelligence amplification can be reached by collective intelligence. The example is KidsCam, which is used to support the development of skills in the context of everyday activities (Panayi et al. 1999). The project involves children between the ages 4 and 8 years and was applied in two schools, one in Israel and one in Denmark. The children wore wireless web cameras that were connected to a push button. They were instructed to use the buttons when there was something that they found relevant (positive or negative). There were several technical issues related to how to actually capture what the children saw. These issues are not discussed here. The outcome of the project was to capture the story of the day, creating two benefits. First, the children used the video for reflection on their activities of that day and what worked remarkably well. Second, parents would got to know the story on that day, allowing them to better understand the mood of the child.

Interestingly, the project was able to overcome an obstacle that we did not at first consider to be a problem, but the normal constraints of cognitive abilities. It is hard for the child to reason and think abstractly. This makes it difficult for a child to reflect on what happened during a day or even to express their current mood in respect to what has happened in that day. This can result in communication problems between children and parents. At first, the snapshots of relevant events during a day were given to the parent who could then better understand the mood of their child. A serendipitous spillover of this setup was that it allowed children to reflect on a higher cognitive level than normal. The videos simply show the experience and thus overcome the more difficult task of reflecting with abstract knowledge. At the end of the school day, children can watch the videos. This results in a clearly advanced reflection moment for the children, helping them to better digest the experience of that day.

The intelligence amplification with the KidsCam case can be considered exceptional. However, this insight allows us to think differently about the relationship between technology and intelligence. For example, a relative straightforward extension of the KidsCam case is to use similar event capturing for babies between the ages of 0-4. This can be done with current arousal technology that can be measured by sensors on the skin. The arousal technology can replace the instruction and push buttons and can capture the relevant moment experienced by the child without any need for conscious regulation of the child (pushing the button). The arousal technology is only an example. It cannot help with the validation for novelty regulation.

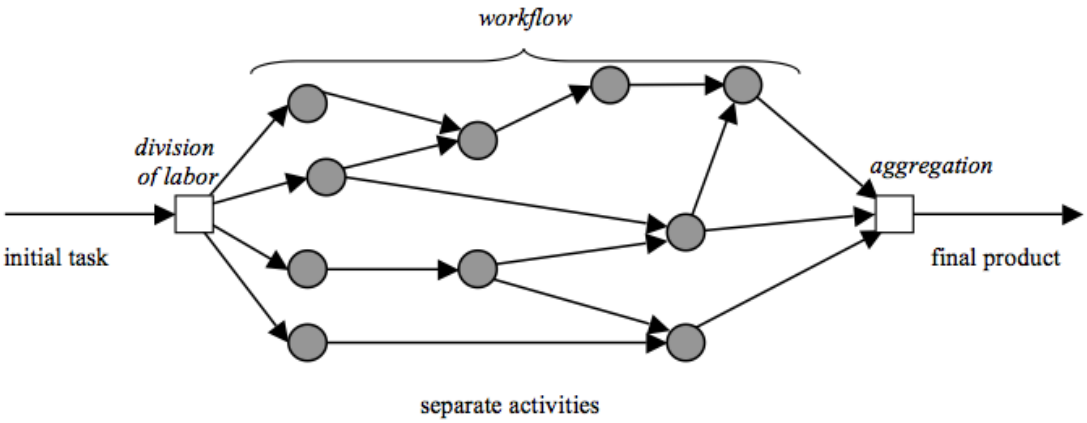
2.1.3.5 Synthesizing collective intelligence

For novelty regulation it is important to understand how intelligence amplification can help adults to be more innovative. Only a few visionary people have the intelligence to truly understand all aspects of innovation. The question that arises with the KidCam case is whether technology can help to mediate a collective and amplify the intelligence of individuals. The interaction between individual and collective is interesting. Let me first analyze the KidCam case with totters in order to better understand the feedback dynamics involved. Next the SOLE case investigates teenagers before getting to the actual focus of adults working around innovation.

While one child initially pushed the button of the KidCam, it would later be given to all children for reflection. This is the bundling of multiple intelligent agents focused on the same event. Not every agent has seen every relevant event, but together they may. The flow of knowledge created by agents performing some task may have some distortions and noise. For example, a child trying to grasp something and accidentally pushing the button or a child just playing with the button, etc. The flow created is raw and needs filtering. In the KidsCam case, the adults involved in the setup (researchers, developers and caretakers) become the moderators. Once the flow of information is filtered it has become a tool for reflection with the children and to inform parents of their kids' development.

By combining The KidCam case with the SOLE case, it becomes even more interesting to see how technology can replace portions of the role of the moderator. Computer-based learning environments, in particular, are good cases. Schank et al. (1994) introduce the concept of Goal-Based Scenarios (GBS) as a framework for such a computer-based learning environment. Just like KidCam, GBS shows how instructions and interfaces are essential. Collective intelligence happens by a workspace that allows for a workflow to arise. It starts with a division of labor and results in the aggregation of the solution (Heylighen 2012, Figure 3.14).

Figure 3.14 The coordination created by collective intelligence, it starts with a division of labor a workflow and finally the aggregation to a product.



Learning is easier when the knowledge is already clear for adults. Adults can improve the learning by creating a structure like instructional scaffolds. Learning becomes a bigger challenge if we are not dealing with knowledge transfer (from one generation to the other), but with knowledge creation. The first educational experiment is going to deal with the challenge to change education from knowledge transfer to knowledge creation (see Section 9.1). For innovation, knowledge creation is only one of the many aspects to be considered. The support of innovation by amplifying intelligence is going to be a much larger challenge to address. This chapter will only focus on the dynamics of learning.

2.1.3.6 Gamification

The use of simple but effective instructions and interfaces to create flow has been the focus of game designers. A game needs to capture the attention of the player in respect to skills and challenges. The game must do so without the players having much patience because the game needs to be entertaining. In contrast to other tasks, the investment to train the game is relatively low. This is particularly true with computer games, since no one finds it fun to learn computer interfaces.

Computer games have developed rapidly in recent years with technological developments. The investment by the entertainment industry to ensure good game design supports the fact that this is not a simple task. The profound understanding of instructions and interfaces, built by game designers has reached an interesting point. While the games initially had simple problem solving capabilities, the adaptation to improve the flow has allowed players to become very committed to the problem solving and the tasks have become all but trivial. Games now get exapted for other problem solving activities, like business games and educational games. Let me consider some of the contributions created by game design.

Good games incorporate the learning curve of the skills as part of its operation. For example, more advanced games use levels to unlock new possibilities once the gamer has mastered the previous skills. Games are often also about playing with other people and include peer mediation. In some online games, the peer mediation truly binds the player to the game, as players see their social live shift in the game. In these online games, communities get formed and the online communities also start organizing offline events, like barbecues. Games use rewards, exclusivity, reputation and many other techniques to develop a guided emergence for the players. Reputation, represented as badges, is one of the most recognized exaptation of games. It shows up in Question & Answers (Q&A) sites, learning platforms, developer platforms, online peer-to-peer shops, etc.

Computer games go far beyond any kind of instructional scaffolding that is found in education. This is because games are intended to be entertaining, not educational. A need for more exaptation is required so that gamification can turn into mobilization. This means that it has a very advanced collective intelligence where a community takes on a challenge and shows a well-coordinated division of labor and eventually creates an integrated solution. While education can be fun, it is not entertainment. The KidsCam artifact illustrates how shifting the focus of education becomes possible without slipping off into entertainment. In some cases, the subtle separation has not always been made, resulting in almost similar cases, where one has a positive effect and the other has a negative effect. To truly understand how the mediation of collective intelligence works requires more research. We will next consider other research that has been carried out on individual and collective.

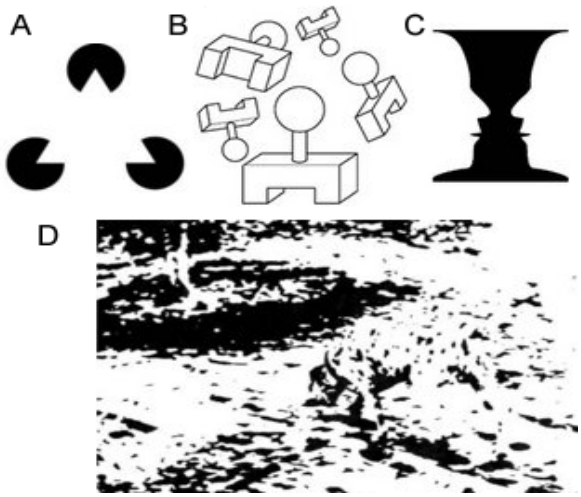
2.2 Individual intelligence

This section starts with well-known concepts in psychology. The first subsection is about Gestalt perception and the second subsection is about change blindness. Both insights help to understand the dynamics behind the sensory-motoric coupling. By considering the research on the extended mind hypothesis, the relevance of the environment becomes more refined. In the last subsection, the refinement is used to give more insight about the novelty regulation process.

2.2.1 **Gestalt Psychology**

The principle of Gestalt psychology is that our mind works in a holistic way. This is a theory formed during the early 20th century in the Berlin School. Lehar (1999) elaborated some Gestalt properties including: reification, invariance, multi-stability and emergence. Reification shapes more spatial information than the sensory stimulus actually perceives: in Figure 3.15.A a white triangle is falsely recognized. If we reason rationally about it, those boundaries are no actually there. The invariance property is about the recognition of a similar object, although each drawing is very different (illustrated in in Figure 3.15.B). Multi-stability is an ambiguous perceptual experience. In Figure 3.15.C, two white faces or one black vase can be seen. The last and trickier property is emergence. Figure 3.15.D is first seen as random dots. However, once the true picture is recognized, our mind fills in the hidden shapes. The picture is a Dalmatian dog sniffing the ground just in front of a tree. The tree creates shade, which forms the larger black circle in the picture.

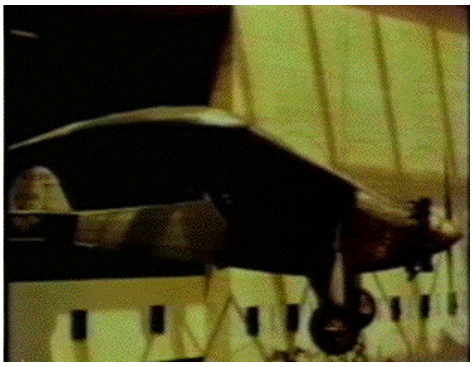
Figure 3.15 Reification (A), invariance (B), multi-stability (C) and emergence (D)



2.2.2 **Change blindness**

The limits of perception were investigated by change blindness (Shapiro et al. 1997; Simons & Levin 1997; O'Regan et al. 1999; Simons & Rensink 2005). The examples show how people fail to detect large perceptual changes. One example is the flicker technique. In that experiment, two almost similar pictures are shown with a blank screen between them, each is shown for circa 250ms. In some examples, the change is easily recognized, but other examples require several seconds before recognition. For example, the change between the two pictures in Figure 3.16 takes an average of 15.7 seconds to get detected.

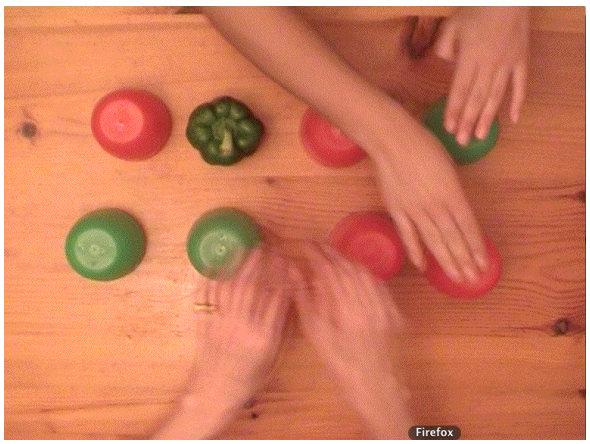
Figure 3.16 Left and right almost the same picture, only the shadows in the upper right corner changed



Another type of change blindness is inattention blindness. In these cases, the motivation of conducting a certain action makes you blind to changes in plain sight. The best known example is the man in a gorilla suit walking though the scene (Simons & Chabris 1999). Half of the observers did not notice the man in a gorilla suit. This is because, like with Gestalt property emergence, the scene was complex in many ways. People are asked to count how often a ball is thrown, but many balls are in the air and the participants are moving in complex patterns. The complexity required to properly perform the counting requires zooming out many of the ongoing activities and which seemingly also zooms out unexpected changes.

Another example is seen in Figure 3.17[1] were two pair of hands are changing cups simultaneously. The goal is to follow the little ball hidden in one of the cups. A green capsicum enters and leaves the scene as it replaces one green cup. In Figure 3.17, the capsicum is clearly in plain sight, but most observers would not notice the capsicum.

Figure 3.17 Inattention example, the green paprika in plain sight is hardly seen during the event, especially if one focuses on the task to track the cup with the ball in it.



The given task is making sure that only one particular cup is followed, but our brain would still need to be informed about perturbations. The shape and color of the capsicum is similar to the green cup. We can say that the anomaly is being

[1] The example comes from O'Regan, as presented at the Association of the Scientific Study of Consciousness (ASSC8) in 2004. He gave the video to me personally and permission to use it for my PhD.

camouflaged. The better the camouflage the worse it is for our perception to recognize it. In fact, in nature many animals make use of the camouflage technique, which illustrates the exploitation of the blind spot.

Another way to interpret inattention blindness is that the internal process was used to cope with the overload of information, by replacing the actual different cups by one prototypical cup. This abstraction can have the benefit of still keeping track of most of the cups. We could argue from an evolutionary point that it is more important to know how the cups move, than to see if such a cup would suddenly change. This is not likely to happen in a natural setting. Using this reasoning, just as with the reification in Figure 3.15.A, we can see how abstraction was relevant for perceiving alone.

2.2.3 Embodied and extended mind

The mind-body problem and the idea of an embodied mind date back to Immanuel Kant. It is out of the scope of this thesis to give an overview about embodied cognition. The basic idea is that the mind is not "a brain in a vat", meaning that it is not disconnected from its body. The extended mind hypothesis takes, based on evolutionary insight, the relation with the environment one step further, showing also that our mind cannot get disconnected from the environment. Clark (1989, p64) expresses this fundament as follows:

> In general, evolved creatures will neither store nor process information in costly ways when they can use the structure of the environment and their operations upon it as a convenient stand-in for the information-processing operations concerned. That is, known only as much as you need to know to get the job done.

To demonstrate Clark's claim, consider how bad our memory is for things that are easily verified, like color, length, weight, etc. In some cases, the environment becomes part of the memory. For example, one can do simple calculations in the head, but by using pen, paper and some simple rules one can make large and complicated calculations. (Clark 1998, p47) sees it as a shift from description to instruction:

> The idea here is that the brain should not be seen as primarily a locus of inner *descriptions* of external states of affairs; rather, it should be seen as a locus of inner *structures* that act as operators upon the world via their role in determining actions.

This fits well with the representation of knowledge as processes in my simulation. Let me again consider a case of breakdown to gain more insight. Clark and Chalmers (1998) created the famous thought experiment of Otto who suffers from Alzheimer's disease. Alzheimer has the effect that your memory does not work accurately and you cannot rely on it. Otto uses a notebook to compensate for the effects of the disease. In this case, the notebook is seen as a more reliable source for information than Otto's own memory. The claim in this famous case is that no distinction can be made between the notebook and memory. Therefore, the mind is

extended to the notebook. In his later work, Clark (2008, p79) answers criticism on his case that results in four criteria for making an external object a part of the mind:

1. That the resources be reliably available and typically invoked. (Otto always carries the notebook and won't answer he "doesn't know" until after he has consulted it.)
2. That any information thus retrieved be more or less automatically endorsed. It should not usually be the subject of critical scrutiny (e.g, unlike the opinions of other people). It should be deemed about as trustworthy as something that is clearly retrieved from biological memory.
3. The information contained in the resource should be easily accessible when required.
4. That the information in the notebook has been consciously endorsed at some point in the past and indeed is there as a consequence of this endorsement.

A cognitive agent can only be aware of what is in sensory range. As a consequence, many tools are created to shift what cannot directly be measured into sensory range. Clark (2008, p207) mentions something similar:

> The human sense of presence, of being at a certain place in space, is fully determined by our ability to enter into closed-loop interaction, in which willed sensor motions yield new sensory input, and by our ability to act upon at least some of the items thus falling within sensory range.

For most animals, the sensor-motoric coupling is fixed during embryonic development. Primate brains are different. They have evolved "bimodal neurons". Maravita and Iriki (2004, p79) elaborate how such neurons extend our embodiment:

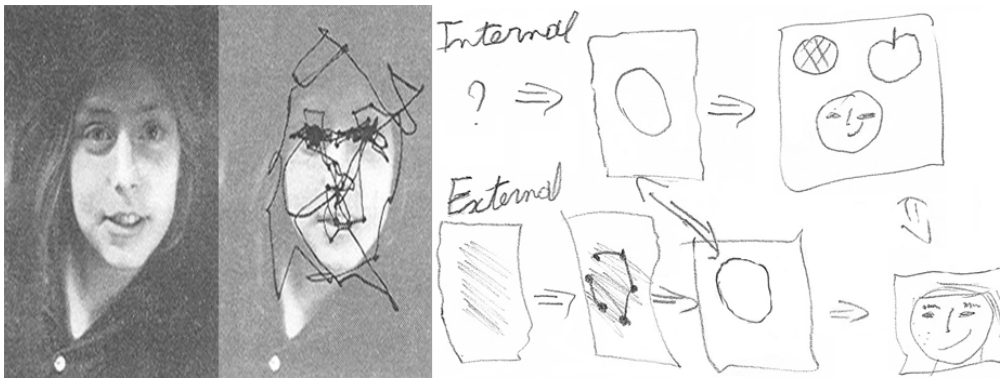
> In a series of experiments, recordings were taken from bimodal neurons in the intra-parietal cortex of Japanese macaques while the macaques learned to reach for food using a rake. The experimenters found that after just five minutes of rake use, the responses of some bimodal neurons whose original vRFs picked out stimuli near the hand had expanded to include the entire length of the tool, "as if the rake was part of the arm and forearm".

2.2.4 Cognition and novelty regulation

Gestalt and change blindness help to elaborate the complex feedback mechanism that initially existed out of three parallel processes (Kiemen 2006). Later, by recognizing other novelty models the feedback got described as four parallel processes (Kiemen 2008). For cognition, the parallel processes are anticipation processes working on the same workspace. The solution shifts the problem of complex regulation to simply regulation by complex knowledge. The main problem is recursion. You need to start with an existing and working complex knowledge base. Thus, while it becomes easier to answer a particular adaptation, there is a need to elaborate the origin. Babies have reflexes as scaffolds to their first motoric regulation. The origin is traced to more primitive functions that are formed by an even longer natural evolution process. As this is the case for motion, we wonder how it can help us to understand perception. The following is a possible evolutionary perception mechanism that emerges from primitive functions.

In the very first milliseconds that light touches our retina, it creates boundaries that can be explored by a rapidly moving eye. It has been demonstrated that our eyes make rapid movements while perceiving an object (Judge et al. 1980). This can be measured as the camera follows a movement of the pupil. By projecting the movement back to the drawing being perceived it becomes easier to understand (left side of Figure 3.18). Now consider how such rapid movements can help us to understand advanced perception, starting with simple functions. In the first milliseconds, the rapid eye movement may identify the general shape, which in our case is a round shape. The eye processes the shape by tracing the boundaries of the shapes. Tracing the boundaries requires an anticipation of where that boundary can be perceived externally. For a picture this is trivial. It is simply the difference between light and dark. If you consider a moving object, in that case the speed needs to be considered to anticipate where that boundary will be in a few milliseconds. In addition to the external anticipation, an internal anticipation exists that associates the current shape with past experience. Thus, round can be associated with ball, apple and face. Now the external process can verify the shapes related to the associated concepts. In our case, it results in the recognition of a face (right side of Figure 3.18). Notice that the external and internal anticipation are simple rules and the richness of the cognitive process is shifted to the knowledge.

Figure 3.18 Left side is a picture and shows how a rapid eye moves over the picture. The right side shows the possible cognitive processes behind such a perception.



This whole process happens unconsciously. You don't direct the rapid eye movement or wonder if something is a face or a ball, you perceive it. Still, there is a fine line; you may, for example, wonder about the emotion that the face is experiencing. These would be the next steps in the perception of the face and would require you to focus on the interesting facial signals such as that seen in the left figure with the picture's eyes, mouth and nose becoming repeatedly revisited by the perceiver's eyes. The coordination between internal and external process are basic enough to perform even such a complex task as long as the knowledge is rich enough.

Gestalt cases create a defense in this evolutionary process of perception. The method may elaborate why the Gestalt properties arise as they do. With the described feedback process, the reification in Figure 3.15A can be expressed as the

inability to falsify the association of the triangle, the multi-stability, then, because the two associations are equally positive. The emerging case was complex and it took the internal and external processes a while before they could create a positive relation with the knowledge. However, once it does, the shape is reinforced.

The process to describe perception shows how modeling is deeply rooted in primitive functioning, just like mastering finds its origin in reflexes. This brings the problem of the prior-knowledge back to the primitive evolutionary mechanism. Clark (2004, p81) expresses the constructive process of modeling and shows how it becomes a social issue:

> Just as I might use pen and paper to freeze my own half-backed touches, turning them into stable objects for further thought and reflection, so we (as society) learned to use the written word to power a process of collective thinking and critical reason. The tool of text (and to some extent speech) thus allow us, at multiple scales, to create new stable objects for critical activity.

The reference to an evolutionary mechanism makes us want to investigate in more detail what evolutionary studies can contribute. This is done in the next chapter in order to remain focused on the concept of intelligence in this chapter. What Clark describes as the process of collective thinking, is something that has to get elaborated with studies on collective intelligence.

2.3 Collective intelligence

The individual cognition is creating an ambiguity between the mind and the environment by using an internal workspace. The trend is extended by collective intelligence, since the environment becomes the workspace of the collective. By first examining in more detail the nature of collective intelligence, I can go back to the brain and its internal workspace in the last subsection. The first subsection is about the concept of stigmergy. Stigmergy was introduced to describe the intelligence of swarms. With stigmergy a new ambiguity becomes recognized which is between individual actions and collective actions. It shows a new center point of description where the brain is not the center but the challenge is. The new center-point is equally applicable to individual reasoning and collective collaboration. The environment becomes more important and the concept of environmental enrichment gets examined. The synthesizing of intelligence (individual or collective) is reached by systems internalizing a workspace. The brain is such a workspace and the last subsection considers an advanced brain study that was recognized as a novelty regulation system.

2.3.1 Stigmergy, a fundament of the social fabrics

The eusocial animals are interesting case in evolution. Eusocial systems reduce the autonomy of an agent in favor of the swarm. The division of labor becomes genetically encoded, such as with workers, soldiers and queens. The best known eusocial animals are insect swarms (e.g. termites, ants and bees), but eusocial

mammals exist too (the naked mole). Swarms are a unique hybrid. The swarm is much more open than any multi-cellular system, but much closer than a social system. Just like hormones regulate our body, most hives are regulated using hormones. For example, the queen bee constantly gives off a hormone that makes the workers act in a certain way. If the queen dies, the workers, in the absence of the hormone, transform the diet of the larvae in order to breed a new queen. This knowledge is common in the honey production industry.

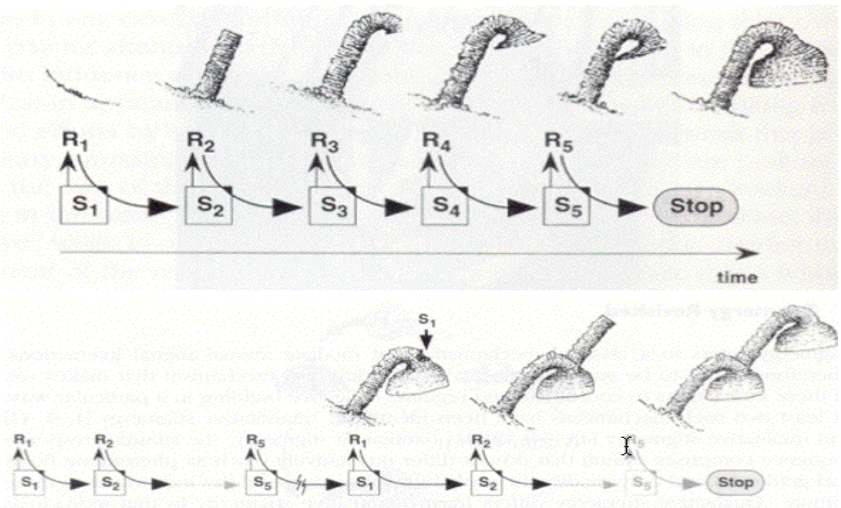
Hormones are one way of communication. Stigmergy can be more virtual using language as method of regulation (e.g. dancing bees, ants tapping with tentacles, etc.). Hormones could be considered part of the biochemical language. On a neural level, the language becomes more abstract and embedded in symbolic representations. The essential dynamic of the swarm allows us to recognize how the hormones and language are both stigmergic activities.

Theraulaz and Bonabeau (1999) present a good overview of the research on stigmergy. Grassé (1959) introduced the term stigmergy in the context of termites' nest reconstruction. Stigmergy is the contraction of two Greek words. (Heylighen (1999) expresses it as follows:

> An activity is stigmergic if the action by an agent leaves a mark (stigma in Greek) in the environment that stimulates an agent (the same or another one) to perform further work (ergon in Greek).

Smith (1978) illustrates how a solitary wasp builds their nest in a stigmergic way. This case demonstrates how stigmergy is part of the internal regulation by the agent. In Figure 3.19, each state (S) leads to a construction (R) until the nest is built. The second picture demonstrates a malfunction where the wasp recognizes S_1 and not S_5, which clearly demonstrates the stigmergic effect.

Figure 3.19 Stigmergy in the wasp's 5-stage nest construction.



To connect this to the insights on novelty regulation, it seems that the workspace and what is inside the workspace that makes the difference. This is independent if

this workspace is memory or the actual environment. The workspace is the new center-point. A brain can have a virtual workspace and use it as used by the agent to extend into environmental workspaces. The more enriched the workspace, the more it is considered intelligent. To say that this is true for an internal workspace is evident. Claiming that an enriched external workspace is intelligence requires some explanation.

2.3.2 Environmental Enrichment

Kirsh (1995) makes a strong claim about the relationship between space and thinking:

> The way we use special arrangements is not an afterthought but an *integral part* of how we think.

Clark (2008, p. 65) makes an interesting remark that Kirsh recognized how spatial arrangement "*ploys work*". The Oxford dictionary describes 'ploy' as: "a cunning plan of action designed to turn a situation to one's advantage". The use of ploy indicates that the environment has a plan for action. At first, it may be strange, so let us look at the case that introduced environmental enrichment.

It turns out that an information rich environment increases the neurological fitness of animals, such as the number of synapses and the propagation depth of the synapses. Experiments with mice show how different the neurological development is between mice living in dull cages and mice living in cages rich with toys (Renner & Rosenzweig 1987). The experiments have been repeated several times, excluding the possibility that the mice in one case were simply smarter. Because the mice are not different, we have to recognize how an environment facilitates intelligence. This insight has created the concept of "Environmental Enrichment" as a key to supporting intelligence.

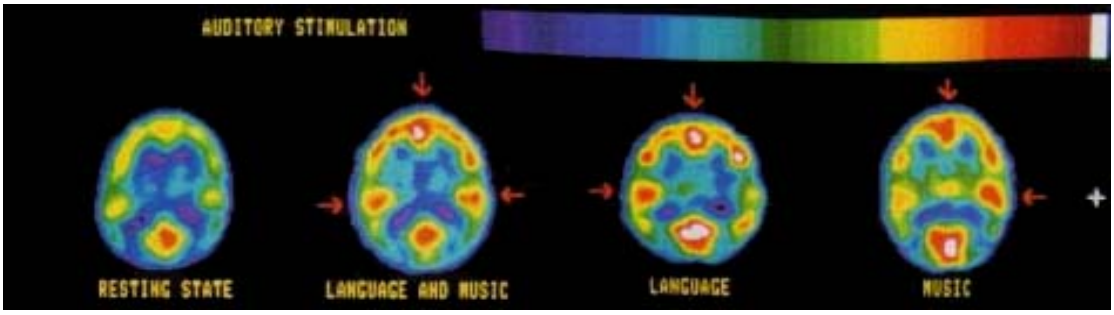
Environmental enrichment is the way to support innovation by intelligence amplification. Consider the previous education cases like SOLE and KidCam. In both cases, environmental enrichment was at the base of the solution. The dynamics of collectivity were at first not well understood. The cases can now be understood in a different way as technological mediation creates the enrichment, while instructions creates stigmergy that together overcome cognitive limits. To actually use such a mechanism for innovation requires a more refined understanding of what innovation is.

2.3.3 Global Workspace Theory: the first novelty model

In many primitive animals sensory-motoric coupling is relatively straightforward. It shows the embodiment of cause and effect. Reflexes are the most primitive of such relations, where a simple cause creates a programmed motoric response. Some reflexes are temporal, like the sucking reflex and the swinging reflex of babies. The higher cognitive functions are between sensory and motoric skills, allowing

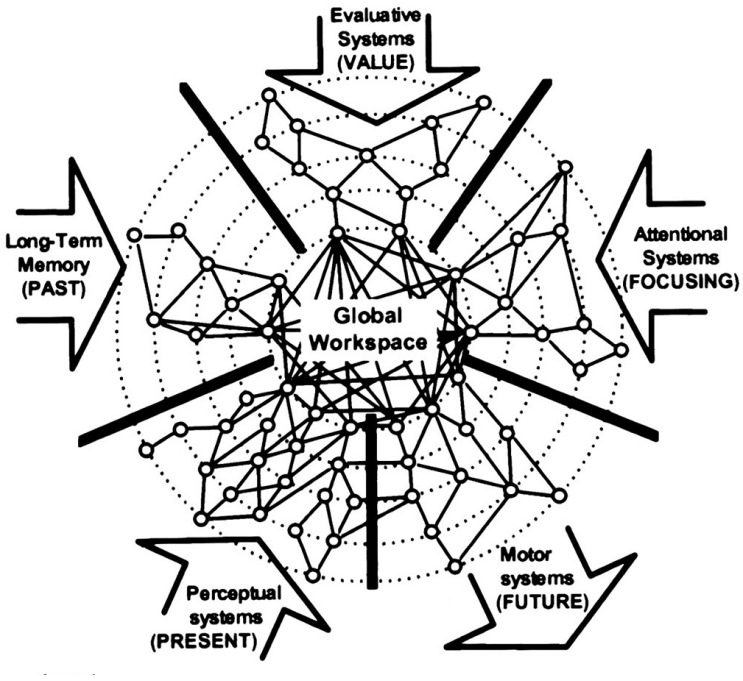
reasoning before taking action. In the process, the neurons that are involved burn energy which can be visualized using scans. The scans (Figure 3.20) have laid out a modular architecture of the brain related to the tasks being performed (memorizing, strategizing, counting, observing new things, etc.).

Figure 3.20 Brain PET scan shows patterns created in the brain.



The modularity of the brain made Baars (1993) design the Global Workspace Theory (GWT). The theatre metaphor is used to illustrate the GWT. A spotlight follows the players and helps focus the observer on those aspects. All the brain modules can be considered observers while the stimuli are the spotlight illuminating the global (internal) workspace. Dehaene et al. (1998) built the architecture to show how clusters of brain modules connect to the global workspace (Figure 2.21).

Figure 2.21 Entries to the Global workspace



The similarities between the feedback mechanisms of my simulations on exaptation (Section 2.1.1), the architecture by Dehaene and the architecture by Latour (Section 5.1.5) were too great to be a coincidence and resulted in the definition of the novelty

research (Kiemen 2008). Considering the relevance of Dehaene's model, let me give some details of the different entries for the global workspace:

- **Perceptual circuits** give the workspace access to the present state of the external world.
- **Motor programming circuits** allow the content of the workspace to be used to guide future intentional behavior
- **Long-term memory circuits** provide the workspace with an access to past percepts and events…
- **Evaluation circuits** allow representations in the workspace to be associated with a positive or negative value
- **Attention circuits** allow the workspace to mobilize its own circuits independently from the external world. Changes in workspace content need not necessarily lead to changes in overt behavior but may result in covert attention switches to selectively amplify or attenuate the signals from a subset of processor neurons.

The feedback by the entries are considered identical to feedback in the novelty model. The "Motor programming circuits" is not considered a necessary part of the novelty regulation, but a unique structure for the current embodiment of neurons. In other novelty models, this embodiment happens differently.

2.4 Research question I.1

What is the mechanism behind exaptation and can it help us to understand intelligence?

The first section showed the basic experiments by agent simulations. It provided insight on how the ambiguity was an essential component and argued for an embracing of complexity. It created a focus on examining technology for intelligence amplification that identified the relevance of proper sensory-motoric coupling and makes us focus on the effect of a workspace. Educational cases give insight on how intelligence amplification is about synthesizing collective intelligence and how it can overcome cognitive limitations. In general, the process requires a workspace and some feedback mechanism. The effect is a division of labor creating a distributed workflow and eventually a moderator filters the most intelligent contributions to give them back to the participants. It is by the combination of division of labor and moderator filter that intelligence can indeed get amplified.

After the introduction of the cases, there is an examination of the mechanism by going into more detail about the cognitive research. By focusing on individual cognition, particularly on perception, a case is made on how two parallel processes, working in one workspace, can create an internal reasoning that aligns with the observation about the perception of a person. The workspace shows how a mind extends to the environment and uses the environment for cognitive activities. This brings us to studies on collective intelligence where the role of the environment is even larger.

Eventually it results in the identification of environmental enrichment as a way to amplify intelligence. The support is described as a guided self-organization. It indicates that the support system only allows relative regulation and not absolute

regulation. It is, in fact, a kind of domestication. This chapter combined several disciplines working on cognition. We have only traveled through the domains in search of answers on novelty regulation. It is by having a thematic interest in the domains that a pattern can emerge across the domains to give us the required insight on novelty regulation. In a way, the answers were hidden in plain sight. The same will be the case when traveling across other domains to continue this journey.

3 Complex adaptive evolutions

3.1 Evolving systems: a general introduction

The research on exaptation shows how embracing complex adaptive solutions are needed. It is in fact a trend in science to move from simple environmental conditions to complex adaptive environments. Chapters 5, 6 and 7 show how such trend makes other domain construct, within their own discipline, the novelty model. Prigogine and Stengers (1997) describe this trend as the shift from the classic science to "Darwinian science". In physics the Darwinian science can be seen as a counter movement to Newtonian science. For the other domains different comparisons exists.

The Newtonian science was challenged in 1893 with Poincarés solution to the "three body problem", a prototypical problem in the Newtonian paradigm. The solution involved letting go of trajectories. Trajectories are very important to represent Newtonian mechanisms. Dynamic systems cannot calculate trajectories as recursion redefines the starting condition and so irreversible and instable processes arise. Irreversibility and instability are central to evolutionary studies. While irreversibility is a necessary condition for constructive growth, instability triggers self-organization.

The work of understanding Darwinian science is far from complete and it is what makes this modern science better known under the trendy names during a particular period, (e.g. "system & cybernetic theory", "chaos theory" and "complexity theory"). Projects like Principia Cybernetica (Turchin et al. 1993) work on building a coherent glossary. New ontologies get build to grasp the complex adaptive environments, like the Action Ontology (Turchin 1993). Heylighen (2011b) describes the Action Ontology as follows:

> The fundamental constituents of reality are seen as actions and the agents that produce them. … Thus, states are defined by actions, while actions are defined in terms of states. … An agent can then be defined as an aspect or part of a state that is necessary for the action to occur.

The way Heylighen describes an agent makes it indistinguishable with a catalyst. In section 4.1.2 I argue for a different articulation based on the studies done in this chapter. It is part of an ongoing study of evolutionary-cybernetics by evolving systems. Heylighen (1992) introduces the term evolutionary-cybernetics to indicate how variation and selection give rise to organization. Evolving systems is just a general description I suggest to consider the many specific studies done, like living systems (Miller 1965), Autopoiesis (Maturana & Varela 1980) and Complex Adaptive Systems (Holland 1996). Each of the concepts has a different accent to describe the structure and functioning of evolving systems. The added details by

each concept have value, but it would distract the focus away from novelty regulation, which is why no details are given.

The novelty regulation has been created to understand exaptation. Exaptation is a concept relatively new to studies on innovation. It has been more developed in biological studies on evolution. Adaptation cannot explain many structures recognized in biology. One of the examples considered by Gould and Vrba (1982) was on the evolution of bones:

> Halstead (1969) has investigated the question: granting its subsequent importance as body support in the later evolution of vertebrates, why did bone evolve at such an early stage in vertebrate history? ... Calcium phosphates, laid down in the skin of the earliest vertebrates, evolved initially as an adaptation of storing phosphates needed for metabolic activity. Only considerably later in evolution did bone replace the cartilaginous endoskeleton and adopt the function of support for which it is now most noted.

While many interesting cases of exaptation in evolution can get identified. I need to focus on understanding how studies on evolution can improve the novelty research. What made my investigation different to most research on exaptation is to take an engineering approach to study the design of the feedback mechanisms behind exaptation. This, then, result in a design perspective journey across many cognitive studies. In a same way, this chapter is going to be a design perspective journey crosses several evolutionary studies to better understand the origin of novelty regulation.

3.2 A design perspective on self-organization

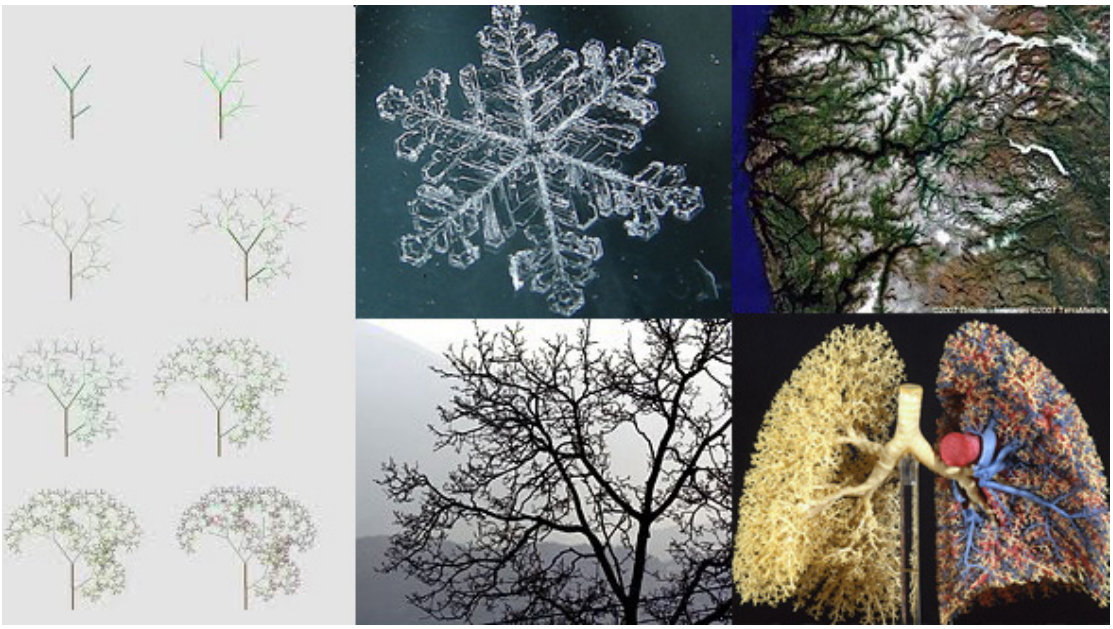
Considerering the importance of recursion for Darwinian science makes us start with fractals and how self-similarity links to fitness. The second subsection introduces dissipative systems to elaborate self-organization as an environmental condition. It can help to understand the concept of guided self-organization. The third subsection is a bit more complicated showing how the concept entropy becomes a way for self-direction to emerge. The self-directing introduces design science by evolution, giving a deeper investigation of interfaces, workspaces and the embodiment of the information. Such structures are important to gain self-regulation by the natural evolution around homeostasis. The cause-and-effect relation information has by sensory-motoric couplings gets used for homeostasis and creates a new level of abstraction.

3.2.1 Self-similarity, a mechanism for fitness

Recursive functions in mathematics are functions that have a reference to the function being defined. Fractal geometry is a good example to illustrate recursion as it visualized the self-similarity nature. The self-similarity means that the object is approximately similar to a part of it. For fractal geometry this appears, as the whole structure is copied on the structure's parts, creating a rich topological structure (see

left figure 2.1). What is fascinating about fractals is their common occurrence in nature for both non-living structures and living structures (see right figure 2.1).

Figure 2.1 Left, the self-similarity in a treelike fractal shows the recursion. Right, natural shaped fractal the top presents non-living systems, the bottom living systems



Very complex fractals are created by simple mathematical functions. This allows us to render fractals easily on a computer and it has led to the popularity of fractals. The mathematics does not elaborate why fractals are so frequently recognized in nature. What does it mean if you have a mathematical function representing a tree?

The reason why fractals are so common in nature relates to fitness. Let me give two possible reasons for the fitness. Fractals can occupy space and transport resources optimally. Notice how in the first structure in the fractal (top left figure 2.1) the structure is already spread in diverse directions. With next iterations the space between get more dens, which shows how the whole surface can get occupied. A second argument in favor of fractal fitness is how robust the structure is against perturbations. Take that a force would push on the basic structure. Let's be more specific, take a leaf (the fractal) and consider a branch falling on it (the perturbation). The fractal structure exists of nerves, showing how the base nerve gets split into smaller nerves. The material is a bit flexible. The branch would slip from the base nerve and break some of the smaller nerves, creating a hole in the leaf. So the weakest points are where the perturbation is most likely to create damages to the structure and it is where the destruction has minimal effect on the overall structure.

Consider that fractals apply to both living and non-living systems allow us to use fitness outside the domain of biology. For example, it can become a concept to

understand geological distributions. Heylighen (1994) gives us a better understanding of fitness for non-living systems by default assumptions:

> A physical example: “stones are hard” is a typical default assumption. For stones, hardness is a part of fitness: soft stones will tend to pulverize or crumble under the effect of erosion, and, hence, will be quickly eliminated. Therefore, the “abstract” default assumption that a stone is fit, implies “concretely” that it is hard. Another example, “water is liquid”, reminds us that fitness is relative to the environment: this assumption is valid only in the more common situations where temperatures are in between freezing and boiling.

Heylighen's argument about "fitness as default" applies to the design solution in my simulation on exapation. Indeed, the defaults in my simulation are also tautological descriptions. Working with default opens up opportunities for serendipitous observations and creative exaptations, replacing what used to be default by more refined insights. I plan to demonstrate the use of serendipity and exaptation for evolving systems, just as it was shown for cognitive systems. With recursion introduced, let me now consider how it can lead to the guided self-organization.

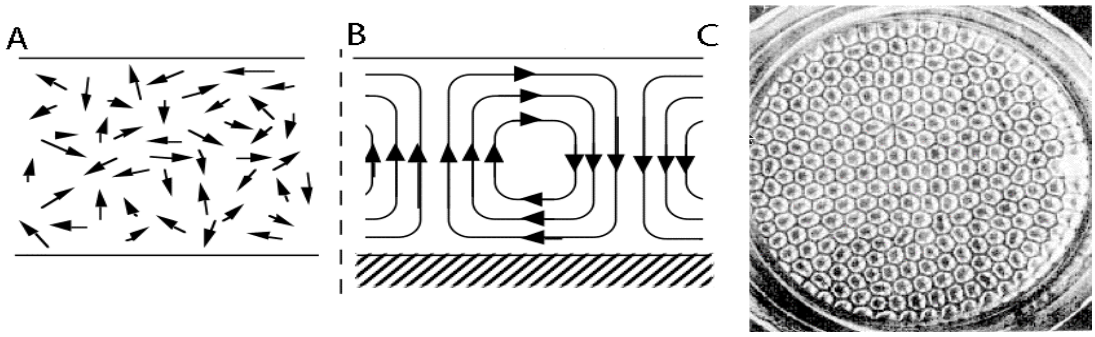
3.2.2 Guided self-organization, an environmental condition

Self-organization happens with a medium is far-from-equilibrium. Equilibrium is a state where the structures are stable. Static features can describe systems in equilibrium. Far-from-equilibrium the interactions are chaotic. At this point it becomes more reasonable to describe the system by its feedback processes. Dissipative systems are good examples to describe the dynamics. Like fractals, dissipative systems are common in both living and non-living systems (e.g. cyclones, whirlpools, etc.). Induced physical and chemical examples of dissipative systems (e.g. laser, Bénard cells, oscillating reactions) have created credibility to the research on self-organization (Prigogine and Lefever 1968). A famous dissipative system is the Bénard cells (figure 2.2). I use it to describe the general architecture of dissipative systems: *an external continuous source dispersing energy across a medium creates a far-from-equilibrium state fit for self-organization*. In case of the Bénard cells the large continuous force is heating, while the medium is a fluid. In some other dissipative systems the large continuous force can be more hidden and more virtual, like the oscillating chemical reactions, where the force are the laws of chemistry enforcing the reaction to deploy as they do. The Bénard cells allow a simpler visual description of the same dynamics.

In the Bénard cell the fluid becomes heated at the bottom stimulating an upwards movement. The fluid cools at the surface and then flows down. In the initial state the fluids moves randomly, like illustrated in figure 2.2.A. The self-organization emerges as a solution to the friction by the increased movement (via the heating). Cyclic motions emerge, creating positive feedback that reinforces the flow. By the distribution the development of such cyclical flows emerges all across the medium and at first it happens randomly. Some cycles may merge with other cycles; some cycles may collide and disappear. Eventually the dynamics settle on large cycles, optimally aligned for transportation of heat from the bottom to the surface, as

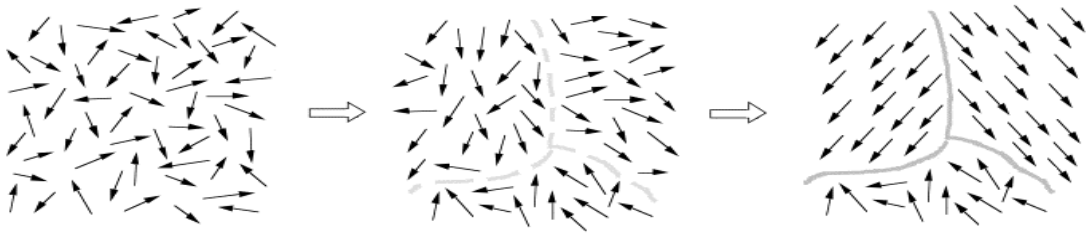
illustrated in figure 2.2.B. By shifting from a side view to a top view, these movements can be observed as hexagonal patterns, like illustrated in figure 2.2.C.

Figure 2.2 The self-organization of Bénard cells as a dissipative system.



Notice that some level of irregularity exists in figure 2.2.C. This happens with local alignments create stable subsets as a consequence of distributed self-organization. To demonstrate how local alignment can lead to some irregularity. Let me give a different example. The example is about self-organization in a magnet. At first no alignment exists and by self-organization some alignment emerges (figure 2.3). The positive feedback would align the arrow in the same direction, still as this is happening simultaneously across the whole medium, some other local alignment may be in conflict with each other. In figure 2.3 you see how three sub-sets emerge, creating a boundary between the different alignments before the whole system has reached the sub-optimal alignment, strengthening the boundaries.

Figure 2.3 Local self-organization making boundaries emerge



For dissipative systems the pattern is created by the energy flowing through the medium. This does raise some questions on when something is a flow and when it is an open system. In case of the Bénard cell it is evidently an open system, as the liquid stays the same, while the heat flows through it. In contrast to a whirlpool where the liquid is part of the energy flowing trough the system. The whirlpool becomes more virtual structure than the Bénard cells. Still, in both cases the system is not defined by the parts, but by the flow. The Bénard cells or the whirlpool are invariant patterns by motion and not solid objects. In cognitive studies flow is an optimal condition for intelligence. Clearly flow is a fascinating concept that requires our attention.

What is interesting about the dissipative systems is that it describes a mechanism how to create conditions for self-organization: a constant energy source + a medium

to disperse = self-organization. By creating proper environmental conditions, it thus becomes possible to guide the self-organization as to gain some kind of benefit. The gas-laser is probably the best example of it. The mechanism is creating conditions optimal to get concentrated bundles of light. The tricky part of evolving systems is to gain the ability to guide the self-organization for its fitness, which can get expressed as "self-directing".

3.2.3 Self-directing and asymmetric transitions

With the artificial creation of self-organization (e.g. Bénard cells, oscillating chemical reactions, lasers, etc.) the self-organization became well proven. We do need to remark that many scientists were skeptical because of the paradox that existed with the 2nd law of thermodynamics. The 2nd law of thermodynamics states that *entropy in closed systems cannot decrease*. Entropy is a thermodynamic property that can be used to determine the energy available for work. Self-organizing according to Ashby (1962) is a reduction in the number of reachable states, which means the statistical entropy is diminishing. Statistical entropy or Shannon entropy is based on the probability distribution of the different options. Shannon was creating a theory on information and not aware that the same mathematical function was used in thermodynamics. Von Neumann (1956) made the connection and elaborates how Shannon's work relates to the original entropy concept by Ludwig Boltzmann. This has lead to much confusion, as the thermodynamic entropy and statistical entropy seem to claim the opposite. The simple solution is to consider self-organizing systems to be losing entropy to the environment (Von Foerster 1960). However, this does not help understanding the commonality between thermodynamic entropy and statistical entropy. Heylighen (1992) improves our understanding:

> A deeper understanding can be reached by going back from the statistical definition of entropy to the thermodynamic one, in terms of energy or heat. Energy is defined as the capacity to do work, and working means making changes, that is to say exerting variation. Hence energy can be viewed as potential variation. A stable configuration does not undergo variation. In order to destroy a stable equilibrium, you need to add energy, and the more stable the configuration, the more energy you will need. Therefore stability is traditionally equated with minimal energy.

Introducing "potentiality" is binding thermodynamic and statistical entropy, while creating an opening for design science to become part of evolutionary theory. Design is often considered the ability to create change and this "potentiality" is neither a physical nor a chemical feature. It should be considered a design feature. Let me continue to elaborate how Heylighen (ibid) uses potentiality to better understand entropy with open systems:

> In an open system, where new energy is continuously added, the configuration will not be able to reach the minimum energy level. In that case we might assume that it will merely tend to maximally dissipate incoming energy, since transitions where energy is emitted are (much) more probable than transitions where energy is absorbed. That hypothesis seems equivalent to the Law of maximum entropy production (Swenson, 1989), which describes dissipative structures and other far-from-equilibrium configurations. In such configurations

the stability is dynamic, in the sense that what is maintained is not a static state but an invariant process.

This description of open systems helps to understand how stability is reached so the statistical entropy is diminishing, according to the principle of self-organization, and at the same time energy is dispersed into the environment, according to the 2nd law of thermodynamics. While entropy creates with "potentiality" an entrance for design as a natural science, the "maintaining invariant processes" allows the design to flourish. I describe this with three subsections: on interfaces, on workspaces and on embodied information.

3.2.3.1 Self-organization of interfaces

The statistical entropy comes from Shannon's information theory. Shannon (1948) was searching for the meaning of information. Bateson (1979, p99) would later define information as: *a difference that makes a difference (see also Jacob 2004)*. Bateson made this claim in a particular context. Let me consider a correction. A difference that makes a difference does relate to the concept of entropy as a measure of the uncertainty. Figure 2.3 gives an example how uncertainty decreases while self-organization makes the elements align. I claim it makes design emerge, but it is not yet information. Information needs more conditions as I show in the next subsection.

Design is about making a useful difference, which adds meaning. Boundaries create a difference that makes a difference. Boundaries should be recognized as primitive design aspects. The meaning emerges as boundaries become useful. The usefulness can have no direction and no purpose. Let me elaborate this by considering how filters could emerge without the filter having any purpose.

Consider figure 2.3 and take that the arrows represent particles in a fluid, so they could move, but with the same conditions as magnets has, being a side that attracts and a side that repulses. Such biochemical artifacts exist, for example fatty acids repulse water, while most biochemical artifacts are attracted to water. The top of figure 2.4.A has a clear organization, making the particle align and unlikely to change. They can become the boundaries of the filter.

The bottom still has randomly moving particles. Take a particle moves directly into the cross point of the boundaries, working as a chisel where other particles hammer the first particle deeper in the slit (figure 2.4.B). The space created by the one particle getting into the boundary would stimulate the process and so it makes the top alignment become a gate, filtering the fluids at the bottom (figure 2.4.C). Such filtering is recognized with rivers hammering through rocks based on the gravity and indeed the water can cut the hardest stones when giving it enough time. In more advanced systems, like cells, such filtering becomes a common practice, allowing some particles to enter the cell, while others cannot.

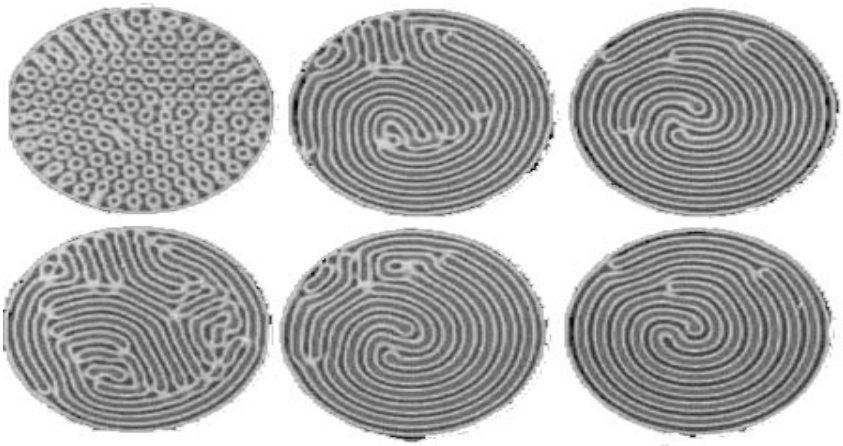
Figure 2.4 From self-organizing boundaries to interfaces

This example demonstrates a selection based on direction, in this way it is quite similar to how a laser function. In a laser only photons under the right angle with the right frequency pass, creating the concentrated bundle of synchronized light. I consider filters but an example, what is fundamental new is the interface. To consider another example of an emerging interface I consider workspaces.

3.2.3.2 Development of information in workspaces

Workspaces have boundaries and interfaces. The basic requirement for a workspace is a neutral medium. What is considered neutral depends on what is trying to propagate through the medium. For the neutral medium to be a workspace the space is constraint and has a consistent sensory-motoric coupling. The consistency is important, as similar values of the input needs to generate similar patterns. The description fits with how electrical current runs trough the neural connections in the brain creating patterns like shown in figure 2.21. The description for workspace can fit more primitive systems in nature. To demonstrate this, consider the advanced Bénard cells, where the edges are heated. The heated edges create a regulating force and so can be considered the sensory input. Depending on the temperature, different invariant processes transport the heat (see figure 2.5). In this case, the pattern arising and the motoric coupling is the same. For brains more disconnection exists between the patterns and the actions. In essence the same dynamics get recognized.

Figure 2.5 Bénard cells with different heated edges demonstrating workspaces.



The advance Bénard cells setup demonstrates the most primitive form of information. The pattern is the result of the value of the input (boundary conditions). Note that the Latin word for 'information' comes from 'in' (into) + 'formare' (to form). The literal translation is pretty good description of what the advanced Bénard cells are doing. The information is in my opinion only something that develops in a workspace. In the Bénard case the information is the fittest way to dispose the heat.

What Bateson describes as information was when the workspace is taken for granted and the question becomes how to distinguish a relevant pattern from all the other patterns. In other words, when is information useful for an agent? Notice, meaningful and useful are not synonyms. A lot of meaningful information can exist that is irrelevant for a particular task. What is useful depends on the purpose given by the agent.

The advance Bénard cells setup is a unique event creating rare conditions to make information arise in a workspace. The advanced Bénard cells are very simple compared to the workspace by more advanced evolving systems. Interestingly, the more advanced the evolving systems, the more workspaces become abundant. Humans are advanced evolving systems and our ability to work with information has made everything become a candidate for a workspace. Simple space is required to gain a workspace. All other requirements are created by our extended mind and projected in the space, in a virtual way. Like demonstrated by the case of Otto, who has Alzheimer and uses his notebook as a memory deposit (see section 2.2.3).

To study the nature of workspaces more, the biochemical world, and the study of the origin of life, becomes essential. It requires several conditions before life can emerge and evolve (space is not enough). For the origin of life the ecosystem becomes a workspace, while natural selection becomes the input and the emerging of species are the emerging patterns. The species are agents and transform the medium; it shows a succession of ecosystems. So, the self-organization turns into a constructive process that is bootstrapping the medium (the ecosystem) and the invariant pattern (the species). To understand evolution in this way requires a closer look to a biochemical world and how it embodies information.

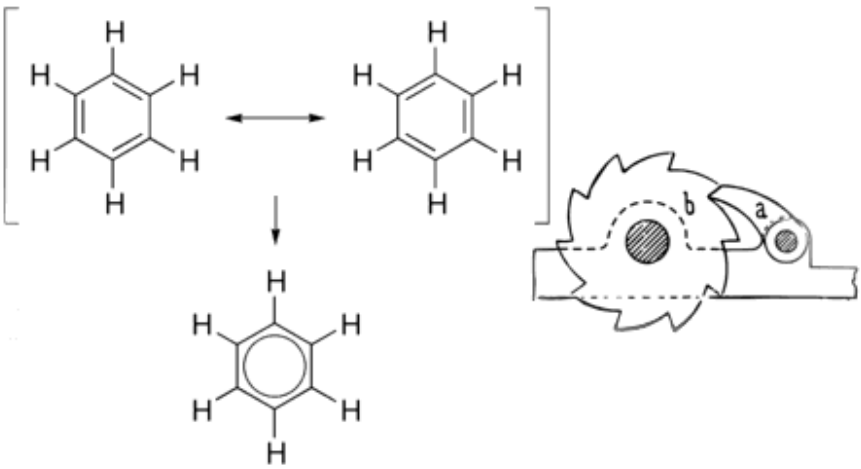
3.2.3.3 Self-reproduction by embodied information

The advance Bénard cell was an example of a fluid-based medium becoming a workspace. The problem with fluid-based medium is when the physical forces disappear, the system goes back to a state of equilibrium and the information is lost. So before it is possible to get to a system that can use information, the information needs to get embodied first. The most primitive storing of information is the composition of chemical elements. So consider an environment where a flux of breaking and making chemical connections exists, which would make far-from-equilibrium chemicals arise creating invariant chemical processes. To make far-from-equilibrium chemicals, a neutral element is required to build networks. This is what makes carbon so interesting. Carbon-based mediums are considered the required neutral mediums. The examples are plenty in biochemical world.

To demonstrate invariant chemical processes consider benzene. The basic benzene structures exist of six carbons, connected in a hexagon pattern. Each carbon has one hydrogen atom. The last connection is a second connection between one of the two edges, but this connection is unstable and moves internally, like presented at the top of left figure 2.7, it becomes alternatively represented as a cycle for the inner changes. While the inner is instable, benzene itself is a common and stable artifact in our biochemical world.

Chemical system can create irreversible connections. Some of those irreversible connections create a ratchet effect. The ratchet effect refers to a ratchet device, which is a mechanism that allows movement in only one direction as illustrated in figure 2.6. The wheel (b) can only rotate counter clockwise as the hammer (a) blocks any clockwise movements. This is the constructive development of information, as the ratchet effect builds regulation on regulation. It makes both functional and structural complexity grows (Heylighen 1999). What makes more advanced design structures emerge.

Figure 2.6 Left benzene's inner instability, right the ratchet device



Advanced structures of invariant chemical processes can be recognized with the metabolism of species showing catalytic reactions. Kauffman (1986) demonstrates an autocatalytic set that can construct the elements making up the set. The chemical information embodied in this set is extensive, but still primitive considered to self-reproduction of living systems. Living systems have the ability to use information for the development of the new system, adding inheritance to the self-reproduction. Considering that the complex adaptive dynamics are all without purpose makes one wonder when purpose becomes an issue.

3.2.4 Self-regulation and homeostasis as the emerging of purpose

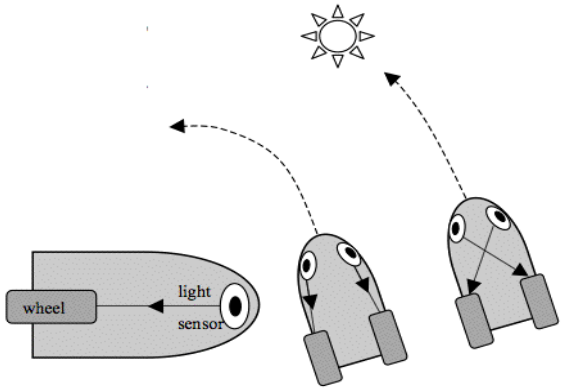
The most primitive purpose that arises is for a system to use information to improve its existence. While this existence of a system itself can still be purposeless, the internal regulation becomes useful in respect to the system's existence. There is nothing magical about this existence, as mentioned earlier fitness is a tautological concept useable for both living and non-living systems. Systems can increase their fitness by a mechanism to keep internal variables within acceptable parameters. This mechanism is called homeostasis(Cannon 1929). Living-systems use homeostasis all the time. Like thyroid hormones effect on brown fat to increase heat production in case the boy is too cold and sweating to decrease the temperature in case the body is too hot. Non-living object can show homeostasis too, it is just, as fitness with fractals, a fundamental dynamic in our Darwinian science.

Homeostasis can exist without workspaces and information. It is when information is used for homeostasis that self-regulation has emerged. In all other cases the regulation is by external forces and then it is a basic self-organization. So far the most primitive systems where such homeostatic regulations are recognized is with the studies on the origin of life. In how far this means that purpose only emerges as life emerges is unknown, but it does seem logical that the two are entwined. The emerging of information as a tool for regulation is complex. Once it has emerged it can simplify complexity tremendously by the use of sensory-motoric coupling.

A simple example of the causal relation by sensory-motoric coupling is observed with chemotaxis. Chemotaxis is the movement of an organism in response to chemical stimulus. For example, bacteria move randomly (tumble) and the variation of the random move depends on the state of the environment. When the concentration of toxic increases the bacterium tumbles more to get out of the toxic environment. When the concentration of toxic decreases the bacterium moves more in a straight line (Berg 1993). To give some idea of the simplification, consider the Braitenberg vehicle (figure 2.7). Braitenberg (1986) demonstrates how a simple causal coupling of sensory-motoric relation can make a vehicle behave complex adaptive and natural. It only requires two sensors and two wheels. When the sensor receives more light the wheel goes faster. So no light means no movement. Figure 2.7 shows that if the coupling crosses, the vehicle moves toward the source of light, a bit like bullfighting, where the light works like the red draping. The vehicle moves faster to the light and once it is under the light will slow down and turn to chase the

light again. In case the coupling is direct, the vehicle seems to flee from light and comes to a standstill in a dark place.

Figure 2.7 Braitenberg vehicle by a simple sensor-motoric coupling, the light regulates the speed of the wheel.



The simple cause and effect rules were also examined with the simulations on exaptation, where it got examined how such rules can be added. The next advancement in the evolving systems is to create self-awareness by novelty regulation. I prefer not to enter the delicate domain of consciousness. The self-awareness is a higher-level cognition creating constructive growth of the knowledge base (see section 2.1.1). How such regulation relates to consciousness is another issue entirely. Instead of investigating consciousness, I like to take a step back and go deeper into the richness of biochemical reactions to study self-directing and self-regulation by the origin of life.

3.3 The origin and evolution of life

In an attempt to understand the evolution of life, researchers have tried to find the environmental conditions that would explain the self-organization of life. In other words, they have investigated the workspace for life. Miller (1953) created a primitive soup experiment to mimic conditions expected to exist on earth before life. There wasn't any oxygen in the environment. Under equilibrium state oxygen is far too unstable. Instead a hot, far-from-equilibrium environment exists. By creating a particular chemical mixture with electrical charges the construction of first biomolecule was demonstrated. Miller's experiment has boosted the research significantly. By examining the origin of life I can continue the investigation of self-directing and self-regulating systems.

I begin the first subsection with a proposition about meta-workspaces. This proposition allows me to continue with the design perspective on the origin of life. The second subsection considers how the medium allows feeding systems and the ability of guided self-organization. The third section on the major transitions describes the emerging of a new neutral medium, being the nucleotides-based

medium. The fourth subsection gives more details on the nucleotides-based medium by examining coding and embryonic development. The fifth subsection considers a discussion about relative and absolute novelties by brain development, adding a second absolute novelty. The last subsection considered self-communication as a very primitive form of self-awareness.

3.3.1 A proposition on meta-workspaces

The gradual improvement by natural selection in a niche is a common concept in biology. Niche, what comes from the French word 'nicher' and is translated to "make a nest" describes the specific environment to which a species adapt. For example, if an animal inhabits a cave, the animal adapts to fit better in this niche. Such adaptations can be recognized by convergent evolution, meaning that different species under similar environmental pressure create similar 'fit' solutions. Living systems can also change their environment to make it more fit, leading to the concept of niche construction (Laland et al. 1996). Like a beaver creating a dam to artificially create a lake. In an attempt to find the origin of life intermediate stages of development need to be recognized(Smith and Szathmary 1999, p56):

> As always when explaining the evolution of novelty, we seek an intermediate stage that would work well enough to survive, give an opportunity for gradual improvements by natural selection. The semicell, relying on mineral surfaces for nutrients, provides such an intermediate.

The niche, in this case, is an environment that allows self-organization. The big questions are how major transitions, like the first semicells, can have occurred. Such major transitions are phase transitions in the ecosystem, changing many parts at the same time creating radical change. While radical change can be reached by a novelty regulation, also an intermediate regulation, with simpler, but less efficient structure has to get considered. I propose meta-workspace for it. The meta-workspace is a workspace of workspaces. The benefit of such a structure is that each workspace may create unique components. It may well be that the unique components are unstable. Because the workspaces are in close proximity, the unique components can interact amount each other before they break down. What happens is very comparable to the dissipative systems with a significant advancement: *the invariant patterns are embodied*. Not only energy is needed, but also building blocks to keep this self-organizing system stable. It is a feeding system that only exists as long as the feeding continues. The most primitive example of such a feeding system is a fire. Notice that a fire is often used as example to elaborate how a living system's metabolism works. Consider that fitness is about equilibrium raises questions on why feeding systems become such dominant elements on earth. More detail is needed to understand how creating instability results in higher-order system showing advanced fitness.

3.3.2 **Guided self-organization by feeding systems**

A feeding system is a system that has to consume resources from its environment in order to survive. Feeding systems are not yet living systems, but most of the dominant feeding systems are, which relate to other functions of the system like reproduction. Consider most systems try to get in equilibrium by losing energy in favor of stable connections. Feeding seems to do exactly the opposite. Living systems store and use resources to maintain their far-from-equilibrium structure. The first living systems fed by autotrophy, which gets energy from inorganic sources. This first type of feeding has become marginal because it is a very slow process to more advanced feeding methods like photosynthesis (feeding on sunlight) or heterotrophy (eating other life). Photosynthesis requires advanced components, while heterotrophy cannot be the first method by definition. Autotrophy is only found in in rare niches, like volcanic vents, while it is a slower process it is the foundation that made all other life possible.

The feeding system is an advanced self-composition system, the metabolism becomes used as energy for construction and for homeostasis. It is beyond my understanding how this exactly has emerged (if one is the exaptation of the other etc.), but this is not important for my argument. The argument is that biochemical-base systems start feeding to gain self-regulation over its far-from-equilibrium environmental conditions and it the process the system become more robust. The robustness relates to the homeostasis. Where other system would have fixed variables, the feeding system had to get constructed with dynamic regulation, keeping the variables within acceptable boundaries. Such flexibility can create conditions for further evolution (more detail in section 4.1.4).

3.3.3 **Meta-workspaces creating major transitions**

In the meta-workspace a central niche can become the global workspace, in the sense that the many unstable constructs are brought together in such a central workspace and can create a complex structure that reaches stability by self-organization. The invariant process can be very complex. The benzene was the simplest example. The autocatalytic set shows how more complicate invariant process can result in self-replication. The catalytic sets by nucleotides shows a whole new level of regulation. Before considering nucleotides I make some more propositions to create the proper mindset to understand the dynamics nucleotides add. This requires me to consider the internalization of meta-workspaces.

For example the brain is an ecosystem of neurons clustered in modules and the global workspace in the brain is central to this ecosystem (see section 2.3.3). It is my proposition that many animals may have an internalized meta-workspaces, but that fuw species have brains wired in a way that it becomes a novelty model is only seen with the most advanced species and can get related to the ability of that species to create artifacts. The brain is not the only place the internalization of meta-

workspaces is recognized. A more primitive internalization of meta-workspaces is recognizable with the embryonic development.

The neurons create artificial regulation by the causal relation between patterns emerging in the workspace. This process makes information virtual entities we call concepts. The recombination of concepts is simple, compared to a biochemical recombination that needs to deal with an embodiment of the information. In that way the embryonic development can help us understand better the novelty regulation, but it will also become complicated because of the constraints. In the biochemical world recombination needs to take into account all kinds of extra constrains, like how the nearness of other elements may interfere with the reaction. Consequently specific spatial constructions of the artifacts are observed.

Both embryonic development and brains show the internalization of meta-workspaces, which is the intermediate to a novelty regulation emerge. The increase in fitness by internalization of meta-workspaces speed up the evolutionary game. This internalizing of meta-workspace brings me to an assumption that is only described in this research; the validation is left for future research:

> **Claim**: To get a phase transition requires a meta-workspace. To get a meta-system requires internalizing a workspace.

For the first part of the assumption I'm introducing the study on major transitions in the origin of life. From such introduction I'm gradually getting to the second part that investigates the meta-system transition. The study of major transitions is most advanced in the origin of life studies. Smith and Szathmáry (1997) split the major transition is order of first appearance, but this may raise some questions of its own. My own adaptation is tables 2.1. I have split the transition between transitions of the scale and transitions of the function. The transitions of scale go from pre-cells to cells to multi-cellular. Let me mention that also in physics studies of such scale transition are examined around the unified field theory. In physics different level shows different laws. By scale the lower laws become less essential while on upper levels new laws become dominant. The unified field theory tries to create general physical laws that can explain the laws on the different scales. For a historical overview on the research around unified field theory, consider Goenner (2004). It is not our intention to work on a unified theory, just to mention the apparent similarities with scale transition.

Other major transitions happen related to the function of the living system, they are harder to grasp, and counter intuitive. For example, why would sexual reproduction be preferred over cloning? Sexual reproduction is a decrease of autonomy. It turns out that the decrease in autonomy can be explained by the increase in the autonomy of the meta-level (Heylighen 2004b). For example, sexual reproduction creates conditions for the social skills to evolve more profoundly, like seen with eusocial creatures (see section 2.3.1). Biologist create extensively argument on how to understand the social advancement from a pure genetic reasoning (Dawkins 2006). Such argument shows a logical reason for the functional transition to occur.

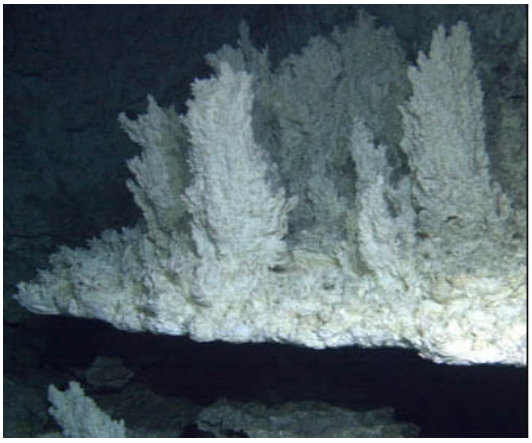
Table 2.1 Simplified description of meta-system transitions into two categories

Scale	From	To
Pre-cells	Miller's experiments	Prokaryotes
Cells	Prokaryotes	Eukaryotes
Multi-cellular	Eukaryotes	Multi-cellular
Eussocial	Animals	Hives
Function	**From**	**To**
Reproduction	Cloning	Sexual
Coordination	Solitary	Colonies
Regulation	Survival	Sociocultural

To give some detail, consider one of the ongoing investigations of the major transitions. Let me take the studies on semicells. Researches have come to the conclusion that DNA could not exist outside a cell and proteins have not evolved by natural evolution. RNA and ribosomes are considered more primitive structures that could have build the DNA and proteins, which lead to the so-called RNA-world hypothesis. Wächtershäuser (1988) suggest the iron-sulfur world theory that is based on environments created by deep undersea volcanic hydrothermal. Such a world makes semicells more likely by the intermediate stage of surface metabolism.

The debate is still ongoing. Martin and Russell (2007) suggest alkaline hydrothermal vents are more suited than iron-sulfur vents. An alkaline hydrothermal vent, like the "Lost City" (left figure 2.8), was only discovered in 2000 and explored in 2003 (Knittel & Boetius 2009). An alternative theory focus on foam-bubbles as niche (right figure 2.8), such a environment takes into account radiation from the sun as a needed part of the environmental conditions to create the required biochemical components (Cleaves & Miller 1998).

Figure 2.8 Two niches considered the possible ecosystem for making semicells emerge: left, alkaline hydrothermal vents creating, right, foam-wave.



Both the hydrothermal vent and the foam-bubbles are biochemical ecosystems, allowing possible meta-workspace to arise. Nucleotides are the building blocks of nucleic acids, which is what RNA, DNA and ribosomes are made of. Nucleotides also

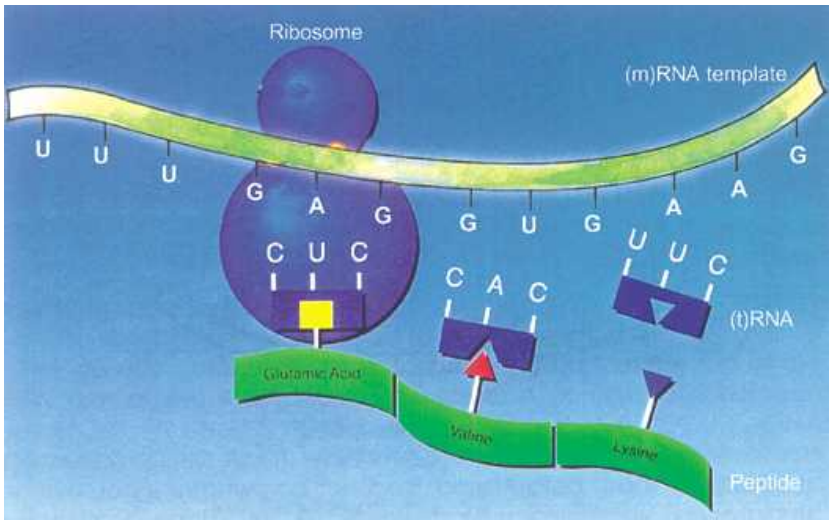
play a central role in metabolism as sources of chemical energy. This different role of nucleotides creates an argument how nucleotides can be a new kind of medium. When all the nucleotides components got together in the meta-workspace, creating higher-order invariant processes that make a meta-system transition arise. In this new medium bootstrapping process get recognized, like RNA creating proteins that build the RNA, which are used to build RNA.

3.3.4 **Organic code by nucleotides**

The nucleotides allow a different kind of dissipative system to arise and this time designs are more outspoken. While carbon-based mediums has allowed self-regulation to arise, the nucleotides-based mediums create the true foundation for life. The new medium allows a new kind of evolving system to arise that is significantly different from systems like autocatalytic sets. The new dissipative system emerging from nucleotides-based mediums are feeding systems that have many controversies that requiring our attention. Organic coding and embryonic development

Digging deeper to understand the nucleotides-base world shows some advanced design structures like coding and modularity that allow for general-purpose machine to arise. It is commonly accepted that DNA contains the code of life, but hardly do we understand what the code means. Lets me shortly elaborate the dynamics at this level. The DNA is the memory unit and RNA function as a chemical interface to code proteins. This happens with a message (mRNA) being copied from the DNA. The mRNA can leave the nucleus and go to the cytoplasm where it interacts with the transfer (tRNA). The tRNA contains modular slots of peptides, once a new messages binds to the coder (ribosome) the chain of information is transformed to a particular protein, as illustrated in figure 2.9. Each peptide can get connected to another peptide, thus making a general-purpose machine. Once the transcription is done, the protein folds creating a particular function based on the spatial structure of the protein. Memory, interfaces and coders are explicit designs in the nucleotides-based medium.

Figure 2.9 Translation process from DNA to mRNA to tRNA to proteins.



Single cell organisms have only one chromosome. In case of multicellular systems, one cell contains multiple chromosomes containing the code of the whole multi-cellular system. Multi-cellular organisms have sexual reproductive cells contain only one half of the chromosome, with all the stops removed. Once the two chromosomes merge during fertilization, the cell division follows the germ line, switched on and off some of the chromosomes. For example, take a germ line 'abcd' where all genes are switched on, now a differentiation of cell division could turn off some of the genes (indicated with *) like: a*bcd, ab*cd, etc. Once a particular cell is reached (e.g. lever cell, brain cell, etc.) the germ line has ended.

In embryology the germ line study has lead to identifying "Hox genes" that regulate the number and placement of segment structures (e.g. wings, legs, eye, etc). Just like the peptide, the hox genes illustrate the modular coding in biology, anywhere you look at this level you see design being created by the system. The germ line may form the impression that genes control the development, but a certain nuance is needed (Smith and szathmary 1999, p 122):

> The startling finding is that, if the mouse gene is transferred to Drosophila, then, wherever it is activated, it causes an eye to appear. The kind of eye that develops, of course, is a compound insect eye, not a vertebrate eye. So, when we say that the gene 'controls' eye development, this is rather misleading. What the gene does is to initiate a series of events at a particular site in the embryo, causing an eye to develop at that site: it does not control the kind of eye that develops. In effect, it signals 'make an eye here'. … A particular Hox gene in Drosophila switches on, not one other gene, but a whole cascade of genes. To alter the signal would alter many features if the resulting structure.

In other words, the genes do not control the development and the DNA does not contain blueprints. Instead the whole structure seems to create conditions for guided self-organization. In other words the information gained some regulation, but it is not a strong control as with blueprints, such level of control is not reached with nucleotides-based mediums.

3.3.5 Relative versus absolute novelties

A contribution to the foundation for novelty research comes from embryonic brain studies. Barbieri (2008) separates relative from absolute novelties. While relative novelties have emerged, absolute novelties only exist as some system has fabricated them. According to Barbieri the first absolute novelty is proteins, produced by ribosomes. The second absolute novelty is feeling that likewise only exist because brains fabricate them. It is my understanding that absolute novelties only emerge when meta-workspaces are internalized and become the regulation of the development. A pattern is observed related to the medium. Flow-based mediums make the design emerge, carbon-based mediums embodies the emerging information, which makes autocatalytic growth possible. Nucleotides-based medium make code emerge that explicitly creates designs by the guided self-organization. Only with brains, being a neural-based medium, do we truly see control arising as the disconnection between the patterns, stored as knowledge, becomes used to intelligently regulate actions.

Technology is another example of absolute novelties that only emerges with a social-based medium, build as a meta-system with neural-based systems. So, with a certain medium, a certain workspace can arise that are capable of creating certain artifacts. It seems to correlate to something discovered in media studies by McLuhan (1967) who claims that "the medium is the message". The reason is logical, with a particular medium a particular propagation can arise and so a particular self-organization is recognized. This insight is essential to create a stronger definition for novelty regulation in section 4.1.1.

Let's get back to Barbieri (2011) to get insight on how three types of brain emerge. The most primitive brain is a cybernetic brain that is based on a condition-action rule. It is considered the default brain. Out that cybernetic brain an instinctive brain has emerged and it is this part that creates feelings. Feelings improve the fitness of the animal in the complex ecosystem. For example a snake stops chasing when the pray is out of sight, while a mammal would still search for the hidden pray (ibid, p14). From the cybernetic brain a third type of brain emerges, which is called the interpretive brain. This brain allows recognizing abstract signs in the environment and allows language to evolve.

The evolution of three types of brain shows that once a particular module exists, it can be exapted for other functions. The cloning of brain modules is used by Hawkins (2004) to argue how the brain can produce higher-level reasoning with multiple similar modules. He shows how simple anticipation processes get hierarchical composed to become much stronger anticipation processes that can deal with abstract information. His insights align well to our understanding of evolutionary based perception (see section 2.2.4). In section 4.2 the anticipation processes become the building blocks to describe the novelty model for knowledge creation.

3.3.5.1 Self-communication a foundation for self-awareness

Another contribution to the foundation of the novelty research relates to basic self-awareness studies. As argued before my use of self-awareness is much more primitive than consciousness. The concept of self-awareness can get applied to simple insect brains, which are not considered in consciousness studies. The simple brains have simple reasons to create memory and they seem to hide a social dimension. Sharov (2009) describes it as the simplest case of communication, being self-communication:

> The agent uses his memory to communicate with its own future states.

Sharov's articulation allows thinking differently about communication as a feature for inner reasoning. Note how self-communication is an intermediate stage to actual communication that requires externalizing the communication by language. Communication is fitter when many agents interact, by a simple division of labor rule. Again, some bootstrapping process is recognized as a language can improve self-communication by internal monologue. Consider that the social dimension is already so important at this fundamental level should create the understanding how important the social dimension is going to be in the study of innovation.

3.4 Research Question I.2

> *Can a foundation be built for novelty research by integrating design into studies on evolution and if so in what way?*

Like with the cognitive study a very selective part of the research on evolving systems is considered that only touches on the vast amount of knowledge in the domain. The focus this time was to find some grounding for design in evolutionary development. As argued it shows up around some of the most fundamental concepts like entropy and homeostasis. By creating a constructive investigation the concept of "self-X systems" arises, where the 'X' is what is being internalized. To internalize a pattern requires a medium in the case of the most primitive mediums the construction shows self-organization. In more advanced mediums the construction results in more interesting forms, like self-construction and self-regulation. The study only shows the very beginning of bridging some of the gap between cognitive studies and evolutionary studies. In particular the concept of workspace seems essential. The workspace is a neutral medium that transforms sensory input by patterns to motoric responses. The advanced Bénard cells seem the most primitive case of a workspace, creating the sensory-motoric coupling. In cognitive studies neurons are way more advance systems capable of disconnecting the embodiment of information and by it, it gains higher-order of autonomy.

In respect to our investigation of design in evolution, it is particularly the studies on the origin of life that should be considered where many designs have emerged that can guide us to a better understanding the evolutionary principles of design. The

concept of internalization becomes truly interesting, like how DNA may contain the code of cellular systems, but not contain any blueprints, which are higher design concepts requiring higher regulation systems. For higher design concepts it is required to have meta-systems and once investigated in more detail, it seems as many such mediums exist (fluid-based, carbon-based, nucleotides-based, neural-based and social-based).

A new kind of schooling is required to understand the logic of evolutionary principles of design. New concepts like self-communication can help us understand the buildup to self-awareness. The study makes an explicit contribution to the theory on novelty with the division of relative versus absolute novelties. The study has also inspired the insight of some of our social development (see section 5.2.8). Such evolutionary studies are to be sure fundamental to understand the self-organization in other domains. Consider that the attempt to create a Darwinian science has already spread across several generations, it is clear that the study is important, while it may require several more generations before we gain a good enough understanding of the dynamics.

Our focus on novelty regulation is only a small part of the larger change of a Darwinian science. The focus on novelty brings us deeper into particular topics, like the concept of ecosystems, creating meta-workspaces that enable a phase transition. Some challenges for fundamental research can be created. For example, it would be fascinating to investigate if novelty regulation has some relation to major transitions, like the emergence of semicells. As argued, it seems evident that such steps in evolution have happened in meta-workspaces. To claim that it has happened with novelty regulation is something very different and ways to even design a test for such a claim are still mysteries.

By moving away from the fascinating events around the origin of life it may become possible to understand meta-workspaces in the context of innovation and maybe later try to bring our insights back to the studies of the origin of life. Before going to studies of innovation we need to synthesise our understanding and create at least a start for a theory on novelty. Concepts like meta-workspaces are new and require to get situated in a more traditional system and cybernetic investigations.

4 The novelty theory

4.1 Variation and selection bootstrapping artificial evolution

This chapter is divided into two sections. In the first section, we examine how the evolving systems of the previous chapter can provide us with a more formal understanding of artificial evolution. In the second section, novelty regulation is examined more formally, taking another look at artificial evolution. Evolution is a process of variation and selection. The artificial evolution is a process of artificial variation and artificial selection, which happens when potential variation and potential selection become actual variation and actual selection.

In Section 3.2.3, Heylighen describes energy as potential variation. Based on this description, we elaborate on the artificial variation. When potential variation changes to actual variation, it means that the energy is used for the fabrication of an artifact. The fabrication of an artifact is only the beginning. A bootstrapping process between more advanced forms of artificial selection and artificial variation can be created. Natural selection is created by the evolutionary pressure in similar niches a convergent evolution: *different species under similar environmental pressure create similar 'fit' solutions.* Within some environments, some interactions are simply more likely or more fit than other interactions. The evolutionary pressure can become artificial selection if we artificialize the process.

The evolutionary pressure relates to McLuhan's (1967) observation that "the medium is the message". In other words, fabrication (variation) in some medium (selection) creates the artificial evolution. The energy is only potential variation and potential selection can also be recognized. The actual selection comes from the interaction. In case no interactions exist, we have just "a collective" and not yet a medium. A collective is potential selection because it already hides what interactions would be possible.

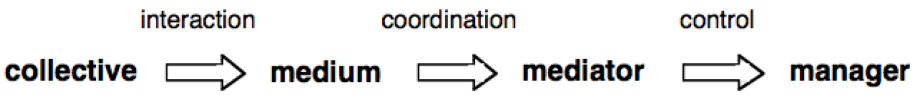
The artificial evolution is a bootstrapping process between variation and selection. A bootstrapping process implies intermediate stages. From potential to actual evolution is the first stage transition. Under the assumption of evolutionary cybernetic, more stages exist for variation and selection. The stages for variation are elaborated as stages of agency. The stages for selection are stages of mediation. This brings us to the definition of artificial evolution:

> Artificial evolution is a bootstrapping process between agency and mediation

The stages of agency start from basic fabrication and eventually make agents emerge. In the intermediate stages, fewer of the agent-capabilities are recognized. The stages of mediation stretch from collective to meta-systems. Heylighen (2006) elaborates how the stages of mediation eventually create a meta-system:

> Every collection of interacting agents has an aspect system that is simply the medium carrying the interactions. While this medium initially exploits the agents' activity to survive and grow, selection will make it evolve into a cultivator that improves the collective fitness of the agents by attenuating conflict and promoting synergy. We have called the next stage of this evolution the "mediator" (see Figure 5). A mediator reduces obstruction, waste of resources and risk of conflict or cheating, and increases complementarity and mutualism by constraining or directing the agents' autonomous actions so as to achieve the best possible coordination. In the final stage, which we called "manager", the mediator intervenes actively to make agents perform the precise actions that most benefit the collective.

Figure 4.1 The stages of mediation show how relations (interaction, coordination and control) also change the state of the environment (collective, medium, mediator and manager)



Refinements to Heylighen's description are required. In particular. the description only explains the emergence of meta-systems by agents and not the relation with the intermediate stages of agency. Separate subsections examine the complex bootstrapping by artificial evolution. The first subsection creates some context for artificial evolution where fabrication happens by environmental conditions. The second subsection investigates the stages of mediation and how the workspace is central to this mediation. Subsection Three considers the stages of agency when agents can also create the fabrication, creating a richer understanding of the artificial variation. With the richer understanding, Subsection Four can focuse on the emergence of novelties. The last subsection uses chemical organization theory to examine the dynamics in a more formal way.

4.1.1 Artificial evolution and emerging of knowledge

To understand agency, let us introduce some of the basic cybernetic laws describing the nature of regulation. The **law of requisite variety** is fundamental to cybernetics insight created by Ashby (1958):

> The variety in the control system must be equal to or larger than the variety of the perturbations in order to achieve control.

The law was created to describe the fixed control systems. Heylighen (1992) has adapted the definition for evolutionary cybernetics, so the law can fit evolving systems:

> The larger the variety of actions available to a control system, the larger the variety of perturbations it is able to compensate.

A second important law by Conant and Ashby (1970) goes as follows:

> Every good regulator of a system must be a model of that system.

The law later became known as the **law of requisite knowledge**. Heylighen (1992) adapts the law for evolutionary cybernetics into:

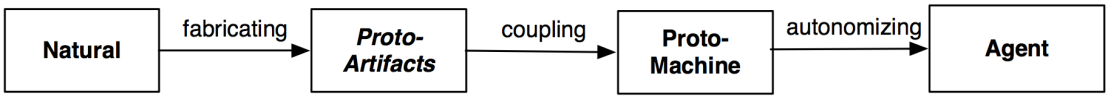
> In order to adequately compensate for perturbations, a control system must "know" which action to select from the variety of available actions.

The law shifts the problem of regulation to understanding how knowledge can emerge, which also relates to the stages of agency. Let me first just introduce the stages, like we have introduced the stages of mediation. Notice that stages of mediation explain what the different relations are (interaction, coordination, control) and not how they came into existence. Let me do the same for stages of agency.

First, with energy the natural world gets enriched with artifacts. To distinguish between artifacts created by agents and artifacts emerging from specific environmental conditions, the latter are called proto-artifacts. The previous chapter elaborated how fluid-based mediums can create proto-artifacts like cyclones and whirlpools. They are artifacts, since they only exist by releasing energy in a medium (fabrication). Notice how the artifact is created by specific environmental conditions. Under environmental conditions, coupling of proto-artifacts can result in proto-machines. Just like with the proto-artifacts, chance also creates the first proto-machines. Machines are capable of producing complex functions. For example, the autocatalytic set is a proto-machine has a self-reproduction function.

The coupling makes the function emerge, which is necessary, but not sufficient to get to an agent. The last transition requires regulation by knowledge, which makes the machine autonomous. The process of making something autonomous lacks expressivity in our language. There is no verb that describes it. From the adjective "autonomous" I construct the verb "autonomize", using expressions like "autonomizing". This will be consistent with Section 5.1.4 where Latour expresses similar dynamics with "autonomization". Figure 4.2 gives an overview of the stages of agency (Figure 4.1).

Figure 4.2 The stages of agency by different development processes: fabricating, coupling and autonomizing.



Each stage of agency (variation) stands in a bootstrapping relation with each stage of mediation (selection). It starts with random variation and selection by evolutionary pressure of the natural environment. First, fabrication creates a variety of (proto-) artifacts. The selection makes some artifacts more common or more stable than others depending the conditions of the environment. With the

enrichment by artifacts, coupling now creates a variety of (proto-) machines. A new kind of selection occurs. The ability of a machine to create complex functions requires that those functions align with the environment. In other words, a kind of self-coordination occurs. The self-coordination is when a proto-machine aligns with the environment. More complex coordination appears when other proto-machines exists, allowing coordination between the machines, which makes an ecosystem emerge. To illustrate how the self-coordination is a selection process for machines and how it can make knowledge emerge, let me consider an example created by (Heylighen & Joslyn 2001):

> Let us illustrate this by considering a primitive aquatic organism whose control structure is a slightly more sophisticated version of the thermostat. To survive, this organism must remain in the right temperature zone, by moving up to warmer water layers or down to colder ones when needed. Its perception is a single temperature variable with 3 states X = {*too hot, too cold, just right*}. Its variety of action consists of the 3 states Y = {*go up*, *go down*, *do nothing*}. The organism's control knowledge consists of a set of perception-action pairs, or a function f: $X \rightarrow Y$. There are 3^3 = 27 possible such functions, but the only optimal one consists of the rules *too hot* → *go down*, *too cold* → *go up*, and *just right* → *do nothing*. The last rule could possibly be replaced by either *just right* → *go up* or *just right* → *go down*. This would result in a little more expenditure of energy, but in combination with the previous rules would still keep the organism in a negative feedback loop around the ideal temperature. All 24 other possible combinations of rules would disrupt this stabilizing feedback, resulting in a runaway behavior that will eventually kill the organism.

The example shows how 27 possible variations exist with only four that would result in self-coordination (alignment with the environment). Once selected, the machine has very primitive knowledge. Selection, by interaction, is still very natural. The self-coordination is also very natural. With coordination the artificiality of selection increases, because selection becomes a bootstrapping process: *selection of machine A depends on the selection of machine B*.

Consider that the primitive knowledge is coded in one or another way. A specific variety can arise by an evolution of the code, which creates autonomization. In other words, the machines become agents that are taking their evolution into their own hands by exploring the possibilities with code. This again has an effect on the artificial selection. In case of coordination, fitness became dynamic. In this new situation of exploration, fitness can even become defined. In other words, the artificial selection becomes control. The niche constructions are examples of controlling fitness. Details with stages of medium are required to understand better what control is.

4.1.2 Intermediate stages of mediation

Convergent evolution shows the basic selection by a medium. Design thinking needs to be applied to understand convergent evolution properly. For example, it is wrongly argued that under convergent evolution, water animals would develop fins and therefore water snakes become an anomaly. Describing fins as the fittest tool to

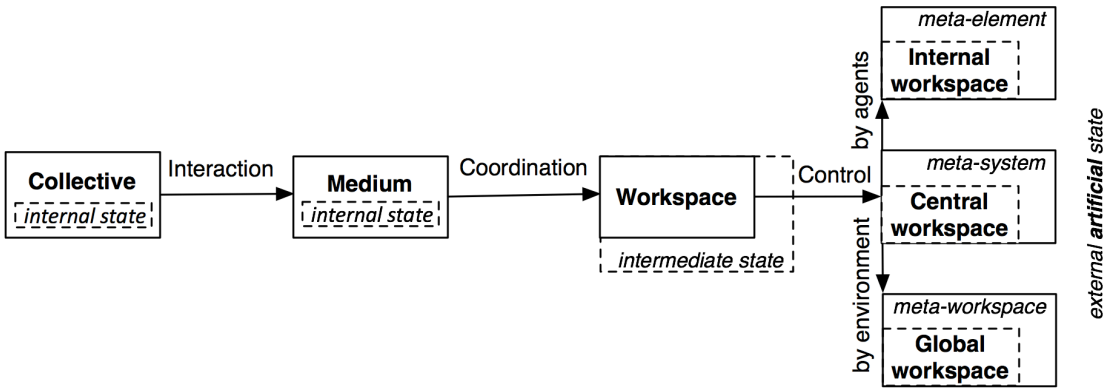
move in water is from a design perspective a simplification. Let's do better. A more accurate description is to recognize how an animal needs to handle the boundary conditions of the medium to move in that medium. Considering actual types of medium allow us to become more specific about the design.

Three different mediums are recognized for motion: swimming in water, flying in the air, and walking on the surface. Every animal that swims has a body fit to use the viscosity of water. Notice that with this description, snakes also fit the profile. To fly in the air, the body needs to capture the lift of the atmosphere. Bodies walking over surfaces need to reverse the impulse reaction. Details of the process are given in the next subsection. Notice that surfaces may exist in water or in the air. The crab is a good example since it walks both in water (e.g. ocean floors) and in the air (e.g. beaches). The interesting design feature of a snake is that it is appropriate for swimming in water and for gliding over surfaces.

The stages of mediation start with the collective being potential selection. It becomes actual selection by interaction, transforming the collective into a medium. The medium is a special case of workspace where only one static boundary condition exists. Where in a medium the interaction between the elements results into some selection, the workspace shows coordination between the elements, making a type of input result in a type of selection. In the last transition, the workspace is an essential component of a meta-system. The meta-system produces control and the workspace is central for the distribution of control (by stigmergy, see Section 2.3.1).

The description of a meta-system with a central workspace is an abstract representation that becomes more specific as we consider where the control comes from. When control comes from agents, I call the meta-system a meta-element (what Heylighen called a manager). When control comes from the environment, I call the meta-system a meta-workspace. The need to have an abstract representation relates to the entwined relationship between meta-element and meta-workspace. In one interpretation, the meta-element is a special case of the meta-workspace. After all, the meta-element requires agents while the meta-workspace does not. To compensate for the loss of regulation, the meta-workspace requires more specific environmental conditions (workspace or workspaces). Therefore, in another interpretation, the meta-workspace is a special case of the meta-element. As such, we need to generalize and therefore Heylighen's initial description gets transformed to Figure 4.3.

Figure 4.3 Cybernetic stages of the workspace



By aggregation, the collective has an internal state as the shared state between the elements (see also left side of Figure 4.7). In the medium, that state defines the selection. In the workspace, it becomes more refined. The selection now depends on the input. The initial state becomes an intermediate state because of the relative relationship between fitness and coordination. Fitness is an environmental aspect by coordination getting artificialized, showing how the state is not only internal any more. I consider the state intermediate because of the relative relationship. When fitness becomes defined by control, the state changes to an external artificial state.

In the abstract description, a central workspace exists. In the concrete controls, the central workspace becomes more specific. In case of the meta-element, a whole complicated mobilization can be created to get the specific resources in specific quantities into the central workspace, which therefore is called the internal workspace. In the case of a meta-workspace, the mobilization is external to the system. It is the special environmental conditions making the central workspace become a global workspace. Global, in this case, refers to the fact that many local workspaces exist to create this one central workspace. In a special case, a meta-element may actually internalize a whole meta-workspace so we get to an internalized global workspace (see Section 2.3.3).

With the two types of meta-systems creating external artificial states, another bootstrapping process is recognized that shows how a constructive process of enrichment becomes possible. On the one hand, the meta-workspaces can create agents, needed to create the meta-systems. On the other hand, the meta-systems can create refined workspaces, which lead to refined meta-workspaces. For example, in next chapter the social fabric (the meta-element) creates laboratories (the refined workspace). The Internet is an example of refined meta-workspaces where software agents are created. Notice that software agents show autonomy, but are not based on an evolution of self-regulation or self-reproduction such as recognized with living systems. They only exist because human agents have developed them. The feature of lesser artifacts and even object gaining autonomy will be examined in the next chapter.

4.1.3 **Intermediate stages of agency**

Under only environmental conditions, is the bootstrapping between agency and mediation still relatively simple. The stages become more complicated if we consider the possibility of agents producing agency. The bootstrapping relation between meta-element and meta-workspace shows how this complexification exists with mediation. In addition, for agency the fabrication of artifacts by agents creates complexification. A separation is made between two types of artifacts that the agents can fabricate. The artifact enhances the agent or it enhances the environment. Enhancing the agent results in a specific type of artifact called tool, while enhancing the environment results in scaffolds. For both tools and scaffolds, the effect can *amplify a function or restrain a perturbation.*

For example, a stone used as a hammer amplifies force and so the stone becomes a tool. Using a branch to hold off an attack is an example of restraining perturbation. In both cases, it is a tool extending the agent. To understand scaffold, let me refer to example discussed in more detail during next this chapter. Figure 4.6 shows rice terraces that transform hills into cascading swamps. The leveraging into terraces is restraining the perturbation of floating. After all, in swamps the water doesn't flow. Creating basins allows for several centimeters of water that amplify the water level.

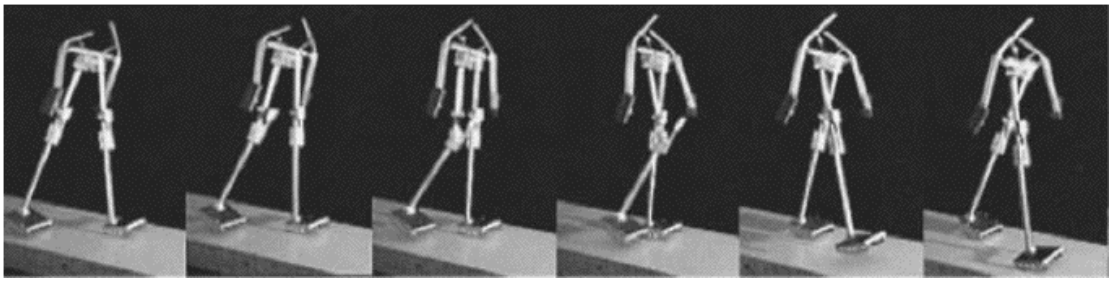
The separation of tools and scaffolds allows us to gain a more detailed understanding of what the difference between an advanced artifact and a machine is. Machines need coupling of tools and scaffolds. For example, a bike is an advanced artifact consisting of many components. It is, however, still only extending the agent. In contrast, a combustion engine is a machine transforming energy into mechanical motion. The combustion engine is different from a bike because it couples scaffolds and tools. The carburetor is a scaffold that reduces the atmospheric pressure, creating conditions for the mixture of air and gasoline. The mixture is then compressed in the piston just before combustion in order to capture the energy of the explosion and transform it to mechanical motion.

Changing the atmospheric pressure is impossible in the environment itself, so part of the environment needs to get internalized. It is a first example of actual physical input. Compare it to the input of a workspace that could only be informational. The coupling of scaffold and tools create transducers. A transducer is a device that converts a signal in one form of energy to another form of energy. It is creates the basic system structure: input, internal and output. Miller (1965) describes input transducer, internal transducer and output transducer. The carburetor is an example of an input transducer, while the piston is an example of an external transducer. For an example of an internal transducer, we examine the relationship between body and brain.

Bodies that walk over surfaces have a complicated framework to transform the impulse reaction from the surface back to the surface. If done well, motion is reached with little energy. For example, a human skeleton has, by evolutionary pressure, resulted in a very good framework to transform the impulse reaction, as

can be demonstrated with a toy using some counterweights to the skeleton (Figure 4.4). When this toy is giving an initial push, it keeps on walking in a human kind of motion and it does this for a considerably long time. This illustrates how well designed our skeleton is to walk and how the skeleton determines the pattern of our walk.

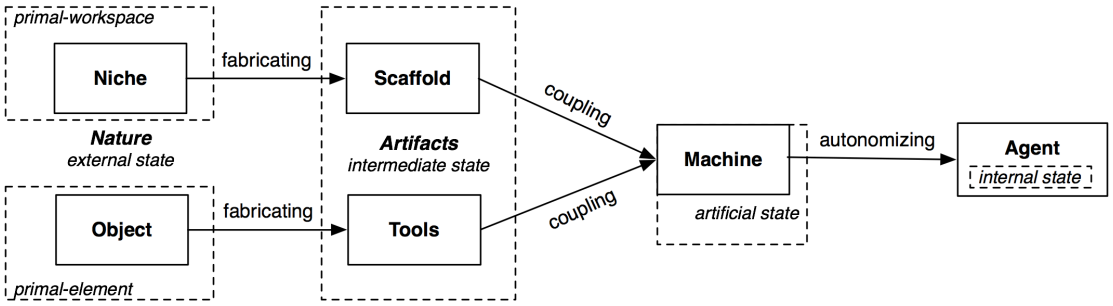
Figure 4.4 an AI experiment on fluent motion using counterweighs and a skeleton will make an initial impulse create impressive distance.



With muscles wrapped around the skeleton framework, to manipulate and change the default motion, the body has become a tool. This tool is regulated by electrical pulses. The transformation from physical motion to electrical pulse is an internal transducer. Both body (the tool) and brain (the regulator) evolve in a bootstrapping relationship. In primitive bodies, the electrical pulses are reflexes encoding simple causal relationships, as elaborated by chemotaxis (see Section 3.2.4) and it creates the self-coordination. With more advanced bodies, more advanced brains become possible.

Creating artifacts is embodying some kind or relation (amplifying X or restraining X). By coupling it becomes causal relations (if X then Y else Z). In Figure 4.5, a presentation is made to understand how the changing state eventually allows for an internal state, which is the transformation of the causal relations to knowledge. The causal relations create an artificial state by coordination. The artifacts show an intermediate state, having the pre-condition for the artificial state (without coordination).

Figure 4.5 The stages of agency by different development processes: fabricating, coupling and autonomizing.



The very first state is external, it is nature, where niches are primal-workspaces and objects are primal-elements. The primal object is simply a reference to the building blocks at a particular level. For example, on a sub-cellular level, the atoms would be the building blocks, creating complex chemical structures. The level of living systems shows how cells become building blocks, creating interesting multi-cellular systems. The primal workspace can explain the transition of natural selection, by evolutionary pressure, into artificial selection, by coordination. Fitness is understood as the boundary condition (the input), while evolution (the self-organizing process) makes species emerge in the niche (the invariant patterns in the workspace). The primal-elements and primal-workspace can help us understand the emerging of novelty.

4.1.4 **Novelty construction by meta-systems**

To gain the bootstrapping process with the two types of meta-systems requires a special case where the meta-workspaces need to create agents and meta-systems need to create workspaces. In general, meta-workspaces can create new objects, while meta-elements can create new niches. Therefore, novelty regulation is what the meta-systems are capable of generating, while gaining a bootstrapping process is a special situation. The effect of meta-workspaces creating new objects has been argued in Section 3.3.1 to understand the origin of life. Meta-elements creating new niches is being introduced here and examined in more detail in the next chapter.

Niche construction by single agents – like beavers building a dam and in the process making the lake emerge (the niche) – is rare and the niche being created is only a transformation, not an environmental enrichment, as required in the bootstrapping process. Objects and niches with environmental enrichment will have a special condition that needs to be resolved by the meta-system. The essence is that the constructs in the central workspace would only exist locally for the meta-system if particular environmental conditions for the constructs were not artificially imposed on the environment. Let me elaborate.

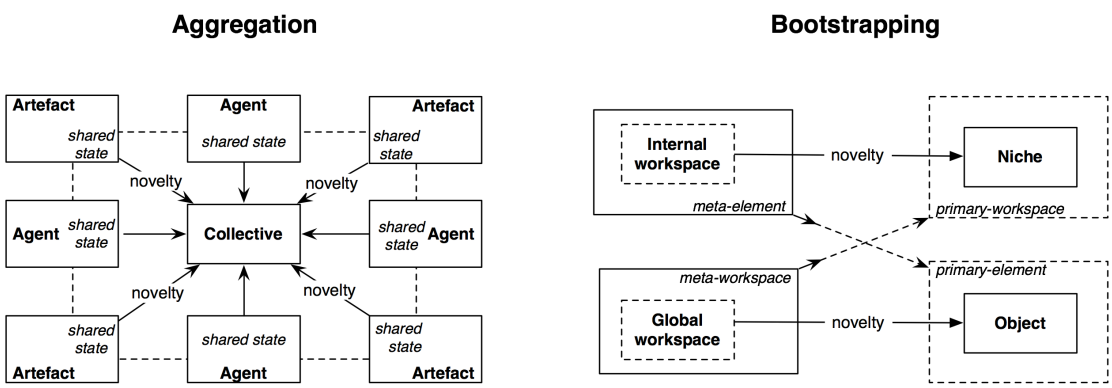
In the case of a new object, created by meta-workspaces, it primarily comes down to getting the production external to the meta-system. In the previous chapter on evolving systems, the production was reached by self-reproduction, allowing the new object (e.g. cells) to abandon the meta-workspace and create further evolutions in a variety of niches. In the next chapter, this is more profoundly demonstrated with new objects in laboratories requiring changes to the social fabric. The meta-element can create new niches. It mostly comes down to changing the state of the environment. In Section 3.3, it was argued that the first living systems create oxygen as waste, transforming the whole surface of the earth. In the next chapter, the evolution of the social fabric shows how the surface of the earth is still being transformed. To give an example, let's get to where the social fabric starts, which is domestication (see more in Section 5.2.2).

For example, rice has been domesticated around the Lower Yangtze region of China (close to Shanghai). The niche for rice domestication was a coastal swamp (Zong et al. 2007). While the domestication process would amplify the beneficial aspects of rice (making it a tool for societies), it would still require the swamp conditions. As an effect, much of the hill landscape in China would transform into terraces (the scaffold), transforming the hill into cascading swamps (Figure 4.6). We need to recognize that no single agent has been able to transform these hills. It was a social effort, showing how the enriched niche construction happens by meta-elements (e.g. societies).

Figure 4.6 Examples of rice terraces, transforming hills to cascades of swaps (Anon n.d.)

Meta-elements creating niches and meta-workspaces creating objects are already advanced ways for novelty to emerge. The default way is aggregation, creating the internal state of the collective. Each element in the collective has some internal state and combined we can see novelty as the aggregating shared state (left side of Figure 4.7). The state in the meta-system bootstrapping process is very different (right side of Figure 4.7). The meta-element creates niches, and niches were considered primary-workspace, while the meta-workspace creates objects, which are considered primary-elements. It shows the nature of the bootstrapping process that appears to turn things inside out.

Figure 4.7 Left the default aggregation of novelty, right bootstrapping process creating novelty.



With the definition of artificial evolution, it also becomes possible to define novelty in a more formal way:

> Novelty is what did not exist before, but emerges into existence by artificial evolution, where the mediation defines the novelty and the agency embodies the novelty.

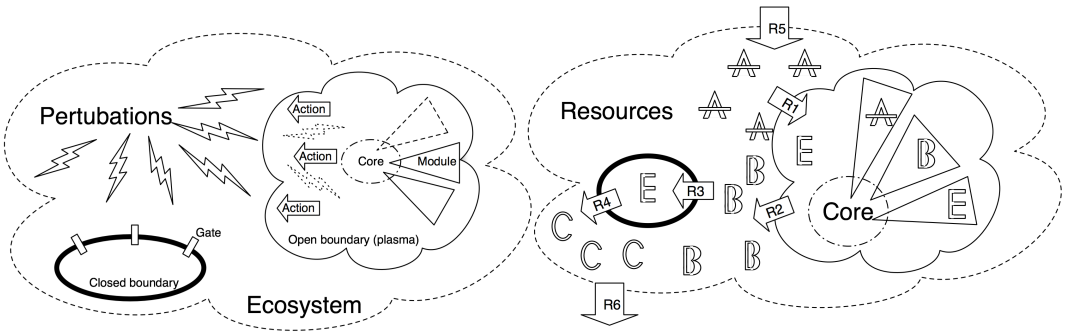
The workspace is the manifestation of artificial selection and so it defines the novelty. The agency creates the invariant patterns (information). These patterns can only become building blocks when they are embodied. Considering the relevance of the central workspace to the novelty creation, it is necessary to try and describe the dynamics more formally.

4.1.5 Mediation by central workspaces

A meta-system with a central workspace can adapt to changes in the environment by constraint perturbations. Constraint perturbations were essential in the simulation of Section 2.1.1.2 that shows how pickup transforms smoothly to breaking. Adaptation by constraint perturbation is a way that we train our bodies. For example, vaccinations infect a weak version of disease to train the immune systems. Another example is the miniature fractures in muscles after sports that tell our body where to grow.

To create a representation considers how perturbations would be different in a pioneering system versus a complex system. The pioneering system has a simple architecture: it has a boundary to protect against perturbation and an interface consisting of gates that define what can enter and exit the system. The complex system works with a workspace for regulation and creates actions against the perturbation. The left side of Figure 4.6 was inspired by the design of cells, and in that case the workspace is, in fact, the cytoplasm. A weak boundary exists allowing restrain perturbation to enter the workspace (dotted lightning in figure). It is from such restrain perturbation that the complex system can learn and adapt to become more fit.

Figure 4.6 Left, perturbations against a closed system and an open system. Right resource allocation in the ecosystem.



The complex system can then use the restrain perturbations to evolve with the changing environment. How this happens in detail is research in progress. One way that we are approaching it, is to consider how resources between the pioneering system and the complex system exchange. In the first case, the exchange is possible by an external flow (right side of Figure 4.6). The complex system is eating A's and the pioneering system is eating B's. We shall now refer to them as system S_A and system S_B. The eating produces waste for S_A which is B, while for S_B the waste is C. For the whole setup to work, a flow needs to exist by the ecosystem, providing an inflow of A's and an outflow of C's. We can present this as reaction rules:

R1: $S_A + A \rightarrow S_A + 2E + B$	R3: $S_B + B \rightarrow S_B + E + C$	R5: $\phi \rightarrow A$
R2: $S_A + E \rightarrow S_A$	R4: $S_B + E \rightarrow S_B$	R6: $C \rightarrow \phi$

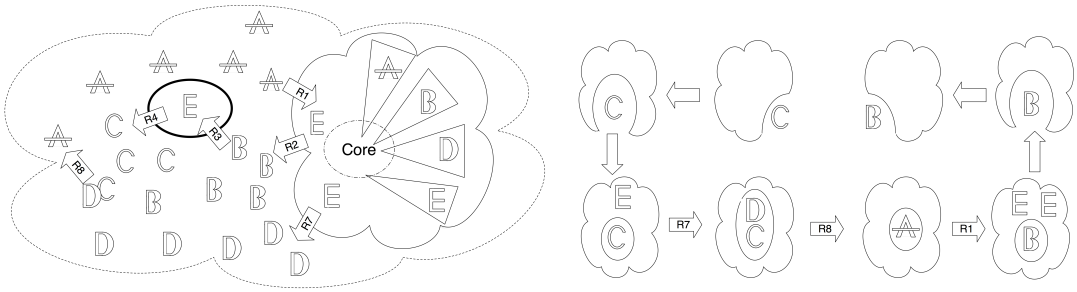
Rules R1 and R3 show how eating creates waste and energy (E). In these two rules, the system functions as a catalyst for the reaction, which is recognized as the system appears on both sides of the reaction. The systems need to eat to keep existing, which leads to R2 and R4. You may notice that S_A gains more nutrients (2x energy). This is not relevant now, but will become relevant in the next setup. Rules R5 and R6 show the flow in the ecosystem, where A's flow in and C's flow out, allowing the whole setup to be stable.

Some interaction exists between S_A and S_B, but it is not coordination. So consider a closed ecosystem, for example, where some of the reaction could be stimulated by solar energy (an abundant source of energy), creating a closure that allows the population to grow in coordination between the systems. The left side of Figure 4.9 shows the situation. The rules R5 and R6 have been replaced by:

R7: $S_A + E \rightarrow S_A + D$	R8: $C + D \rightarrow A$

The reaction rule R7 means that S_A is using energy to create another product D that can interact with the C's to transform them to A's, which is rule R8. At first, this situation seems less beneficial to S_A since now energy gets used to create D's. However, because of the coordination it may actually grow in an unlimited manner. Of course, this is all a simplification, e.g. the construction of D's would also require resources. The essence is that ecosystems learn to optimally use the scarce resources supported by a variety of abundant resources. The simplification is not only related to resources. The reactions are also simplifications that are in reality more complicated mobilizations. For example, the right side of Figure 4.9 shows a more realistic situation where C's get absorbed into a separte workspace by S_A. S_A now needs to put energy into the workspace to create the D's and then the energy gets released, showing how, in fact, system S_A is eating C's and having B's as waste.

Figure 4.9 Left, coordination of the resources between the pioneering system and a complex system removes the need for flow. Right, an alternative presentation of the reaction, showing a bit of the involved mobilization.



To represent the benefit of the coordination, requires us to consider the reaction time next to the reactions themselves. This becomes possible by applying the Chemical Organization Theory (Matsumaru et al. 2005) or in short, COT. Evolution is presented by COT with the formula: M.v(x). Where M is the stoichiometric matrix and v(x) is the flux vector. The stoichiometric matrix contains all possible reactions, while the flux vector describes the rate of a particular reaction. Each row in the stoichiometric matrix presents an element in the reaction and each column presents a reaction (Table 4.1). Each cell shows the quantitative change of an element. If elements are consumed, the number becomes negative, while if elements are created it is positive. Notice that the systems S_A and S_B are catalysts, in the stoichiometric this results in rows with only 0's, as their quantity stays unchanged in the reaction.

Table 4.1 The stoichiometric matrix, black cells are informative. The first row shows which columns relates to which rule and the first columns shows which element is affected:

	R1	R2	R3	R4	R5	R6	R7	R8
A	-1	0	0	0	1	0	0	1
B	1	0	-1	0	0	0	0	0
C	0	0	1	0	0	-1	0	-1
D	0	0	0	0	0	0	1	-1
E	2	-1	1	-1	0	0	-1	0
S_A	0	0	0	0	0	0	0	0
S_B	0	0	0	0	0	0	0	0

The flux vector presents the time of reaction and the type of setup. To examine the interaction between the systems, I use variables in the flux vectors that allow me to show the sensitivity between the reactions. For both setups, I consider X to be the reaction speed for S_A and Y to be the reaction speed for S_B. In the setup of an open flow (right side of Figure 4.6), two more variables exist: U for the inflow and V for the outflow. The flux vector becomes: v_{open}(X,2X,Y,Y,U,V,0,0). When calculating $M.v_{open}$ we get:

$M.v_{open} = (-X+U, X-Y, Y-V, 0, 2X-2X+Y-Y,0,0) = (U-X, X-Y, Y-V, 0, 0,0,0)$.

The first cells relate to the quantity of A's in the setup. It shows that the inflow by the ecosystem needs to be similar or larger than the feeding needs of S_A, so $U \geq X$. Conversely, $U < X$ would lead to starvations of S_A's until U=X. The second cells shows

the interaction between the two systems (by resource B), now the feeding needs of S_A needs to be similar or bigger than the feeding needs of S_B. In other words, the requirement is $X \geq Y$. By contrast, $X < Y$ would lead to starvations of S_B's until X=Y. The third cell relates to the quantity of C's and now the outflow is by definition smaller or similar to the creation of C's by S_B meaning $Y \geq V$. The fourth cell shows the energy usage in this interaction, which becomes 0. The last two cells relate to the quantity of systems that do not change in this setup. To get a stable ecosystem requires: $U \geq X \geq Y \geq V$. When one of the variables is larger it means that more of that resource geta into the ecosystem than gets out of it.

The flux vector for the closed coordination (left side of Figure 4.7) is relatively similar where U presents the speed of creating D's and V presents the speed of reactions with the D's: $v_{closed}(X,X,Y,Y,0,0,U,V)$. When calculating $M.v_{closed}$ we get:

$M.v_{closed} = (-X+U, X-Y, Y-V, U-V, 2X-X+Y-Y-U,0,0) = (U-X, X-Y, U-V, 0, X-U,0,0)$.

Many of the dynamics look similar, but some significant differences exists. Let us consider the quantities of D's. Of course, only less or equal reaction can be created than the amount of D's that can be created so $U \geq V$. The energy variety now depends on how many D's can be created. No more D's can be created than the number of A's that S_A can consume. In other words, $X \geq U$. Only one stable situation exists, which is when $X = U = V = Y$. A more realistic situation would be where the S_A would be able to create more D's with the energy it has to spare or when we consider the creation of D's and the reaction with C's to exist only internally in S_A as presented in the right side of Figure 4.9.

The real challenge is to understand how the S_A in the open flow setup can learn to create D's in the first place. In other words, we like to a shift from the first setup to the second. The way that this can be reached is to have for v_{open} $Y > U$. Therefore, fewer C's flow out, creating an accumulation of C's. The buildup of C's would create the constraint perturbations (left side of Figure 4.6) making a C get inside S_A (right side of Figure 4.9) so that the system needs to learn how to dissolve this anomaly by creating D's. Special rules exist in COT allowing for reactions to only occur when particular concentrations are reached. However, with the current simple setup the learning cannot be described.

More realistic examples exist of more elaborate chemical organization applied to sugar metabolism (Centler et al. 2007). Such cases are already complicated and they are not adequate to describe the learning required for the case we have in mind. To have the system explore the C's, it needs to be able to create experimental enzymes. So the COT presentation needs to be about enzyme creation by RNA. Attempts to present this in a simple and formal way, is research in progress. For the experimental enzymes, it is required to have novelty regulation. The novelty regulation is something profoundly different that has to be described by its own formal presentation, which brings us to the second section of this chapter.

4.2 The novelty model "Cohering"

The novelty model is quite complicated. It is an abstract architecture existing of three different mediums and four novelty anchors. Novelty anchors are abstract constructions, like meta-systems they become specific when considering an actual implementation of the novelty model. The essence of the novelty anchors is that they allow agency to arise. The four different anchors can together create the bootstrapping for the novelty model to overcome a conservation constraint. The case of sailing upwind should introduce the mechanism of novelty regulation in a fluid-based medium, where the anchors are physical forces.

Consider that in a fluid-based medium the artifacts were limited. So the novelty regulation in a fluid-based medium is limited as well. The sailing upwind, examined in the first subsection only creates novelty in respect to the movement. Because of the primitive nature, the case can demonstrate the fundamentals of novelty regulation. All other subsections focus on the novelty model that I call "Cohering". The Cohering model can show how knowledge can emerge. In this case, there is no limitation to the agency and so with the Cohering model we build an argument of how the novelty model is essential for an agent.

Sailing upwind overcomes the paradox of momentum conservation. The Cohering model overcomes the bias of knowledge. The bias of knowledge is also a conservation constraint. Knowledge is both a barrier and the source for knowledge creation, similar to how momentum is both a barrier and the source of sailing upwind. This is the essence of the novelty regulation: *the ability to overcome a seemingly unbreakable barrier.* In following chapters, other novelty regulations are examined, while, depending on the implementation of the medium and anchors, some kind of conservation gets tackled. The novelty regulations for these chapters all relate to innovation, they are more complicated to understand and therefore the Cohering model seems most fit to demonstrate the general novelty model.

For the Cohering model, the mediums are memories and the anchors are anticipation processes. The second subsection creates an argument for the three involved memories. The third subsection introduces the anticipation process, as the building block for the novelty regulation process. The following subsections create an extension of a basic process to build the novelty model. The internalizing and externalizing processes create a default flow, which was demonstrated in Section 2.2.4 by the perception of a face. The example is also going to be used to demonstrate a more formal notation. The default flow uses default categories for associations and tags. It demonstrates the default bootstrapping cascade and involves the three mediums. This default flow has to be extended twice to get to an actual novelty model.

The first extension changes the default flow to a directional flow by adding challenges. Challenges change the default categories to context dependent categories, which allows control by focusing on the context. Just like associations

and tags, the challenges have to get anticipated. The anticipation can lead to a cascade of different associations and tags that may lead to reinforcing or falsifying the anticipated challenge. The challenge creates the required tension for novelty to emerge.

The last process is for the novelty to evolve. It changes the directional flows to a constructive flow. With the Cohering model, the evolving process works on experience in the workspace. The evolving process is anticipating what aspects in the workspace are relevant and creates conceptual networks of the novelty. The directing and evolving process are part of the regulation and they can focus on internalizing or externalizing. By focusing on internalizing, the novelty regulation is modeling experiences into knowledge. By focusing on externalizing the novelty regulation is mastering the novelty. It creates, metaphorically, the same oscillating movement as seen with the sailing against the wind. The modeling and mastering are examined in the next section on learning novelty.

4.2.1 **Novelty regulation: the case of sailing upwind**

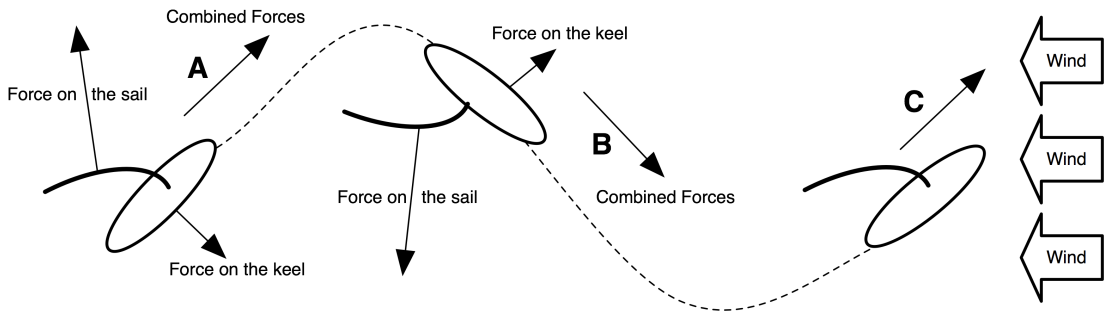
The source for sailing is the wind working on the sail. There are actually two forces on the sail: drag and lift. The drag force is the commonly known force. It pushes the boat along in the direction of the wind. Drag is not useful for sailing against the wind. The lift force is more difficult to understand. The basic principle of lift force is to create a curved surface so that a flow (the wind in this case) would pass with different speeds, creating a difference in pressure. The effect of the difference is a force in a straight angle to the sail. The lift force is not only important for sailing against the wind. It is the same force that keeps airplanes in the sky and makes our modern wind turbines work.

The lift, acting on the sail, is not enough to move against the wind. At best, there would be almost no drag force and only the lift force, resulting in an angle close to 90° opposite to the direction of the wind. A price needs to be paid to move in the direction of the wind. This requires a mechanism existing of some extra forces. The mechanism involves the viscosity of the water and the specific position of the keel. Viscosity is a measure of the resistance against a deforming of the fluid. Boats are designed to use viscosity to their advantage. The keel of the boat is a counter weight at the bottom of the boat that often looks like a long blade. It makes sure that the boat can easily cut through water along the length of the boat, while at the same time restricting sideway movements. By positioning the boat in a 45° angle with the wind, a reaction force occurs on the keel that is optimal to move against the wind.

The reaction force and the lift force create a tension. The combined force is smaller (the price paid) and goes into the direction of the wind (forces A, B, C in Figure 4.10). One fascinating conclusion is that without tension, no novelty can exist. It gives part of the friction experienced in innovation a very different meaning. Consider that the medium defines what novelty can arise. In this case, the novelty related to the movement. According to the law of conservation of momentum, it is paradoxical to

move against the wind. Thanks to the described mechanism, it does become possible, which requires a saw-like path of movement (from A over B to C in Figure 4.10). The same reasoning applies to other novelty regulations showing how bootstrapping can overcome some conservation. The following subsections describe the novelty model around knowledge creation called Cohering. In this case, knowledge creates bias and fundamental new knowledge can only emerge by the saw-like path between mastering, meaning actions to refine the regulation and modeling, meaning actions to refine the internal representation.

Figure 4.10 How sailing against the wind can be achieved



After examining the Cohering model in detail, Subsection 4.4.1 returns to the sailing against the wind case. Because fluid-based mediums do not store memory, it becomes a fascinating case to generalize novelty regulation as a mechanism to overcome conservations and deal with complex adaptive environments. It creates the proper context for the following chapters where different domains have approached complex adaptive environments and develop at least part of the novelty model for the conservation they get challenged by.

4.2.2 Three types of memory

The mind needs a memory to work. An extended mind makes it complicated, as memory does not restrict itself to the brain but extends to workspaces like note books, blackboards, kitchen tablets, desks, online spaces, etc. In other words, the environment is a memory too. A workspace is needed to create information, which is a third required memory. As argued before, for a cognitive system only space is needed to make an external environment become a workspace. For example, Clark illustrates how space distribution in the kitchen contributes to problem solving, like separating washed from unwashed vegetables. (Clark 2008, p 46) makes an important contribution to our investigation:

> It is intuitive that once descriptive complexity is reduced, processes of selective attention, and of action control, can operate on elements of a scene that were previously too "unmarked" to define such operations over. Experience with tags and labels may be a cheap way of achieving a similar result.

Tags are the element regulating the external anticipation process in the default flow. The last remark by Clark "tags are cheap" needs some nuance. It seems to indicate that spatial distribution would be more expensive than labeling. Spatial distribution

is less robust, but a label requires a culture to make sense of the label, the production of paper and markers for the labeling itself. Once the environmental enrichment has built tagging, it can indeed become cheaper, but not by default. Workspaces are mostly overloaded with tags, at least for the trained eye. An untrained eye can show remarkable blindness to such tags, as it is usually not the intention to attract the untrained eye's attention.

The environment is its own best representation. For example, it is hard to memorize spatial aspects exactly, like colors, because it is so easy to perceive the color. Having a general description is often enough. Even for more abstract aspects, the environment can be a proper space to store knowledge. This can include creating maps or writing books. One misconception is that retrieving information from the environment would be slow. (Clark 2008, p 380) mentions Gray and Fu (2004) to prove this is wrong:

> Instead, they [Gray and Fu] argue that their results show that "the time retrieving something from memory is weighed the same as time spend in perceptual-motor activity" and that it is therefore a mistake to "presume the privileged status of any location or type of operation" (Gray and Fu 2004, p 378, p 380).

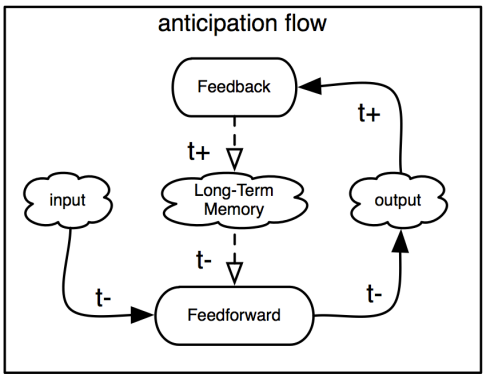
In summary, three types of mediums are essential for the novelty model. In the Cohering model it becomes three type of memories:

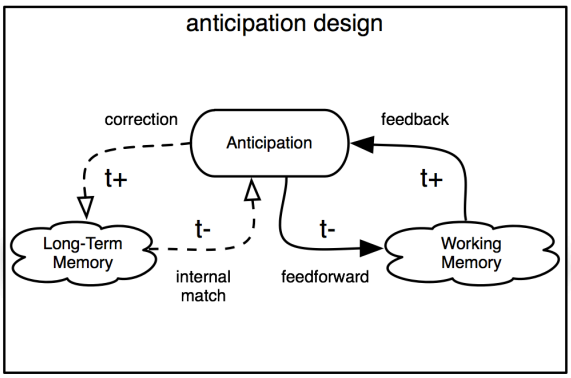
- **System Core** = *Long-Term Memory*: the memory contains knowledge. Knowledge is experience processed to abstractions and ready to use concepts.
- **Workspace** = *Working Memory*: the temporal memory that creates tension and focus, allowing novelty to emerge. The workspace is the centerpiece in the novelty model.
- **Environment** = *external memory*: tags, signs and meaning in the environment. Some are created by the agent, other are serendipitous.

4.2.3 Anticipation as a building block

The anticipation process is considered the cognitive building block of the novelty regulation process. Anticipation works on an information flow with feedback and feedforward. To provide additional detail of what is happening during an event (t), I consider a time moment just in front of the event (t-) and a moment just after the event (t+). At t- the feedforward suggests what may happen, at t+ the feedback contains what has happened. The moment that things are happening is when output is created. The t- and t+ are relevant to understand the anticipation process. Figure 4.11 illustrates two ways to present an anticipation process. The left side of the figure illustrates the information flow from input to output. On t- input to the feedforward process predicts an outcome. After the output, t+ feedback updates the long-term memory used by the anticipation process. The right side of Figure 4.9 shows an alternative presentation by combining input and output to the same workspace. The benefit of this figure is that multiple anticipation processes can work in parallel on the working memory, which is required for the novelty model.

Figure 4.11 Two presentations of anticipation: left side focuses on the flow, the right side on the system structure that can get extended.

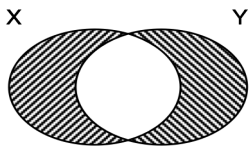




An event progresses in time, which can be approximated by a discrete number of steps (t_1, t_2, t_3, …). Each step has a feedforward t- and feedback t+. In real situations, the t_1+ feedback and t_2- feedforward would overlap. So t_2- may still be working on the incorrect memory. To simplify the process for the theory, consider small enough steps, so no overlap would exist : $t_1- < t_1+ < t_2- < t_2+$. The pattern used in the anticipation process will be presented as a set of variables $X = \{x_1, x_2, x_3, \ldots, x_n\}$. The variables can be presented as numbers. It is, however, essential that we consider sets, as networks of associations, tags, challenges and experience are in some way connected and the connections allow for the novelty regulation to manifest.

The anticipation function ' ϒ ' predicts what X would be. We can use t- and t+ to describe when an anticipation is incorrect: $\Upsilon(X_{t-}) \neq X_{t+}$. Delta-Learning in neural networks (Jacobs 1988) uses the difference between target output and the actual output to calculate a delta: *Δw = (target – actual) * neural_activation*. For the novelty regulation, a similar delta is expressed as the symmetric difference:

$$X \Delta Y = (X \cup Y) \setminus (X \cap Y)$$



The symmetric difference contains the novelty. It is the set of what was expected and did not manifest (wrong knowledge) and what manifests that was not expected (unknown observation). In case what was expected and what manifest are the same we get an empty set. This delta can be used with the anticipation function:

$$\Delta_N (X) = X_{t+} \Delta \Upsilon(X_{t-}) = (X_{t+} \cup \Upsilon(X_{t-})) \setminus (X_{t+} \cap \Upsilon(X_{t-}))$$

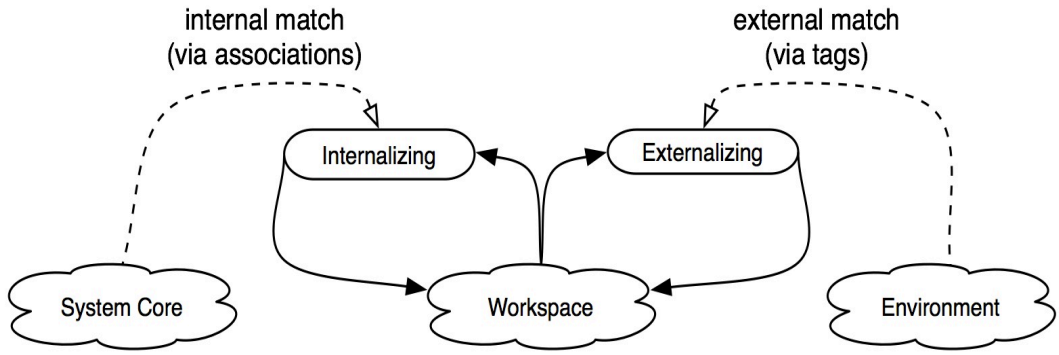
When an anticipation is correct we get $\Delta_N (X) = \emptyset$, if not we get $\Delta_N (X) = Y$, where Y is the set of differences that need to be understood. To express this, consider two experiences at a different time around the same set of events: $\exp_1, \exp_2 \in event_X$. For example, pouring out some liquid in a glass can be an event. By pouring out different liquids and by using different glasses a more general conceptualization of the event is reached by the different experiences.

A correction has occurred if $\Delta_N(exp_1) \neq \emptyset$ and $\Delta_N(exp_2) = \emptyset$. The correction does not directly mean novelty, maybe exp_1 was a miscalculation, maybe the anomaly did not occur any more at exp_2. To deal with such perturbations, it is essential that many experiences exist of a particular event. The event would be incomprehensible if: $\Delta_N(exp_i) \neq \emptyset$, .

4.2.4 **Default flow**

The default flow is the bootstrapping cascade between associations and tags as illustrated with the perception of a face (see Section 2.2.4). The associations and tags are specific to the Cohering model. In general, the associations become internal matches, while the tags become external matches. The basic anticipation design (right side of Figure 4.11) only has a working memory(the workspace). With the default flow, the basic anticipation design is extended, relating to the System Core (the Long-Term Memory) via an internalizing anticipation process and the environment via an externalizing anticipation process. Notice that in contrast to the basic anticipation design, this design does not contain a correction, which is reinstated with the constructive flow. The default flow does use all three mediums of the novelty model and allows regulation, if knowledge exists.

Figure 4.12 Internalizing and externalizing creating a default flow



The memory element X now gets a dimension related to the four processes involved: internalizing (in), externalizing (ex), directing (di) and evolving (ev). With the default flow, the memory element becomes: $X = \{x^{in}_1, x^{in}_2, x^{in}_3, \ldots, x^{in}_n, x^{ex}_1, x^{ex}_2, x^{ex}_3, \ldots, x^{ex}_{n'}\}$, where there are n associations and n' tags. The information flow from the design that is defined as a specific anticipation becomes Υ^{α} and works on $X^{\alpha} = \{x^{\alpha}_1, x^{\alpha}_2, x^{\alpha}_3, \ldots, x^{\alpha}_n\} \forall \alpha \in NovDim$. $NovDim$ is short for the four dimensions that the novelty can have (in, ex, di, ev). The anticipation processes are parallel processes that have no overlap of values: $X^{\alpha} \cap X^{\beta} = \emptyset$ for $\alpha \neq \beta$ and $\forall \alpha, \beta \in NovDim$

To illustrate the default flow, I reconsider the Gestalt bootstrapping example for perceiving a face (see Figure 3.8). This example has some simplification that I undo in the later formalization, but it seems best to introduce the notion in a simplified way. The example demonstrates how anticipation happens with intermediate stages before a stable pattern would emerge: $\Upsilon(X) = X'$, meaning that the X was get refined

to X', in that case X was a more simplified description than X'. Many steps may be required before a useful description is reached: $\Upsilon(X') = X''$, ..., $\Upsilon(X^{n-1}) = X^n$ In our face recognition example, only a few steps existed: Υ^e first finds X_{round}, became more concrete with X_{face} to finally fix on X_{Alice}. To indicate that intermediate steps exist, I use the $\Upsilon(X) \rightarrow X^n$ as a simplified notation.

The face recognition demonstrated how two anticipation processes can reach what each cannot do separately, starting from nothing it recognizes the face: $\Upsilon(\emptyset) \rightarrow X_{face}$ while Υ^{α} (Ø) $X_{face} \forall \alpha \in NovDim$. In other words, coordination between the anticipation processes is needed. The initial step in the figure is $\Upsilon^{ex}(\emptyset) = X_{shape}$ and $\Upsilon^{in}(\emptyset) = \emptyset$. The externalizing gets light as input and recognizes a shade, resulting in $X_{shape} = \{ x^{ex}_{position_1}, x^{ex}_{position_2}, ...\}$. X_{shape} only contains concrete tags and no associations. Internalizing only works if there is some concept to also start associating. Shapes are recognized in milliseconds resulting into $\Upsilon^e(X_{shape}) = X_{round}$. Round is a concept that triggers associations: $\Upsilon^{in}(X_{round}) = \{ x^{in}_{ball}, x^{in}_{apple}, x^{in}_{face}\}$. In the meantime, the external is too complicated and no information is gained: $\Upsilon^{ex}(X_{round}) = X_{round}$. This local maximum is only temporal and leveraged by the internal process. To visualize this, think of the Gestalt emerging where no clear pattern was recognized (Figure 2.15 D of a dog sniffing a tree). In the case of the phase, the working memory contains $X_{round} = \{x^{in}_{ball}, x^{in}_{apple}, x^{in}_{face}, ..., x^{ex}_{round_{part-1}}, x^{ex}_{round_{part-2}}, ...\}$, where part-1 and part-2 are concrete external tags and x^i_{face} refers to X_{face}.

By retrieving the X_{face} from the Long-Term Memory, a new set of relations is added to the workspace: $X_{face} = \{X_{nose}, X_{upper\text{-}lip}, X_{left\text{-}eye}, ..., x^{in}_{friend\text{-}or\text{-}foo}, ...\}$. If an object is more complex, as with the face, several steps are needed to make the object concrete. In the novelty model, an operation queue exists. It contains the first associations and push new associations to the back: $Q = \{X_{ball}, X_{apple}, X_{nose}, X_{upper\text{-}lip}, ...\}$. In the next steps $\Upsilon^{ex}(X_{round}) \neq X_{ball}$ *and* $\Upsilon^{ex}(X_{round}) \neq X_{apple}$, meaning that external feedback rejects the conceptualization of a ball or apple. While $\Upsilon^{ex}(X_{face})$ is falsifying the associations, Υ^{in} would get the next associations related to round, maybe $\Upsilon^{in}(X_{round}) = \{X_{wheel}, X_{plate}\}$. Of course, it becomes harder to find more associations if no new verification comes from the external. Lucky $\Upsilon^{ex}(X_{round}) = X_{face}$ is verified, so the next steps in the bootstrapping cascade can be explored, which leads to X_{Alice}. Notice how both $\Upsilon^{in}(X_{round}) = X_{face}$ *and* $\Upsilon^{ex}(X_{round}) = X_{face}$ are needed to become concrete. This is seen as an alignment effort that also becomes relevant for the other anticipation process and shows how the tension in the workspace is relaxed by synergy.

Even in this simplified case, the processing could go wrong. A complex concept, like the face requires several steps to get progressed. It is, for example, simple to misjudge a stranger for a friend. In that awkward moment that you greet the stranger as a friend, it becomes clear that the person does not respond as anticipated, which makes you recognize those details (the nose or lip etc.) that verify your mistake. Maybe it was the size of the posture, or the color of the hair, or because you are used to meet the person here (e.g. defaults), that made you jump

too fast to the wrong conclusion and project a concept falsely onto the external object.

Once the abstract and simplified concept kickstart the control system, the details ensure a level of complexity that makes the control truly interesting. In my simplified case, a distinct list was suggested like $Q = \{X_{ball}, X_{apple}, X_{face}, ...\}$, but in the actual case I expect more complicated processes to exist, like the spreading activation algorithms(Heylighen 2004). For example, it could be $x^{ex}_{blond\text{-}hair}$ and $X^{ex}_{posture}$ that would lead to $Y^{in}(X_{face}) = X_{alice}$ and not any of the many other possible persons. Another simplification in my example is the use of concrete labels (e.g. blond-hair). Labeled knowledge is already more processed knowledge. Implicit knowledge is less defined. For example, association x^{in}_{144332} and tag x^{ex}_{643222} may have a clear and distinct meaning for one agent, but that agent is not even capable of expressing why or how. Indeed, the agent simply "does stuff". You can find this by asking craftsmen to elaborate how they do what they do. Often very skilled craftsmen are not capable of elaborating it. The craftsmen have processed the experience to become ready at hand, but not processed the knowledge to become transferable. The latter would be the focus of a teacher.

I'm also considering how this actual case could become engineered. My method is to stay on a particular conceptual level to elaborate how the model works, but at the same time consider how this could be implemented with more flexible algorithms. I have been using this method with my earlier AI experiments (see Section 2.1.1) and consider it an important task since it can create a better framework for some of the existing challenges with strong AI. I would consider the Hidden Markov model a good candidate to actually engineer this model. The Hidden Markov model has been useful for temporal pattern recognition like speech (Rabiner 1989). How $x^{ex}_{blond\text{-}hair}$ and $X^{ex}_{posture}$ would lead to $Y^{in}(X_{face}) = X_{Alice}$ could be a projection of several Hidden Markov layers. I'm well aware that this still needs to be tested. Maybe Hidden Markov is not the best solution and some other machine learning algorithms are better suited to the task, still it is not my interest to work on that level, but to allow engineers at that level to have a framework to validate their algorithms. So I have to stay abstract to a certain level, but hope that my engineering training would be enough to ensure a level of detail enough to make my models useful for engineers.

4.2.5 **Directional flow**

Each anticipation process works on a control element. The default flow populates the workspace with associations and tags, which are artificial and coupled, in other words it relates, in the stages of agency, to the situation of a machine with an artificial state. For the novelty regulation, this artificial state is recognized again. Association can create relations to a special subset of values (see Figure 4.13). This creates a particular state of the workspace that can best be elaborated as emotion. The emotions allow the directing process to anticipate challenges. The challenges coupled back into the workspace and can trigger reaction with the internalizing and the externalizing.

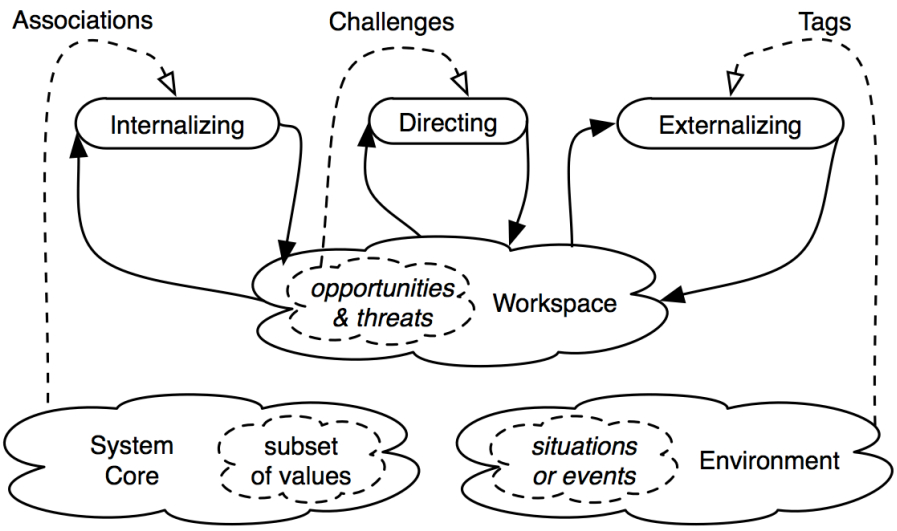
For example, the state of the workspace may create an initial state of fear. The directing process can anticipate if the fear should result in running away, hiding, attacking, etc. Each of the challenges creates different associations and some are mutually excluding. To run away open space is needed, while hiding requires obstacles. Each of these associations can be aligned with the environment by tags, making the agent recognize opportunities and threats. So the novelty model is not creating simple challenges. The challenges are being bootstrapped from the state of the workspace to the challenges most fitting the default flow of associations and tags.

A third process anticipates challenges. It transforms the default flow to a directional flow and adds context to the equation. Associations and tags would first be ordered according to default categorization. The challenges changes this defaults by valence. Heylighen (2010) elaborates valence:

> Valence can be understood as the subjective appreciation by an agent of the global utility, well-being or fitness offered by a particular phenomenon or situation. It can be formalized as a scalar variable, which is positive for positive situations, negative for negative ones, and zero for neutral ones.

While internalizing and externalizing connects the three different memories, directing adds a level of control over the working memory. There are default challenges and challenges that emerge out of complex concepts. The memory element is extended with $x^{di}_1, \ldots, x^{di}_n$, where 'di' stands for directional. The default motivations are related to the default flow. A dummy memory can be created to kickstart the directing: $Y^{di}(\emptyset) = X_{default} = \{ \emptyset \}$, which triggers $Y^{in}(X_{default})$ *and* $Y^{ex}(X_{default})$. Indeed the default flow is enough to retrieve any relevant information from any memory. For directional flow, a subset of values exists within the LTM and inside the environment situations or events can be recognized. With the default flow, the two subsets get combined in a subset for the workspace, containing the opportunities and threats (Figure 4.13). The opportunities and threats can result in a challenge changing the default flow to a directed flow.

Figure 4.13 Extension of the model with a directional anticipation process



Abstract concepts can lead to abstract challenges, for example $X^{di}_{face} = \{x^{di}_{talk\text{-}too}, x^{di}_{observe}\}$. Detailed challenges require detailed concepts. For example, if Alice is both a friend and a colleague that has some interesting but less known friend Lily, the motivations can be $X^{di}_{Alice} = \{x^{di}_{suggest\text{-}cinema}, x^{di}_{feedback\text{-}of\text{-}yesterday\text{-}report}, x^{di}_{inquire\text{-}about\text{-}Lily}\}$. The relevance of challenges does not depend on how detailed or abstract the challenges are, but how well the challenges align with the agent's values. The directional process does not add a level of detail like the internalizing and externalizing processes do. It works on the alignment of all the information to work on a hierarchy of challenges. An motivational category is added, for example, $Y^{di}(X_{face}) = X_{face} + X^{di}_{face}$, where $X^{di}_{face} = \{x^{di}_{talk\text{-}too}, x^{di}_{observe}\}$. The internalizing and externalizing may react to the challenge by adding relevant associations and recognizing local tags. For example, $Y^{in}(x^{di}_{suggest\text{-}cinema}) = \{x^{in}_{movie\text{-}A}, x^{in}_{movie\text{-}B}, \ldots\}$

Note that there is no overlap between $X^{in} \cap X^{di}$. The effect of $Y^{in}(x^{di}_{suggest\text{-}cinema})$ is similar to $Y^{in}(\emptyset)$, what changes is the state that it takes into account $State = \bigcup_i X_i^d$ that changes the equation from '$=_{Default}$' to '$=_{State}$'. The default state is not represented and the previous example could have been written as: $Y^{in}(X_{round}) =_{Default} \{ X_{ball}, X_{apple}, X_{face}\}$, but if a particular context exists this could be different. For example, if the agent is in a state of hunger, the first internal matching could be $Y^{in}(X_{round}) =_{Hunger} \{ X_{apple}, X_{cake}, X_{candy}\}$. Let me apply this to $Y^{in}(x^{di}_{suggest\text{-}cinema}) = \{x^{in}_{movie\text{-}A}, x^{in}_{movie\text{-}B}, \ldots\}$, what would be written more correctly as $Y^{in}(\emptyset) =_{Talk\text{-}to\text{-}Alice} \{x^{in}_{movie\text{-}A}, x^{in}_{movie\text{-}B}, \ldots\}$. The state emerges gradually $(Y^{di}(\emptyset) \rightarrow S)$ by the elements in the working memory. Compare it to how the face emerged gradually, but now apply it to challenges and just like those other elements, this state is also temporal in time.

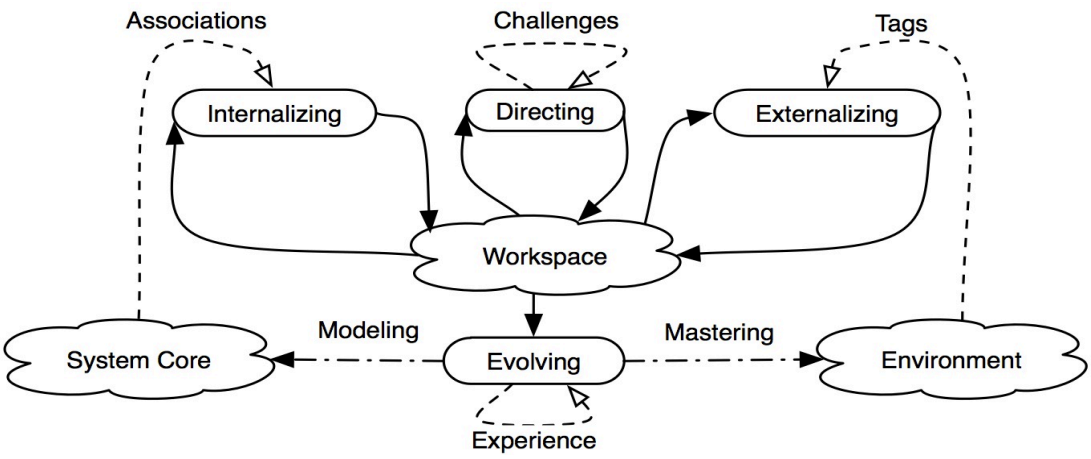
Only a limited number of elements can exist in the working memory and the state can affect the operation queue. In other words, directing throws out elements too unrelated for the current state. Take that the operation queue (Q) contains $\{X_a, X_b, X_c, X_d, \ldots\}$, where X_d has more relation to S then X_b and X_c has no relation to the state. In that cas, the directing changes the operation queue as follows: $Y^{di}(Q) = Q' = \{X_a, X_d, X_b, \ldots\}$. It is expected that X_a would already be relevant by prior actions of the directing process. New association tags and challenges are pushed to the end of the queue. The directing, therefore, works mostly on the tail of the queue. In a way, the tail sways in an explorative space beyond the boundaries of what is known and reaching out to the challenge.

4.2.6 **Constructive flow**

The information processing has become quite complex, but at this moment the design is not capable of creating knowledge. By adding one more anticipation-process, the directional flow is transformed into a constructive flow, which becomes the novelty model. Elaborating the constructive flow becomes much more complicated. In this subsection, I introduce the design and in the next sections I elaborate the learning of novelty in more detail. The biggest difference between the evolving process and the previous three processes is the output. Evolving makes information emerging in the workspace transform the internal and external medium.

By the effect that the internal and external medium has on the regulation, a recursion is reached. The inner feedback to the workspace is much faster than the outer feedback by the evolving process to the other two mediums.

Figure 4.14 The novelty model by four processes and three mediums. Specific to the Cohering model are the associations, challenges, tags and experience.



The feedback of the evolving process has to be explained, which brings me back to considering events. Parts of an event may reoccur, the different experience for a same event eventually lead to the abstraction of that event. Each event is an experience and learning works on experience, so that the same concept has more than three relevant experiences: $X^{ev} = \{x^{ev}_{exp_1}, x^{ev}_{exp_2}, x^{ev}_{exp_3}, \ldots\}$. Not everything in the working memory can be captured as an experience but Υ^{ev} anticipates what is relevant. Challenges play a key role in remembering. This is why dull events are forgotten, while aroused events or new events would be stored. If the memory could predict the event correctly, there has to be experience 'exp' about such event. When the anticipated is wrong, a new event needs to be labeled with the relevant part of this event: $\Delta_N(X_{t1})$ =exp$_1$ *and* $X^{ev} = \{x^{ev}_{exp_1}\}$. In this case, exp$_1$ is a set and $x^{ev}_{exp_1}$ is the link to this set. Notice that the set contain associations, tags and challenges, but the set is not itself similar to any associations, tags and challenges, so we have no validations of the rule $X^{\alpha} \cap X^{\beta} = \emptyset$ for $\alpha \neq \beta$ and $\forall \alpha, \beta \in NovDim$. The system stores new experience when the event reoccurs: $\Delta_N(X_{t2})$ =exp$_2$ and *and* $X^{ev} = \{x^{ev}_{exp_1}, x^{ev}_{exp_2}\}$.

At this moment, the system has no clue if the part of the experience stored is relevant or not, but when enough experience exists some pattern may get recognized and the many varieties of that pattern get stored so that the learning will result in:

$$\Upsilon^{ev}(\emptyset) \rightarrow X_{pattern} \text{ while } \Delta_N(X_{pattern}) \rightarrow \emptyset.$$

How learning is able to reduce the uncertainty is examined in next section.

4.3 Learning novelty

The outer loop by the evolving process creates recursion. A focus can exist to change the system core, which was the long-term memory for the Cohering model. This development process is called modeling. The focus on changing the environment is called mastering. Because of the recursion a basic case and advanced case can be considered. The mastering is more invasive than the modeling because of the embodiment. Therefore, modeling comes before mastering. The basic cases show how an individual tries to be logically consistent, hence the name of this model. The advanced case of knowledge creation shows how the problem shifts to a social dimension around scientific and technological development. This is going to become the starting point for the next chapter.

The basic modeling introduces one of the fundamental concepts in novelty regulation: retrofitting. Retrofitting redefines already existing knowledge. Such adaptation can come by adaptive changes in the environment or by rare events. In both cases, they enrich the knowledge. The basic modeling shows how the challenge happens after the event took place. The challenge is then to make sense of the occurred event, creating the basic modeling of experience. The basic mastering requires training. The novelty is now an adaption process coming from training. This case demonstrates the basic bootstrapping cascade of modelling and mastering. The advanced case of modelling takes this basic mastering to a new dimension, showing how abstract frameworks get created to make sense of much more complicated experiences. In the last case of advanced mastering, the enrichment becomes central, leading to a more formal notation of cybernetic stages of agency and workspace.

4.3.1 Retrofitting after perturbations

There are situations where each process is more or less capable of anticipating the outcome, but still the combination may have never occurred before. For example, take a cup made out of glass. When the agent pours the tea, the cup breaks. However, the agent has the experience of other glass cups used for tea. Almost every aspect of this event is known, but a small difference created a drastic effect. The agent would not have used that specific glass if it had anticipated the outcome, so the agent creates a cohering challenge to understand what has happened. In this case, the "pouring" event had: $\Delta_N(X_{glass\text{-}cup\text{-}pouring}) \neq \emptyset$ because $x_{break} \notin X_{glass\text{-}cup\text{-}pouring}$ but $x_{break} \in X_{glass\text{-}cup\text{-}pouring}$. So while Y^{in} did not create the association to breaking, Y^{ex} did tag it. In this case, the learning is very simple. A distinction is made between the current and default glass cups: $X_{glass\text{-}cup\text{-}default}\ \Delta\ X_{glass\text{-}cup\text{-}current} = \{x^{ex}_{density\text{-}cup\text{-}default}, x^{ex}_{density\text{-}cup\text{-}current}\}$ and so a breakpoint is identified as: $x^{ex}_{density\text{-}cup\text{-}current} \leq x^{ex}_{break\text{-}density} < x^{ex}_{densety\text{-}cup\text{-}default}$. The learning can be described by $Y^{ev}(X_{glass\text{-}cup\text{-}pouring}) \rightarrow \{x^{in}_{break}, x^{ex}_{break\text{-}density}\}$. Next time the agent checks against this break density to validate if the glass has the appropriate features for hot water. Note that the agent does not know exactly the value of $x^{ex}_{break\text{-}density}$. This may get investigated by advanced cases of observation.

4.3.2 **Bootstrapping novelty**

No mastering was needed for the basic adaptation, so no bootstrapping has been examined yet. Mastering requires raw experience $\{x^{ev}_{exp_1}, x^{ev}_{exp_2}, x^{ev}_{exp_3}, \ldots\}$ that first transforms into implicit knowledge. The raw experiences have weak (dispersed) relationships between associations, tags and motivations. Those default patterns can be found by machine learning techniques, but they may not be the most relevant part of the experience. The learning needs to find what the essential variables are. Each time the dispersed relations are subdued to the learning process (Y^{ev}) that tries to use the new essential variable to make the event easer to comprehend. I demonstrate this with the case of riding a bike without hands.

While riding a bike normally, the relevance of balance may not be so explicitly know, but it has to be implicit otherwise one cannot ridw the bike. Now, once the idea exists to ride without hands, a challenge state emerges to reflect on how such an action would be possible, artificially constructing what is envisioned. It is like riding, but with a straight back, so it is a bit like walking: $Y^{in}(X_{no\text{-}hands}) =_{Modeling} \{ X_{walking}, X_{biking} \}$, Just as with the glass cup, we need to find the difference that makes a difference. There is now no default or current knowledge, but the associations walking and biking can be used to create $X^{ex}_{walking}\ \Delta\ X^{ex}_{biking} = X^{ex}_{no\text{-}hands.}$ Notice that some parts of the biking have now been left out. The new concept is to focus on what is essential, but it is not certain if it will work. While trying out this imagined action, things do not go as anticipated: $\Delta_N(X_{no\text{-}hands}) = exp_1$ and $Y^{ev}\ (X_{no\text{-}hands}) = \{x^{ev}_{exp_1}\}$. The agent has tried out $X_{no\text{-}hands}$, but had to go quickly back to X_{biking} or the bike would fall. This threat is bigger than the goal of driving without hands. During this short experience, novelty is retrieved as raw experience $x^{ev}_{exp_1}$.

With $x^{ev}_{exp_1}$ a first adaptation is possible, since the agent has noticed that the steering did not stay straight,. In the next attempt, the agent tries to keep the focus on that feature. From the $x^{ev}_{exp_1}$ a tag is identified $x^{ex}_{steer\text{-}stable}$ as the essential variable, which becomes part $X_{no\text{-}hands}$ and the agent adapts its balance to keep the steering straight at exp_2. Now $\Delta_N(X_{no\text{-}hands}) = exp_2$ and $X^{ev} = \{x^{ev}_{exp_1}, x^{ev}_{exp_2}\}$, where $exp_2 < exp_1$, meaning that the anticipation was better than before. In this new experience, the relation = $x^{ex}_{steer\text{-}stable}$ *and* $x^{ex}_{balance\text{-}by\text{-}hips}$ can be made, which is an unfamiliar way of regulating balance and requires more exercise to apply properly. At this moment, the agent has an implicit understanding. To become explicit will require reflecting on X^{ex} and connecting it to other parts by abstracting it: $X_{no\text{-}hands} \cap X_{biking} = X_{balance}$. The abstraction allows for new associations and challenges around balance to be created.

The example required bootstrapping between internalizing and externalizing. First, $X_{no\text{-}hands}$ had to be imagined (internalizing) by Y^{in}. This was possible by following associations and merging $X_{walking}$ and X_{biking}. The next actions are taken that result in identifying the proper essential variable: $x^{ex}_{steer\text{-}stable}$ and $x^{ex}_{balance\text{-}by\text{-}hips}$. Finally, a reflection is needed to recognize the external tags and to build appropriate associations and challenges with it. The description is still a simplification of the actual complex interactions. With some more detail it can become clearer how the

process is able to deploy. For example, I expect $x^{ex}_{balance\text{-}by\text{-}hips}$ to be a minor control aspect recognized in X_{biking}. With the challenge, of riding without hands, amplification arises of the hip-control. In the complex reality, the amplification of some effects and suppression of other effects allow us to understand the emerging of the novelty.

This example is considered an activity that only takes a few attempts before it reaches a satisfying solution. In time, it may take only a few minutes or hours. This is, of course, significantly longer than the Gestalt recognition case that takes between milliseconds and seconds. The breaking glass cup should take between seconds and minutes to get to a proper insight. Such examples are very short compared to profound reflection (e.g. education) and profound mastering (e.g. craftsmanship) that can spread over years. I'll examine how such profound states lead to unique setting and how they show the relevance of environmental enrichment.

4.3.2.1 From implicit knowledge to explicit information

The biking example shows how an agent becomes more aware about the concept balance. While the control is explicit, the expression can still be implicit. In all previous examples, labels were used as a subscript to memory element X_{label}. This was done to make the example readable. For an agent, the labels would not be explicit and creating a label is itself a challenging learning activity. Implicit knowledge does not have a label. For example, $X_{no\text{-}hands}$ may actually be $X_{84285326}$, where this number is a reference in the memory. Creating explicit labels to identify concepts are, however, very useful to gain stigmergy between agents. The labeling is thus considered a social act that is only relevant if it is clear and if it is simple and understandable for all agents. The process to align the labeling between the agents can be understood as the same bootstrapping between internalizing and externalizing but now they are better considered as an audience and a speaker.

The audience is interpreting what the speaker is articulating. They are aligning the meaning of the expression in respect to their own knowledge model. The speaker is searching for the proper words to express meaning. The speaker is mastering the linguistic embodiment of the meaning and externalizing the concept. So audiences are modeling, while speakers are mastering expressions and articulations. The interactions show how implicit internal knowledge becomes explicit external knowledge. The transition of knowledge creation undergoes several stages (see Section 7.2.2).

In some cases, radical changes are recognized showing a phase transition. For example, old languages did not have the same level of abstraction as our current language, which can particularly be observed by how those languages got written. An example is the difference between the Egyptian hieroglyphs and the later Greek alphabet, where the former eventually had over 5000 hieroglyphs while the latter only consisted of 24 letters. Creating such abstract models are advanced cases of modeling. This transformation of knowledge is already a case of environmental

enrichment of the social fabric. The next chapter investigates the enrichment in more detail. Let us attempt here to express the advanced modeling more formally.

In the previous example, a simple abstraction was created $x_{balance}$ from $x_{balance\text{-}by\text{-}hands}$, $x_{balance\text{-}by\text{-}hips}$. The modeling was trivial. Balance was already an existing concept that had just required adaptation. More profound cases of modeling require the construction of frameworks, e.g. the alphabet. The profound reflection requires the change of the external in such a way that the externalizing becomes part of the modeling. Scaffolds like blackboards, working papers and weekly seminars, etc. have created environmental enrichment that supports modeling. In offices of scientists, blackboards may contain mental maps or "half-baked thoughts" that sometimes don't change for years. The frameworks are advanced abstractions that can be presented in set theory as Cartesian products. Take a problem space cluster $X_p = X_{frame} * X_{alternative}$. Notice that the frame is not solving the problem, but only creating an alternative way to present the problem in such a way that the alternative presentation of X_p becomes easier to understand. In science, frames on frames are built. Some become so important that the whole society has to learn it, like language and basic mathematics. The closer we get to the frontier of our knowledge, the more complicated the frameworks that can arise. Latour (1987; 2005) calls this "building controversies on controversies" and how any absolute truth of science gets lost in the mass of frameworks built to deliver the truth.

4.3.3 Crafting environmental enrichment

The abstract framework is only sustainable if it gets integrated into our daily activities. This required the use of the abstract frameworks to create new artifacts allowing environmental enrichment that improves our fitness. In this respect, the fabric of society has to be taken quite literally. If we look at our current surroundings, it should be clear how strongly it is fabricated. What used to grow naturally is under artificial regulation now. For example, a wildlife reservation is a fabric. It is mostly a social fabric which enforcs a space were nature revives. However, don't mistake the ecosystem for natural. Rangers regulate the wildlife and in other words ranger enforce control. Rangers prevent mostly human perturbations, but also natural perturbations like large fires or the extinction of one species by another species.

The artifacts creating environmental enrichment are found everywhere and they exist to leverage our agency. For example, I may not have much talent in cooking, but a book or video may guide me through the process, a store provides the resources and cooking machinery provide the tools to get the job done. If you take away all the tools and scaffold for cooking, then cooking would require years of training and even after years of training it still takes most of the day to process this task, gathering all the resources, preparing them, making fire, etc. It would indeed be "mastery", while it is in our enriched environment a commodity.

The cooking example should draw the attention to how deep the environmental enrichment goes. Let me get back to formalization. What I consider missing in previous formalization is the effect of mediation and agency. I transform the normal variable X to indicate the different stages of agency: object and niches (^{0}X), artifact and scaffolds (^{1}X), catalyst (^{2}X) and agent (^{3}X). Similarly for the stages of mediation: collective ($^{/0}X$), medium ($^{/1}X$), workspace ($^{/2}X$) and meta-system ($^{/3}X$).

Let me consider a simple example using carbon dioxide (CO_2) as an object in nature ($^{0/0}CO_2$). In chemical reactions and early living systems, carbon can be part of the interactions ($^{0/1}CO_2$). In ecosystems, the carbon becomes part of the coordination ($^{0/2}CO_2$) between animals that emit them and plants that absorb them. In an attempt to regulate this effect, some societies have created a carbon tax ($^{0/3}CO_2$) to control carbon emissions. Notice how CO_2 stays an object because CO_2 did not change itself. In society, CO_2 does gain power, but this power is related to the mediation of the CO_2, not the agency of CO_2.

The extra notation could be relevant when different elements are in play. Knowledge X belongs to some agent A. By mastering the agent and the knowledge change: $A(X) \rightarrow_{Mastering} A'(X')$. Transforming A to A' is to emphasize that the mastering changes the agent's embodiment. The agent, for example, grows muscles in the proper place, and connects neurons, that make it easier to do some actions. A more refined presentation can be made with the notation for agency and mediation. For example, how a painter is mastering: $(^{3}X_{painter}+^{0}X_{resources}) \rightarrow_{Mastering} (^{3}X_{painter} + ^{1}X_{painting}+ ^{0}X_{waste})$ In the following cases, resources and waste are not mentioned, because they are always part of the process.

To illustrate advanced mastering, consider a state where a particular challenge *C1* with knowledge Y by an agent ^{3}X does not allow the agent to answer to create any useful action: $^{3}X(Y) \rightarrow_{C1} {}^{3}X(Y)$ *and* $Y \rightarrow_{C1} \emptyset$. While the initial challenge is not reached, a reachable sub-challenge (C0.1) can be set. Take that this results in creating all kind of fabrics: $^{3}X \rightarrow_{C0.1} {}^{3}X + {}^{1/1}X_1 + {}^{1/3}X_2 + {}^{1/2}X_3$. In this example, three artifacts are created X_1 is needed to create an interaction, X_3 is the medium for the interaction and X_2 is a control artifact. In the example of the painter, X_1 could be the paint, X_2 the paper and X_3 the pencil. The artifacts are the resources for our agent to gain a workspace: $^{2}X = {}^{1/1}X_1 + {}^{1/3}X_2 + {}^{1/2}X_3$. Now the agent is able to act on the challenge: $(^{3}X + {}^{2}X)(Y) \rightarrow_{C1} {}^{3}X(Y') + {}^{1}X'$. In the case of our painter $^{1}X'$ is our painting and the experience has changed the agent's knowledge Y'.

Let me use simulation in Section 2.1.1 to give another example: the main objects were nuts $^{1/1}X_{nut}$, a simulation environment existed $^{1/2}X_{simulation}$ and the agent's knowledge system can be presented by $^{1/3}X_{knowledge}$. The $^{1/3}X_{knowledge}$ is now a scaffold only relevant to the agent in the simulation $^{3/3}X_{ape}$. Note how the agent in the simulation is part of a controlled environment. The simulation investigates the regulation behind exaptation. This was not done by simply *C1*, but five iterations *(C0.1 – C0.5)* were needed before *C1*, being a proof-of-concept about the regulation behind exaptation, became possible. The ^{3}X is the researcher and it can be argued that $^{3}X_{researcher}$ is part of some workspace.

So far, the mediation of the agent has not been considered. Consider research in part of a research organizations: ${}^{3/1}X_{researcher}$. PhD students get supervised, which means being coordinated: ${}^{3/2}X_{researcher}$. Researchers are often not controlled, because of the nature of such work. In other organizational structures, people can get controlled, like a patient that is undergoing hospitalization: ${}^{3/3}X_{patient}$. The notation is but an extension of precious description, in many cases the agency and mediation is debatable. The notation does not create any clarity on such debate, but just on how it is possible to enrich the environment and how it affects actions. In the next chapter on science and technology, some cases give more detail on the dynamics of agency and mediation for scientific development.

4.4 Related research

Let me finish this chapter by considering some point for future research. First, I'm going back to the sailing upwind case to consider how it is a novelty regulation model. I then give a glimpse of what is coming in the next chapters, where each advanced use of a novelty model requires another novelty model until a recursion is reached that creates a meta-model. Finally, I would like to make some suggestions on how to extend the formal work by investigating the relationship with other mathematical modeling.

4.4.1 Back to sailing upwind: introducing novelty anchors

Novelty regulation does not need to be about knowledge. In essence, it is to overcome conservation. For sailing upwind it was the law of momentum conservation. From the Cohering model it was the bias of knowledge. The main difference between the two cases is that the Cohering model works on information and can therefore create a constructive internal model. Another difference between the sailing model and the novelty models in the next chapters is that the sailing model does not play any part in the meta-model. Let me keep the introduction of the meta-model for the next subsection. This subsection is about the how sailing upwind is a novelty model.

For the Cohering model, the medium are memories allowing the constructive force of knowledge creation. The sailing upwind is an exceptional case having no constructive force, because it works with physical mediums. In fact, there is only one medium: the water is the environment of the boat, the workspace for the saw-like path and the system core. The system core is simply the mechanism transforming the force into the direction of the wind. The four novelty anchors for sailing upwind are the physical forces. To explain the novelty anchors a comparison with the Cohering model is useful.

The associations can be considered imagination that, metaphorically, are 90° opposed to the experience. What makes the internalizing process comparable to the lift force in the sailing case, and so lift is the internalizing force. Imagination can

create more associations then get aligned by externalizing process. This selection by the externalizing process can be described as a reaction to the imagination, making the anticipation processes become pragmatic. It can be compared to the viscosity force that pulls against the lift, creating the cost to move against the wind. Notice that the same cost exists for the Cohering model, where more imagination is possible, while actions limit the options, showing a virtual cost. For our comparison, it makes viscosity the externalizing force.

If we examine the mechanism, it should be clear how tension overcomes the law of conservation, by what is described as the default flow. The directing anchor transforms the flow. In the case of sailing, this directing depends on the pivot angle. With a 45° angle, an optimal motion became possible, to move against the wind. For the Cohering model, some challenge allows novelty to arise easily, while other challenges may be much less reachable. With the virtual nature of information, it is less evident to indicate what exactly is an optimal way to gain novelty. In the cases of innovation, it gets better recognized, as some inventions stay dormant until the proper workspace arises that can make use of the invention to improve the social fabric.

The evolving anchor gives the ability to mobilize. For the sailing the mobilization is literarily, for the Cohering model it is metaphorically to describe knowledge creation. In both cases, the mobility creates a saw-like path. Sailing this zigzag path is called beating. For the Cohering model, it is the relationship between mastering and modeling, which can happen more chaotically and the zigzag path is only recognized in theory. The sailing upwind should thus show that other implementations of the abstract novelty model are possible next to the Cohering model. In fact, each of the following chapters will introduce one. A summary of the similarities is given in Table 4.2.

Table 4.2 Relation between sailing upwind and learning with the Cohering model

Model	***Sailing***	***Cohering***
Source	Wind	Experience
Medium	Water	Memory
Anchors	Forces	Anticipation processes
Internalizing	Lift	Associations
Externalizing	Viscosity	Tags
Directing	Pivot angle	Challenges
Evolving	Motion	Knowledge

4.4.2 An glimpse on the meta-model for innovation

The Cohering model is the first model relevant for innovation. The transition from basic modeling, basic mastering, advanced modeling and advance mastering become

stages of a phase transition for innovation. In the case of the Cohering model, it is related to knowledge creation (see Section 7.2.2). Knowledge creation is only part of what is needed for innovation. In the meta-model, the novelty models become the internalizing anchors, because the development is about internalizing by the brains of individuals. The system core (Long-Term Memory) and workspace were internal to the brain, while the environment as memory is an extension of the brain. The other novelty models in the next chapter relate to one of the other novelty anchors. Each advanced case of one novelty model pushes us to the next novelty model. Only with the meta-model a full closure can be found. In Chapter 7, the closure will be elaborated.

With the Cohering model, the advanced cases of mastering and modeling bring us to the development of science and technology. In Chapter 5, I show how Science and Technology Studies (STS) came up with a novelty model I call "Eventuating" that focuses on events created by type of agents and so the novelty that emerges is agency of the social fabric. The social fabric is an external feature, so the Eventuating model is going to be the externalizing anchor of the meta-model. The Cohering model and Eventuating model create the default flow of the meta-model. In Section 5.2, the default flow relates to the natural evolution of the social fabric.

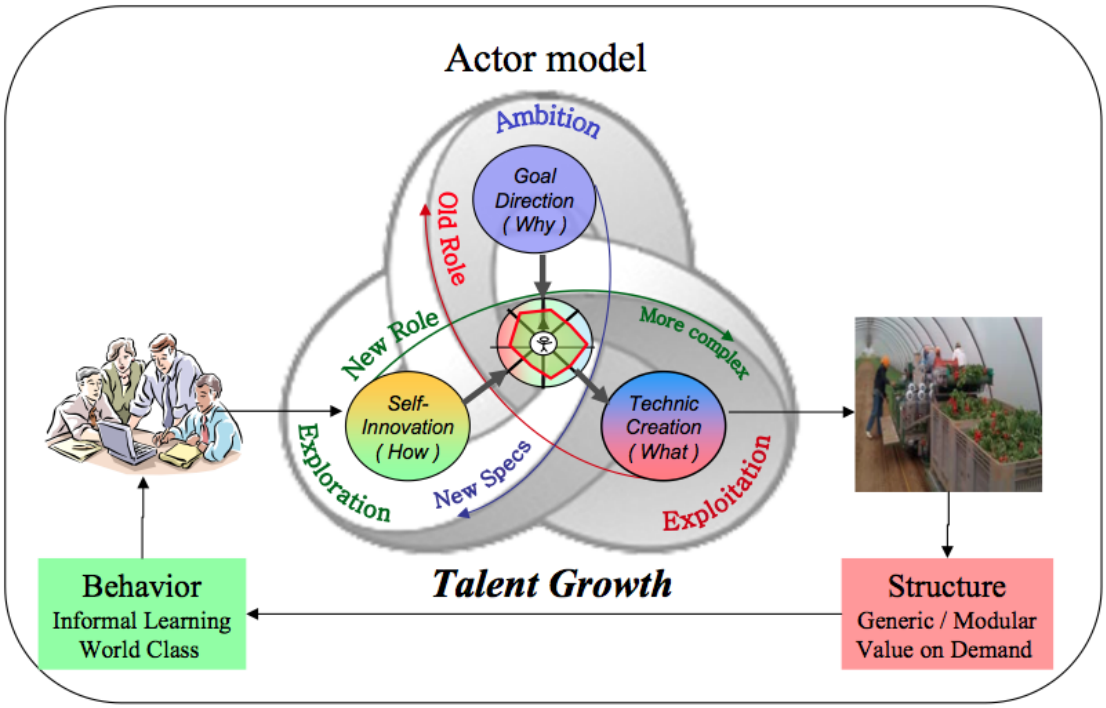
The advanced challenge of the Eventuating model argues about the construction of organizations to enforce scientific and technological development. This brings us in Chapter 6 to Strategy Management Studies (SMS). Again a novelty model can be recognized in SMS when the domain investigates complex adaptive environments. The model now describes dynamic capabilities as the anchors of the novelty model, which I call the Strategizing model. For the meta-model the Strategizing model becomes the directing anchor allowing the default flow, by evolution of the social fabric and transforms into a directed flow by the innovation of organizations. The advanced development of the Strategizing model brings us to project development. I call this last model, the Establishing model which is going to be the evolving anchor of the meta-model and will finally show how closure is reached.

4.4.3 **Relation to other mathematical modeling**

The notion so far is to model the dynamics of the novelty as investigated in the earlier chapters. To avoid unnecessary complications, no mention is made of existing mathematical models. Some relation can be made with advanced mathematic models. This part of the research has only just started. In Section 4.1.4, the use of Chemical Organization Theory (COT) show some of the early development around more advanced mathematics. It is not yet developed enough to express the novelty regulation. The special case of mastering and modeling, as audience and speaker (Section 4.3.2.1), bridges the research on novelty with the research on linguistics in Artificial Intelligence. De Beule and Stadler (2014) investigate the relationship between AI linguistics and evolutionary cybernetics.

For the entire novelty regulation, an alternative presentation can be reached using the trefoil knot. Kauffman (2013) shows how anchors can be created to the trefoil knot using a mathematical approach. It is clear that this topologic study requires investigation in future research. Lohman (XXX) has used the trefoil knot for a presentation of Integral Innovation (see Section 11.2.3). In this presentation (Figure 4.15), we recognize the first three anchors of the novelty model. The evolving anchor is presented here as the 3rd dimension of the trefoil knot, showing an interesting alternative presentation of the entwinement that the evolving anchor achieves.

Figure 4.15 The novelty model presented a trefoil knot with the research on Integral Innovation (Picture original created for MSF project, see Section 11.2.3).



4.5 Research Question I.3

How can the novelty research be articulated as a system and cybernetic theory and how can it be expressed more formally?

By moving to a system and cybernetic domain, the meaning of novelty regulation can become better understood by the laws of requisite knowledge. In particular, a system must know what actions to take and this requires novelty regulation. Novelty can become more formally defined as what did not exist before but emerges into existence by artificial evolution. Artificial evolution, then, is a bootstrapping cascade between mediation (that defines the novelty) and agency (that embodies the novelty). Artificial evolution is a concept with considerable potential, but there are few advanced studies to describe the artificial evolution in an evolutionary cybernetic way. I've made some attempt in this chapter.

The description of mediation and agency show how state can change. In the case of agency, external states exist (niches and objects) that become more internalized until they are an internal state of an agent (knowledge). The increase in regulation shows the transition from an internal state, which simply is the collective, to external artificial states, enforced by control systems (enterprise or laboratory). The whole description shows how primary elements and primary workspaces relate to meta-workspaces and meta-elements. Some attempt to describe this more formally by Chemical Organization Theory (COT) was done. What became part of this PhD is only the simple part. The ongoing research investigates how to express the emergence of novelty more by COT.

The formalization of novelty regulation has been undertaken during the second part of this chapter. First, each novelty anchor had to be more formally described and then the learning could be investigated. Challenges can have one of two directions: developing the environment by mastering or understanding the experience by modeling. The advanced mastering and modeling show limitations of individual learning and introduce the need for another novelty model. Each of the following chapters is going to introduce a specific implementation of the novelty model and combined they create a meta-model that elaborates how innovation is happening. This chapter concludes the first part of the PhD. The second part is about the meta-model and the third part takes on the challenge of validating the novelty research.

5 Science and Technology Studies

5.1 Science and Technology Studies (STS)

Chapter Five describes how Science and Technology Studies (STS) have investigated the evolution of the social fabric. The first section describes the relation to artificial evolution and the novelty model recognized in STS, which is called the Eventuating Model. In the second section, the enrichment of the environment by the social fabric is investigated. It shows how the environment becomes enriched constructively and artificially.

The Eventuating Model revolves around events, in the same way that the Cohering Model revolves around insights. The conservation overcome by the Eventuating Model is the scarcity of an event by environmental enrichment. It requires us to understand how mediation mobilizes scare resources (see Section 4.1.4). Mobilizations should not always be taken literally. However, as an example, consider how transportation has evolved in the social fabric: from walking (our own bodies) to riding animals, to building technology that allows traveling over water, air and entering outer space. If we examine modern air travel, it becomes clear how many rare materials, scattered all over the globe, had to be combined to make a single aircraft. A mechanism of scales makes such an expensive artifact become a commodity. Indeed, today large fleets of such aircraft exist and traveling by air has become possible for the masses.

Another way to understand the difference between the two novelty models is to recognize how the Cohering model allows for inventions to arise while the Establishing model is about the emergence of innovations in the social fabric. In STS, scholars have pointed out the power of institutionalization as the evolution of the social fabric, creating environmental enrichment. Only when we unravel the process and see how many people and resources are involved, does the regulation become clear. The process is always similar. Let me elaborate.

When the new ability has been discovered or invented it is a rare event. At the start, only a few people are involved, with a high maintenance cost for creating a single event. Such events are created today in laboratories and workshops. A pervasive process then drives the invention by artificially creating the environmental condition fitting the novelty (e.g. the rice terraces in Section 4.1.4). The pervasive process shows a scale effect that makes inventions of individual agents, become innovations of the meta-element (the social fabric). The transition is smooth, going from individual to groups to organizations, to governances and finally the innovation becomes systemic development by the whole social fabric.

The subsection goes into detail. The first subsection gives context as to how the STS is used for the novelty research. Subsection Two considers how science and technology is embodied in the fabric of society and how it describes the mobilization. Subsection Three makes an investigation of the anchors and the mediums for the Eventuating model. Subsection Four gives an example by considering a historical case in science with more detail. Subsection Five examines the original STS model and how it describes most of the Eventuating model. Subsection Six considers STS quotes that give details on the bootstrapping between modeling and mastering by the Eventuating model. With the Eventuating model and the Cohering model, the meta-model shows how the two novelty models create the default flow of novelty regulation (see Section 4.2.4) at the meta-level.

5.1.1 Retrofitting STS for novelty research

Heidegger, Polanyi, McLuhan are pioneers of the STS. However, when considering their work in detail, it becomes clear that it is only circumstantial. What happens is that a second generation, who are the actual STS scholars, have enriched the pioneers' work. This process of pioneers becoming more well-known by next generation interpretations is called retrofitting (Latour 1999) and is very common in science. In the same way, STS scholars produce circumstantial work for the novelty research that can be distillated and combined to create a stronger position for the research on novelty regulation.

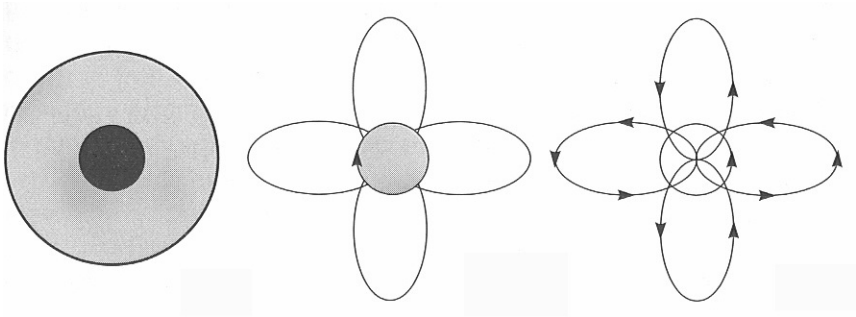
My approach does not make it a STS study. For example, I am placing too much emphasis on only a few scholars to take any position in STS. My approach is to generalize and describe the novelty research of STS. The base of my argument is built on the Rouse (1987) book chapter "local knowledge". My argument gets extended with more recent insight, by the contemporary scholar Van Den Eede (2011). While those two references can create a rich contextualization, it has, in particular, been Latour who contributes the most to the novelty research.

Latour does not create well-referenced work to his colleagues, but his action approach to STS is essential. One book (Latour 1999), in particular, has touched on many elements that are essential to the novelty research. In this book he questions how the social fabric embodies science and technology by circulating references. The dynamic of circulating references is elaborated in next section. Circulating references become essential to understand the novelty regulation, which Latour metaphorical describe as the "blood flow" of science (see Section 5.1.5).

5.1.2 From isolation of science to mobilizing the world

Latour questions how the emergence of science and technology is systemically embodied in the fabric of society. It begins by breaking down the over simplification of the divide between an internal science and an external society (left side of Figure 5.1). Investigating the complex dynamics results in invariant processes that flow into the fabric of society (right side of Figure 5.1).

Figure 5.1 Investigating how science and technology is entwined with society. Left, an oversimplified view is commonly used. Right, a deeper investigation shows invariant processes hooking into the fabric of society.



STS scholars elaborate that once we take a detailed look as to how science and technology develops, it becomes clear that it is an artificial evolution embodied by society and extended in the natural world. Rouse (1978, p 106-107) describes the embodiment of the artificial development with laboratories:

> Let us return to the example of Davis's measurement of solar neutrinos to help clarify the distinction between laboratories and the micro-worlds they contain. Davis's experiment constructed a single micro-world, consisting of a measured volume of perchloroethylene (containing the CL-37 isotope of chlorine) and a continuous stream of particles passing through it. His "laboratory", however, included the sun, which was the source of much of his particle stream, several miles of the earth's crust, which effectively isolated the desired particle stream from the background of cosmic radiation, and the detection devices outside the tank to extract and count the argon-37 atoms expected to result from neutrino-chlorine interactions. Laboratories, then, need not be bounded by walls. They extend outward to incorporate features of the natural world within the artificial worlds they construct.

Rouse uses the concept micro-world. We prefer to use niche to align it with the earlier evolutionary studies. Mobilization can be important for a meta-element to get the required resources into the central workspace (see Section 4.1.2). Latour (1999) describes the mobilization that science creates:

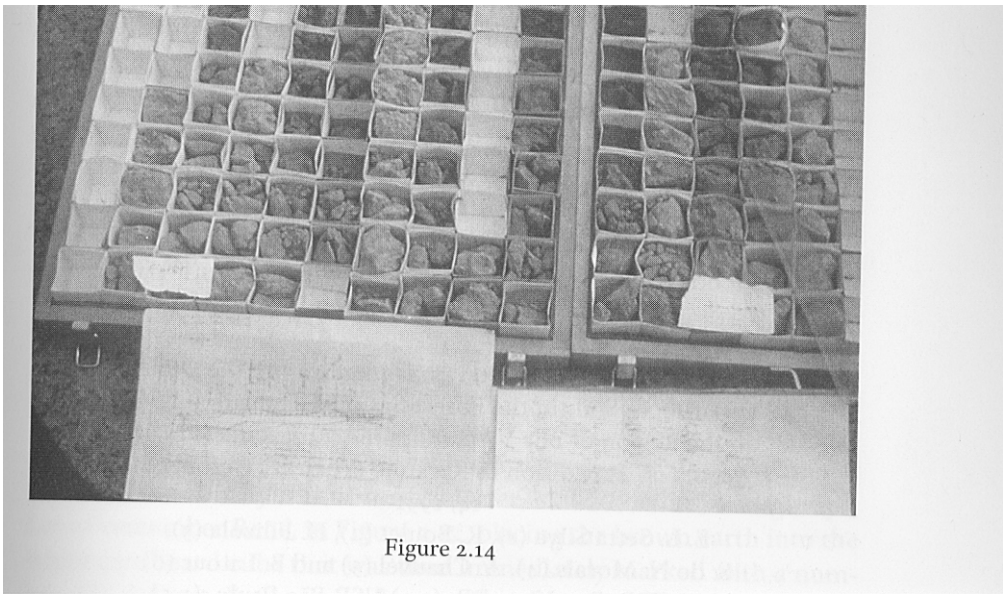
> Bringing it [the world] to the site of controversy, keeping it engaged and making it available for arguments.

Scientists can speak with more authority because their modeling makes signals in the world be transformed into facts that then are available for arguments. Latour describes the process of increased authority as "circulating references" (ibid, p. 24-79). He demonstrates this using a research expedition to investigate the question: "Is the forest or savanna gaining ground?" Three scientists took part on the expedition and each has their own set of tools and methods to mobilize and transform the world to scientific facts. There was a botanist, geographer and pedologist. I shall look at the last in more detail to give an example of how mobilization creates scientific information that shows an advanced stage of agency.

A pedologist studies the composition and distribution of soils by using a pedocomparator. The pedocomparator (Figure 5.3) contains a compartment that gets filled by soil. The filling requires the execution of a strict procedure. The soil

needs to be retrieved from a specific part and specific depths which results in a cognitive map representing the change in the composition of a particular area.

Figure 5.2 Top, a pedocomparator to separate different soils samples, bottom a schema as analysis of the pedocomparator (Latour 1999, p 55)



The methods and tools of a discipline create a scientific workspace allowing the natural itself to gain autonomy. Autonomy is an advanced stage of agency and it is strange to recognize it now for very simple objects like soil. The autonomy only exists because of the social fabric (the meta-element), so while natural elements can become agents in the social fabric, they are by themselves not agents. Another example is found with the recent attempt to minimize carbon emissions by enforcing a carbon tax. While carbon becomes an agent in the social fabric, the agency relates to the social fabric, not the carbon. This should reinforce the claim that meta-systems create external artificial states (see Section 4.1.2).

5.1.3 **Anchors of Eventuating model**

Each novelty model overcomes some law of conservation. The eventuating model is about events. The conversion relates to the seemingly impossible task of making rare events become common. It happens by an artificial evolution enriching the ecosystem. In case of the Cohering model, the artificial evolution is enriching memory. It shows how the internal state of the agent can become possible by modeling and mastering knowledge. Modeling and mastering is also recognized for the Eventuating model. In order to get to the learning first requires the introduction of the anchors of the Eventuating model.

By coordination a division of labor is recognized creating group formation where the elements have different roles. Roles are the anchors for the Eventuating model. In STS, the division in roles has been investigated specifically for scientific development. I generalize these roles for innovation. For example, the main agent in STS is the scientist. A scientist (creating facts) is a specific developer, just like an engineer (creating technology), an artist (creating culture), a politician (creating governance), a programmer (creating code), etc.

There are four anchors in the novelty model. For the Eventuating model, it means that four roles exist. The developer is the internalizing role. Latour (1999) recognizes the external force for innovation as the public. The public is a medium. It is necessary to understand the type of agents in this medium to get to the role. I suggest "delegates" as the externalizing role. Delegates represents the public and give agency to the public. Based on which alliances can be forged, we recognize how the innovation is able to develop in a particular direction and not another direction. Therefore, allies are the directing role. Colleague describes the evolving anchor in STS, which again must be generalized for innovation. In the case of businesses, the role is primarily described as "competitors". Both colleagues and competitors can generally be described as "peers", leading to the four suggested roles for the Eventuating model (Table 5.1).

Tabel 5.1 Overview of the anchors in the modulating and eventuating model

	Cohering	**Eventuating**
Anchor	Anticipations	Roles
Internalizing	Associations	Developers
Externalizing	Tags	Delegates
Directing	Challenges	Allies
Evolving	Experiences	Peers

The separate roles are an artificial division. In practice, one person can have many roles. For example, a software developer needs hardware to work. Being involved with hardware allows the software developer to express their likes and dislikes in an online medium. These actions make the developer a delegate for all the other users that search for third party information about the hardware. The developer can be collaborating in a project with peers. The developer may like the development to go in a particular direction. This requires forging allies to move the development in that direction. Therefore, at different times the developer has taken on all of the different roles.

The artificial division is important to understand how the division of labor and the division of roles can emerge. At the start, innovators must take on all of the roles. However, as the Eventuating model has its effect and the enrichment of the social fabric takes form, the roles get assigned to different people. The separation into different roles allows a system study independent of who is actually producing the agency. The dynamics show how a particular project would require more of one or

the other types of roles depending on the conditions of the environment. In order to understand this better it is useful to look at an example.

5.1.4 Eventuating agents, the case of nuclear chain reaction

I use the case of a nuclear chain reaction described by Latour (1999, p 81-98). The main developer in this case is Joliot in 1939, at the beginning of World War II. Joliot wanted to start an experiment on nuclear chain reactions. He found an ally in the Minister of War, who was concerned about the recent developments in international affairs and was interested in any scientific advantage that could help. Laugier was the director of the newly established institute for science called CNRS and was very interested in the scientific advantage. Union Minière sold radium to doctors, but uranium was at that time a waste product. This made Union Minière a powerful ally, who provided uranium, money and technical assistance. Scientists had demonstrated that 3.5 neurons could be released per fission. To get a chain reaction, the neutrons had to be slowed down. While alliances were forged, the scientists also had to make the facts work. In the process of finding a good moderator that could slow down the neutrons, different candidates were tested and rejected, such as paraffin and graphite. It was the colleague, Halban, who suggested deuterium. The only problem was that deuterium was very rare. Only one plant was capable of making it on an industrial scale. The plant belonged to Norsk Hydro Elektrisk.

Table 5.2 is constructed with the most relevant agents and artifacts in the story. It is possible to see that a pattern emerges. Developers and peers have the same goal, while allies have complementary goals. In this case, the challenge was mostly scientific and so many of the developments were also scientific. Several artifacts had a catalyzing effect on the development, but the social context is also one of the variables. The social context removes the resistance against high-energy research. After World War II, the public opposed the further development of the nuclear chain reaction, even for peaceful purposes, because of its long-term waste problem. In order to better understand position that the public has on development, it is useful to consider some other cases. For example, other cases where the public was opposed to development were genetically manipulated organisms and human cloning. In other cases, the public embraced scientific development as seen with the Internet, GPS, mobile devices and social media. Depending on this opposing or embracing effect, the work of allies becomes harder or easier.

Tabel 5.2 The system dynamics in the fabrication of chain reaction.

Name	Type	Adds	Goal
Joliot	developer	mediation	nuclear chain reaction
Halban	peer	deuterium	nuclear chain reaction
Laugier	ally	network	institution of science
Minister of War	ally	network + resources	sovereignty of France
Union Minière	ally	resources	profits
Norsk Hydro	ally	deuterium	???
uranium	developer	emits neutrons	nuclear decay

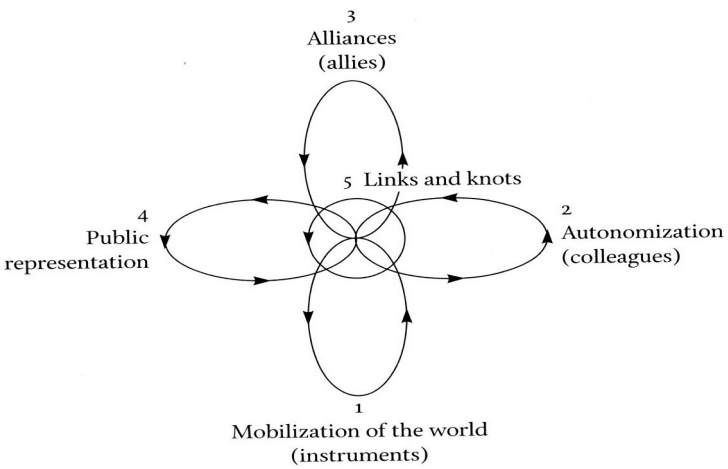
money	developer	mediates people	social mobilization
neutrons	developer	chain reaction	moderation
threat of war	delegate	removes resistance	increase security
…	…	…	

In this story, only one developer is known and several resources are elaborated. Notice how some objects and tools gain the role of developer. The goals of the resources only exist as the developers projecting these goals to the objects. The story of a nuclear chain reaction is an example of a successful scientific undertaking. Examples of failed undertakings are just as relevant. However, an overview of this is less evident – every success story has some pattern, but every failure breaks down for its own reasons. One case of failure is about MOS chips in Brazil (Latour 1987, p 150-153). The goal was to have a purely Brazilian computer, but there was no restriction on importing chips. The setting did not create the environmental enrichment to incubate the science of MOS chips. The small number of scientists became smaller and development in other parts of the world quickly made this research redundant. It would be fascinating to investigate if some numeric insight can be found related to the challenge, which could become a study on project risk assessment.

5.1.5 Circulation of scientific facts

By investigating the regulation system of how science and technology flows into our society, novelty regulation becomes recognized. Latour describes it as "the blood flow of science, by circulation of scientific facts". If we go into more detail on the scheme created in Drawing 5.1 it becomes possible to recognize the roles of the Eventuating model (Figure 5.3).

Figure 5.3 The circulation of scientific facts (Latour 1999, p 100)



Some differences between Latour's original model and my Eventuating model exist, but they are minor. The Eventuating model is focused on roles, while Latour's description combines very different parts. This is understandable, since the model

needs to address all aspects. The Eventuating model is more narrowly focused on one aspect (making events abundant), while the other novelty models in the meta-model handle other aspects of innovation. Another important difference is the absence of multiple mediums. Latour only has one place where all connections are made, being the links and knots (loop 1 in Figure 5.3). Latour recognizes the difficulties of the fived loop:

> Why does this fifth loop, which I call links and knots so as to avoid for the moment the word "concept," have the reputation of being much harder to study than the rest? Well, it is much harder. I don't pretend to crack it now, but simply to redefine its topology, so to speak, one of the reasons for its solidity. (Latour 1999, p 106).

The effect of failing to separate the three mediums make the loops overlap with the learning by modeling and mastering. The mastering is described as "mobilization of the word" (Loop 1 in Figure 5.3) and it overlaps with the internalizing anchor of the Eventuating model, since instruments refer to the developer. The modeling is described as "autonomization" (Loop 2 in Figure 5.3), since it relates to an advanced agency stage (see Section 4.1.2). The modeling now overlaps with the evolving anchor of the Eventuating model, since colleagues are peers. The last two loops have a clearer relationship to the Eventuating model. Allies are the directing anchors and "public representation" is by delegates who are the externalizing anchors. The relations are summarized in Table 5.3.

Tabel 5.3 The relation between Latour's model and the novelty model

Circulation of scientific facts	Novelty model	Eventuating model
1. Mobilization of the world (instruments)	Internalizing	Developers
2. Autonomization (colleagues)	Evolving	Peers
3. Alliances (allies)	Directing	Allies
4. Public representations	Externalizing	Delegates
5. Links and knots	Workspace	Lab/Workshop
	System Core	Libraries
	Environment	Social fabric
1. Mobilization of the world	Mastering	R&D
2. Autonomization	Modeling	Creating Text

For the novelty model, we need to become more specific and transform the "links and knots" into three mediums for the Eventuating model. The workspace is, for science, the laboratory, while for technology it is the workshop. The system core is our collective knowledge, which gets stored in libraries. The environment for the Eventuating model to operate is, of course, the social fabric. This is more than just an environment, it is enriched with many artificialities. With the mediums and anchors it becomes possible to reason about modeling and mastering. The modeling is the creation of all text in libraries, such as books, journals, etc. With more

enriched media, we now also get video, simulations, virtual environments, etc. Mastering is Research and Development (R&D) that can be about scientific progress, technological progress, organizational structuring, etc. To gain more understanding of how the Eventuating model works, the next subsection considers quotes in STS describing part of the processes.

5.1.6 **The bootstrapping principle in STS**

The novelty model creates a bootstrapping process between modeling and mastering. Rouse (1987, p66) describes this bootstrapping process for STS:

> Considering first discoveries, or novelties of facts, and then inventions, or novelties of theory. That distinction between discovery and innovation or between fact and theory will, however, immediately prove to be exceedingly artificial. Its artificiality is an important clue to several of this essay's main thesis. Examining selected discoveries in the rest of this section, we shall quickly find that they are not isolated events but extended episodes with a regularly recurrent structure.

A problem with Rouse's description is to call inventions "novelty of theory". In my formalization, both discovery and creativity lead to theory. Mokyr (2002), in his framework to analyze the concept of useful knowledge, demonstrates how both science and technology has a body of knowledge. Where scientific knowledge is propositional, elaborating what the phenomena is, technological knowledge is prescriptive, elaborating how to build or use it. Rouse uses innovation in a more limited manner than I prefer. I would articulate it as "novelty of fabrics". Although Rouse does not call it fabrication he does recognize it:

> Just as Foucault finds it not "surprising that prisons resemble factories, schools, barracks, hospitals, which all resemble prisons" (Faucault 1977, p 228) Latour thinks we should not be astonished to find that laboratory know-how tells us something about the world around us. We have helped *make* the one relevant to the other. (Rouse 1987p 119).

Making one relevant to the other shows how the niche construction by the social fabric changes the world around us, in the same way that rice terraces transform hills into cascading swamps (see Section 4.1.5). The relevance of niches in transforming the world is further elaborated:

> They [laboratories] constitute attempts to circumvent the chaotic complexity that so thoroughly limits the natural occurrence of the phenomena by constructing artificial simplified "worlds"… We know enough about the object to identify it and to characterize our interest in it, and we introduce it into a controlled microworld in order to isolate and amplify its appearance or its effects. (Rouse 1978, p 101-102).

What Rouse calls the micro-world is the workspace. It is important to notice that workspace has a specific meaning (an invariant pattern that only exists by boundary conditions). The specific conditions of a workspace are also recognized in STS:

> The instruments that enable the phenomena to appear do not exist outside laboratories or other places constructed to duplicate laboratory effects. The phenomena themselves are usually manufactured, isolated, and manipulated within the laboratory (Rouse 1978, p 111)

The phenomena are only useful if they can be extended outside the workspace by the niche construction of the meta-element (see Section 4.1.4). It is the transformation of inventions to innovation by a pervasive process that shows the constructive process of the Eventuating model:

> Most of the work in laboratory would stay there forever if the principal physical constant could not be made constant everywhere else. (Latour 1983, p 166).

Rouse and Latour both make note of how a process is required that changes the social fabric. Latour calls it "*the transformation of society into a vast laboratory*". Rouse (1978, p 101) makes the following remark:

> I shall suggest (as does Bruno Latour) that this [The creation of new phenomena] involves transferring the conditions of the laboratory itself out into the world.

They describe the niche construction that was earlier demonstrated with rice terraces (see Section 4.1.4). A laboratory is created by a challenge to solve scientific questions and so that even the directing process is easily recognized. According to Latour and Woolgar (1979, p51) *"a manic passion of marking, coding and filing"* exists in the laboratory. Latour questions what would happen if he would sneak in at night and remove all of the labels. The answer is that the whole process would have to be done over again and could set a research lab back many years. Therefore, the coding and filling is not just organizational, it is also constructive.

5.1.6.1 Modeling events

Once enough experience exists in the Cohering model, the challenge arises of abstracting the experience. It can be expressed as an attempt to standardize the experience. In an attempt to understand how experience is transformed into knowledge, we look at a quote of Heidegger who tries to understand knowledge from within the STS:

> In the 'physical' assertion that 'the hammer is heavy' we *overlook* not only the tool-character of the entity we encounter, but also something that belongs to any ready-to-hand equipment: its place. Its place becomes a matter of indifference. This does not mean that what is present-at-hand loses its 'location' altogether. But its place becomes a spatio-temporal position, a 'world-point', which is in no way distinguished from any other. (Heidegger 1957, p 361-262).

Rouse summarizes Heidegger's remark as follows:

> He [Heidegger] points out the transition that can be made from contextually situated claims like "the hammer is too heavy" (for the task at hand) to "the hammer is heavy" (a decontextualized assertion of a contextual property) to "the [specified] hammer has a mass of 1.2 kg." (Rouse 1987, p 77).

Rouse claims that what Heidegger, and later Dreyfus, characterizes as theoretical de-contextualization is better construed as a process of standardization:

> What Dreyfus takes to be a "theoretical" de-contextualization of those phenomena is more akin to the transformation of a tool originally designed for a highly specific task within a particular context to a more general-purpose item of equipment. (Rouse 1978 p113).

The standardization of the hammer has led to a new concept of "mass", which can be quantified. Not only hammers, but a whole series of fabrics have led to the standardization of concepts, where "mass" is just one aspect. Interestingly, the richness of events often allows modeling to take place long after the initial description.

The standardization is, in fact, part of a larger development of institutionalization. While STS does have a lot to say about institutionalization, I do not consider it a feature of the Eventuating model. In the same way, knowledge creation is important for STS, but is not a part of the Eventuating model. In fact, institutionalization is central in the Establishing model (see Section 7.2.5).

5.1.6.2 Mastering events

Common in most studies of science is the observation that scientists make things happen in the laboratory rather than just observing what goes on around them. Tacit knowledge is created in the process of making things happen. Polanyi (1958) mentions how tacit knowledge is embodied and needs to be felt. Rouse seems to think along the same line:

> This "feel" for the instruments, more a practical craft knowledge than a theoretical representation, does not just tell scientist when their equipment is working properly. It also suggests possible directions for investigation [The importance of such craft knowledge has been discussed extensively by Ravetz (1971) and Ackermann (1985), but the emphasis on the role of tacit knowledge in science goes back at least to Fleck (1979) and Polanyi (1958)]. (Rouse 1978 p100).

I believe that Rouse is referring to expressions of (Ackermann 1985, p 132):

> Theory and data can be described, but one must learn how to operate an instrument.

The use of instrument is always a question of mastering. Such mastering is even observed for theoretical studies:

> Although the experimental manipulations in which phenomena like the Wassermann reaction are created are the most obvious place in which local, experiential skills are essential to science, even theoretical and mathematical tools have an experiential basis. Learning how to attach these techniques and models to particular situations, and to avoid the various problems and pitfalls that arise there, requires tacit craft skills as much as any experimental procedure. (Ravetz 1971, p 88-101 according to Rouse 1978, p 109).

Many scientists do not like to acknowledge that science requires tacit knowledge and intuition, since science is expected to be objective and formal. The act of science is to transform what is emerging in events to a formal model. Nevertheless, the motivation for the action or even the ability to act on itself cannot be objective and formal. Inevitably the act of science is tacit. The tacitness is not beyond a level of

control: scientists hold seminars, create working papers, hold conferences and conduct experiments. These are events and the events can be controlled. The multitude of actions create the complex scientific behavior:

> For every bit of published "method", there seems to be a bit of unpublished know-how, which not only reconstructs the recipe sequence of steps in the paper into that of feasible doings within the situational logic of laboratory actions, but also provides routines for diagnosing and coping with many unspecified problems. (Knorr-Cetina 1981, p 128).

5.1.7 **Towards a meta-model**

With a more detailed understanding of the Cohering and Eventuating models, it is now possible to turn to the meta-model. Each novelty model is producing some kind of novelty, related to the type of anchors. However, these novelties are entwined, creating fascinating hybrids that can only be understood by artificial evolution. One interesting concept that has been developed by scholars in STS is hybrid energy. With energy being a potential variation, it provides additional insights on artificial evolution. Van Den Eede (2011, p 321) describes some of the dynamics of hybrid energy:

> Whenever technologies, media, modes of perception collide there is released 'hybrid energy', out of which in turn new creations arise. '[C]ulture that is engaged in translating itself from one radical mode such as the auditory, into another mode like the visual, is bound to be in a creative ferment, as was classical Greece or the Renaissance (M. McLuhan 1962, 72) … What assures us that 'hybrid energy' actually attests to a phenomena taking place on the side of beloved objects ? … But the term 'energy' may put us on the right track. 'Energy' suggests a power within the things themselves relatively independent of human or even relational intervention. In chapter 8 we discussed the hidden 'core' of objects – on the singular level. The notion 'hybrid energy' can help to make sense of how – on the plural level – hidden forces within singular objects may *come together* in order to create something totally new, i.e., a hybrid.

Van Den Eede tries to emphasis the presence of a hidden core. To make the hidden core emerge into an actual system core requires the development of interfaces. Building interfaces affects the reality of both the local-level and the meta-level. McLuhan and Nevitt (1972, p 138) describe it as:

> Natural interfaces are never neutral channels. The medium always is a barrier.

Building the interface creates closure, which is recognized by many scholars (Van Den Eede 2011, p 97-98):

> From McLuhan to Heidegger to Latour to Feenberg to Bateson, a thread can be said to run that unites them in one great perceptual project, namely the spotting of the blind spot and the accompanying attempt of remedying them. In each case a "closure" – more or less tied to our preconception or to our perception – takes place: McLuhan's 'sensory closure', Latour's and Feenberg's 'closure' of the black box, the 'organizational closure' analyzed by the cyberneticist (von Foerster and Poerksen 2002, 59-61) and not to forget, the closure brought on by the 'natural attitude', mapped by the phenomenologist (beginning with Husserl).

It is by examining the closure and how it affects the environment of the system that STS scholars investigate the recursive dynamics of local regulation versus meta-level regulation. To investigate the emergence of the meta-level regulation, the next section considers the evolution of the social fabric.

5.2 The evolution of the social fabric

To understand the evolution of the social fabric requires a historical and evolutionary study. Latour (1999, p. 213) described the bootstrapping evolution of society, but his schema lacks validation and the articulation is making it more complicated than it has to be. Instead other scholars, from other domains, have made stronger and more profound studies that clarify some of the major transitions in the evolution of the social fabric. Before the study can start, it is necessary to introduce a theory about the phase transition. The theory elaborates why phase-transition happens by using an S-curve shape.

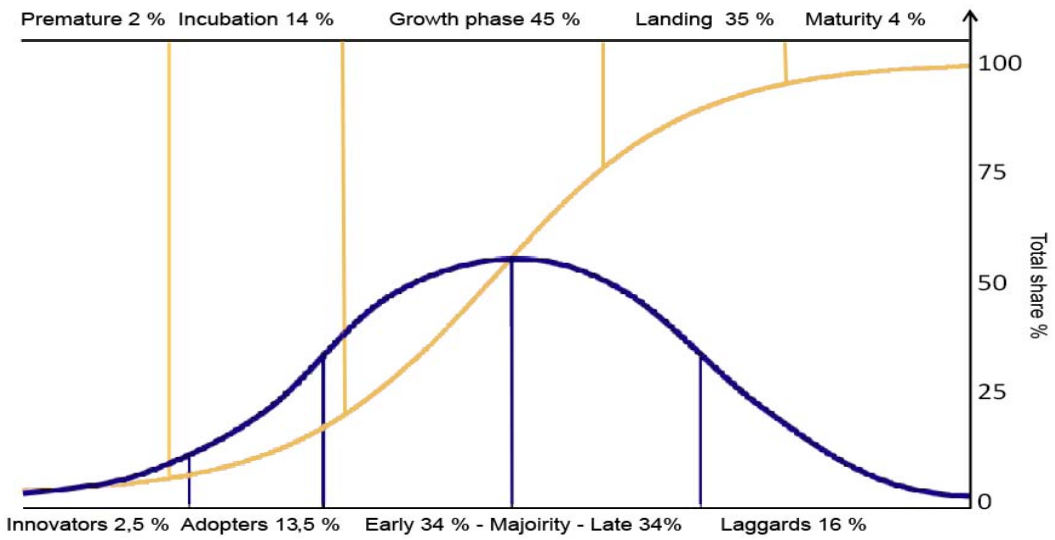
After the theory, this section investigates some of the major transitions of the social fabric. It starts with a Paleolithic society were geography and physiology defined the major transition from hunters to farmers. These studies were done by Diamond (1998) who found an interesting relationship between the emergence of societies and the domestication of plants and animals. Domestication is the most natural of all artificial evolution, creating the essential free energy for societies to arise. With the free energy we see societies becoming more concentrated, which improves the ability of a society to mobilize. The mobilization stimulates the innovation of bureaucracy. The first bureaucracies appear with cities, and the fittest of such early societies can make empires develop. Later on, mobilization also arises by technology. The different evolution of both bureaucratic mobilization and technological mobilization is receiving considerable attention.

The oldest transitions stay general because many of the required details are missing. As history progresses more details become available. The reason to go so far back is because of the difference of the scale that some phase transitions are in. If we create a rich enough picture, it becomes clear on what the influences of some of the older transitions are playing on our contemporary development. The contemporary development brings us to Internet innovation waves. By eventually focusing on particular Internet innovations, it become most clear where this PhD can find direction to validate the research with innovation studies.

5.2.1 Phase transition S-curve and evolution scales

Phase transition in theory happens by a S-curve. It only has S-curve shape if no forces disrupt the natural flow. To introduce the S-curve, let me begin with the relation it has to a wave of successive groups. Rogers (1962) defines successive groups of customers for new market penetration (Figure 5.4). The use of Rogers' studies is limited, but the dynamic is general and can be applied to innovation, where the successive groups refer to developers.

Figure 5.4 Successive groups, adopted from (Rogers 1962, p. 134)

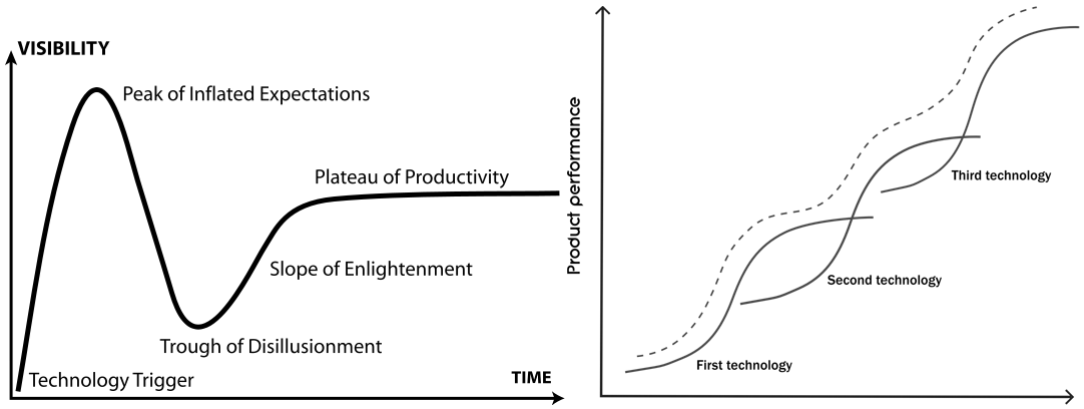


A wave, in the shape of a normal distribution, explains the relative increase of the people who are involved (blue line in Figure 5.4). The S-curve shape appears by considering the total share of involved people (yellow line Figure 5.4). Rouse has named the successive groups, ranging from innovators over adapters to majority and finally the laggards. The five stages of the S-curve are my own description of the S-curve. More often the shape is divided in three stages. I have divided the first and last part into two more phases because I can recognize different dynamics in these stages.

The first phase is almost a flat line and is named the premature phase. Where the phase starts is hard to describe for almost all of the phase transition. During the premature phase, the development is very slow and happens by focus on a rare event. In the premature phase, inventions are often created independently and by chance. During the incubation phase, the inventions show interactions and allow for agents to gain control over phenomena. During the incubation phase, a true understanding of the novelty arises as well the insight as to how the novelty can be useful. During this phase, tools and scaffolds are created in the process of advanced mastering and modeling (see Sections 4.3.3 and 4.3.4). The growth phase is the most visible part of the phase transition. During this phase, coordination gets recognized and the tools and scaffolds get coupled into machines. It is when the novelty gets recognized as technology. During the growth phase, many more people get involved and more applications for the technology get recognized. In the maturity phase, the cost becomes a big issue and the scale is used to reduce the cost. We now recognize how control is executed by a meta-system. The last phase is again a slow phase. It is about fully automating the development and showing how it dissolves into the social fabric. The dissolving shows how the artificial becomes a foundation for the social fabric creating more free energy for other phase transitions.

For an S-curve to take form, it is essential that the vision relate to actual events. The problem with the artificial level is that some visions may lack grounding to reality and create hypes. Hypes change the S-curve into a different form (left side of Figure 5.5). They show a peak of exaptation followed by inflation before the whole development can stabilize (left side of Figure 5.5). Sometimes we also speak about waves of innovation. The wave can be recognized as overlapping S-curves (right side of Figure 5.5), creating a rippled constructive development.

Figure 5.5 Left the hype-cycle, right the waves of innovation by successive S-curves.



The development becomes much more chaotic if we consider phase transitions of different scales. For example, I argue that the whole evolution of the social fabric shows a huge S-curve where we are almost in the middle of this phase transition (discussed in more detail in Section 5.2.9). A smaller, although still large phase transition are major transitions recognized in history, like the agricultural revolution and industrial revolution. We can argue that, in the past century, an information revolution has started and the Internet is now a strong mediator in this revolution. The Internet innovation allows us to recognize smaller waves of particular technological development. To simplify this chaotic development, I use meta-scale, societal-scale, organizational-scale and technological-scale as different phase transitions that are occurring simultaneously.

5.2.2 **Domestication**

Domestication creates the first free energy required to make the social fabric emerge. The nomadic hunter-gatherers society is where we start to investigate the social fabric. The hunter-gatherers had the ability to create more artificiality than other social mammals. In addition to artifact crafting (tools and scaffolds), domestication is recognized. Taming is the natural origin of domestication. Tamed animals and plants still undergo natural selection, while domesticated plants and animals undergo social (artificial) selection. Hunter-gatherers already knew how to domesticate animals. Therefore, domestication is a necessary but not a sufficient

condition for the transition to farming. The artifact crafting knowledge had a positive effect on settling. Crafting was a necessary, but not sufficient condition.

Both domestication and artifact crafting creates agency. To see the artificial evolution, we need to also consider the mediation. In particular, fertile niches would create an important change, since in these niches the need to travel – to find new hunting and gathering grounds – would diminish and sedentary society could emerge. The condition of settling does not yet mean farming. Today, some hunter-gatherers sedentary villages still exist in the rainforest.

If a population would stay long enough in the same place, they start perceiving their environment differently and the agency (by artifact making and domesticating) would have started an irreversible transformation. To stimulate the hunter-gatherers to become farmers would require an easy transition with directly perceived benefits. Diamond (1998) has investigated different fertile niches to understand why farmers first emerged in the "Fertile Crescent" and later in other comparable niches. The evolution at different moments in time makes it easier to validate the essential variables of the self-organization. Diamond points out that the Fertile Crescent had many plants and animals more suited for domestication, which other fertile niches did not have to the same degree. The difference in degree can explain the time that it took for development in the niche.

The difference in degree depends on the characteristics of the plants and animals. The plants and animals would have to be easy to maintain, not too aggressive and have short reproduction cycles. For example, annual plants would make the domestication more visible, since each year the effect of the selection could be seen. In addition to domestication there would also be usability features. For example, grain has more energy than other grass plants and can be stored for long periods. Goats produce not only meat, but also milk. Sheep provide meat and clothes. Other animals like oxen and donkeys would turn out to be useful for transport and labor. The difference between the fertile niches is one of degree and the degree relates closely to the amount of time it took before farming societies emerged in those areas.

While farming may emerge spontaneously in fertile niches, there are other richer locations for farming. The basic knowledge and the adoption of more advanced tools and scaffolds allow the takeover of the richer farming niches. Mokyr (1990, p XX) gives the example of how advanced tools allowed a shift from a Mediterranean climate to a Central European climate. The clay land was richer, but would further challenge the farmers' to transform their tools and build more shelter (scaffolds) to protect themselves against less favorable climate conditions (cold and moisture).

Domestication has evolved ever since its natural occurrence. While grain was domesticated early in history, other food was only introduced later. For example, only with the ancient Greeks does the domestication of apples emerge, while rabbits only were domesticated during the Middle Ages. It is important to notice that hunting and domesticating can co-exist. Wild apples still exist and wild rabbits are still hunted. During each major transition a boost in farming is seen. With ancient

societies farming became more regulated (bureaucratically organized), during the Middle Ages, land rotation systems were invented and new crops for the animals like clover was used (ibid). During the industrial period, farming also became industrialized and in modern times intelligent processes are used to boost food production, such as the manipulation of genes.

5.2.3 Social Mobilization systems

Farming made it possible to allow many people to live in the same place allowing villages and then cities to become possible. The population concentration creates a new dynamic and shows how artificial niches become possible by specialization and by using the bureaucratic governance of society. Early cities' selection criteria were natural: easy to protect, natural disposal of waste, plenty of resources, etc. Consequently, early cities arose in specific geographical locations. The environmental features only explain the emergence of early cities, not the rise to power of later cities. Governmental regulation – like commerce, writing systems, military, politics, law, etc. – can explain the rise to power. The fittest governances can mobilize empires. It is mostly by these empires that our ancient history is written. The earliest empires go back almost 50 centuries. All over the world empires have emerged at different moments. Each empire had its seat of power in some city where a professional bureaucracy was established. In some cases, these cities were not at all sustainable and required a huge resource mobilization across the whole empire to maintain the central city.

Finding the essential variables of this niche is less evident. The literature on the issue is fragmented in respect to our needs. Empires write history of their major successes and have books about their governmental work. However, this detailed information buries our search for the dynamics relating to novelty. There are two interesting books about the failure of societies that focus more directly on the issue that we are concerned with. Diamond (2005) was intrigued by the collapse of the Mayan empire and investigated the subtle balance of their ecosystem. Another scholar was able to express it better. De Soto (2003) was intrigued by the failure of third world countries to adopt capitalism and found a discontinuity with social contracts related to property rights, which he called "dead capital". Social contracts are discussed in the philosophical literature (Hampton 1988; Scarry 1991; Rousseau 1994), but our interest is more practical. I use De Soto to elaborate how social contracts embody a new dimension of the social fabric, which De Soto calls "the essence of capital".

De Soto (ibid) gives an interesting example of how social contracts change in relation to the environment. During the colonial period, official landowners were often appointed to territories by an old European law system. While this was accepted in some parts of the world, the so-called "Wild West" in North America was a niche that had a different philosophy. The soil of America belonged to anyone for the taking. This created a conflict. Settlers claimed land based on their own social contract, e.g. the Tomahawk rights. Eventually, integrating the Tomahawk in the old

European law system solved the conflict. Any improvements made to the land were the property of the settler and if a landowner wanted to claim that land, the settler would have to be paid for those improvements. This new rule transformed a conflict into a synergetic relationship between settlers and landowners. It stimulated the professionalization of a new profession called settling. Professional settlers would move on once a region became more developed.

A similar transition from conflict to synergy is recognized just before the industrial revolution (ibid). Guilds used to regulate the production of any trade, but their legal rights were restricted within the city walls. Entrepreneurs start setting up activities outside the city, creating an "extralegal" zone, similar to the settlers in the previous case. Extralegal is characterized as "nor legal, nor enforceable". It is a gray zone where legality breaks down. While these extralegal entrepreneurial activities were first considered to be a problem, they became vital for the industrial revolution. Considering such stories makes one think about current extralegal activities and how they may hide the architecture of new social contracts. An example is the conflict between free information culture on the Internet and Intellectual Property protection by organizations. In Section 6.1.3, I give some examples related to the new social order arising from the Internet.

Mobilization by professional bureaucracy is a social mobilization. The processes are mechanistic, but it is way too early to talk about technological mobilization. With the rise of these first mobilizers the need to change the environment in favor of mobilization arises. For example, the Roman Empire of Augustus Caesar created a networks of roads that led back to Rome. With the roads Augustus maintained a tremendous grip on the Empire, since it allowed the mobilization of its army much quicker. The empire always had a clear military mindset and created particular military innovations. However, several innovations were better for different purposes. In modern times, new types of roads had military intentions, like the first highways that got built for military purposes at the brink of World War II. In both cases, the roads turned out to be more suitable for activities like trade. Even today, many great innovations have a military origin, with many opportunities for social exploitation, like the GPS.

Cities became important early in our history. Their relevance only increased during the other periods (Middle Ages, industrial revolution and today). Cities are still a source of new emerging novelty. Today's city building concepts are focused on sustainability and require a profound investigation of the city's history (Haughton and Hunter 2003). In fact, building cities is becoming a high-tech industry. For example, charter cities are considered to be a radical new way of development aid (Romer 2010). Charter cities stop the brain drain from underdeveloped countries by building a state of the art city inside the country. The charter zone is a special economic zone, the size of a large city, which attracts large-scale entrepreneurial projects. Migration also has an intriguing relationship with innovation and cities. Florida (2002; 2004; 2005) considers the strength of a city its ability to attract creative people that become the driving force of an economy.

5.2.4 **Nationalism, globalization and enterprises**

Although bureaucratic mobilization may have emerged in cities and eventually even led to city-states, it needs to be recognized how more fitting the bureaucratic mobilization was when national systems were organized. Just like cities, many nations emerge independently of each other in different geographical areas showing a similar dynamic of fusing the local rulers into larger national bodies. Thousands of city-states existed in Europe in 1300, while by 1900 tens of nations became the ruling powers. The diversity of Europe has been an essential meta-workspace for the technological revolution, while that fragmentation creates a weakness for contemporary globalization. The larger nations have shown more ability to play in a globalized world.

Both nations and globalization can be investigated in more detail with the five phase transitions of the S-curve. A simplified view for the phase transition of nations should suffice. In Europe, the incubation phase for national development took place between1400 and 1800. This is when the organizational structures of nations took form by fusing the local rules. Between1800 and 1900, the so-called "Age of Imperialism" exhibited a growth phase where the power of the national organization was exploiting the world. After 1900, the World Wars and their aftermath would change the game, making the phase transition shift to a maturity phase. During the mature phase, frameworks are created that connect the different nations. During the wars these are alliances and after the great wars they become international institutions to ensure that no great wars can develop anymore. Today, nation building is still in a maturity phase. Some indications demonstrate that we are at the brink of the enrichment phase. For the enrichment phase, the national organization needs to dissolve. The creation of international organizations is one aspect. The recent technological support also allows for some national structures to dismantle, for example in favor of direct democracy. The change to the national organizations is going to take time. It will be at least several decades before such structures are present in a large proportion of national organizations.

The incubation phase of nation-development becomes the premature phase of the global development, sometimes called the proto-globalization. It is when global agents get created that the globalization has entered an incubation phase. Private enterprises become such agents. Early enterprises are commercial agents. The first private enterprises were created under royal charters, like the East India Companies (EIC). The two best known cases are the English company and the Dutch company created around 1600. The success of the enterprise structure makes a diversity of enterprises arise (e.g. non-profit, non-governmental, development communities, etc.). Such enterprises are very young when compared to the commercial and governmental enterprises.

5.2.5 The premise of the technological evolution

Often when considering technological evolution, one goes back to the very first tools in the Stone Age over 3 million years ago. This shows how early a prematurity phase can be. It is the reason to separate the prematurity phase from the incubation phase. It can even be argued that the prematurity phase is not unique to humans. The incubation phase is and can even get more clearly recognized in historical writing. Mokyr (1990) in his study on the history of technology identifies the start of the incubation phase for technological mobilization by the social fabric. It relates to the mentality change after the classic period. He elaborates how a classical period was using slaves and therefore the medium did not have the proper state to innovate on labor. The life style and philosophy of monks become essential to innovate on labor. For example, the Benedictine Rule (ibid. p 204):

> The concept of penitential labor was supplanted by the idea of labor as a positive means to salvation. (LeGoff 1980, p 107-21)

During the classic period, the intellectual class was interested in the military, politics and philosophy. Monks in their small communes started using their intellect to stimulate local development and show how these organizations start intentionally building self-managing villages. Monks investigated labor (often without actually doing any labor), which made all kinds of related innovations emerge. Innovation of labor relates to automatization, which is considered a feature of the Industrialization. However, Mokyr shows how it is actually slow innovation during the Middle Ages. Even factories were seen before the industrial revolution. They were just called mill-parks, but there could have been 400 people working at such a park (Mokyr 2002). What this demonstrates is that automatization by factories is not the product of an industrial revolution, but its premises.

The evolution of technology can get more clearly projected onto the stages of the innovation S-curve. Inventions are the building blocks for innovations. Cultural hubs, being a workspace for inventions have been recognized in different places in the world. The prematurity phase shows the slow emergence of technology and can be recognized in multiple places in the world. The European monks are just one example. It was a slow spreading over several centuries. Interaction between the different hubs allowed for acceleration. Previous phase transition, like farming and the first empires have happened isolated from each other. The technological evolution at first was isolated, but it increasingly became a global phenomenon. Alignment is recognized with inventions happening between the 12th and 15th century. In particular, the Mongol empire rose to power in the 13th century by assimilating the engineers of the concerned places and duplicating their skills though out the whole empire. We see how at different places different technologies arise, e.g. the windmill in Europe and movable types (for printing) in China, while the assimilation of the one invention into the other culture creates the acceleration. The interaction with the different hubs stimulated the world trade networks that were relevant later in history. The assimilation of different technologies can be considered the incubation phase of technological evolution.

The growth phase is the industrial revolution. It is interesting to recognize how it has only happened in one niche. The reason why this event only happened once is simple: the world was too small to have multiple events of this kind. Indeed, the industrial revolution would affect the whole world, not just Europe. China had seen an age of inventions, but did not evolve itself into an industrial revolution. To understand this requires us to recognize the driving force behind the evolution of technological mobilization:

> The central idea that technological progress needed a bridge, however narrow, between the educated class and the working class seems a logical proposition. In China, this bridge was provided by the government. (Mokyr 1990, p 236)

China is well known for its professional bureaucracy and has a very different governance structure from the European democracy. Both create the bridge for technological progress, but Europe had no control over the bridge while China had. China's innovation depends on the mood of China's ruling class and the mood changed from technology to culture. This is very different in Europe where the closely related empires extended their power by colonies. The effect was a strong competition that forced the nations to continue evolving. In other words, Europe was a meta-workspace, while China was a meta-element.

Inventions would go much faster by the Industrial Revolution compared to the technical development of the Middle Ages. However, this could still require a considerable amount of time. The reason is that the still limited environmental enrichment for innovation and invention would get inspired by chance and was not intentional. It is, in other words, more like a domestication process than how technology is pursued today. More systematic Research and Development (R&D) has emerged with the second Industrial revolution and is the beginning of the maturity phase of technological development, which develops in laboratories. The enrichment phase of the technological innovation happens when the development of technology becomes automated. It is a contemporary development requiring considerably more environmental enrichment. To become more concrete, let me consider more cases of technological evolution starting with the steam engine.

5.2.6 **The steam engine case**

The steam engine emerged with little environmental enrichment. It was more of a domestication process than an intentional innovation process. Before its invention, mills were the primary source of engines, already showing a lot of complexity and applicability (sawing, making paper, weaving silk, drilling cannons, grinding grain, etc). One specific niche made the steam engine emerge: mining. A problem existed with deep mining showing how horsepower was simply not enough to pump out water from a dept of more than 10 meters. Torricelli understood that it related to atmospheric pressure and created an experiment with mercury to investigate the problem. Mercury, being a lot denser, shows the same phenomena after one meter. The Torricelli experiment resulted in the invention of the barometer. The barometer shows a vacuum that relates to the atmospheric pressure. Torricelli and Galileo in

1630 made the experimental setting to investigate an artificial vacuum. In 1654 the Magdeburg hemispheres by von Guericke became an important test of the artificial vacuum to show its strength and it led to the insight that such a dynamic could be used to develop an engine.

Aristotle had, in fact, mentioned the concept of artificial vacuum, at a time that did not allow for its development. It was until the 17th century that this prematurity phase for the steam engine lasted. The first prototype of the steam engine would become an important part of the eventual steam engine: the piston. In circa 1690, Denis Papin developed the steam digester, which had the design of the piston. Its application was limited. Thomas Newcomen improved Papin's digester to build an atmospheric engine by circa 1712. This engine became broadly used for mining, reaching deeper than 10 meters. The atmospheric engine needed to cool down. Between 1763 and 1775, James Watt improved Newcomen's engine by separating the condenser so that the engine could stay hot. Watt's improvement was the last missing piece for the steam engine to become a more general engine for several applications. The century from Magdeburg hemispheres experiment until the Watt engine is considered the prematurity phase of the steam engine.

The growth phase is recognized by the multitudes of applications for the technology. For example, the idea of a steamboat and a steam road locomotive was inspired by the Newcomen engine. However, only with the Watt engine would such a steam vehicle become applicable (both in 1783). Eventually the most used steam vehicle became the locomotive, which only became possible after the invention of high-pressure engines (1800). The 25 years from Watt's first engine to the high-pressure engines can be considered the growth phase of the transition. After this period, new applications became rare.

The shift from the maturity phase to the enrichment phase can be considered the moment when the basic design of the engine is used as the foundation for a very different engine. Such an effect occurred in 1860 when the design was used for the internal combustion engine. This was the beginning of an incubation period for this engine. The prematurity phase of internal combustion can be traced back much earlier. It is now a clear exaptation that identifies the incubation period. It should also be noted that the maturity phase has only lasted 60 years and is not symmetrical with the incubation period. As mentioned, the S-curve is theoretical and other forces can influence the development. In this case, the time was reduced by an improved landscape for entrepreneurship. In later technology cases, the time of development is shorter. This shows less influence of longer-term development of the social fabric itself.

5.2.7 Increased virtuality and information technology

The virtuality with the artificial evolution makes it important to focus on the actual event to understand how things have emerged. For example, ballooning has a fascinating history. For over 20 centuries, Chinese Kongming lanterns made of

paper were used as miniature hot-air balloons, but never led to actual ballooning. It required the conceptualization of atmospheric pressure before ballooning became applied. However, from a technical perspective it could have existed centuries earlier. It is essential to understand why ballooning was not recognized earlier. Let us consider a more recent case involving computing. While many of the building blocks existed in engineering, like code used in music boxes, the drive to create the innovation came from a specific angle which was the Hilbert (1928) logical decision hypothesis. Hilbert believed that an algorithm could be created that calculated whether every logical statement was true or false. Gödel (1931) proofed that this was impossible, which shocked the scientific community. Turing (1936) reformulated Gödel's method to a computational machine and with it effectively built a bridge to all of the engineering tools available. By exaptation, the computer would quickly follow.

Radical change can be traced to a wicked problems. As metioned in the introduction, Rittel and Webber (1973) describe how some mysteries create wicked problems for developers. They compare how developers deal with problems with the wicked or devious action of taming aggressive animals (e.g. lion). It requires time to build trust with the creature and once that trust is built, the tamer gains higher status as the master of such dangerous creatures. For example, artificial vacuum was a wicked problem during the first industrial revolution, electricity was a wicked problem during the second industrial revolution and artificial intelligence is a wicked problem during the contemporary information revolution. All these wicked problems are about artificiality, which is a very hard concept to grasp. Simon (1969) is one of the first to address the artificial as a science onto itself. When the wicked concept was first formulated it was hard to imagine what change to the social fabric that they could create. It was a challenge to separate the crazy (as in mentally deranged) from what is crazy (as in mind blowing).

With the industrial revolution, the world became so interconnected that the world was too small to have more than one such event. The contemporary information revolution is making the world even smaller. Freidman (2005) recognizes and elaborates how the Internet is changing the world into one huge playground. The Internet is our contemporary meta-workspace. With Internet innovation, the virtuality becomes even more important. For example, it allows innovation to emerge unrelated to location, which is different from previous innovations. This is a very new trend since Information Technology (IT) first emerged in a local hub in Silicon Valley. It is my position that the most recent Internet Innovation has become distributed and global requiring face-to-face meetings to compensate for the loss of local connection (see Section 7.2.3).

The first computing application began during World War II, when the Turing machine became a strategic tool to hack encoded messages of the German submarines. In the 1950s, the mainframe computers emerged. At that time, it was expected that only a small number of large mainframes would become dominant in the world. However, after the 1970s, mainframes lost market share to personal

computers. It started a trend of computers becoming smaller, more personal and more numerous. For example, during my participation research, one developers' conference in 2011 had three thousand participants and over four thousand devices trying to connect to the Internet (e.g. laptops, tablets and smart phones). Being in a developers conference makes this a special case. However, it is expected that such phenomena are only going to increase in other places. It is similar to how the niche domestication was first specific to a local niche and later transformed to other landscapes. Consider the transformation of the landscape with riche domestication where hills would transform to terraces (see section 4.1.4). The terraces make hills as wet as the swamps where the riche first came from. In the same way, we see a landscape of apps introduced that allow non-technical people to use more technical functions via simple interfaces.

5.2.8 The Internet and the Global Brain

With the rise of the Internet as a mediating force, the concept of a Global Brain emerged (Heylighen 2002; Heylighen 2011). The Global Brain is a wicked concept that compares the connectivity between people and machines to the neural connections in a brain. The Global Brain is considered a self-organizing phenomenon with local events of collective intelligence that radically change the social rules. For example, the Arab revolution, starting in 2011, is sometimes called a revolution by a social-media generation. Heylighen et al. (2012) investigated these events to propose a stronger definition of a technological mobilization system:

> A socio-technological system that motivates and coordinates people to work towards a given objective.

In some cases, the effect of coordination is smoothly adopted. In others cases, it has led to fascinating conflicts. For example, Wikipedia has been well received by both public and national powers. Compare this with WikiLeaks, which created strong reactions by the public, increasing the distrust in their government, while national powers consider it to be a threat. WikiLeaks can be considered a case of digital rebellion. Digital rebellions are the contemporary extralegal activities showing the rise of a new social order. It is possible to compare the digital rebellion to how entrepreneurs rebelled against the guild during the late Middle Ages. It is a new culture with values that are incompatible with the old system.

Battles around this new social order have been deployed. An example is the entertainment industry and its attempt to stop IP losses by formulating two legal bills: Stop Online Piracy Act (SOPA) and Protect IP Act (PIPA). On January 2012, Wikipedia and several other agents of the new social order applied self-censorship to protest against the SOPA/PIPA bills. They successfully created public awareness about the dangers that the bills contain. This resulted (overnight) in the loss of support for the bills. The New York Times on January 2012 said:

> This is the first real test of the political strength of the Web.

It may have been the first battle so clearly in the media, but many such local cases can be found under the surface of the Internet innovation wave. The effect of the Internet on the social fabric is ongoing and I believe that it has not yet shown its full potential. One thing seems clear: the Internet is the current meta-workspace, where many new workspaces create part of the major transition.

5.2.9 Waves of Internet innovations

Previous investigations show how waves on waves emerge where one wave enables the potential next waves. In the case of Internet innovation, waves can be clearly recognized. The growth phase of the wave takes about one decade. Currently wave 1.0 and wave 2.0 have deployed and wave 3.0 has just entered a growth phase. The growth phase is one of organizational innovation. Considering that our interest goes to experimental research we need to identify a wave in the incubation phase, which is considered to be wave 4.0. Let us first take a closer look at the waves that are already further in their phase transition.

The origin of wave 1.0 is related to the history of the Internet, which started in the 1950s. It happened in information hubs working on better computer networks. Around the 1980s the development of standards was the focus, like TCP/IP (late 1970s) and WWW protocols (early 1990s), the solution spread like wildfire to the other information hubs in the world and gave birth to the Internet. The Internet only became truly public when the first web browsers and search engines were built (1993). It made the Internet approachable for less technical people. The growth phase for wave 1.0 was between 1990 and 2000, while an "under the surface" development was recognized as stretching back a few decades.

The same story is true for wave 2.0, which is actually called Web2.0, a term that surfaced as reaction to the dot-com crisis around 2000. Social networking tools are effects of wave 1.0, such as mail and chat rooms which emerged in the late 1980s. O'Reilly (2004) popularized Web2.0 by showing a user-generated tag cloud creating a self-explanation of the term Web2.0. Projects like Wikipedia, and Delicious had the proper interface to make the social web emerge. Other projects like YouTube, Facebook and Twitter made Web2.0 go mainstream. Similar to wave 1.0, wave 2.0 grew between 2000 and 2010. I assert that other waves are coming and their incubation and prematurity phases can be recognized.

Wave 3.0 (2010-2020) is currently focusing on massively managing problem solving. This includes online education tools and open governance. The problem solving ability of wave 3.0 goes beyond the current social media of wave 2.0. Several potential interface solutions currently exist. Identifying which tool can create the interface for the masses is possible in retrospect but not at the moment of creation. It would be relevant to create such reflection in the year 2020. A long premature phase can be recognized from the 1990s onward. Interestingly, it builds on wave 1.0. This is related to what I call the last phase. It is the enrichment phase that creates a foundation for the next innovations. So wave 3.0 builds on wave 1.0, is incubating

during wave 2.0 and takes over the growth once wave 2.0 shifts to a maturity phase. A similar dynamic is expected for wave 4.0. That wave is expected to have a growth phase between 2020 and 2030, but of course many dynamics in the social fabric could accelerate or slow down the development.

Because of the complexity, later innovation wave become less predictable, compare it to a wetter forecast that can be accurate for the next day, give some indication for next week, but becomes a lot more abstract for the wetter in next month. Hypothetically we could argue how next waves build on previous waves and solve some of the harder problem. By identifying some of the features recognized in a particular stage of the phase transition it is possible to make some speculations, but for each next wave it becomes more abstract.

Wave 4.0 addresses the more difficult problem that is not solved with wave 3.0. The wave is expected to be in an incubation phase, which means that a prototype is being made. Wave 4.0 may have several aspects. For our research, particular the innovation of innovative organization is relevant. One wicked problem about innovative organizations is the combination of an enterprises, which is big and lean, with startups, which are small and agile. The wicked problem is described in Enterprise Architectures literature where the new organization is named Agile-Enterprises. The concept of Agile-Enterprises gets investigated in Section 7.1.2.

5.2.10 **Prematurity waves**

The Agile-Enterprise is an exaptation based on two organizational structures (enterprises and startups) that existed for decades all around the world. To say anything reasonable about waves in a prematurity phase requires less demonstrated events that show great potential. As a thought experiment to investigate the state of wicked problems in a premature phase let me describe two possible waves. Wave 5.0 would be in the later prematurity phase where the events relate to more formal knowledge. Wave 6.0 would be earlier in the maturity phase showing fascinating events that are much more a mystery.

Crowdsourcing has Internet events showing a lot of potential. Crowdsourcing can be related to more formal knowledge that exists around collective intelligence. How to create organization around crowdsourcing is a wicked problem that requires more investigation. For example in 2007 a crowdsourcing solution to search for crashed plain of Steve Fosset showed a clear failure of the method. It is just one example that argues about the immaturity of crowdsourcing. Considering the state of crowdsourcing makes it likely that it would be a concept for wave 5.0.

By becoming more abstract it can be possible to say more about wave 6.0. One wicked problem that emerged around a problem of artificial intelligence can be used to demonstrate this. In the 1960s a criticism about artificial intelligence related to the limited computer power. Good (1965) response to the criticism results in the description of an ultra intelligent machine that would be more intelligent then a human. Scientist began plotting the technological acceleration to understand when

computer power would be strong enough for such a machine, resulting in a point in time called the Technological Singularity (TS).

Kurzweil (2005) pinpointed TS to 2045, which hypothetically makes it the center of wave 6.0. TS is a moment when technology progress goes so fast that its effect has become unpredictable and so it creates a wicked problem around intelligence. In section 2.1.2.1 on brain plasticity, very different wicked problem around intelligence were given (e.g. mirrorbox brainport and kidscam). The relation between TS and cases of brain plasticity are a mystery, but it seems essential to create the knowledge to have a comprehensive understanding of artificial intelligence. In next chapters, when addressing the waves I consider particular our central concept for each wave: problem solving for wave 3.0, Agile-Enterprise for wave 4.0, collective intelligence for wave 5.0 and artificial intelligence for wave 6.0. Each next wave the concept becomes more abstract because the knowledge around it shows more gaps. It is however relevant to have longer-term vision to direct our development, even if they become more abstract.

5.2.11 **Towards the Technological Singularity and beyond**

In an attempt to position the waves in the larger macro-evolution, examined in section 5.2, a bigger picture is created that becomes even more abstract then the description the prematurity waves. To create this bigger picture, I like to combine the Global Brain with Technological Singularity. It is my belief that both Technological Singularity and Global Brain require some adjustments. For the Global Brain, it has been a study of cells that made me recognize the scale problem. Cities-scale organization (not people) should be considered the cells of the global super organism (and by extension the brain). It is important to notice that cities also transform with the major transition in the social fabric. The cities-scale organization is at the moment hard to imagine. In a reversed way, it was Barbieri (2008) that made the claim:

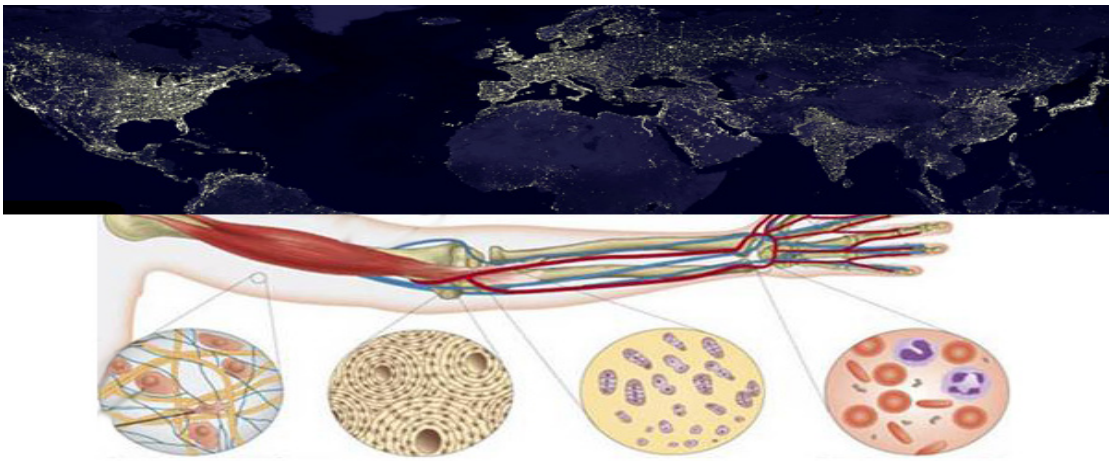
> Genes, proteins, and ribosoids are all manufactured molecules, but only ribosoids can be also makers of those molecules. This concept can perhaps be illustrated by comparing the cell to a city where proteins are the objects, genes are the instructions, and ribosoids are the 'makers' of both objects and instructions, i.e., the inhabitants of the city.

Barbieri used the city metaphor to explain how ribosoids are like people. The macroevolution of the social fabric may well be a meta-system transition where the new building blocks are city-like structures. To really understand what these city-like structures are requires the adjustment to the Technological Singularity.

I do not consider the Technological Singularity an asymptote, but the midpoint of a huge innovation S-curve describing the meta-system transition of the social fabric to the eventual global super organism. Consider that early empires existed 50 centuries ago, with the first metropolises. I wonder whether it will take another 50 centuries before the macroevolution is completed and a meta-system transition is realized.

By using a metaphor, some abstract comparison may be reached. The first metropolises from 50 centuries ago are like the simple plants, while what is expected at the end of the meta-system transition should be more like an animal. To visualize this, consider how cities have been connected and have made other cities emerge. This is metaphorical similar to "rhizomes". Rhizomes are creeping rootstalks spreading and creating new offspring. The offspring is genetically similar to the parent. Similarly cities are today not so different from each other. By looking at the world by night the rhizome metaphor of cities become very visual (top Figure 5.4). The Internet is stimulating a globalization and it is expected to stimulate more variety. If we take a closer look to a human body it is clear how a strong variety of cells exist (bottom figure 5.5). A transformation of the top figure 5.4 to the bottom figure can indeed need millennia to develop.

Figure 5.4 Visual metaphor of the current state of the global super organism. Top: cities at night look like a fungus. Bottom: the diversity of multicellular body to consider profound city specialization in front of us for the meta-system transition to the global super organism.



One last issue that needs to be addressed is why the huge innovation S-curve indicates that the innovation would slow down. The slowdown has to do with physical limits. Cities are now built from scratch and take decades to develop. This process may become faster, but the scale does create physical limits. The variety between cities is an innovation process that is constraint by the scale. If technology development becomes depended on the larger scale diversity then it is expected that innovation is slowing down simply by the physical limits. If we consider millenniums it is also relevant to address colonization of nearby stellar bodies (moon, mars). For such colonization other physical limits, like distance and hostile environment, are constrains on the development. It has been over half a century after the first man enters space. While scientific and technological development has been improving, it has shown a slow space development by the physical constraints. So for the meta-system transition it is expected that physical constraints can slowdown the innovation.

5.3 Research Question II.1

How does the social fabric produce novelty and how does this relate to the evolution of science and technology?

To answer our research question, the gap between the first section on the Eventuating model and the second section on the evolution of the social fabric needs to be dissolved. The Eventuating model is a very recent observation of R&D in laboratories. The Eventuating model is being observed. It has not been intentionally fabricated. The research on the Agile-Enterprise (wave 4.0) may require the intentional development of the Eventuating model, as part of the intentional development of the meta-model, which is the regulating architecture for the Agile-Enterprise. This is going to be the topic of Chapter 7. However, we first need to introduce one more novelty model in Chapter 6 before this all can be integrated in the meta-model.

This chapter has investigated the default flow of the meta-model by first introducing the Eventuating model as an externally oriented novelty model. The Cohering model was an internally oriented novelty model working with concepts and developing knowledge. The Eventuating model works on events and develops the social fabric. The anchors of the Eventuating model are roles. The internalizing role is "developer". Developers create the novelty. The externalizing role is by the delegates representing the interest of the public. The directing role is by alliances that make the motivations complex and adaptive allowing innovation to go in different directions. The evolving happens when peers allow co-development to occur and show how radical change happens as ecosystems bootstrap themselves.

With the description of five stages of the phase transition it becomes possible to focus on where new waves are emerging. In particular, the Internet innovation waves have investigated the nature of successive waves. The level of environmental enrichment is high for the Internet and the waves show much clearer the constructive development of the different phases. By examining the dynamics during a particular phase, it becomes possible to at least suggest stronger theoretical structures, which is the aim of a science on innovation.

By examining cases, it becomes clear how a particular mediator exists for each phase. During the premature phase, it is the wicked concept, demonstrated by some event and resulting in the creation of the first artifacts. During the incubation phase, a fragmentation exists of artifacts that need to get coupled. As a result, machines arise that find applications in a specific niche. The growth phase is when a machine has multiple applications. In respect to the social fabric, it becomes more autonomous, showing how the technology is an agent that ensures the adaptation of the technology into many aspects of the social fabric. During the maturity phase, the focus changes from the individual agents (some implementation of the technology) to the support framework of these agents (e.g. electrical grid for electricity, railroad for the steam locomotive, WWW for the internet, etc.). During the enrichment phase, the frameworks gain the agency and the individual technology becomes a mere

building block for future development. In order to understand the changing mediator of the phase transition, the next chapter will investigate how organizations produce the embodiment of the mediation.

6 Strategy Management Studies

If I had asked people what they wanted, they would have said faster horses

Henry Ford (via retrofitting)[2]

6.1 Value creation by the Strategizing model

The previous chapter on Science and Technology Studies (STS) was a clearly defined domain. The domain I'm now entering has been given several names, such as organizational studies, innovation studies, etc. To simplify matters, I use the term Strategy Management Studies (SMS) as a reference to a cluster of domains. In SMS the focus is on added value and organizations are created to capture it. Organizations require strategy. For example, businesses in the same market fabricating a similar product can have very different organizational structures which makes a difference.

The first section investigates the Strategizing model as a third novelty model. The conservative nature that this third novelty model overcomes is the determinism of the system by its parts. Where the Cohering model makes insights emerge and the Eventuating structures events, the Strategizing model creates an organization's leverage. What the Strategizing model adds is best understood by considering the meta-model and how a default flow, being the evolution of the societal fabric, changes to the directional flow and by organizations developing innovations.

The chapter is divided into two sections. This first section investigates the Strategizing model. The first subsection introduces Schumpeter's concept of creative destruction and Porter's concept of competitive advantage. The second subsection introduces the bootstrapping cascade between modeling and mastering before examining the anchors of the novelty model. The third subsection goes into more detail about the anchors. The fourth subsection examines how the Strategizing model changes the default flow of the meta-model and gives us a deeper insight on organizations as the medium for the Strategizing model.

A novelty model is able to create exaptation while for the Cohering model it was knowledge exaptation. With the Eventuating model, an environmental exaptation allows beneficial effects of events to be applied in a different context. In this chapter, value exaptation gets elaborated. The last subsection considers some contemporary cases to become more familiar with the challenges surrounding value exaptation.

[2] For details on the ambiguity, see http://quoteinvestigator.com/2011/07/28/ford-faster-horse

Section 6.2 investigates the phase transition again. The phase transition now relates to different types of innovation, each of which have a different type of value exaptation. It is a more systematic description of the dynamics of the phase transition introduced in Section 5.2 and allows us to begin building the Enterprise Architecture about innovation, which is the topic of Chapter 7.

6.1.1 Porter and Schumpeter on value creation

Both Porter and Schumpeter found inspiration from pioneers like Karl Marx who studied revenue growth. Interestingly, the same circle of German philosophers is coming back as the foundation for different domains. In the cognitive studies, it revolves around Gestalt studies. In STS it was Heidegger. For SMS, Sombart is more fitting. In the design studies that are discussed later, the relation is made again (see Section 7.1.1). Sombart introduces the term "creative destruction", which is so often ascribed to Schumpeter. Sombart did not get recognition for it for a long time. As STS teaches us, politics cannot get disconnected from science and Sombart's controversial relationship to Nazism buried his work under that contextual weight (Reinert & Reinert 2006). Consequently the description of Schumpeter (Schumpeter 1975, p. 73) is more commonly used:

> The opening up of new markets, foreign or domestic, and the organizational development from the craft shop and factory to such concerns as U.S. Steel illustrate the same process of industrial mutation–if I may use that biological term–that incessantly revolutionizes the economic structure *from within*, incessantly destroying the old one, incessantly creating a new one. This process of Creative Destruction is the essential fact about capitalism. It is what capitalism consists in and what every capitalist concern has got to live in.

According to Sombart, the origin of capitalism is related to the act of double entry bookkeeping (Yamey 1949; Carruthers & Espeland 1991; Miller & Napier 1993). Records allow us to position the Strategizing model in the meta-model. Double entry bookkeeping is a record of an event, which means an overlap with the Eventuating model. Records are also information entities, which also indicates an overlap with the Cohering model. Records are more than events and information alone; they are also part of the social organization. Companies use records to design strategy and maximize revenue. Porter (1980) defines this strategy by competitive advantage:

> Competitive advantage is only reached when a company implements a value not simultaneously being implemented by any current or potential player.

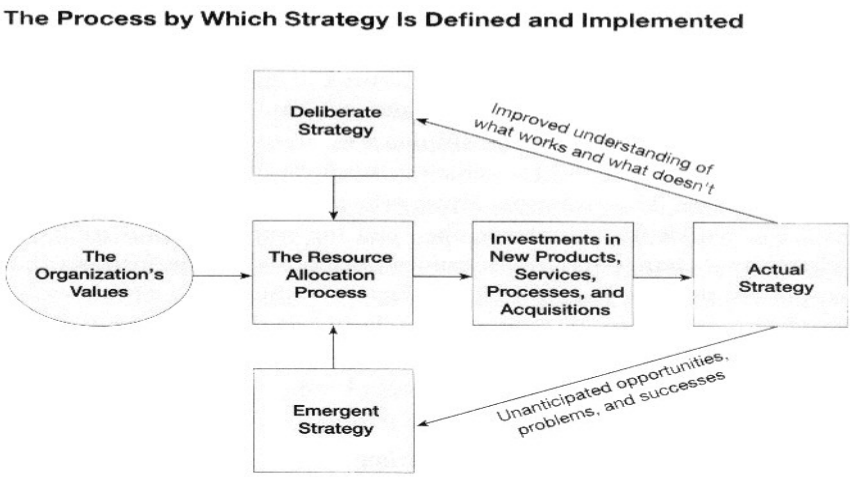
Both creative destruction and competitive advantage consider companies as the medium of operation. Companies are a particular kind of organization, mostly examined with SMS. In STS the focus is on scientific institutes, while the fabric of society focuses on governance. All are specific kinds of organizations. For the Strategizing model, it is organizations in general that become the medium. In other words, the tree mediums of the novelty models are: the organization core, the organization workspace and the organizational environment.

6.1.2 The feedback of organizational strategy

To introduce the Strategizing model, consider how the novelty model allows exaptation (see Section 2.1). Exaptation has been a focus for both evolutionary studies and for studies on organizational innovation. Andriani and Carignani (2014) use the case of the magnetron to argue about the exaptation of innovation. The case starts with Percy Lebaron Spencer, who sees a candy bar melt in his pocket. The only possible explanation is the nearby radar. This serendipitous event results in the construction of a technological exaptation challenge: how to use radar for cooking? Challenges around an insight set the change in motion, as examined in the Cohering model. Spenser becomes the main developer, but he cannot develop it alone. The Eventuating model shows *how* the challenge becomes easier to bear by the successive groups, but not *what* makes the change. In other words, with the knowledge creation (the Cohering model) and events (the Eventuating model) the basis is set for an organizational challenge that becomes the focus of the Strategizing model.

It is through the organization that change becomes possible. The organization forms a protective layer around the group, creating local enrichment. In other words, by creating organizations, innovations develop their own niche. For the organization, the value becomes the driving force. Christensen (2003) makes a schema (Figure 6.1) that expresses the bootstrapping cascade between modeling and mastering around strategy. It starts with the organization's values. They drive a process of resource allocation to invest and eventually deploy the actual strategy. The actual strategy can improve the understanding which contributes to the modeling of the deliberate strategy. It can also result in unanticipated events that requires mastering of the emergent strategy.

Figure 6.1 How strategy is implemented and how it creates a bootstrapping cascade.



In the Cohering model, the anticipation processes (the anchors) transform the memory (the medium). In the Eventuating model, the roles (the anchors) transform

the social fabric (the medium). For the Strategizing model, the capabilities (the anchors) transform the organization (the medium). Capabilities become more outspoken in the literature extensions of Porter's competitive advantage. The first extension is the resource-based view (Wernerfelt 1984; Mahoney & Pandian 1992; Peteraf 1993). Resources may relate to several capabilities for an organization. By considering how resources can be combined, bundles arise, which are considered the internalizing capability showing the intrinsic value of a company. The bundles of resources are tangible (e.g. the building) and intangible (e.g. the brand). For example in section 6.1.5 Apple and Google, while both are IT companies they have very different resource bundles, what allows them to pursuit very different opportunities. Resources are assets of an organization, such as technological, reputational, structural, financial and the brand, etc. Assets can be tangible (e.g. the building) and intangible (e.g. the brand) values, which makes them the externalizing capabilities. With the intrinsic value and tangible value, the default value of an organization can be recognized. Like in other novelty models, a tension produces change. The tension for organizations comes from the difference between the default values and the values that the stakeholders hold. Strategy is required to direct change, which creates the bootstrapping cascade described in Figure 6.1.

6.1.3 The dynamic capability framework

The resource-based view allowed some insights on competitive advantage. Teece et al. (1997) create an extension of the resource-based view to dynamic capabilities that can cope with complex adaptive environments. Their framework describes three capabilities: processes, positions and paths. The relation to the novelty model can be constructed from it. Organizational processes are needed in order to coordinate and learn. It is what develops the organization and so they are the evolving capabilities. Positions are determined by the assets of an organization and so it relates to the externalizing anchor. The paths are about the momentum and orientation that an organization has. They show in what direction the company is capable of developing. As such, the path describes the directing capability. Together the four anchors of the Strategizing model are:

- Internalizing capability: **bundles** make particular **values** tangible
- Externalizing capability: **positions** connect the values to actual **assets**
- Directing capability: **paths** shows the **momentum** of an organization
- Evolving capability: **processes** allow organizational **development**

It is not my position to argue if the dynamic capabilities framework is the correct way to articulate the capabilities of an organization. The framework aligns best with the four anchors of the novelty research, but it does not do well in articulating other dynamics. To argue about the enrichment that the organizations create, let me consider different descriptions of capabilities. Hamel and Prahalad (1992) describe blindness for competing in future markets and describe organizational capabilities like "stretch" and "leverage". A company with ambition (stretch) but no resources (leverage) is a dreamer. A company with resources, but without ambition is a

sleeper. Both dreamers and sleepers are unlikely to win the future. Only when an organization has both stretch and leverage does it show the ability to win the future. Environmental enrichment can solve some of the organizational shortages. For example, most start-ups are dreamers that gain leverage by venture capital.

While the proper articulation of the capabilities can be disputed, it seems that my general approach with the Strategizing model is independent of the dispute. The benefit of the Strategizing model is to overcome paradoxes around values. In SMS, this relates to the joining of conflicting cultures in a single organization. Such organizations are called ambidextrous (O'Reilly & Tushman 2004). Recent research on ambidextrous organizations tries to support the organization by creating monitoring and measuring of the dynamic capabilities (Teece 2007; Schreyögg & Kliesch-Eberl 2007; Barreto 2010). This makes the workspace of the Strategizing model become much more aligned with our definition of workspace (sensory-motoric coupling). The research on monitoring and measuring is in an early phase and not yet developed enough to be useful for the novelty research. It is a research development that is being watched for future research.

6.1.4 Strategizing and the meta-model directional flow

Organizations should be considered invariant patterns arising in the workspace of the meta-model, comparable to knowledge in the Cohering model. It also starts for the meta-model with a default flow, which is the evolution of the social fabric. In the Cohering model, challenges change the default flow and create a tension that allows novelty to form. They then strengthen existing knowledge or create new knowledge by abstractions (see Section 2.4). Something similar happens to organizations, where values now create the tension and abstractions become the modular hierarchies of an organization.

Simon (1969) shows how clustering parts into modular hierarchies can improve the system's resistance to perturbations. He demonstrates this with a case of two watchmakers, where one creates an integral system and the other has split the development into modular parts. Without perturbations the former would only require to recreate the module, while the later requires the entire system to get recreated. So as perturbations increase the former becomes fitter then the later. In other words, for complex adaptive environments modularity is fitter than integrated systems.

The modular hierarchies show self-similarity, like studied by fractals in Section 3.2.1. McKelvey et al. (2012) describe it as "the law of requisite factuality", as an extension of the law of requisite variety (see Section 4.1.1). They show how modular hierarchies are needed both internal to the organizations and external to have creative destruction in the ecosystem. Andriani and Carignani (2014) show how the modularity can result in internal and external exaptation. Internal exaptation is when the architecture of the artifact undergoes exaptation and the function of the artifact does not. External exaptation is the opposite. Radical exaptation is when both architecture and function show exaptation. By taking a more holistic view, it

becomes clear how radical exaptation happens by meta-systems, where a phase transition allows many parts to change simultaneously.

Each novelty model overcomes a law of conservation: Cohering overcomes the bias of knowledge, Eventuating overcomes the rarity of event and Strategizing overcomes limitations by organizations. The study of the phase transition in Section 6.2 will elaborate how decomposability of systems can be caused by different types of innovation during different stages of the phase transition. Most of the cases that are examined describe one type of innovation as the radical change during one phase. It becomes harder to recognize whether each phase adds a bit to the radical change.

6.1.4.1 Development ecosystems

Moore (1996) describes the nature of development ecosystems. He uses a metaphor of how a gardener maintains a garden and claims that this is how businesses should create their own niches. His definition of business ecosystems includes a bootstrapping relation:

> An economic community supported by a foundation of interacting organizations and individuals—the organisms of the business world. The economic community produces goods and services of value to customers, who are themselves members of the ecosystem. The member organisms also include suppliers, lead producers, competitors, and other stakeholders. Over time, they coevolve their capabilities and roles, and tend to align themselves with the directions set by one or more central companies. Those companies holding leadership roles may change over time, but the function of the ecosystem leader is valued by the community because it enables members to move toward shared visions to align their investments, and to find mutually supportive roles.

While Moore in his initial work is comparing business ecosystems much more to their biological equivalent, the concept itself was interpreted as markets and production chains. Today, with more development that involves the public, the concept can return to its original interpretation. The public has an effect on globalization, leading to a new system of interaction (Friedman 2006). The globalization and recognition of recent radical change allowed Prahalad and Hammond (2002) to re-introduce the concept of development ecosystems, now articulated as " the Bottom of the Pyramid" (BoP).

The BoP is an example of value exaptation, based on disruptive insights. The poorest countries are the best development workspace since they have a less negative response to the drawback of new products. Moore (1996) demonstrates a case of financial transactions using mobile devices. Let me use this to argue about the drawbacks. Imagine that with the current prototype, the transaction would fail 1% of the time. In the developed world the loss of 1% of your financial transaction is unacceptable, because our current transactions have zero tolerance factor. In undeveloped countries, the loss of 1% would be preferred over having no ability for any transactions. The same dynamic was described with disruptive innovation

where cases demonstrate that a new market having a prototype with drawbacks is preferred over having nothing at all. What BoP adds is that SMS should focus on finding the proper workspace for a particular prototype. Let me extend the study of value exaptation with more contemporary cases.

6.1.5 Contemporary cases of value exaptation

Value exaptation is the ability to recombine the values from different domains and use it for the creation of new organizations. For example, social entrepreneurship is the creation of organizations using values that are know from commercial entrepreneurship and applying it to non-commercial domains. Value exaptation is, in fact, a very common principle that can be recognized in contemporary SMS, but it has not yet been described. Because value exaptation is the essence of the Strategizing model I use two contemporary cases to introduce the concept. Historical cases hide the difficulties of radical change in value, because the good innovations have become absorbed in our society. By investigating the contemporary cases, the wickedness of value exaptation can be examined. The two cases relate to Internet innovation. The first is already more established than the second case, allowing more support for the claims. It should show how much the value perspective challenges our understanding of competitive advantage and how it can only be radical if an ecosystem emerges.

6.1.5.1 Internet Innovation case 1: iTunes

The music industry could not value the rise of digital products, because it was incompatible with the value of the copyright mechanism that was the cornerstone of the music industry. The copyright mechanism is an issue showing disagreement between the public interest and the owner interest, which makes it interesting for novelty research. A good way to understand the current state is to follow the historical path. Until the 1950s, music was directed to the working class, with innovation around transistors as a shift that occurred. Pocket radios and later compact cassettes targeted a much younger audience. The music industry favored the shift since it increased the market, but with it they opened the doors to new social contracts since young people have limited budgets and are by nature more rebellious. Without the Internet, the emerging digital rebellion was relatively harmless to the music industry, creating an extralegal state of cassette sharing in local networks. With Internet peer-to-peer file sharing services, like Napster, there was a change from the prior local networks to a global network which created a breakdown of the industry.

The blindness of the media industry to the changed social contract was partly because they listened to a small group of high-demanding costumers who made their voice heard. The large mass of low-demanding customers is a much more challenging group to comprehend. Once the change was perceived, the incumbent did not try to understand the new values but tried to fight them. Such value battles

are common in historical cases of innovation and in some cases conservative measures can stop the change. Mokyr (2002) reasons about the innovativeness of conservative solutions. Today, the media industry has been trying to establish conservative solutions, as described in Section 5.2.8.

The company, Apple, eventually competed with the pirates, which was radical, since the pirates were not making money with the music itself. Just as with other piracy, the quality, range of product and security cannot be given. By providing a fair price for the extra service, Apple successfully challenged the pirates with a valid business model.

We again need to follow the historical path to better understand what happened. The iTunes software was at first a file management tool with extra features for music. It was part of the operating system created by Apple. The initial product had a niche to survive in, but was a relatively marginal product. Only later did it develop into the online store for digital products (e.g. music, movies and applications). The market for digital music was a bootstrapping problem as mp3 carriers were marginal. So the iTunes got bootstrapped to an online music store by the launch of the iPod product. iPhone later extended the product range in the store by including applications.

The success of iTunes is easy to demonstrate. The online store was launched in 2003 and by April 2008 iTunes surpassed Wal-Mart as the number one retailer for selling music. From not being a player to the market leader in five years is an accomplishment. What is even more fascinating is how a high-tech incumbent, focusing on high-value that competes for the top of its market has suddenly become a competitor for low-cost retail incumbents like Wal-Mart. It is a spillover effect creating an opportunity for competitive advantage of future markets. This first requires a closer look at the historical value exaptation Apple reached by competing against pirates in the music industry.

Apple had a competitive advantage, but not all of the required capabilities. It learned along the way and in the process the organization has transformed its core. Apple used to be a personal computer manufacturer, but now has more revenue by producing smart phones, tablets and other ICT products. The revenue of the online store has become a major part of the total revenue. It did not start from scratch. Apple's technological advantage consisted of: digital composition applications, media players and a file management system for music. Apple's advantage is not only technological. Their human resources included software developers, hardware developers, designers, marketers, lawyers, business analysts, managers, etc. This showed how Apple had both the stretch (competing with pirates in the music industry) and leverage (the resources of Apple).

Describing the bundles, assets, paths and process can provide more clarity about the transformation. Of course, it is easy to reason about such issues after they took place, so let’s discuss future opportunities. It is curious how Apple became a competitor for Wal-Mart. Is it possible for Apple to explore this more? The development around

the iPhone shows how Apple can create alliances with mobile carriers. Apple also has some history with re-inventing their retail stores. It shows how Apple may have an entry to explore the opportunity. The online store is a medium, while iPod and iPhone became the technology (creating agency). It is possible that another technology is needed to fully understand the opportunity for Apple to become a retail competitor. Radical change requires a meta-system, so let me examine another related case and then come back to the agency required for a high-tech player to enter the retail market.

6.1.5.2 Internet Innovation case 2: Driverless Car

The second case is an innovation in action and because the effects are in an incubation phase the actual outcome is not yet known. Google is a company that specializes in data processing. It has been growing in the niche around its Internet search engine, where it gained extensive revenue, particular by having a marketing competitive advantage. For Google, there are other interesting data hubs to explore in addition to search engines and particularly those places where no players yet exist are where Google can create a competitive advantage. A recent strong interest revolves around the driverless car. The case is relevant to the novelty research for several reasons. It has a fascinating sensory-motoric approach of generating data, showing how the driverless car is creating an interesting new workspace for machine learning. Google is also a fascinating player for the emerging Global brain and has been an important stimulus of Internet communities (see Section 10.3.3.1). In this section, I argue how Google's driverless car may be the technology (creating agency) that makes the ICT business grow upmarket and get into several classic markets.

The story of the driverless car began in 2005 when the Google team won the DARPA challenge to make a car drive automatically (Markoff 2010). First, Google improved the prototype and created exposure. A few years later, the company lobbied to create laws that would allow the cars on the road. In March 2012, such a law was passed in Nevada (Slosson 2012). Next, consider other resources that Google has developed in the recent years, like the online map tool. It is already useful for mapping your routes. Eric Emerson Schmidt, the executive chairman of Google, recognized the synergy with the driverless car, which he called “Google maps on steroids.” (Tsotsis 2012). The idea is that you don't just map out a path, you also ask a car to pick you up and drive you across that path. Some similarities can be made with the iTunes case. Google maps is the medium comparable to iTunes and the driverless car is the technology creating the agency that can set the change in motion, just like iPod and iPhone were for the online store.

By considering how different emerging technology can get connected into an ecosystem, it becomes possible to recognize a radical change. While iTunes disrupts large retailers for music, Google could well become a major disruptor for city taxis (Fitzsimmons 2013; Davies 2014). It is again an example of an ICT company gaining

opportunities in classic markets by automatization of complex activities. The cost of creating the medium and the agency (embodied by the technology) is large, but by scaling to a global level it becomes extremely cost efficient. The market for cabs is much smaller than the market for transportation of goods. Just as the music market for Apple is a lot smaller than the retail market. Apple and Google are both now strong competitors in the ICT market. If they would, however, recognize the radical opportunity ahead they may become the biggest allies to overrun the transportation and retail markets. The idea of Apple and Google teaming up is just one of the many possible radical opportunities currently emerging. They are only opportunities; actual alliances may be very different and are only expected with the growth phase of Agile-Enterprises (wave 4.0 between 2020 and 2030, see Section 5.2.9).

Let us try to imagine Apple and Google as two important agents in a new ecosystem that bring ICT automatization to the classic transportation and retail markets. Many other agents and artifacts are required for such an ecosystem to become a reality. For example, today large state-of-the-art harbors are fully automated. The driverless delivery vehicles could interact with these harbors and get the product to the customer's home, cutting out not just the business of retailing, but also of transportation. The ecosystem emerging by co-development becomes fit for many inventions currently existing around autonomous transportation that seem unlikely to be applied in the current niche that is being entered (taxis). For example, an energy efficient way for vehicles to drive over highways is to connect to other vehicles. For transportation of people this may find a lot of resistance, but transportation of goods would not show the same reluctance to such complicated operations.

Driverless delivery vehicles may show swarm dynamics, where large container size vehicles from harbors are decoupled on the highway as some of the delivery vehicles drive onto smaller roads. The process can happen recursively until distribution for delivery to a person's front door. At this moment, the size of the vehicles may be the size of a postbox, let's call it a post-vehicle. For security reasons and maintenance reasons, the post-vehicles could have a docking station at the customer's home. Once the content is retrieved the reversed process of integration can be recognized when the empty vehicles drive back to the harbor for reassignment.

The coordination of delivery would present a huge data processing challenge, which seems to fit the capabilities of Google. The design of the vehicle and the shops would be a challenge fitting Apple's capabilities. Each company separately does not have the required capabilities for this scale of radical change. It is an extreme case just to make the point clear. Other radical innovation opportunities can be recognized that only become possible as an ecosystem of development is created. The principle that the current thought experiment tries to contribute is how ICT companies can invade the classic market and how it leads to the wicked concept of high-value players becoming competitors in low-value markets. For the wicked concept to dissolve, more environmental enrichment needs to be developed. The current trend of

Internet of Things (Atzori et al. 2010) and of big data (Manyika et al. 2011) are development trends that may just be the required stepping stone for ICT companies to break into the classic market.

6.1.5.3 Value exaptation, a trend in ecosystems.

To show that the two contemporary cases describe a trend, I consider other cases revolving around the same principle of *growing upmarket by going down market*. De Soto (2003) investigates "dead capital" in extralegal cases and how the reintegration of this dead capital can be reached. For example, the real estate of slums may be marginal to developed countries (e.g. below $200 per house), but the mass of such buildings would make the dead capital in such slums large enough to have more capital than some of the top ten markets. The dead capital relates closely to the Bottom of the Pyramid (BoP) concept mentioned in in Section 6.1.4.1. Prahalad and Stuart (2002) describe the welfare in the world by a pyramid to show how large the bottom of a market is, with billions of people living on 2$ a day which is yet untapped. For digital products the opportunity of marginal revenue by great numbers is also recognized. Because digital products have a negligible cost, the marginal revenue becomes profitable. The statistics show that products would at least get bought once. By the zero cost this means that every extra product creates revenue. It can be visualized in a graph by what is called "the long tail" (Anderson 2004).

The concepts of dead capital, BoP and long tail are working on an economy of scale. All the examples show how economy of scale is driven by a quite mass. Replacing the high-demanding customers (as driver) by a quite mass is an interesting case of value exaptation. The problem with value exaptation is that those who did not understand the insight are blind to the added value that it produces. Those who did gain the insight create the emerging development ecosystem and change society. In Section 10.2, I demonstrate that individual agents can create the change unintentionally, driven by the existing enrichment. All the cases address in some way or another the need for an ecosystem to gain radical change. Moore (1996) recognizes how it transforms the friction of competition to the synergy of co-creation. Co-creation by ecosystems is essential for radical change and relates to the phase transition as examined in the next section. In respect to the theory of Chapter 4, we can argue that an ecosystem is a meta-system that may even be a hybrid between a meta-element and a meta-workspace. In other words, it is showing the bootstrapping of both the technology and the niche where such technology can be fit.

6.2 The phase transition by types of innovations

Like the previous chapter, the second section is about the phase transition. Section 5.2 focused on events and on succession. In this section, we work on a more theoretical understanding around the specific agency and mediation during each

stage of the phase transition. The type of agency and mediation creates with the organization a particular kind of innovation and it can refactor a particular aspect of the social fabric. An overview is shown in Table 6.1. Details for each phase become examined in separate subsections.

Table 6.1 The phase transition has a different type of innovation for each stage. The agency and the mediation make a particular kind of creation.

Phase	Agency	Mediation	Innovation	Refactors
Prematurity	Concept	Laboratory	Worldview	Knowledge
Incubation	Prototype	Workshop	Disruptive	Technology
Growth	Product	Organization	Breakthrough	Market
Maturity	Framework	Ecosystem	Architectural	Value Chain
Enrichment	Intelligence	Global Brain	Meta System Transition	Governance

The two phases with little change are not a topic that is covered in SMS. The prematurity phase has been the primary topic of STS, while the enrichment phase is the topic of system theory. The reason is simple, since the slow development of these phases makes it more relevant to the evolution of the social fabric (default flow) than to the innovation by organization (directed flow). The most studied part of the phase transition is the acceleration and the slowdown. The acceleration of the incubation phase is studied by disruptive innovation. The slowdown for the maturity phase is studied by architectural innovation. The growth phase suffers from the opposite of the prematurity/enrichment phase. By being in the middle of the development, the overview gets lost. As a result, the growth phase relates more to the practice of venturing than to any specific theory of innovation.

Phase transitions are distributed and self-organizing. The change in speed during the different phases makes it appear as if they succeed each other, but that is not the whole truth. It is true that some of the development can only happen when a previous phase has created the foundation to build on top of it. The absence of environmental enrichment can keep an innovation dormant for a long time and disrupts the natural flow of the S-curve. Phase transitions are also happening on different scales. For example, during the industrial revolution (societal-scale innovation) different technologies (e.g. the steam engine) would have their own phase transition (technological-scale innovation). The evolution of companies also shows a phase transition (organizational-scale innovation), with a speed somewhere between the previous two scales. All of the influences make the development in practice look very different from the theoretical S-curve.

6.2.1 Concepts by worldview innovation

During the prematurity phase, there is little to hold on to. It explains the slow development during this phase and how strongly the development is constrained by beliefs. In the first subsection, I consider how scientific events have helped to change the way that society perceives the world and how it affects the ability to

develop the world. For that reason, I suggest calling this "worldview innovation". The first subsection introduces the concept. The second subsection considers some historical cases. The third subsection is a contemporary worldview in SMS, around open innovation, investigating the dynamics of viral concepts. Viral concepts produce the agency in most parts of the prematurity phase. To show how a transition to a new phase can be recognized, I describe in the last subsection the late premature phase with its prototypic concept. Prototypic concepts show how a concept relates to an actual observable event (e.g. artificial vacuum). The prototypic concepts give us something to hold on to and stimulate a guided development. With the enrichment of the social fabric, the mediation also becomes stronger. For the prematurity phase, laboratories allow more refined ways for stimulating the worldview innovations.

6.2.1.1 Worldview innovation concept

A distinction has to be made between worldview research and worldview innovation. Worldview research is often used by scholars of philosophy. There is a variety of related studies with names ending in "ism". A total of over 266 such names can be recognized (Saucier 2000). Let me simplify it by calling them worldview research. Worldview research often creates a lot of jargon that only is understood and studied by a small group of scholars. Some dynamics of ecological succession allow the fundamental insights, by pioneering scholars, to seep into our social fabric. The next generation scholars would work on clarifying the fundamentals of the pioneers and popular scientific writers would create an even simpler version for the mass media.

Worldview innovation, in contrast to worldview research, is a pragmatic transition more related to the social fabric. The worldview is the conception of the world and it both constrains and stimulates the innovation. For example, one of the key inventions of the industrial revolution was the steam engine (see Section 5.2.6) The vision of such an engine only became possible by the worldview around atmospheric pressure. The worldview innovation requires events. Torricelli's experiment on artificial vacuums has been a milestone in the development. A scientific debate existed that the experiment did not show an artificial vacuum, but "ether". Ether was the postulated medium for the propagation of light. It was based on the belief that light has weight and because light could travel through the empty space it could not be vacuum. The ether concept was abandoned after failed experiments and the construction of quantum physics that paved the way for a different worldview model. The mistake around ether was to consider light having weight.

The story around the vacuum is not an isolated incident. Other well-known scientific mistakes exist. For example, there was the misconception around metallurgy, such as the failure to transform lead into gold. Mokyr (1996) gives another example, which is a belief that metals had crystal structures. With the creation of steel that

belief was rejected. Notice that the problem is the *beliefs* in concepts. It is essential that experiments with real events create the prototypic concepts.

New concepts, emerging in academic environments, are often not comprehensible for most except a few peers. An example is the concept of "viral" versus memetics. Memes come from a metaphorical description of genes, where memes are a cultural code (Dawkins 1976). Memes are defined as cognitive or behavioral patterns that can be transmitted from one individual to another one by learning and imitation (Ball 1984). Today, the value of "meme" is articulated with the concept "viral", but only because the Internet has diffused the meaning of viral and made it a commonly known concept.

Through recent developments of the social fabric, another concept more examined in academia has become more generally known by a different name. For example, in the research on distributed intelligence the concept "stigmergy" is essential, but only a few scholars from different schools seem to know it, while the concept has been around for half a century (see Section 2.3.1). The Internet is again the medium that has diffused an alternative name, being "crowd", like crowdsourcing. Just like "viral", "crowd" is a new abstract concept that can get combined in different ways e.g. viral marketing, viral videos, crowdvoting, crowdfunding, etc. The difference between emerging concepts, like viral and crowd, versus academic concepts like memes and stigmergy should argue for the difference between worldview research and worldview innovation.

Worldview research in academia may contribute to the fundamental understanding, but it is not the same as the worldview innovation that emerges from the social fabric. It would be an interesting study to understand the synergies, and the absence of synergies, between worldview research and worldview innovation.

6.2.1.2 Worldview innovation cases

Worldviews drove the evolution of the social fabric. For example, the Benedictine Rule (see Section 5.2.3) created worldview innovation by changing how intellectuals perceive their world and helped to create slow development around labor reducing machinery. With concepts like the artificial vacuum, slow development for the later steam engine can be recognized.

Finding the first person that mentions some concept is making us blind to the actual dynamics of worldview innovation. It is expected that some exceptional person would have had the vision long before its time. For example, the concept of artificial vacuum goes back to Aristotle, but it does not tell us anything about the dynamics of the worldview innovation that happened in the 17th century. There is a need to identify the actual challenge that has transformed the worldview. For the artificial vacuum, it is the specific environment that is needed to pump water out of mines deeper than 10 meters that becomes the niche.

During the 20th century, there were cases that showed clearly how worldview innovations can arise within their own niches. By considering three cases, the similarities in the phase transition can be investigated. The first case is about radioactivity, which was discovered in 1896. Events like the first nuclear reaction in 1917 reinforced the understanding. It took until 1939 to formulate the prototypical concept well enough to recognize the opportunity of a chain reaction. The second case is vacuum tubes. Fleming received a patent for them in November 1905 (U.S. Patent 803,684) and a prototype was built in 1930 (U.S. Patent 1,745,175). The third case is about computers and a trace is found in 1900 when Hilbert posted a set of problems for formalizing logic. His famous completeness theory triggered an event resulting eventually in the development of the computer. Gödel (1931) would deliver the incompleteness theorem (an anti-thesis). It was Turing (1936) who reformulated Gödel's mathematical model to a state-machine, which built the bridge to the actual technological development of computers.

What the chain reaction, vacuum tube and computer have in common is that some wicked articulation was first required before a set of reactions resulted into the required artificial development. Thanks to an actual workspace for the wicked articulation, the development does not stay dormant for centuries, but triggers a cascade of investigations. The workspace for wicked articulation requires strong constraints. Starting in the 20th century, laboratories became these workspaces. Before the 20th century, more primitive workspaces existed that were less capable of triggering a cascade of investigations, like coffee houses, gentleman clubs, etc. Such workspaces were already more advanced than the agora from the classic period. Indeed, a bootstrapping process existed that made earlier mediators get enriched with the next layer of the artificial evolution in the social fabric (as discussed in Section 5.2). Laboratories are considered the true mediators for the prematurity phase. After the 20th century, the laboratories became more enriched but we keep recognizing the workspace as a laboratory.

The development starts with the wicked problem that is transformed into a prototypic concept (e.g. artificial vacuum). After an average of 35 years a prototype arises beginning a technological evolution that is considered the start of the incubation phase. In fact, for all stages in the phase transition, the same transformation is recognized for the agency. In the late stage, the agency transforms from a viral concept to the prototypic concept in the prematurity phase. It requires a last transformation to become the agency for the next stage. For the incubation phase, the prototypical concept transforms into the prototype, as discussed in subsection 6.3.

6.2.1.3 Stickiness of the open innovation case

Open innovation is a wicked concept that has been receiving considerable attention in innovation management literature. Open innovation is the idea to innovate with partners and share both the risk and the reward in contrast to the more classic

closed innovation where organization try to do all the innovation themselves. While open innovation was the most popular concept in SMS when this PhD was written, it was at the same time the most trivial one. I consider open innovation to be a wicked problem for SMS. Working on the problem creates a prototypical concept and so it produces agency. I do not consider it a type of innovation. However, it does allow an investigation about the agency in the prematurity phase. Open Innovation has a viral force that allows a concept to become popular. A viral force requires several conditions. It can only be popular if many people relate to the concept and stick to it. Heath and Heath (2007) give six conditions to make a concept sticky:

1. Simple: find the core of any idea
2. Unexpected: grab people's attention by surprising them
3. Concrete: make sure an idea can be grasped and remembered later
4. Credible: give an idea believability
5. Emotional: help people see the importance of an idea
6. Stories: empower people to use an idea through narrative

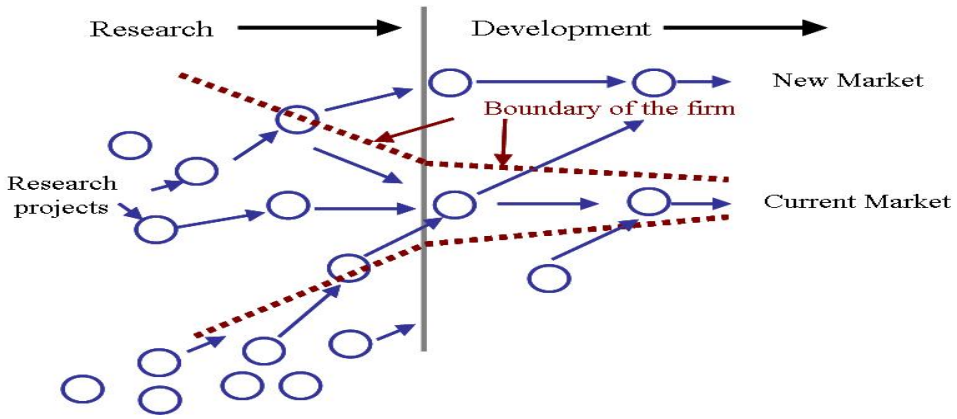
Let me reconsider the sticky aspects in Chesbrough's (2003) open innovation concept:

1. Simple: By creating the contrast between open and closed innovation. He demonstrates how the flow of people always takes away the experience. Consequently the effect of "closure agreements" makes knowledge sharing more difficult, but it won't lockup the IP.
2. Unexpected: Many essential technological inventions for the Internet can be recognized in Xerox PARC's portfolio. They did not transform to innovations by Xerox PARC, demonstrating the core problem of innovation management.
3. Concrete: Using Xerox PARC portfolio to discuss the different inventions and how they eventually become innovation outside of Xerox allows a level of detail to investigate the core problem.
4. Credible: Taking a historical case and not a hypothetical case creates credibility. Simple observed around us validating the relevance of the historic case.
5. Emotional: Xerox PARC was so close to all the innovation, but eventually failed, which makes this a dramatic turn of events. Drama has always been a good emotional ground for a sticky story.
6. Stories: Good stories have a moral and a pattern that can be applied to other cases. The moral here is that inventions are not innovations and that closed innovation is an illusion. The moral can easily get applied to other organizations and other inventions.

Chesbrough suggests a breakout ability of the classic R&D funnel to allow new market creation (Figure 6.1). For the story this is convenient, but, in my opinion, it hides the essential constraint of the development. It seems more correct to recognize Xerox managers' blindness. Novelty requires retrofitting and at this moment it is clear that Xerox managers made mistakes. The managers at Xerox were not stupid. The blindness may be easily recognized now via retrofitting, but at

the moment of creation no models existed that could remove the blindness. Xerox has focused on a particular strategy of copiers and not on the ability to create new markets. If Xerox managers would understand the value of new market creation, the story may have developed very differently. It may have had a constructive effect, trying to proactively build the new markets or it may have had a conservative effect, trying to create better barriers to protect the IP.

Figure 6.1 The R&D funnel and open innovation leading to new markets (Chesbrough 2003)



The open innovation concept is part of a bigger trend around "openness" that has become recognized in several domains (e.g. open source, open governance, open space, open university, etc.). The Internet is the general mediator reinforcing the relevance of openness. It seems more accurate to see the worldview innovation around the wicked concept "openness" as the real focus. Openness is a concept that has been around for a while and it is still wicked in many respects. In Section 10.2 the dynamics of contemporary development around openness are approached by participation research. In this chapter, I will continue the theoretical investigation.

6.2.1.4 Natural versus cultural grounding of concepts

A sticky concept creates a viral force. A concept becomes viral when it makes other innovators adapt their alternative conceptualizations and build a conceptual network. It can start by metaphorical descriptions and simple guidelines producing the agency of the knowledge creation. A difference needs to be made between a concept having natural grounding and a concept having cultural grounding. Both can result in the required prototypic concept or fail to develop, but how they develop is very different.

The natural grounding links a concept with an actual observable event. When the social fabric is rich enough, the event can result in a constructive development. Our history shows how many concepts with natural grounding have stayed dormant for a long time and even becomes lost. For example, Aristotle discussed the artificial vacuum, but it did not result in a cascade of investigations. In other words, the artificial vacuum had a natural grounding, but without the environmental

enrichment it could not develop into a prototypic concept until the Torricelli experiment.

The cultural grounding shows a viral concept creating hypes allowing a fast growing ecosystem to arise. This happens, for example, by well-formed rhetorical reasoning about the concept. When the growth is too fast, without natural grounding, the ecosystem can burst as a bubble. When it becomes clear that the link with reality is weak, the ecosystem can inflate like a balloon. Because many people are involved, some developer may create the link to reality, allowing the prototypical concept to arise and stabilizing the growth (the schema is shown in Figure 5.5). If the link cannot be made, the inflation would become absolute.

The tricky part is that grounding a concept can only start with metaphors. Many successful cases make explicit remarks about the metaphors, like Pasteur's life-metaphor in his study on yeast, Gutenberg's press that was inspired by screw-type wine presses and Papin's steam digester that was inspired by a pressure cooker. The developer's intuition, created by its discipline, needs to properly recognize the hidden dynamics in different experiences. The metaphors allow for knowledge exaptation. When the dynamics are similar, the knowledge network around the metaphor becomes a toolbox for investigations and experiments. This is similar to what was illustrated with the agent experiment in Section 2.1.

The prototypic concept is often more complex than hypes and the tension often creates a mixed feeling about the development that gets perceived as necessary compromises on the vision. The attitude should change, by the insights retrieved with novelty research. The tension creates opportunity and is not a drawback. It should be clear that any vision is naïve in respect to the novelty that can emerge. The compromises create opportunities to truly grow beyond our existing knowledge.

6.2.2 Guiding prototypes to handle blindness

The prototypic concepts create the fundament of the ecosystem by priming the collective mind and directing the artifact development to move from a prototypic concept to a prototype. In the case of the artificial vacuum, the Torricelli experiment was the prototypic concept. The Magdeburg hemisphere was still part of the prototypic concept, to measure the force of the atmosphere expressed in horsepower. The experiment made a smooth transformation from investigating the nature of the artificial vacuum into an investigation of how to utilize that amount of horsepower. The investigation moved very naturally to a prototype for an engine.

By grounding there are now things to hold on to, but many challenges still exist. Development during the incubation phase is a blind process where a prototype gives guidance. The prototype is creating the agency. The mediation is now a workshop that is different from a laboratory in several respects. In laboratories, a focus on experiments makes methods and instruments, creating discipline in the work and enriching the knowledge. In the workshop, the focus on technologies make scaffolds and tools reinforce the artificial evolution of the technology.

Blindness is a topic mostly studied in cognition (see Section 2.2.2). Where cognitive blindness is about knowledge, innovative blindness is about organizations. The blindness relates to the capabilities of a new organization unvalued by the incumbent, eventually resulting in disruptive innovation. The concept of disruptive innovation is considered in the first subsection. In the second subsection, the effect of disruptive innovation is related to revenue growth, which makes the topic fit more with SMS. The last subsection considers how environmental enrichment resolves the organizational blindness.

6.2.2.1 Disruption by technological blindness

The dynamics of disruption were first the focus of a technology study (Christensen & Bower 1996). It was later generalized to an innovation study. The focus on technology is essential to the novelty research. The disruptive technology can elaborate how to overcome blindness by guidance with the prototype. In the cases of disruptive technology, the new technology had inferior qualities to the existing solutions, which makes their rise to power paradoxical. The disruptive technology elaborates why it is necessary to address the development as a guiding prototype and not as an actual product. A product requires a market. The guiding prototype creates agency to develop a market. It occurs by the pressure that arises because the disruptive technology cannot compete with the existing solutions. It needs to discover the niche that would fit the prototype and allow it to grow.

The prototype is a state between a group of artifacts and a machine (for my definition of agency, see Section 4.1.1). In other words, the prototype is the process of investigating the coupling that can make clear what direction the development is able to pursue. Organizational blindness exists during the incubation phase. To understand the blindness around the disruptive technology, Christensen (1997, p. 96-97) describes a conversation between developers and managers. Person A is a marketer who can work with existing knowledge. Person B is an engineer that has a disruptive technology:

> Manager: "who's going to buy it?"
> Person A: "Well, there's a whole segment in the workstation industry …"
> …
> Manager: "What kind of margins are we looking at up here?"
> Person A: 'That's what really excites me … close to 35 percent. "
> …
> …
> Manager: "who's going to buy it?"
> Person B: "Well, I'm not sure, but there's got to be a market …"
> …
> Manager: "You think we could make money on this project?"
> Person B: '… that depends on how we could price it, of course. "

This short description may illustrate what goes wrong in enterprises. The marketer speaks the language of senior management, but not the language of the prototype. In a complex adaptive environment it is, however, the second person who can create the guided emergence of novelty and not the first. While the marketer's reasoning can be sound, it may well be that the technical solution cannot be created in the current social fabric. The problem is that the marketer is targeting existing markets. So while the marketer can more successfully convince senior management, the project has hidden risks. The engineer speaks the language of the prototype, but fails to create the required alliance with senior management. The risks are now out in the open and by the guidance of the prototype, the proper alliances can be created. By the guided development, markets get explored that were simply impossible to imagine.

6.2.2.2 Disruption by revenue growth

Christensen (2003) generalizes the concept of disruptive technology to disruptive innovation and the hidden disruptive dynamics behind revenue. The relative experience of revenue growth depends on the scale of the organization. For example, when Apple, as a start-up company, announced the quarterly sales for the personal computer it made less sales than when Apple, as a mature company, announced the quarterly sales for the Newton PDA. As a startup, the sales where considered a success, while as an incumbent the sales were considered a failure (ibid).

Radical change only emerges through an ecosystem of small companies around a prototypic concept. The irony is, while incumbents have the resources, they cannot consider the revenue that arises from the new ventures. The iPod and iTunes case shows how the incumbent can actually spin off an ecosystem. The understanding of the distributed nature for growth seems a problem, as many historical studies can show us. Christensen elaborates how it makes incumbents grow upmarket by focusing on the customers with deep pockets. In the process, they neglect the increasingly marginalized revenue of the lesser paying customers. By writing off the low-end of their revenue, the incumbent creates the niches for disruptive competitors. The new players need more agile organizations to create value in the niche, which requires capabilities that the incumbents do not value (indicating the blindness).

The new players also grow upmarket until the incumbent reaches the highest demanding customers. At first, the incumbent does not find it a threat that the new player takes over the part of their business that does not create enough value. The moment comes when the incumbent has no more upmarket to grow in. Interestingly, the incumbent goes from denial to despair. The effect for public companies is a show of panic by shareholders. Reorganization marginalizes the incumbent to a niche market. For example, the vacuum tube has been replaced by most applications with transistors, except for the high-energy applications use, as needed for magnetrons.

In a way, the disruptive competitor tips the incumbents over the edge at the top of the market.

The rationality of revenue growth shows some of the business dynamics for disruptive innovation. For example, the transistor did not only disrupt the market of the vacuum tube, it also disrupted the value chain. The new product had lower revenue and was not as interesting to the existing retailers. Christensen (2003, p 118) elaborates how Sony's disruptive product was particular fit for emerging retailers like Kmart who focus on mass consumption and had no after-sale capabilities. Both Sony and Kmart were emerging businesses in an ecosystem that created a phase transition in the social fabric to more mass consumption. Notice how the technology creates the guidance. Sony only approached Kmart because the transistor fits their model.

6.2.2.3 Workshops and niche construction examples

For disruptive technology, it is essential that the entrepreneurial organizations create their own niche. For example, the benefit of the transistor over vacuum tubes was the lower energy consumption. In the vacuum tube market, quality was essential. A niche for transistors had to make the benefit important and the drawbacks less relevant. Sony found this niche by targeting young people. For adults, technologies like radio and television were heavy ornaments in the living room. For young people, the technology had to be cheaper and mobile. Sony successfully launched this type of radio in 1955 and television in 1959 (Christensen 2003, p 104-105). Through the niche market, it was possible to gain resources for sustaining R&D on the transistors and solve some of the harder problems, like improved quality, which eventually allowed a competition with the vacuum tubes.

In other cases, the same dynamics are recognized. The telephone shows a niche construction (Casson 1910). The first telephone was a local communication device and was not a threat to the incumbent market of transnational communication by telegraph operators. The niche of local telephony sustained the R&D and eventually the technology became strong enough for transnational calls. At that time, the telephone company had many local networks that only had to get connected for transnational communication. The incumbent telegraph operators did not have such extensive local networks at their disposal and recognized the threat when it was already too late. For example, the transnational communication company, Western Union, would get marginalized to the niche for international money transfer (ibid).

While guided prototypes create the agency in the incubation phase, the workshops are the mediators. The workshop allows development of the prototype and transforms it into an actual technology. Workshops are like laboratories and workspaces have existed for centuries. To give an example of a pioneering workshop, consider Leonardo da Vinci's atelier in the 15th century. Just like any other workspace, the workshop is still being improved today. As a contemporary case, consider the fab labs with tools like 3D printers for rapid prototyping

(Gershenfeld 2012). To understand the mediator correctly, we need to recognize how workshops become the R&D department of larger organizations and not the factory floor. Factories allow for mature technology to be mass produced. The factories should be considered part of the maturity phase for a technology and not part of the incubation phase.

6.2.3 Open Products breaking though the barrier

With the late incubation phase, the prototype shifts to become a pioneering product. This is a product that can only exist in a very specific market. For example, Newcomen's steam engine was only used for mining. With the pioneering product, the basic couplings have been made and a technology (machine) is now recognized. One last change is required to enter the growth phase: the pioneering product has to become an open product. The open product emphasizes that the technology is adaptive and can be transformed to fit different niches. For example, Watt's steam engine had multiple applications. With the open product, the growth phase has started.

In the subsections, I discuss the readiness of our environment to make a pioneering product transform into an open product. The innovation is now called a breakthrough, indicating the transition from a niche to a broad social use. The first subsection considers the dynamics observed in this phase. The open product is creating the agency. The open product is becoming more then a machine, it is gaining autonomy and it is transforming into an agent. The mediation is now by the organization. The blindness from the incubation phase is resolved and the organization shifts from guidance by the prototype to organizational strategy. Consider that the phase transition is, in theory, symmetrical allowing for a discussion about the duration of the whole phase transition. The second subsection uses historical cases to evaluate the speed of a phase transition.

6.2.3.1 Re-organization and venture capital

The organizations provide for the creation and improvement of the product and become increasingly more independent of a specific developer. This is seen with larger organizations that have a flow of people coming into the organization (employment), being shaped by the organization (training) and leaving the organization (retirement, restructuring, etc.). The organizations creating the product have legal rights, obligations to the shareholders and provide services to customers. It shows that an organization increasingly becomes an agent. The agent creates an ecosystem with other agents, showing process like feeding and domestication at the level of organizations.

Feeding and domestication can be recognized with the business process of acquisition. Hostile takeovers show similarities to feeding. The acquired organization gets decomposed and their resources get absorbed to reinforce the

dominant organization. Some acquisitions look more like a domestication process, building synergies between organizations. Such domestication is mostly seen to penetrate a market, when acquisitions are entrances. It often implies keeping the structure of the acquired organization intact.

Breakthroughs for radical change require more than one product to enter a market. A whole business ecosystem needs to emerge for radical change. Venture capital is recognized as environmental enrichment that stimulates the emergence of business ecosystems. As mentioned in Section 6.1.3, venture capital creates leverage, transforming dreamers into actual challengers. The environmental enrichment in previous stages was already part of the mediator, because laboratories and workshops have seen centuries of development. The same integration is not recognized for organizations and venture capital because the emergence of venture capital is a recent historical event.

The history of venture capital shows us that venture capital has not yet finished its S-curve. It started in 1946 when venture capital firms, like American Research and Development Corporation (ARDC) arose. ARDC's first big success was in 1957 (Hsu & Kenney 2005). The event can be recognized as a proof-of-concept of venturing (making it a prototype). During the 1960s and 1970s, this proof-of-concept would continue to develop (guided emergence). The incubation phase would turn into a growth phase in the late 1970s and 1980s, making firms like Apple and Compaq become possible. In the 1990s, venture capital matured. Twenty years later, a trend was recognized, indicating that venture capital was to become even more massive with strong governmental interest to improve the innovativeness of nations. It convinces me that venture capital is entering an enrichment phase. In fact, it is believed that the Agile-Enterprises make venture capital an integrated part of the organization, showing how the enrichment and the mediator again become the same thing (similar to how it was with laboratories and workshops).

6.2.3.2 The speed of the phase transition

It is necessary to return to some historical cases and to describe the symmetry of the phase transition. First, it needs to be pointed out that not all developments smoothly follow the S-curve. The case of the steam engine shows a clear deformation of the S-curve shape. The incubation period was about 60 years, while the maturity phase was 85 years. Therefore, it was not at all symmetrical. The reason relates to the enrichment for the phase. While workshops had seen centuries of development, the enrichment for the maturity phase is even more recent than the enrichment for the growth phase. In order to provide a good argument for the S-curve, it is necessary to take into account the enrichment. I therefore start an investigation by assuming symmetry, which should emerge when the enrichment of the later phases improves.

The disturbances of the 20th century cases show clearly how the first half of the S-curve develops and how distortion to the S-curve gets compensated. For example,

the transistor stayed dormant. The Fleming patent in 1905 (U.S. Patent 803,684) was the wicked challenge that stimulated the prematurity phase until the prototypic concept was built in 1930 (U.S. Patent 1,745,175). The prototypic prototype did not directly result into a guiding emergence because the workshop was missing. The development froze for 17 years until 1947 when AT&T's Bell Laboratory start building the prototype. When Sony released the TR-55 transistor radio in 1955 the transistor was developed enough to call it an open product.

In summary, the time of the development had a prematurity phase of 25 years, was frozen for 17 years and had an incubation phase of 8 years. On average, I recognized for the 20th century cases, a premature phase of 35 years and an incubation phase of 15 years. In other words, the prototypic concept for the transistor happened 10 years too fast, also making the prototype stay dormant for 7 years and resulted in a much faster incubation phase. Each case has some minor deviations. For the computer, the wicked articulation was with Hilbert's problem in 1900, the Turing computer in 1936 was the prototypic concept. The prototype cam with the reaction by Von Neumann and Morgenstern (1947) who designed the stored-program computer. IBM adopted the design and made a pioneering product with their 700-machines. The first commercial computer (type 702) was released in 1952 (Bashe et al. 1986), indicating the end of the incubation phase.

For the nuclear chain, it is necessary to provide more detail. Radioactivity was discovered in 1896. Max Bodenstein proposed chemical chain reactions in 1913 and in 1933 a nuclear chain reaction was proposed by Leó Szilárd, not even a year after discovering the neutrons. In 1938, nuclear fission was discovered and by 1939 the nuclear chain reaction by fission was proven plausible. By explaining this in more detail, the origin of the prematurity phase becomes ambiguous. Depending on what discovery we focus on the duration of the premature becomes different: radioactive (40 years), chain reaction (26 years) and fission (one year). The most accurate point seems to be the nuclear chain reaction, but just like any historical case, if we get into detail the dating becomes debatable.

In 1939, the Manhattan project was created, which was the workshop for the A-bomb, which was demonstrated in 1945. The incubation phase was now institutionalized creating a demonstration after only 6 years. It is comparable to the transistor that had also an organization as support and took only 8 years. It is different from the transistor in respect to where the development stayed dormant. With the A-bomb, the chain reaction was close to becoming a pioneering product as a reactor. It still took another 9 years before this goal was reached. The first demonstration of a reactor was given in 1951. An actual useful plant for civilian purposes was operational in 1954. There were 6 years of rapid development by institutionalization and then 9 years of slower development leading to the 15 year incubation phase.

Let us consider the growth phase for the three cases. To enter a maturity phase requires mass production. The transistor became a pioneering product in 1955 and by 1957 the transistor still had a small market with 100,000 units of the TR-63.

Quick growth was seen, since by 1959, 6 million of the TR-63 were sold (Lane & Lane 1994). The commercialization of the stored-program computer began with IBM 700 series in 1952 and with IBM 7000 series in 1958 (Bashe et al. 1986), which is considered the beginning of the maturity phase. It is important not to confuse the development of the stored-program computer that matured as the mainframe computer, with the personal computers that eventually disrupts the mainframe computer.

The last case on nuclear reactors shows a growth phase with the reactors becoming engines, starting with the submarine in 1954 (Cowan 1990) and portable reactors in 1960 (Ingersoll 2009). The average growth phase in the 20th century took about 5 years. This would mean that a phase transition requires (35+15)*2 +5 = 105 years. With a development of over a century for a full phase transition, the development creates a smooth transition in the social fabric.

The longer the period, the more that enrichment should be able to improve the duration. However, the scale also needs to be taken into account. The 20th century cases were local (national). Compared to recent cases of technological adaptation, the same duration of 5 years growth phase is recognized, but the scale has become global. The iTunes online store was launched in 2003 and in April 2008, the online store surpassed Wal-Mart. Another example is Facebook that was launched in 2005 and by 2010 it had 500 million users. After 2010 growth was below 5%, which may be considered an indicator of the saturation leading to the maturity phase.

6.2.4 Support Frameworks, the skeleton of ecosystems

Environmental enrichment improves each stage in the phase transition. For each next stage, this enrichment is more recent history. The enrichment for the premature phase can be traced back to roughly the 18th century (Age of Enlightenment). The enrichment for the incubation phase occurred during the 19th century (second industrial revolution). Enrichment for the growth phase is only seen in the second half of 20th century (venture capital). It should be no surprise that the enrichment for the maturity phase is a contemporary effect.

The enrichment is possible by what I like to call support frameworks. The first subsection considers the nature of product frameworks at the end of the growth phase and how they are transformed to support frameworks in the maturity phase. At the end of the growth phase, the process of acquisitions in the ecosystem would lead to a few dominant enterprises. The innovation in the maturity phase is about the architecture of the large enterprise, as elaborated in the second subsection. In the third subsection, I consider the enrichment for the maturity phase, which is a development in full progress.

6.2.4.1 The rise of product framework with PC market

In the late growth phase, product frameworks are recognized that are transformed to support the framework. The product frameworks can be recognized with large companies that have business ecosystems around them for the development of the parts, e.g. as seen with the car and airplane industries. The effect of the product framework becomes more outspoken and less centralized with the ICT market. In the 1980s, Apple was the dominant PC product, using an integrated strategy (Allan 2001). It lost market share with the emergence of PC compatible products that were sold separately. Both IBM as the hardware provider and Windows as the software provider became the product frameworks, allowing business to business (B2B) services to flourish.

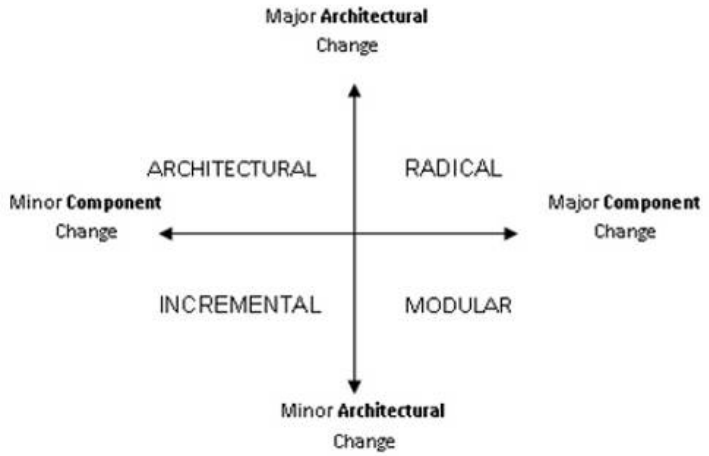
The business ecosystem around big companies, like a car industry, had centralized relations. It was the car manufacturer that delivered an integrated solution to the market. For the PC, Apple gave an integrated solution, while the IBM compatible market allowed shops and customers to build their own PC, since hard disks, memories, processors, etc. were sold separately. It created more flexible ecosystems where the dominance of the specific parts changed rapidly.

The product framework has been transformed to support the framework. This has been recognized with the smartphone market (Ballon & Van Heesvelde 2011). Both Apple and Google are using a support framework to make their product extendable by third parties. Apple extended the iTunes media store to be such a framework and Google created a similar framework for their Android platform. The smartphone market is the niche where they have emerged. It is expected that other industries will now investigate how to use the dynamics of support framework for their own products.

6.2.4.2 The challenge of architectural innovation

Organizational studies on product frameworks (e.g. car and airplane manufacturers) led to the concept of architectural innovation. Henderson and Clark (1990) argue that innovation of a particular component (e.g. the engine) is easier than an architectural innovation of the whole product. With a modular architecture, the major innovation to a component only means replacing the module. For example, it could mean changing the propeller engine to a jet engine. Simple architectural innovation is, in fact, a common practice seen with company reorganizations. In the case of reorganizations, the components do not change. Radical architectural innovations are rare events. One example are the changes created by Steve Jobs when he was reinstated as CEO of Apple in 1997 (Kahney 2009). He did not only restructure the company, but he changed the components radically by releasing the iMac (ibid).

Figure 6.2: The architectural versus component dimension of innovation



Henderson and Clark (1990) elaborate that companies with large products, e.g. aviation or ship construction, are well designed for modular innovation, but not for architectural innovation. The change in architecture is easier with new business development, where new business architecture is proposed in the organizational startup. However, new organizations have a challenge to grow fast. Large organizations are better suited to create the fast growth. A solution to this dilemma does not exist. Research on enterprise architecture is working on this dilemma with the concept of Agile-Enterprise (see Section 7.2.1).

The support framework creates agency. The mediation happens by a development ecosystem producing some value chain. It is also important to note that with disruptive innovation emerging ecosystems existed that redefined the value chain (e.g. Sony's transistor products and Kmart mass consumption retail, see Section 6.2.2.2). The difference with architectural innovation is that now changing the chain is part of the innovation management. In the case of disruptive innovation, an organizational blindness exists. With architectural innovation, a richness of organizational insights is available. The research on Agile-Enterprise will need to demonstrate how building chains from scratch becomes possible. One such investigation involves reinventing the food chain to address a food security issue (see Section 11.3.3).

6.2.4.3 Contemporary enrichment for the maturity phase

Consider that the enrichment of the growth phase with venture capital is now in the enrichment phase. The product frameworks that emerged in the late 1980s created a prematurity phase for the support frameworks until the 2000s. Between 2000 and 2010, the support frameworks have been in an incubation phase as the backbone of the social media (wave 2.0, see Section 5.2.9) and smart phones. While being very effective for ICT, it is only a small part of the social fabric and so the ICT support frameworks are just a pioneering product in the social fabric.

Many support frameworks exist on the Internet. They include frameworks for distributed development (e.g. git), frameworks for content management (e.g. Drupal), frameworks for software development (e.g. Eclipse), frameworks for virtual rooms (e.g. IRC), etc. All of the support frameworks revolve around a culture of programmers. To understand the spillover to other parts of the social fabric, we should not to focus on the culture of programmers. For example, it is more important to examine the effect that the open software culture has on open governance and on open hardware. Indeed, we are getting back to the trend of "openness" that was also investigated with open innovation. The effect is the construction of Internet support frameworks for other usages than programming.

With the explosion of support frameworks, a need is emerging to have a support framework for support frameworks. This can be called a support meta-framework. In fact, between 2005-2006 I have been in a research project to investigate knowledge sharing and how to apply it (Coenen et al. 2006). Such studies investigate patterns of usage that can become the insight to build a support meta-framework. The next chapter will provide an elaborate pattern showing a support meta-framework scheme for innovation. Moving from such schemes to an actual useful support meta-framework is research in progress.

6.2.5 **Intentional Enrichment, a glimpse of things to come**

Considering that the agency and mediator of the maturity phase is only getting in the middle of its phase transition makes it hard to say anything sensible about the enrichment phase. The support frameworks are about scaling the innovation and making it more accessible and cheaper, which are features of the maturity phase.

When considering the ultimate use of the support framework, we recognized collective intelligence. This is related to the discussion on Internet innovation waves. The agency of the enrichment phase seems to be intelligence and it relates to the hypothetic Internet innovation waves (Section 5.2.10). By the late maturity phase, collective intelligence (wave 5.0) is recognized and it needs to shift to individual intelligence (wave 6.0) to become the agency for the enrichment phase. The mediator is the Global Brain. The first subsection considers the mediation by the Internet and the effect of its globalization. It is transforming existing power structures into collective intelligence solutions that can deal with the complexity of the globalization. The second subsection takes on the challenge to understand the enrichment of the enrichment phase.

6.2.5.1 The global super organism creating mediation and innovation

Insights from platforms make Friedman (2005) articulate how the Internet is making the world flat. Florida (2005) reacted to this by claiming that the world is not flat but spiky, again drawing our attention to cities. In a more hypothetical discussion on how the waves of Internet innovation can fit the evolution of the

social fabric, the cities also had a central place. It was argued that cities might be transformed beyond recognition (see Section 5.2.11). Cities are about the oldest mediators and they transform with each enrichment. Today, the concept of smart-cities has emerged. It uses the Internet innovation to also innovate the governance of cities (Schaffers et al. 2011). The smart-cities pilot is pioneering research, creating insight. In other words, they are worldview innovations. An ecosystem of such pioneering pilots, can create the conditions to make a mediator for the enrichment phase emerge.

Another insight relates to open governance. In recent pilots, the open governance is getting heavier based on technology. Examples are "apps for democracy" and "code for America", which are two Internet innovations inspired approaches to create technical support for governance using open data. Open data and the explosion of sensors support creates big data and the opportunity for a Planetary Nervous System (Giannotti et al. 2013). In other words, the metaphor of Global Brain is becoming less of a metaphor. The concept is getting grounded, which means that the agency and mediation for the enrichment phase is still in a prematurity phase and still in search of a prototypic concept.

The mediation by the Global Brain is creating a very selfish innovation, being the actual Meta-System Transition (MST) towards a global super organism (see Section 5.2.11). What we can already see is that such MST innovations are refactoring what governance is, whether it is city governance by smart-cities, national governance by open governance, enterprise governance by Agile-Enterprise, etc. The effects of refactoring governance by MST innovations are only now getting explored with pilots. How it can change our worldview remains to be seen.

6.2.5.2 Enriching the enrichment phase

It is already hard to understand the agency and the mediation. Grasping the enrichment for the enrichment phase is even harder. The acceleration of radical innovation forces requires a new kind of governance to deal with the death of large organizations or the death of sectors. A new workspace is needed that can response to the challenges by spinning off ecosystems to fill the gap. Metaphorically, it is like second order succession. With second order succession, a major disruption (e.g. forest fire) wipes out the ecosystem, the ashes are good for the soil allowing for new plants to quickly populate the open space. For the social fabric, the process is more artificial, requiring advanced institutes.

The spinning of the ecosystem may be reached with next generation universities that are distributed and self-organizing. Universities have three pillars: research, education and public service. The developments of the separate pillars are expected to converge, creating an architectural innovation for universities. The refactoring of the governance makes a University, focusing on universal knowledge, transform into "Interversities", which are capable of creating mass amounts of connections

required for spinning off an ecosystem. Trying to get a better understanding of Interversities is the topic of Chapter 11.

Because of the bootstrapping process of artificial evolution, we can recognize the marginal form of the mediator during the previous phases. For the enrichment of the social fabric towards an Interversity, the Technology Transfer Organization (TTO) is the more primitive mediator. The Interversity is a huge TTO becoming bigger then all current functions of the university together. Debackere (2010) elaborates on the evolution of Technology Transfer Organizations (TTO). The first generation TTO dates back to the 1970s right after the first success of venture capital. Currently, a second generation TTO exists, which arose during the 1990s. Debackere (ibid) argues about a third generation TTO in the making without giving any details on what it means. He only argues that it creates synergy between the three pillars. This PhD is going to create more insight with Interversity on how the synergy is reached.

6.3 Research Question II.2

How can we apply the novelty research to understand innovations made by organizations?

By investigating SMS, another novelty model was discovered that was already mostly described by the dynamic capability framework. The studies show how values drive the organization and how strategy overcomes the organizational blindness of the incubation phase. The novelty model created by such studies is called the Strategizing model and it changes the evolution of the social fabric to innovations by organizations. It is argued that the Strategizing model is the directing anchor for the meta-model and that it makes the default flow (by evolution) become a directed flow (by innovation). The organizations are described as the invariant patterns in the meta-workspace, showing connections to both the Cohering model and the Eventuating model with double entry bookkeeping. To grasp the dynamics better, contemporary cases elaborate on value exaptation.

By taking on the five phase transition more systematically, the agency and mediator during each phase can be examined as to how they relate to a type of innovation. For each stage, the enrichment for the innovation is described. In the first two phases, the enrichment is integrated in the mediator: laboratories for the prematurity phase and workspaces for the incubation phase. Venture capital is the enrichment for breakthrough innovation, but it has not yet been integrated into the mediator, being organizations. It is argued that such integration will happen with the Agile-Enterprises. The agency of the maturity phase (support frameworks) is only recently recognized and the mediator (ecosystem) is still relatively primitive. It is expected that with the development of the Agile-Enterprises, more insight will arise on how to make the mediator more advanced. For the last phase, being the enrichment phase, the discussion is theoretical. Chapter 11 will investigate the enrichment for the enrichment phase.

7 Agile-Enterprise Innovation Planning

7.1 Project management, the interface for innovation

In order to improve development, a good interface is required. Interfaces have been investigated throughout the first part of this PhD. In Section 2.1.2, research on brain plasticity made us think about interfaces of cognition. Section 3.2.3.1 investigated a possible evolution from boundaries towards interfaces. In Section 4.1.3, the skeleton is a scaffold framework transforming the inertia in an optimal way, where the muscles behave as an interface for the brain to regulate motion. For innovation, the support framework is comparable to the skeleton allowing for scale and efficiency. What needs to be examined now is the interface to improve the development of innovation. The interface for innovation is considered project management for complex adaptive environments. In recent research on project management for complex adaptive environments, another novelty model is recognized, which is the topic of the first section. The model is called Establishing since it overcomes the conservative force of procrastination. The procrastination is a natural effect of the complexity, causing the decision making to be difficult.

The Establishing model is the last part of the meta-model, it fulfills the role of evolving anchor. The evolving anchor takes the pattern in the workspace and uses it to evolve the system core or to enrich the environment. With the Establishing model closure is finally reached. Remember that each novelty model has advanced cases that require another novelty model. More advanced cases of knowledge creation require scientific and technological development. More advanced cases of scientific and technological development require strategic and organizational development. The more advanced cases of strategic and organizational development bring us to project management for complex adaptive environments. The more advanced case of project management brings us back to the basics of knowledge creation, showing how the Establishing model reaches closure.

This first section investigates the Establishing model and completes the meta-model. The second section also creates completion, by creating another look at the phase transition that allows us to connect the meta-model to the phase transition. In the first subsection, a recent scientific debate around project management for complex adaptive environments provides the introduction to the Establishing model. This time the details are not sufficient to recognize the novelty anchors, so a suggestion is proposed in the second subsection. In the third subsection, the Establishing model as a meso-level model is examined. It shows how the Establishing model is entwined with the other novelty models. The last subsection gives an overview of the meta-model.

7.1.1 **Action Design Research (ADR) method**

For project development around complex adaptive environments two distinct methods are relevant: Action Research and Design Science. Both emerge from the same influence of German psychology of the 1940s. Lewin (1946) introduced the term Action Research:

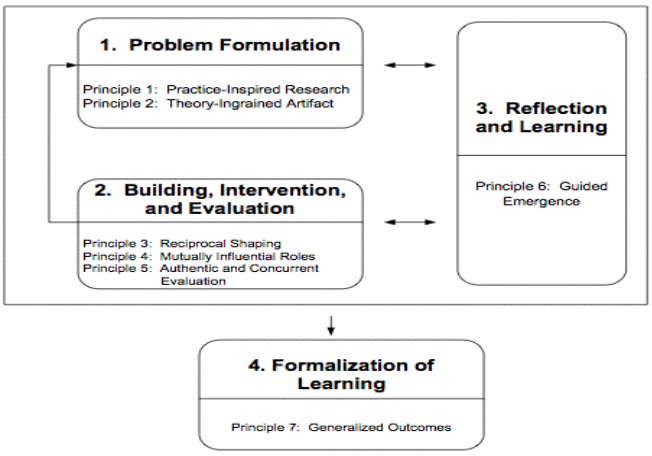
> A spiral of steps, each of which is composed of a circle of planning, action, and fact-finding about the result of the action.

The origin of Action Research is easily recognized, but Action Research later became a rather dispersed discipline. The origin of Design Science is harder to trace, but the recent debate is clearer. The origin can be recognized in Simon's (1947) problem-solving theories that grew into a science of the artificial (Simon 1969). The term Design Science Research (DSR) is only recently found in Information Systems (IS) literature. March & Smith (1995) introduce the term to create a dichotomy between world-knowledge and useful knowledge. Where world knowledge is about how the world works, useful knowledge is how to create artifacts. Mokyr (2002) conducted an extensive study of the difference, but he used a different terminology, namely propositional knowledge for the former and prescriptive knowledge for the later.

Within Information Systems journals, the DSR method was developed more in subsequent years (Aken 2004; Hevner et al. 2004). While authors such as Järvinen (2007) have claimed that Action Research and DSR are similar, scholars such as Iivari & Venable (2009) argue there are clear distinctions. The argument is that Action Research basically refers to test-in-practice methods, while some artifacts cannot be tested that way (e.g. medical equipment). Sein et al. (2011) propose a new method that would combine features of both Action Research and Design Science Research for complex adaptive environments. They called it the Action Design Research (ADR) method, which describes a novelty regulation model.

The ADR method suggests four stages and seven principles (Figure 7.1). The classic development by stage-gate processes follows a sequential path. The gates are milestones in the development process where it gets decided to continue the development or not. By contrast, ADR stages are executed in parallel. Notice how similar Figure 7.1 looks to the schematic representation for the novelty model (Figure 4.14). The parallel operations of the stages makes it align even more with the novelty model. It is important to elaborate on the meaning of the stage and principles before considering how ADR gives us an understanding of the novelty anchors for the Establishing model.

Figure 7.1: The four stages of the ADR method



The Problem Formulation (PF) stage grounds the design, which requires alignment in two directions and therefore results in two principles. The practice-inspired research principle (1) is based on concrete problems. It should not only focus on solving the problem, but should recognize the design that could address a class of similar problems. The theory-ingrained artifacts principle (2) emphasizes that fabrication results not just in pragmatic solutions, but solutions that are based on a broad expertise. While they may look simple and be user-friendly, the solution itself should be smart.

The Building, Intervention and Evaluation (BIE) stage has three principles. The Reciprocal Shaping principle (3) is about solving wicked problems, where "reciprocal" is addressing the entwinement of inseparable influences. It describes the bootstrapping principle in a different way, drawing the attention to the fact that the separation is only reachable by cultivating the different parts simultaneously. The principle of Mutually Influential Roles (4) is the collision of different expertise creating novelty on the level of group formation. The Authentic and Concurrent Evaluation principle (5) argues for evaluations parallel to the ongoing development. This principle is not evident. An example can be given from software development: unit testing. Unit testing is a way for modular development to create feedback for distributed development. After developing functions in the module, a test unit exists to verify whether the function behaves appropriately. When another module is added, the test units of all active modules check the new module that it is not creating any conflicts with existing functions.

There are two remaining stages and each has one principle. The Reflection and Learning (RL) stage has the Guided Emergence principle (6). The principle elaborates that from the initial process, until the final outcome, many things can change, but at each point guidance exists. The guided emergence for innovation is reached by the bootstrapping of agency and mediation (Section 6.2). The last stage of Formalization of Learning (FL) has the principle (7) of Generalized Outcomes. This principle is to move from a "specific and unique" case to "generic and abstract" models, which is described in the many novelty models by the evolving anchor.

7.1.2 The Establishing anchors

In previous novelty models, the existing literature required a small adaptation to fit the novelty model. The authors of the original models therefore provided most of the terms. A better articulation is required for the Establishing model. The first problem with the ADR model is that the principles and not the gates are the anchors of the Establishing model. When considering the dynamics of the principles, it becomes clear that the terms introduced in previous chapters can explain the principles better. Let me elaborate.

For the PF stage, the two principles give the details of the direction of a relation: from the world to the model (Principle 1) and from the model to the world (Principle 2). The two directions create the **externalizing principle** for the Establishing model. Expressing the reaction by two separate principles does not seem to be efficient. By examining which PF stage tries to reach it, is my assumption that the principle can be more effectively expressed by **stigmergy** (see Section 2.3.1).

The BIE stage is different. Two principles seem to be misplaced. Principle 3, about **wicked problems**, makes the **principle** the **internalizing** anchor of the Establishing model. Principle 4 considers roles, but roles relate to the Eventuating model. Principle 5 describes part of the workspace dynamics: "ongoing evaluations by work in practice" become the invariant patterns of a workspace. It is strange that the principle of wickedness was not proposed. After all, the concept of wicked problems comes from design studies.

The RL stage and the principle (6) of "guided emergence" is an alternative articulation of the **directing principle**. Guided emergence is a process. It is not accurate to consider it a principle. The guided emergence relates to **fitness** including: the fitness of knowledge in a model, the fitness of a role in a group and the fitness of organizational capabilities to protect values.

Principle 7 emphasizes the abstractions, which relates to the evolving anchor in the novelty model. What the **evolving principle** achieves, is the transformation of friction, coming from the necessary tension, to synergies. The principle of **flow** (see Section 2.1.3.1) can express the transformation to synergy. As such, the four principles for establishing become:

- **Internalizing** principle: **wickedness** for reciprocal shaping
- **Externalizing** principle: **stigmergy** to connect to the world
- **Directing** principle: **fitness** stimulating guided emergence
- **Evolving** principle: **flow**, when tension transforms to synergy

Most of the principles have been used while elaborating the previous novelty models. The reason that the dynamics of the Establishing model affects the dynamics of the other models is that the mediums for the Establishing model are the mediums other models. In other novelty models, we would investigate the three

mediums to gain an understanding. For the Establishing model, entwinement exists, making the model a meso-level model. The effect is that each of the three mediums are, in fact, the mediums of each of the previous novelty models. The entwinement with each of the previous novelty models needs to be investigated.

7.1.3 The meso-level creating conversion patterns

Principles are even more virtual than the capabilities of the Strategizing model. It makes the Establishing model very tricky, while being able to create closure by recursion. Each previous novelty model is a medium for the Establishing model creating entwinement of the novelty models. Entwinement is the feature of the evolving anchor and the Establishing model entwines novelty models. The entwinement between the models creates what has been called conversion patterns. The term conversion patterns was introduced by Nonaka (1991) to explain different stages in the process of knowledge creation. Therefore, the conversion patterns are about the Cohering model. The different stages make the Cohering model relate to the phase transition as examined in Section 7.2. For each novelty model, a conversion pattern can be recognized. For the Establishing model, the conversion patterns show how the procrastination of the scale of the transitions gets resolved. Each of next subsections introduces a conversion pattern elaborating the entwinement with one of the previous three novelty models.

7.1.3.1 Acting individuals

I use the Cohering model to provide the most detail on the entwinement. In the Cohering model, the anchors are anticipation processes, so it is necessary to examine how the principles affect the anticipation. For the Cohering model, all development is based on actions while the scale relates to individuals, so the conversion pattern becomes "acting individuals".

The internalizing principle was "wickedness", coming from the notion of wicked problems. A problem creates a challenge and challenges allow regulation of the directing anticipation, but the wickedness is also related to the other anticipation processes. The entwinement of the wickedness principle is most clear in a state of modeling. By associating existing actions into an action that was never tried before, a wicked concept is created. It triggers a wicked act and creates wicked experience.

The entwinement with stigmergy becomes most clear in a state of mastering. Many signals can exist, but introducing stigmergy requires identifying an essential variable to gain simple regulation. Putting the wicked action into practice creates stigmergy for each anticipation process. The stigmergy is first a moving target, showing an adaptation towards the new essential variables. The internal essential variables focus on which associations hold and stimulate the stigmergic nature of these associations. The external search is to find what tags are essential. The creation of new concepts redefines the challenge and with it the stigmergic aspect of

such challenges. The mastering connects the associations, tags and challenges into a stigmergic experience that creates knowledge.

For both modeling and mastering, a first attempt may only lead to small success. With each new attempt, more understanding arises also resulting in an understanding of fitness. The fitness relates to associations, tags, challenges and experience. Modeling the fitness relates to efficient abstractions, while mastering the fitness relates to agile actions. The development is not a smooth process, but a messy interaction between the two learning processes. The improvements make the messy interaction become more streamlined, transforming the messy interactions into a flow, which again relate to associations, tags, challenges and experience. Thus, all the Cohering anchors (anticipation processes) are entwined with all the Establishing anchors (principles).

To give some detail, consider the "riding a bicycle without hands" example (see Section 4.3.2). When applying an action that was never tried before, perceptual feedback makes the attention shift to the problem that exists within the wicked act. The wicked action in our case requires changes within the body of the cyclist where balance is the essential variable. Normally, the hands regulate the balance of the bicycle. The challenge is, however, not to use the hands, so the regulation requires rewiring. Other muscles need to regulate the balance. Eventually, this rewires the regulation to the hips. During the mastering, there is no room to reflect. After reaching the challenge, re-experiencing the process can result in an abstract concept, in this case "balance". After several more improvements that make it all fit better, the action becomes less messy and flow is reached.

7.1.3.2 Bootstrapping groups

For the Eventuating model, the anchors are roles. Therefore, we need to examine how the principles affect the roles. All development shows a relation to bootstrapping in a group. The wickedness is now about the heterogeneous roles in a group. The group members get roles and learn to coordinate their actions. The coordination makes the new agent more than the sum of the agents in the group, so the heterogeneity is bootstrapping an agent. A group may imagine how the world reacts to their development, but only by creating the development does the public reaction manifest. The bootstrapping is now by the co-development between the group and the social fabric in a stigmergic way. Allies create the conditions for organizations and the fitness of it is not known up front (organizational blindness) but it gets bootstrapped. Bootstrapping is also recognized in the peer-evaluation. If no peers exist, a single group finds it hard to evolve. In other words, peers create a flow by co-development. Therefore, each role allows bootstrapping.

Let us reconsider the case of a nuclear chain reaction (see Section 5.1.4) to make the relationship between principles and roles more concrete. The wickedness relates to the group heterogeneity, connecting firms who would have otherwise no connection, like Union Minière and Norsk Hydro Elektrisk. The public was experiencing war and

so the research was stimulated. However, during peace even nuclear energy for peaceful purposes gets resistance. The relationship shows how the development depends on the stigmergic state of the environment. The fitness is recognized in the value of resources. Some assets that previously had no value, become essential. For example, uranium was a waste product and deuterium had no use. However, they became the main resources for nuclear chain reactions. The flow provided by peers is, in this case, the suggestion of deuterium as a moderator, allowing the experiment to improve. At first, the interaction between colleagues is coincidental and happens clumsily, like the suggestion of deuterium. When colleagues know better what to exact from each other, the flow is recognized.

7.1.3.3 Leapfrogging organizations

For the entwinement with the strategizing model, the relationship between the principles and capabilities need to be examined, which brings us to the leapfrogging conversion pattern. Leapfrogging is the moment that a person jumps over another person. To be able to do it, requires a sprint in front and enough space behind it to slow down. While leapfrogging is a concept for individuals, it can be used metaphorically to describe the interaction between organizations. In that case, leapfrogging describes the dynamic of an innovation S-curve.

To illustrate the leapfrogging, consider the case of telephony. As long as telephony was a local application, the invention was not considered to be a competitor for the telegraph. The local development is what allows the sprint in front of the leapfrogging. Having a niche to survive allowed the solution of the difficult problem of long distance telephony. The co-development between the local buildup and the hard problem makes the incumbent blind. Once telephony was recognized as a competitor for long distance communication, the battle was already lost for the telegraph operators.

Let me consider the relationship between the anchors (capabilities and principles). Bundles of resources combined in a way never done before can lead to a wicked value, as described in the cases of value exaptation (see Section 6.1.5). A competitive position allows a company to differentiate in a market. Competitive positions create stigmergic markers with brands, allowing people to judge a product based on the history of an organization and not on the new product itself. Paths show the fitness of values, because organizations have a certain momentum and have many implicit values. They create fitness (opportunities and constraints) specific to the organization's path. Business processes increasingly create the flow of the organization. The flow is what makes the organization both more autonomous and capable of creating more added value.

I have used the case of iTunes as a music store to discuss dynamic capabilities (see Section 6.1.3.1). The bundles were related to ICT, but were wicked in respect to the music industry. The products by Apple for the music market were technological and did not help to gain ground in the music industry itself. The stigmergy was

embedded in the iPod, which created agency. Only by releasing the iPod, did Apple create the sprint to leapfrog into the music retail business. The "IT integrated system" expertise was the fitness that gave Apple a competitive advantage. Only their resources, position and paths could convince the music industry to ally with Apple and answer the growing demand for a digital audio market. At the start of the business venture, Apple did not have the flow that it would gain in the music industry. Gaining that flow eventually allowed the company to become the largest retailer of music.

7.1.4 **The meta-model**

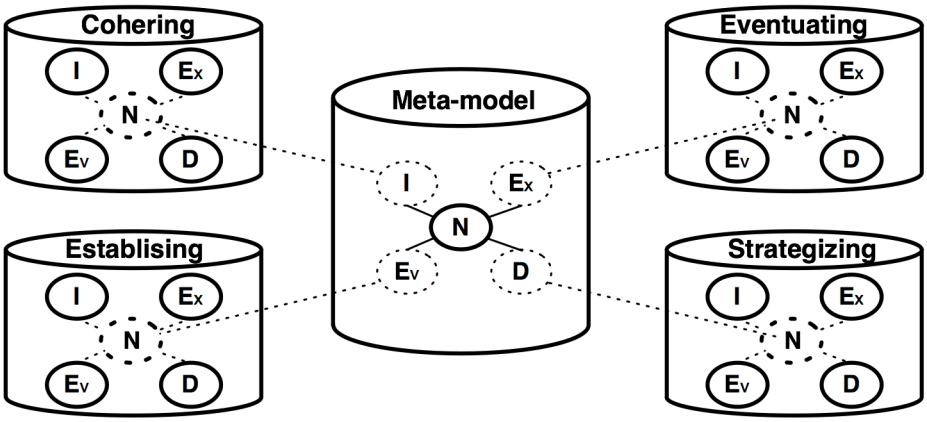
The Establishing model is an intermediate model, which means on a meso-scale. The meso-scale allows for recursion to arise, creating closure to the meta-model. Consider that the novelty model is what allows exaptation. It seems accurate to say that the meso-scale is the most abstract regulation of the exaptation stripped from any concrete application. Exaptation is what the Establishing model truly generates. An overview can now be created showing all the anchors of all novelty models and how it combines into the meta-model (Table 7.1).

Table 7.1 Overview of the anchors in each novelty model

	Cohering	**Eventuating**	**Strategizing**	**Establishing**	**Meta-model**
Internalizing	Associations	Developers	Bundles	Wickedness	Knowledge
Externalizing	Tags	Civilians	Positions	Stigmergy	Agency
Directing	Challenges	Allies	Paths	Fitness	Innovation
Evolving	Experiences	Peers	Processes	Flow	Exaptation
Novelty	Knowledge	Agency	Innovation	Exaptation	Radical change

For the Eventuating model, the three mediums (core, workspace and environment) come back in each novelty model. It does not allow us to simply express what the three mediums are, but it does allow us to recognize a schematic presentation of the meta-model, like illustrated with Figure 7.2. The novelty in each model becomes the input for the meta-model, showing how each of the novelty models becomes related to a novelty anchor in the meta-model.

Figure 7.2 Schematic presentation of the meta-model where each of the four anchors (I, E_x, D, E_v) creates novelty (N).



The meta-model is able to produce novelty of novelty, which should allow for radical change, as examined with the meta-workspace (see Section 3.3.1). The conversion patterns provide a different view on how radical change is reached and how it manifests in each stage of the phase transition. I have so far considered three conversion patterns for the Establishing model: actions, bootstrapping and leapfrogging. A whole grid of conversion patterns can be created, which becomes the focus in next section describing the ÆIP grid. Strategizing

7.2 The ÆIP grid

Similar to previous chapters, this second section is about the phase transition. The STS chapter has examined, with the evolution of the social fabric, the default flow. The SMS changes the default flow by innovation with organizations, creating a directed flow. What remains is constructive flow allowing a systematic approach to radical change. A constructive flow requires an understanding of how the meta-model and the phase transition relate. This is reached by describing the Agile-Enterprise Architecture Planning (ÆIP) grid. The ÆIP grid leaves still several practical problems unanswered that become the topic of the ÆIP architecture in the next chapter on the methodology.

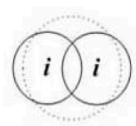
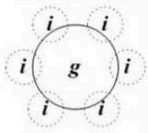
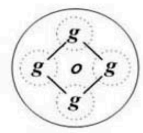
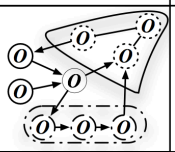
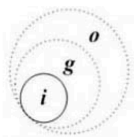
The conversion patterns are the way to connect the meta-model to the phase transition. I have considered three conversion patterns so far for only the Establishing model: acting individuals, bootstrapping groups and leapfrogging organizations. The three conversion patterns already show a scale transition. The level of scale relates to the phase transitions, where the relation between individuals are essential during the premature phase, groups become essential during the incubation phase and organizations become essential during the growth phase.

Two more scales need to be elaborated for the phase transition. A complex network of organizations is recognized during the maturity phase of an innovation. Some organizations may exist on their own while others form a cluster or a chain. In relation to the scale, it needs to be recognized how the network of organizations is

local, being in local to a city, local to a province or local to a nation. The local scale stands in contrast to the global scale of the enrichment phase. The effect is an absorption into the social fabric, allowing us to focus back to the individual. With five stages of the phase transition and four novelty models, a total of twenty conversion patterns create the ÆIP grid (Figure 7.3).breakthrough

Figure 7.3 The content of the ÆIP grid showing the relation between phase transition and meta-model

Agile-Enterprise Innovation Planning (ÆIP) grid

Phase transition					
Stage	Premature	Incubation	Growth	Maturity	Enrichment
Scale	Individual	Group	Organization	Local	Global
Visualizing the relations					
Innovation	Worldview	Disruptive	Breakthrough	Architectural	MST
Agency	Concept	Prototype	Product	Framework	Intelligence
Mediator	Laboratory	Workshop	Organization	Ecosystem	Global Brain
Meta-model					
Establishing	Acting	Bootstrapping	Leapfrogging	Institutionalizing	Globalizing
Strategizing	Viral	Retrofitting	Mobilizing	Governing	Technologizing
Eventuating	Networking	Flocking	Consolidating	Framing	Sprinting
Cohering	Personalization	Socialization	Externalization	Combination	Internalization

In the ÆIP grid, three different regulations exist for each conversion pattern. Some patterns are spontaneous. They are side effects of the other activities in a stage of the phase transition. In Table 7.1, the spontaneous patterns are gray. To move from spontaneous to control requires one hybrid pattern where regulation is reached by coordination. Each novelty model has one such pattern, and they show a staircase like the structure in the meta-model. The effect is that for earlier stages, more of the novelty regulations are happening as side effects and do not require management.

To give the full picture of the 20 conversion patterns, each subsection looks again at the separate novelty models, starting with the Cohering model. By considering the conversion patterns for each novelty model, it can be argued how conversion for radical change truly happens. Before explaining the conversion patterns, I would like to take a moment to elaborate the choice of the name ÆIP and why this is relevant.

7.2.1 The rise of Agile-Enterprise

The inspiration for the name ÆIP comes from Enterprise Resource Planning (ERP). The reason to choose that name is because of the historical similarities. Before ERP existed, companies used to have an invisible barrier to manage day-to-day operations as only a few accountants had a holistic view of the companies' resources.

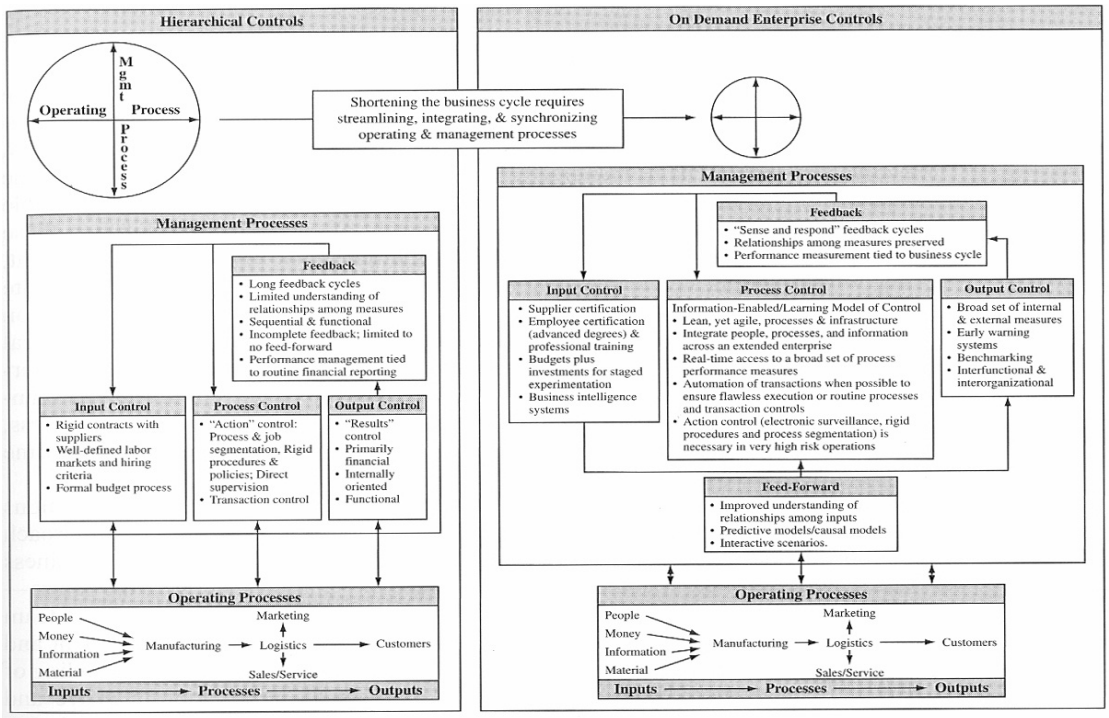
Today's visionary leaders are in a similar position to how super accountants used to be.

The problem with not understanding how some visionary leaders create innovation is that it results quickly in personal cult and celebrity status, which are not a guarantee for success. Moreover, celebrities make the market nervous. The well-known example was Steve Jobs' health and the direct influence that it had on the stock of Apple. Just as ERP did not replace super accountants, the Agile-Enterprise Innovation Planning (ÆIP) does not replace visionary leaders, but is intended to make the system more accountable. Applegate et al. (2003, p 232) introduce the Agile-Enterprise (Æ) as an Enterprise Architecture specifically designed to deal with innovation. In the first subsection, I consider the Æ architecture. In the second subsection, I discuss the relationship between IT governance and Æ.

7.2.1.1 Agile and the on-demand enterprise

Applegate et al. introduce the Æ architecture in the sixth edition of their book and provide more detail in the next edition (ibid. 2006 p. 58-71). It starts from a hybrid organization combining the benefits of a lean enterprise with an agile startup. Details are given in contrast to the classic hierarchical control (Figure 7.4). A separation is made between management processes and operational processes. In the classical hierarchical control, no feed-forward exists to adapt to changes. The new on demand control of Æ starts looking much more like a novelty regulation system.

Figure 7.4 The Æ described as an on demand enterprise controls (from Applegate 2006)

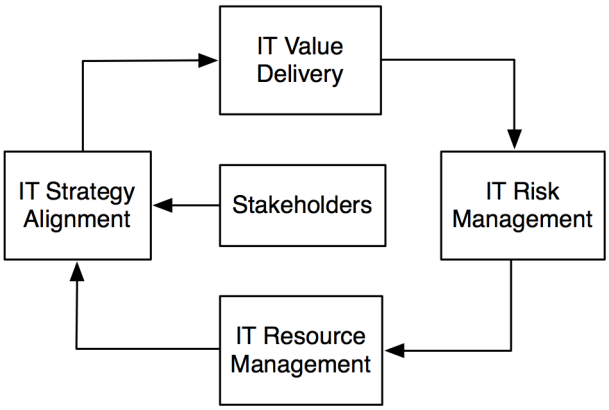


I will not go into the details of the guidelines created for each control element. They are guidelines and don't deal with the complexity of the meta-model. They are, however, created in such a way that they can better respond to a complex adaptive environment. Instead of guidelines, the agency and mediation of the ÆIP grid is required. Because all the regulations become complex, it is essential to have IT governance of the enterprise.

7.2.1.2 IT governance of Enterprises

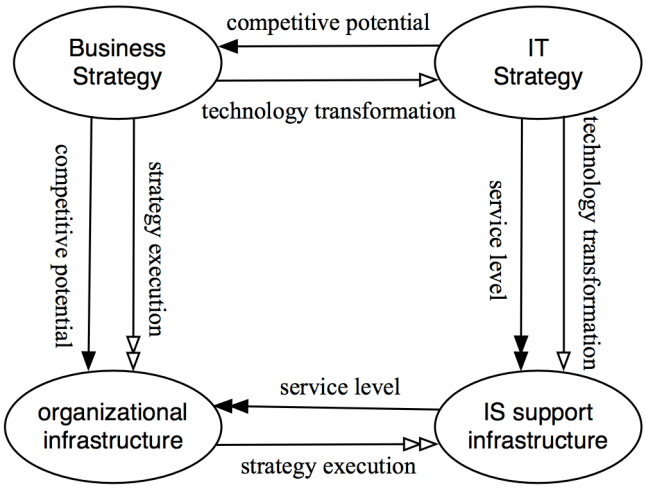
The challenge to create a useful tool with the ÆIP grid becomes an IT governance problem. IT governance (Figure 7.5) shows the systematic method of developing IT of an enterprise. As with any organization the values of the stakeholders are essential. They are required for an IT strategy alignment. The alignment creates an insight on the values that the IT delivers, which results in a risk management of the IT. The risk management affects the resource management, while the resources affect the IT strategy alignment. This creates a loop. The IT strategy alignment is the most essential part of the governance and needs some more explanation.

Figure 7.5 Simplified IT governance model



Henderson and Venkatraman (1993) identify four dominant IT alignment patterns in two categories (Figure 7.6). The categories determine how to move across the organizational structure. The first category is "business strategy as driver". It begins with business strategy and can go in two directions to build Information Systems (IS) support. One direction is "strategy execution" that uses the organizational infrastructure to design IS support. The other direction is "technology transformation", using "IT strategy" – exploring state-of-art technology – to integrate the external infrastructure to design the IT support. The second category is "IT strategy as enabler" and uses IT strategy to design the organizational infrastructure. Once again, two paths exist. Now the "competitive potential" of the business strategy can lead to the organizational infrastructure or "service level", going across IS support can reach it.

Figure 7.6 IT alignment model (from Henderson and Venkatraman 1993)



In all cases the IT alignment is reached by going from one pattern of the company to another, using a third pattern as leverage. Putting IT-alignment in practice is still a tricky management process and has led to a lot of criticism. Chan and Reich (2007) have made a survey to gather the negative remarks on IT alignment:

- Alignment research is mechanistic and fails to capture real life.
- Alignment is not possible if the business strategy is unknown or in process.
- Alignment is not desirable as an end in itself since the business must always change.

In my opinion, the problem with IT-alignment is the way that the context is first simplified to apply IT-alignment. If we keep complexity in place, the IT alignment can be very useful. In other words, we need to replace the classic IT alignment by a self-organizing alignment by collective intelligence. How IT alignment by collective intelligence becomes possible should become clearer with the late stage of the maturity phase. Like previous phases, the later part of one phase shows the agency of the next phase (prototypic concept -> prototype, niche product -> open product and product framework -> support framework). The transition is now from collective intelligence to an alternative artificial intelligence. It aligns with the Internet Innovation waves (Section 5.2.10). Wave 5.0 is about collective intelligence, while wave 6.0 is about technological singularity and artificial intelligence.

An estimate was given for when wave 5.0 and wave 6.0 would get into a growth phase and it is still decades away (2030-2040 for wave 5.0 and 2040-2050 for wave 6.0) Such estimates can, of course, be wrong depending on all kinds of influences in the social fabric that can free the development or accelerate the development. The essence is that both waves are currently in a prematurity phase and so research on it should give us more insight. The research on ÆIP is an attempt to gain insight. Notice that the ÆIP is part of the Agile-Enterprise, which is wave 4.0. In other words, not all parts of the ÆIP grid need to get fully understood to become practical with ÆIP. In fact, for the ÆIP proof-of-concept in this PhD many of the later conversion patterns stay abstract.

7.2.2 Cohering and the SECI model

Knowledge conversion from, e.g. from implicit to explicit knowledge, exist in different patterns, where the patterns can give meta-information of the knowledge conversion. The conversion patterns of the Cohering model are about how individuals learn during the transformation the phase transition. Nonaka (1991) studies uncertainty during knowledge creation and constructs the conversion patterns, which he called the SECI model. SECI is a reference to the four conversion patterns of the model:

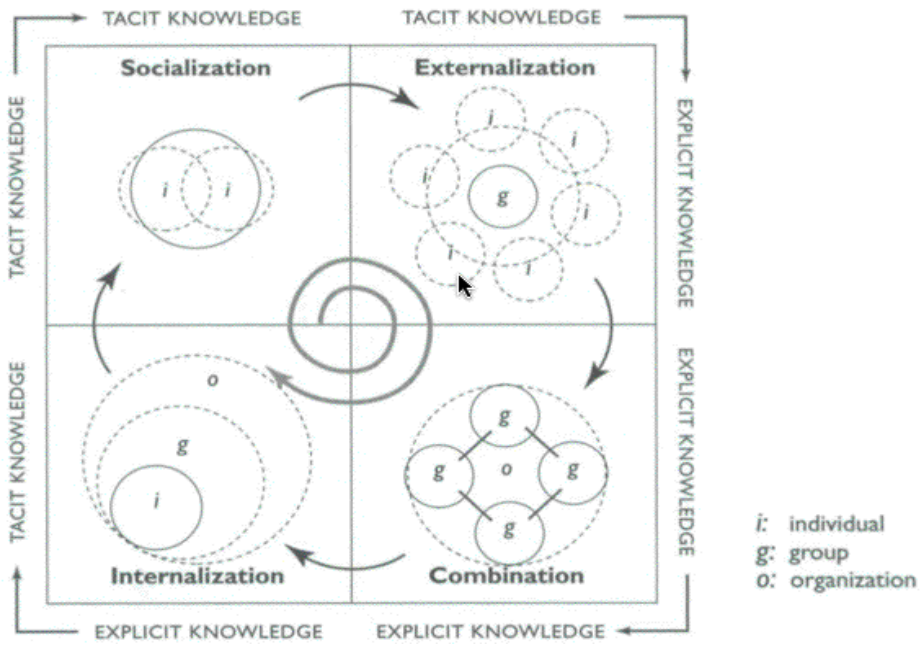
- **Socialization**: *from tacit to tacit*, which is transferring knowledge between people without actually being able to express the knowledge. It is like learning from a master-apprentice relation.
- **Externalization**: *from tacit to explicit*, which is learning by transforming experience into comprehensive forms that can be understood by others in the group. Still a lot of the knowledge will be tacit in the group.
- **Combination**: *from explicit to explicit*, which is learning by combining different pieces of explicit knowledge into a new concept. It is often reached by generalizing the knowledge between different groups.
- **Internalization**: *from explicit to implicit*, which is learning by absorbing the explicit knowledge. Nonaka actually calls it embodying knowledge (ibid).

The SECI model received criticism from Gourlay (2006, p 1421):

> We can more simply refer to learning by doing on the one hand, and to designing new tasks on the other.

Note how Gourlay recognized the mastering (learning by doing) and modeling (designing). With the novelty theory it can be argued that both Nonaka and Gourlay are simply addressing the same problem from different angles and both are sound. The SECI model's four conversion patterns can be elaborated as two effects: "shifting" knowledge (socialization and combination) and "transferring" knowledge (externalization and internalization). Nonaka (1998) created a drawing of the SECI model as a spiral construction (Figure 7.7), showing the two directions (shifting and transferring). That drawing also shows the scale going from individual, over groups to organizations. The images were reused in the ÆIP grid. Only a small adaptation is required to the SECI model to fit with the Cohering conversion patterns, which have five stages.

Figure 7.7 The four conversion patterns in the Nonaka's SECI model. (from Nonaka 1998)



At the front of the phase transition, I have added a conversion pattern called "personalization". However, I don't shift the pictures as well. I do make a different picture for combination, related to an inter-organizational knowledge exchange. This change remains consistent with the spirit of the SECI model. Some retrofitting of the conversion patterns is required:

- **Personalization:** *creation of tacit knowledge*, an individual interacting with the environment can do it or two individuals in a master-apprentice relation.
- **Socialization**: *creation of local knowledge*. The knowledge cannot be shared across groups, because some part of the knowledge is still implicit, while other parts have become explicit (see Section 5.1.1 on local knowledge).
- **Externalization**: *creation of abstract knowledge*, which is knowledge that can be shared across groups by the abstract level of the knowledge. Often the integration requires a transformation of the knowledge to the local context.
- **Combination**: *creation of standard knowledge*, which is the transformation of different abstract knowledge to one standard. Like the metric system using the "meter" as a unit of length, in contrast to using more local units like "elbow".
- **Internalization**: *creation of enriched environments*, which allow actions without a need to understand how the enriched environment transforms the actions to the intended result.

7.2.3 Eventuating and the CACO design

The SECI model is the detailed analysis of many cases by an authority on knowledge creation. With only some minor adjustments, it fits the ÆIP grid. For eventuating, I have cases to demonstrate the conversion pattern. It is only my analysis based on participation research (see Chapter 10). Additional research is needed to validate the conversion patterns. The participation research made clear some unexpected

effects. For example, it is interesting to see the tech communities experiencing fast growth in physical event organizations like meetings and conferences. The tech communities are often called virtual communities, but in practice this creates a wrong perception.

The need for face-to-face interaction is essential to build a community. The reason for the physical events is evident. It is a moment for the collective to feel and experience the community. Often the best technical projects show extensive social activities. Having this moment to meet informally allows: exploring new ideas, discussing difficult problems, dissolving tensions, recognizing similarities and differences, etc. In other words, it helps to establish a culture. Due to the culture of the tech communities, the conference organization has been transformed significantly. A small group organizes classic event organizations. The tech communities use the collective intelligence more. Let me call this new kind of event organization Complex Adaptive Conference Organization (CACO).

CACO has a clear process, starting with an initial day of informal gathering and a training event, followed by the three-day main conference and ending on the last day of actual implementation with "code sprints". The first and last day are created in such a way to use the time optimally, while many participants are still in transit. During the three day conference there is a main track and open tracks. The main track has keynotes and parallel tracks, which look like a classic conference model. The main track is organized well in advance of the conference. The open tracks are spaces for people to create unplanned workshops. Such workshops can even popup from interaction during the event.

The participation research I did for this PhD was related to an open source project called Drupal. For the Drupal project, there was a CACO each year in EU and the USA. The USA would grow steadily with an almost exponential growth. The EU 2006 conference in Brussels that I co-organized had 150 people, which was just enough to have a CACO. In 2011, participation of over 3000 people in the USA conference was attained. Participants are comfortable in the use of high-tech Internet applications and are able to participate in the enriched environment created by the organizers. The experience with CACO gives a glimpse on what is considered possible for Eventuating. Just as the SECI conversion patterns show how knowledge creation changes, we also need to see group dynamic change during the phase transition with CACO.

During the premature phase, the scale of group dynamics does not exist and the conversion pattern of eventuating will be a side effect of individual activities. In table 7.1, this side effect is shown as gray cells. During the incubation phase the group dynamics are self-organizing by coordination. Only from the growth phase on do we see control of conversion. Let me consider details for each of the conversion pattern about group dynamics.

7.2.3.1 Networking to find grounding

The first conversion pattern for the Eventuating model relates to informal learning by individuals. In the CACO, it was observed how the growth depended on the familiarity with CACO which can explain the (almost) exponential growth. Almost half of the participants had experienced the event in the previous year and knew the dynamics of CACO. The other half had to familiarize themselves with the process. This group underwent the personalization of CACO by informal interactions with the experienced half of the conference. The new people were used to the main track, but often not to the open track. In a way, the main track functions as an interface for people to personalize themselves with the whole CACO structure.

The concept "unconference" can elaborate on the conversion pattern "networking". It is the observation that informal contacts during coffee breaks of conferences create important relationships. Therefore, the idea arose to make a conference become one extensive coffee break and have no formal conference organization. The idea has led to open structured meetings, like open spaces, camps (e.g. barcamp, govcamp, bizcamp, etc.), code jams (codejam, govjam, bizjam etc.), etc. In the CACO structure, the open meetings are called open tracks that have specific structure that are discussed in next subsection. The open tracks are already more advanced than the core of the informal gathering.

Coffee breaks allow networking between participants. Some structure can maximize networking, like the guidelines of "open space technology" (Owen 2008). In the CACO, the open spaces are self-organized by Internet interfaces. The drawback is that the participants need to familiarize themselves with such an enriched environment and it takes them time to cultivate such a high-tech culture. In the classic conference, there is often a "sponsor lounge" created in such a way so as to stimulate networking between participants and sponsors. As a side activity, you can actually see other people creating informal interaction too. Some conference organizations don't stop with the actual conference, but also plan the evening social activities.

For the Eventuating model, the networking is a conversion pattern during the prematurity phase as a side effect of personalization. In the conferences, this personalization is oriented towards other participants and the culture of the community, including the structure of the conference. In Section 11.1.2.2, I consider workshops in a design school that shows how students personalize themselves with the materials that they are going to use. In the case of CACO, the structure allows a classic conference to become an interface to more complex adaptive self-organization. The activities are possible thanks to technology and methods stimulating distribution and self-organization. ÆIP experiments have explored technology and methods that stimulate the effect of networking for advanced cases of knowledge creation (see Section 10.3.5.3).

7.2.3.2 Birds of a Feather Flock Together

The second conversion pattern for the Eventuating model shows how interactions turn into coordination in the open tracks. The open tracks are called BoF, which is a reference to "Birds of a Feather (flock together)". The open tracks follow the un-conference structure, which is a distributed and self-organizing structure. The concept of un-conferences was first applied in the 1980s. Harrison and Dourish (1996) called the format Open Space Technology containing simple user guidelines on how to organize such open spaces. The event must exhibit:

1. A real issue of concern, i.e. something that is worth talking about.
2. A high level of complexity, such that no single person or small group fully understands or can solve the issue.
3. A high level of diversity, in terms of the skills and people required for a successful resolution.
4. Real or potential conflict, which implies that people genuinely care about the issue.
5. A high level of urgency, meaning that the time for decisions and action was "yesterday".

BoF sessions arose during conferences as informal meeting spaces for like-minded people (Macz 2002). During my participation research, I noticed how BoF rooms are a simple but powerful structure. During the six years of participating and organizing BoF sessions, I have observed a mixture of people, including those that know the format, and come because of the urgency of the issue, and those attracted to the format for the first time. For the second group, a kind of peer learning arises, which allows the novices to get used to the format. Some topics attract many novices, which results year after year in these peer learning activities, without really creating the coherence required for the group to get to coordination. In that case, frustration arises with experienced participants.

The flocking is different from the networking in the respect that some group formation is being established. During the well-performed BoFs, the participants shift from interaction to coordination. They reduce some of the complex problem to actionable parts, picked up by the proper personalities. The most fluent BoFs was with very experienced participants, often dealing with very technical topics. In that case, all of the participants would be developers with some specialties and break the problem down to those specialties which creates a fluent division of labor. In these events, the flocking shows how the bootstrapping process results in the division of labor.

Knowing the relevance of the flocking is what makes some experienced programmers want to go to the CACO to take the lead on some development that they are very concerned about, but cannot tackle solely by online activities. During the entire conference, considerable development is created in the coder room. Some of the developers only come to the event to be in that room. The coding is, however, considered to be part of the last conversion pattern.

7.2.3.3 Consolidating business ecosystem

The consolidating conversion pattern was only implicitly recognized in the Drupal case and other participation events have been stimulated to consider it as part of the CACO design. With the ÆIP grid, we are now focusing on the growth phase at the scale of organization, which is creating breakthrough innovations. For this stage in the phase transition, I have already considered two conversion patterns: the Establishing model creates leapfrogging and the Cohering model creates externalization. In the margin of the events, some activities have emerged that I consider to be the hidden order of the consolidating pattern. Let me give the clearest example to discuss the conversion pattern.

During the first day of the CACO in 2006, a discussion arose between Bart Van Herreweghe, who was Head of the Cabinet of the Prime Minister of Belgium, and Dries Buytaert, the founder of the Drupal project. The discussion was about the multilingual ability of Drupal and quickly became very technical. While most functions existed, there was incompatibility between the modules. More developers of the different modules got pulled in the discussion, clarifying the complexity of the problem. It was decided to hold a meeting four hours later to solve the problem. The meeting was posted online and everyone walked away. I was skeptical at that time about the method and am happy to acknowledge how wrong my preconception was. During the meeting, about twenty people attended and the meeting is still the most productive I have experienced so far.

Some of the business owners took charge of the meeting, showing their skills and commitment to the problem. Developers were mostly part of one or another organization and were used to the agile meeting structure. This event was, however, a cross-organizational issue. Since both business owners and developers were present, it allowed consolidation across the organizations. During the following days, the developers would go and create BoFs to deal with some of the technical problems and get more developers on board. The business owners took a different approach, which involved more networking which pulled more organization on board. Independent of what role the participant in that meeting had had (manager or developer), they became the bridge for consolidation between the other members of their organization. This created a self-organizing growth of the consortium that was tackling the problem. The consolidation event provided the required coordination to build the foundation to solve the complex problem. The effect demonstrates the guided self-organization and synergism between the business ecosystem and the development ecosystem.

The many steps of consolidating many different people with many different roles were essential to build a foundation. In this case, the CACO only was three days but it was enough to build the foundation. In a few days, the basic problem was tackled and it allowed coordination after the event to pick up the development. The integration of the solution was realized in the next release of the Drupal project a few months later. What normally is an impossibly complex problem that would take

an experienced high-tech organization a tremendous amount of resources and months to coordinate, took only a few days with the self-organization. This "consolidation" in CACO was lean in a way that large high-tech companies can only dream about. This type of event has become the prototypic concept for the Agile-Enterprise.

Some constraints have to be taken into account that allowed the event to take place. The Drupal project was in a particular state allowing the conversion pattern to surface. I have only seen it for the multi-lingual problem and further development (e.g. unit tests), would take a lot more effort by the founder and interested parties. It shows how guiding self-organization by the consolidating pattern was coincidental and not a structure of CACO. In later events, I have seen some pattern again, but instead of being open to all, as it was in 2006, they were more restricted. They took place as hidden meetings, behind the locked doors of the conference and only allowed a happy few to participate. While I can understand the reason for the closed meetings, it is not an optimal solution and I did not observe the same level of efficiency as surfaced with the multilingual case.

With flocking some networking exists, but it becomes more, changing the interaction to coordination and creating a division of labor between the participants. Consolidating is more than flocking. The consolidating is for problems that are too large for pure self-organization and require the structures for guided self-organization. During the multilingual case, all businesses were startups. They all were small and accepted the need for consolidation. The event was an inter-organizational happening, but the startups had a structure more like groups and less like the mature organizations. Therefore, it was more of an inter-group happening. This also explains part of the problem later on, because the organizations would include fewer startups and would have more difficulties adapting, while having more resources to try and tackle the problem internally.

Consider that this phase transition is about breakthrough innovation and Section 6.2.3 elaborates how breakthrough innovation aligns with the activities of venture capital. To make sure that the consolidation is not coincidental would require more organizational structure that makes more use of a venture capital influence. Future research on Agile-Enterprise needs to examine how this is possible.

7.2.3.4 The absence of framing CACO

The suggested conversion pattern for the maturity phase has not manifested, but by what is going wrong with the mature conference organization suggests us to create the conversion pattern. Just as consolidating is intentionally stimulating the flocking, so is framing intentionally creating consolidation. Let me articulate what was going wrong in the mature conference. The Drupal conference in Chicago 2011 was built with several years of experience. One of the interesting things about that conference is the huge open space area. A whole floor of the Hilton Hotel containing many small and medium-size meeting rooms was utilized with 24 dedicated to BoF rooms. The

main problem resurfacing in many BoFs was about the learning curve that had become very steep. As a result, only gifted developers were still able to participate in the core development of the project.

While some of the best developers came into the community thanks to a program called Google Summer of Code (SoC), the numbers of young developers going through the program were much smaller than the growth of the community. While the community had with SoC a good practice, it failed to cultivate the structure. It is my understanding that organizational force was directed differently so that the good practice could not change the conference organization. Most of the businesses that were involved considered the training of Java programmers as the best way forward. I have tried to warn against the difference between training Java developers versus educating youngsters by programs like SoC (Kiemen 2011). Several companies gain revenue by training and demonstrate a resistance to further develop the CACO structure.

In an attempt to stimulate the development, I organized an open space for the first day of the 2012 conference in London. The first day was reserved for training, which generated criticism that some of the potential leaders would be giving training that day and therefore could not come to the Bo However, it was my attempt to protect the self-organization from too strong of an interest by the training companies. The open space was eventually a success with forty participants, but the dynamics of intentional consolidation during the successive days were not perceived. During the main conference, I have tried to use the momentum of the open space to coordinate BoFs. Instead of building more momentum, the attention of participants was dispersed.

Several problems can be identified as to why a pressing issue does not gain the required momentum. First, 20 out of 150 participants in a large conference is still 13.3%, while 40 out of 1751 participants is only 2.2%. The percentage is relevant because it affects the dispersion. In the past conferences, activities to stimulate education were often undertaken without much success. This made many of the relevant people hesitant to start yet another activity not recognizing that the activity was trying to overcome the deadlock.

The size and intensity of a conference with thousands of people creates the need for a protective space in the conference. Such a structure did not exist in general, but for the core development such a space was recognized and called the "core conversation track". The core conversation track was a structure between a BoF and a normal track. The hybrid structure of the track is the key to the missing conversion pattern "framing" for CACO. Framing refers to the need to intentionally organize the consolidating by specific methodological stages of the event during each day of the conference. Details of how framing works requires the details of the participation research. An experiment for framing is suggested in Section 10.3.3.

7.2.3.5 Code-sprints creating autonomization.

The previous conversion pattern has not been demonstrated adequately. As a result, it may appear strange that the last conversion pattern has a clear structure and is named: code sprints. The reason is simple because the tech communities are all about using technology to solve problems, which is what the last phase of enrichment is about. Where framing is to the scale of the whole community, the scale in the last phase is global. In tech communities and particularly in Free and Open Source Software (FOSS) communities, the global participation is part of their inner culture of distributed development. The distributed development is very similar in all the FOSS projects, so code sprints are a common concept. A code sprint is a moment when participants just collaboratively develop code. It is at first a strange view, seeing hundreds of people sitting quietly around tables all with their laptops. It looks almost like a collective study space that is seen in universities.

During the last day of CACO, one big room is still open for the code sprint. Tables are tagged with a topic like "documentation sprint", "module X sprint", "project Y", etc. People collaboratively work on the issue of the table. Leads around the theme guide the novices to the format so they can become productive. The structure creates a foundation that is essential to continue working online after the event. This is a moment when problems have been discussed and choices have been made, but now the plan needs to be put into motion. Sometimes the work results in unforeseen problems that can still get tackled because experts could be working in the same room. The actual development creates the required foundation to continue without the informal interaction.

The code sprint is the best moment to observe innovation of the distributed development. In some cases, it may be recognized that the problem couldn't be solved during the code sprint. In that case, they may decide not to work on the problem, but to find ways to ensure collaboration about the problem once they get back home. Suggestions are created on how to continue working on the problem in a distributed way by creating the proper guidelines and rules. The time limit now creates the proper pressure to tackle the problem pragmatically.

7.2.4 **Strategizing and the leverage of values**

The strategizing conversion patterns are hypothetical, retrieved from the study of the previous chapters on SMS. The conversion patterns are very premature and future research should provide a better understanding. Strategizing is about protecting values by organizations, which creates leverage for the values. Organizations gain regulation with the growth phase, so that the first two stages of the phase transition are side effects of the other novelty models. The conversion patterns of the Strategizing model show leverage of values. During the prematurity phase, this relates to the viral force, as examined with the open innovation case (Section 6.2.1.1). For dynamic groups, the leverage becomes retrofitting, allowing

people to redefine knowledge and roles in relation to the group that they become involved in.

Once organizations gain regulation, the leverage of values allows mobilization. The case of consolidating in the previous section should give some insight of how that mobilization happens in a self-organizing way. The organizations were not in full control of the mobilization, but showed coordination and co-development. It is only during the maturity phase, that the conversion pattern of the Strategizing model shows control. The way that this is control is expected to manifest relates to managerial governance. It is different from the IT governance in Section 7.2.1.2 that had a clearer focus on the technological support for the organization. The IT governance is somewhat related to the both the conversion pattern for the maturity phase and for the enrichment phase. For the enrichment phase, an even stronger focus on technology is expected, which led to naming the conversion pattern "technologizing". It needs to be mentioned that the pattern technologizing is still abstract and requires more research.

7.2.5 Local and global Establishing

For the Establishing model, the first three conversion patterns are implicit and have been elaborated in Section 7.1.3. Very little can be said about the two last conversion patterns, since their nature is relatively unexplored for complex adaptive system research. The model only becomes explicit in the maturity phase, when inter-organizational constructs build institutions to establish large-scale innovations. The cases of STS show how important institutionalizing is to establish innovation. It seems that institutions are mostly efficient on a local level. Of course, a global involvement can be reached, but the innovation institute is often a local campus. Some examples are the CERN institute on nuclear particle acceleration, ITER institute, studying the possibility of commercial use of nuclear fusion. Global institutions exist for political purposes and less for innovation purposes. Such global institutes are clumsy and can only react slowly. With an increase in innovation, it is expected that the limitation of global institutions would stimulate more collective intelligence approaches. The complex system dynamics of the globalization of innovation are not well understood and more research is required. Only an abstract conversion pattern can be given and it seems most appropriate to call it "globalization".

7.3 Research question II.3

> *How can we apply the novelty model as a foundation for the Agile-Enterprise Innovation Planning?*

The first section showed how a last novelty model is the final piece of the meta-model. In previous chapters, two relatively separate discussions were held, one about the specific novelty model and one about the phase transition. It required a meso-scale novelty model to merge the two sections. The Establishing model has

principles as anchors and the other novelty models as the medium, making this model the most virtual of all. While the virtuality makes the model tricky, it also allows closure. To elaborate the other novelty models as mediums, three conversion patterns get introduced. The three conversion patterns happen as a side effect of the other models. For the ÆIP grid in the second section, the conversion patterns become the focus.

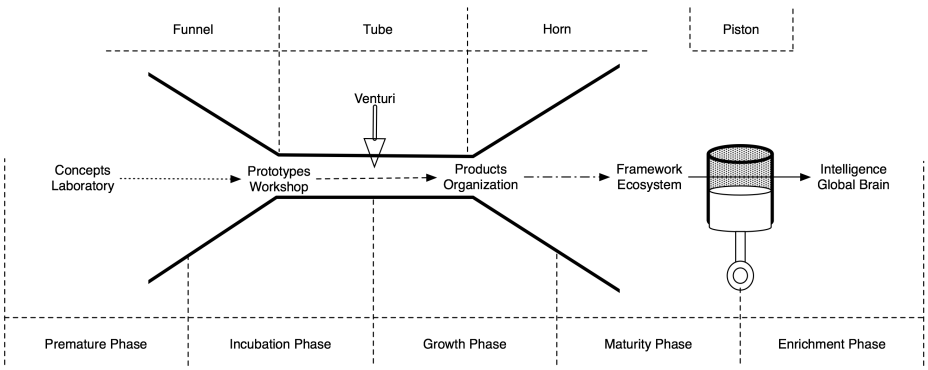
The side effect of the conversion patterns shows an interesting pattern. In each phase, another novelty model wakes up, meaning it is no longer the side effect of the other models. The waking up happens first by coordination, while the next conversion pattern happens in a more controlled manner. The effect shows a staircase structure for the novelty models. The most important is the knowledge creation that already begins coordination during the prematurity phase. In this case, an authority in the domain of knowledge creation creates most of the conversion patterns. For the Eventuating model, actual events can defend the reason for a particular conversion pattern. However, while moving up the phase transition and up the novelty models the conversion pattern becomes more theoretical and more abstract. It shows that the understanding of the ÆIP grid is research in action and for the later conversion patterns many more experiments are required. The challenge of validating brings us to the third and last part of this PhD.

8 Carbureted Action Research

8.1 Prescription to reach ÆIP proof-of-concept

The previous chapter has combined the different novelty models and developed the ÆIP grid. In this chapter, the ÆIP architecture is examined. The ÆIP grid demonstrates how conversion patterns exist for each model during each stage in the phase transition. The conversion patterns are descriptive and create a theoretical understanding. By contrast, the ÆIP architecture is prescriptive and creates a method for development. The Action Design Research (ADR) was described because it implicitly contains a novelty model (Section 7.1.1). In fact, ADR is a method. However the ADR method is more descriptive then it is prescriptive. In this chapter, an alternative method is suggested called the Carbureted Action Research (CAR). The name of the method relates to how the methodological processes envelop around the artificial evolution of the phase transition (Figure 8.1). A carburetor is a tool that speeds up the air by a funnel to optimally mix the fuel with the air. The mixture is then used in the piston for combustion. In the CAR method the first three transitions show a scheme comparable to a carburetor. The last transition is presented as a piston.

Figure 8.1 The schematic description of the Carbureted Action Research (CAR).



The CAR method works on the transitions from one stage of the phase transition to another. During the transition novelty becomes robust, starting from an abstract origin. The emerging novelty is visualized in Figure 8.1 by an arrow that solidifies with each transition. Each transition is a CAR stage: the funnel, the venturi (tube), the horn and the ÆIP architecture (piston). The funnel, venturi and horn form the carburetor and are metaphorically useful for the details of the CAR method.

In a carburetor, the funnel creates acceleration of the airflow and provides an optimal condition for the mixture with the fuel (the acceleration lowers the pressure). For the CAR funnel, the acceleration relates to development and the

optimal condition for the mixture with investors. In a carburetor tube, a venturi injects the fuel. The CAR venturi is an injection of resources (by venture capital) to transform an invention (by groups) into an innovation (by organizations). The effect of the slowdown, in the horn of a carburetor, increases the quantity of the mixture. Increasing the quantity of the mixture is also what the CAR horn is about, by the transition from product to framework that scales the innovation to a critical mass.

The metaphor of a piston is trickier. The way the metaphor holds is by recognizing how a piston compresses the mixture to free the energy for motion. The piston is misleading because the CAR stage is not receiving the mixture, but it is institutionalizing the carbureted process. The piston metaphor is only used here for the introduction. As of now, this last CAR stage is described as the ÆIP architecture.

The ADR method emphasized a need for simultaneous processes, but in doing so the original AR method becomes unrecognizable. The CAR method provides an alternative. Two methodological processes have a clear relation to AR method and they are working simultaneously, with a specific relationship during the different stages: they converge in the CAR funnel, are parallel in the CAR venturi and diverge in the CAR horn.

In the CAR method, three dynamics exist. While one of the CAR dynamics is dominant during one of the CAR stages, the other dynamics can still be recognized. The first dynamic is a *bootstrapping cascade*. It is dominant with the convergence and divergence of the two methodological processes. The second dynamic is *spreading activation.* It becomes dominant during the parallel processing in the CAR venturi stage. The third dynamic, *circulating references,* is dominant in the ÆIP architecture. Circulating references were introduced in Section 5.1.2 as a natural dynamic in the evolution of the social fabric. In the ÆIP architecture, the circulating references become part of an artificial evolution.

The descriptive nature of the CAR method requires us to elaborate the methodological processes. In the first subsections, the relation between CAR processes and AR phases is examined. The second subsection elaborates the relationship between the CAR method and ÆIP grid. The ADR is the origin of the Establishing model, but the Establishing model is only one of the four novelty models in the ÆIP grid. The CAR method has a relationship to the whole ÆIP grid. In a third subsection, more information is given about the relation with the CAR method and how the validation is reached.

8.1.1 CAR processes and AR phases

The two CAR processes are penetration and training. Penetration is the ability to get into unfamiliar workspaces, while training is a way to change the current knowledge to the knowledge required to act in the workspace. Penetration and training can be applied to different types of agents, including individuals, groups, organizations or inter-organizational. For example, the scientist Pasteur penetrates the world of yeast with his research; a group of students working together for a project penetrate

the content of a course; a business with their resources can penetrate markets; the international space programs allow humanity (the social fabric) to penetrate outer space.

For both penetration and training, a relation can be made to modeling and mastering. The modeling of penetration is the emerging of insights and the master of penetration is as the ability to operate in the unfamiliar workspace. Penetration is *"the effect of"* mastering and modeling. By contrast, training is *"the precondition of"* mastering and modeling. The modeling of training is the stage of setting a challenge. The mastering of training is the learning required to gain new skills.

The penetration and training, by modeling and mastering, can be related to the phases of Action Research (AR) (planning, action and reflection). A simple mapping exists for modeling: the modeling of training is the AR planning phase and the modeling of penetration is the AR reflection phase. The mastering is a refinement of the AR action phase; split into the mastering of penetration and the mastering of training. Penetration and training are happening simultaneously and working on sub-targets. While each sub-target follows the AR phases, different sub-targets can be worked on simultaneously allowing the different AR phases to happen at the same time, which was essential for the ADR method.

A distance exists between penetration and training. The distance relates to the virtuality of the novelty and the gap that this creates. A challenge may be very different from the skills that an individual has. This creates the first gap and results in an abstract concept so the novelty is first virtual. By penetration and training, the convergence removes the abstraction and realizes the embodiment of the novelty by the prototype. During the CAR venturi, the virtuality of the novelty does not change. The penetration and training are now developing the organization, making the novelty more autonomous. Eventually the product transforms to a framework by having a variety of applications. The penetration now follows the demand of users, while the organization needs to cope with the diversity and train the required skills for that demand. By the divergence this creates a gap and the support framework fills that gap. The framework is much more virtual than the product, showing again how the distance relates to the degree of virtuality.

8.1.2 **CAR dynamics and ÆIP grid**

The relationship between CAR and the ÆIP grid becomes complicated, because an overlap exists in the two directions of the ÆIP grid. Several of the conversion patterns in the ÆIP grid are implicitly executed as side effects of other novelty models, creating the vertical overlap in the ÆIP grid. The CAR stages are about the transition of the phase, while the conversion patterns are about the stage of a phase. In other words, the CAR stages overlap with the stages of the phase transition, creating the horizontal overlap in the ÆIP grid.

By using a color pallet we can illustrate the overlaps of the CAR dynamics in the ÆIP grid (Figure 8.2). In some conversion patterns, two of the CAR dynamics are

working, resulting in the secondary colors. In exceptional cases, all three dynamics overlap in one conversion pattern, making the cell become white. The implicit conversion patterns (in particular) show such triple overlaps with the CAR dynamics, because they are side effects of other activities.

Figure 8.2 Overlap of the CAR dynamics and the conversion patterns using the RGB color panel: blue = bootstrapping cascade, green = spreading activation and red = circulating references. The second order colors cyan, yellow and magenta are mixtures of two CAR dynamics, while white is an overlap of all three dynamics.

	CAR funnel		CAR venturi	CAR horn	ÆIP architecture
Establishing	Acting	Bootstrapping	Leapfrogging	Institutionalizing	Globalizing
Strategizing	Viral	Retrofitting	Mobilizing	Governing	Technologizing
Eventuating	Networking	Flocking	Consolidating	Framing	Sprinting
Cohering	Personalization	Socialization	Externalization	Combination	Internalization
	prematurity phase	incubation phase	growth phase	maturity phase	enrichment phase

The bootstrapping cascade relates for the most part to the Coherence model. It is about complex adaptive knowledge creation. Some parts of the Coherence model also require other CAR dynamics, like creating insight (Personalization), which overlaps with the spreading activation and the standardization (Combination and Internalization), which overlaps with the circulating references. The bootstrapping cascade is all about the natural occurrence of serendipity that can stimulate the exaptation process. Indeed, this was examined in the simulation (Section 2.1).

The other novelty model shows more overlap with all of the CAR dynamics. An alternative view is needed to recognize where a CAR dynamic is dominant. The spreading activation is about transforming interactions to coordination. In the ÆIP grid, the conversion patterns dealing with coordination form a staircase-like structure (Personalizing, Flocking, Mobilizing and Institutionalizing). Most of those conversion patterns have more than one CAR dynamic working on it, with the exception of the conversion pattern Mobilizing. Mobilization is the essence of the spreading activation and all neighboring conversion patterns show a strong influence of the CAR dynamic.

The last CAR dynamic, which are the circulating references, is mostly recognized in the ÆIP architecture stage. With the ÆIP architecture, the spreading activation becomes managed. The spreading activation is also seen in the CAR horn. The CAR horn is a hybrid of all CAR dynamics. Notice how the spreading activation is not only dominant in the CAR venturi, but also stays dominant in the CAR horn. In the CAR funnel, most conversion patterns are white, indicating a mixture of all CAR dynamics. However, in those conversion patterns the dynamics are a natural side effect and so can be neglected. In other words, only the bootstrapping cascade is dominant in the CAR funnel. The details repeat the earlier made statement of when a CAR dynamic is dominant. Only some nuance is needed for the CAR horn.

8.1.3 Using the CAR method for validation

A different type of validation method takes on each CAR dynamic. The increase in scale of the phase transition makes it impossible to take on all dynamics in the same way, because the resources and time for a PhD are too limited. The bootstrapping cascade is investigated by controlled experiments. This is considered the strongest of all validations and the method closely related to my academic education.

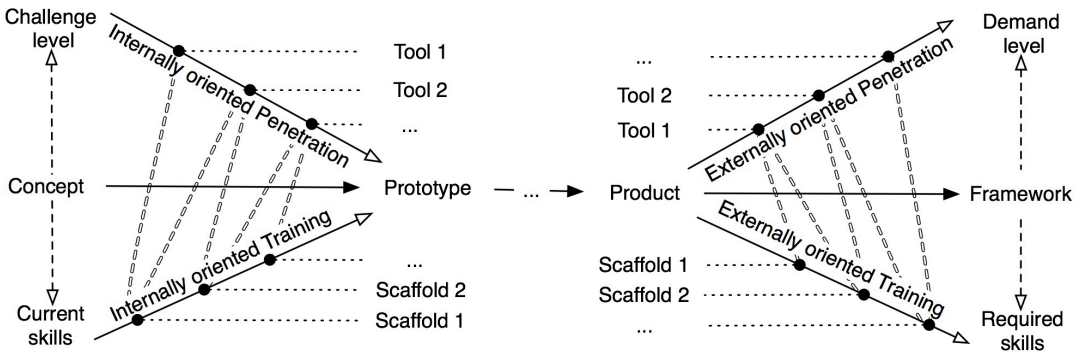
Spreading activation is about a self-organizing ecosystem of ventures and participation research around an Internet innovation project that can investigate the dynamics of the spreading activation. While the validation is thus not controlled, it at least is observed. The CAR venturi creates a constraint as to what Internet innovation project can be used for participation research. Once the proper project is recognized, the participation research is to identify the changes of the phase transition by the ecosystem of the project. After a transition to another phase, it becomes possible to describe the dynamics of the spreading activation by interviewing the developers that have made the transition possible.

For the ÆIP architecture, no event exists and so no observation is possible. Creating an architectural model (maquette) allows the validation of the ÆIP architecture. Architectural models are often used to create some insight of how a construction would look like without actually building the whole construction. So architectural models create a level of detail without the need for the construction resources. The implementation of the ÆIP architecture produces an enterprise capable of spinning off innovation ecosystems. The architectural models give details on how such an institute can operate. The following sections elaborate details of the validation methods. Without an actual application, some of the details may be hard to grasp. The following chapters present the actual application, so some patience is asked for.

8.2 The bootstrapping cascade

In both the CAR funnel and CAR horn, the bootstrapping cascade is dominant. For the funnel, the bootstrapping cascade is internal to make an idea become real. It creates convergence. For the horn, the bootstrapping cascade is external because of the transformation a product makes to a framework, creating divergence. Sub-targets by artifacts can show how the penetration and learning stands in a bootstrapping relationship (Figure 8.3).

Figure 8.3 Left the CAR funnel, the venturi is hidden and right the CAR horn.



For penetration, the artifacts are tools. For example, without a microscope it would be impossible for Pasteur to penetrate the cellular level to research yeast. Sub-targets for training happen by scaffolds to allow the effective learning of skills. Because the scaffolds are about knowledge creation these sub-targets relate to the instructional scaffolds described in Section 2.1.3. Let me consider an example of the bootstrapping. By using the microscope, Pasteur creates a drawing of what is seen through the microscope. Such a drawing becomes a scaffold that is used to compare different states of the cellular level, model more abstract concepts to describe the cellular level etc.

For the CAR funnel, the fabrication of tools and scaffolds allows more regulation over the emerging prototype. Therefore, more tools and scaffolds create the convergence between the current skills and the challenge. For the CAR horn, the product gets applied in more ways, making the varieties of the product the tools of the penetration path, where each new tool allows the penetration of a different market. Managing each new tool requires the training of skills for an organization. In the organization, this becomes different scaffolds, supporting the operation of the organization. Therefore, the variety of the product creates divergence, which is a gap between demand and skills. The divergence makes the support by a framework more pressing.

The convergence increases the speed of bootstrapping between penetration and training. The increased speed can explain why the topic has been so fascinating to researchers across diverse domains. The opposite effect exists with the divergence, where the bootstrapping slows down, creating a soft entrance. Very often frameworks are used and built without getting much attention. Only with the recent development around smart-phone application frameworks do we see an organizational interest as well as a scientific interest (Ballon et al. 2007).

To validate the bootstrapping cascade by experiments requires a specific environment. A strong validation would have been with experiments within a R&D facility (companies or universities). Such labs have many complications and the ability to perform controlled experiments would be too slow for a PhD research. The risk the organization would be taking is also too large because we had to validate the method first. Consequently, both the validation method, as well as what is being validated, needs to be verified. This is only possible by creating several iterations. In

our experiments, the first iterations are by the AR method and with later iterations the method is also improved.

Instead of going for a strong validation, we have applied experiments for project-oriented education. The project-oriented education is a more fitting environment for two reasons. First, the level of scale makes it easier to work with individuals than with organizations. Second, the teacher has the insights, while the students need to learn them. It puts the teacher in a meta-position in respect to the knowledge creation. The meta-position allows the proper investigation of the CAR horn, which is about more than only the bootstrapping cascade.

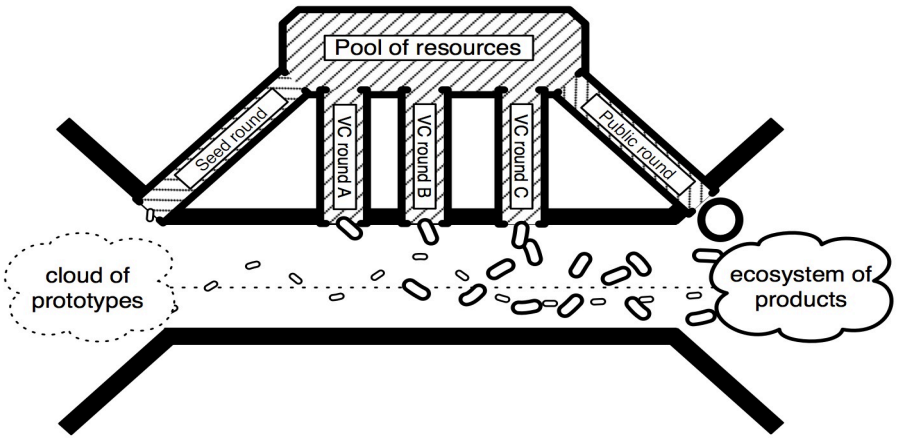
Developing actual technological innovation requires maturity of the students. All experiments where done with master level students or higher (see Chapter 9). Such students have a level of expertise and autonomy that allows experiments on technological innovation. Two experiments were performed, one investigating the CAR funnel and one investigating the CAR horn. In case of the CAR funnel, the prototypes are related to the projects of students, so students become the developers. In the case of the CAR horn, the framework is the support structure of an experimental teaching platform, which makes students the users of the platform and the teacher becomes the developer. The meta-position of the teacher also allows an investigation of spreading activation and circulating references during the platform creation.

8.3 Venturing by emerging ecosystems

The spreading activation is about creating a mixture between investment and developers. The investment comes from Venture Capital (VC). Different stages of VC investment exist: seed, VC rounds, mezzanine and Initial Public Offering (IPO). The mezzanine can be dismissed as an exceptional stage that is rarely used. It has consequences for financing, but not for our investigation. Seed capital comes from personal investment, friends, family, angel investment or any philanthropic interest in the development. Seed capital is considered part of the incubation phase. The motivation during VC rounds is more complex. They change by the alliances that are forged, markets that can be penetrated, trends that change, etc. The VC rounds are the focus of the CAR venturi.

The IPO is like the seed capital out of the venturi scope. The IPO has external motivations and is part of the late growth phase, where the stock exchange is a support framework. The IPO is to sell the stock of a company to the public via the stock exchange. Therefore, the stock exchange provides an interface for the public, which makes the motivation external. The IPO is a significantly larger investment than the VC rounds, which are again significantly larger than the seed investment. In Figure 8.4, the investment is illustrated as bubbles, where the size of the bubble relates to the size of investment.

Figure 8.4: The multiple injections of capital projected during venturing transform a fussy cloud of prototypes to a base for an ecosystem with spinoffs.



An important difference exists between current VC practices and the needs for the CAR venturi. Venturing practices have portfolios (bundle of spinoffs), while the CAR method is about venturing ecosystems. This is illustrated in Figure 8.4 by the cloud of prototypes at the front of the venturi that is transformed into an ecosystem of products. In practice, these ecosystems are created by many different VC organizations. The risk management by VC is to create diversity by investing in different emerging markets. Trying to spinoff ecosystems is thus in conflict with the risk management strategy.

In the CAR venturi, the penetration and training are parallel. They relate to the development of the organization around an invention. FOSS projects are good candidates for participation research, but a specific situation is needed. The spreading activation is about complex venturing so the developers are entrepreneurs, creating an emerging business ecosystem around the existing development ecosystem. By the participation research, it became clear that this business ecosystem has emerged by exaptation. Let me elaborate the details in a separate subsection.

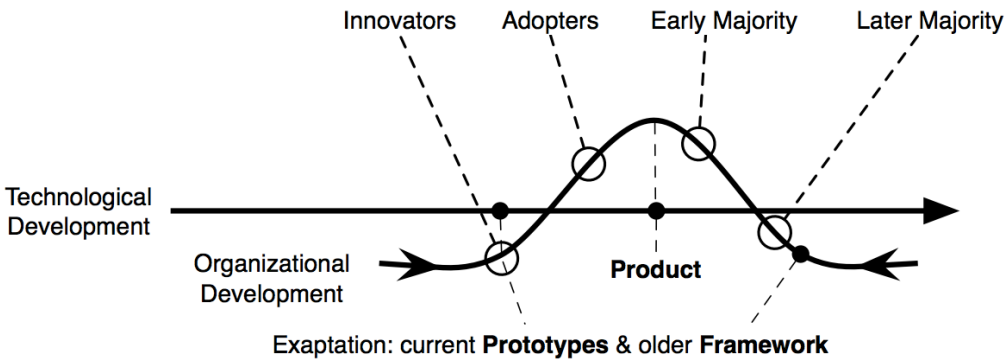
8.3.1 The standing wave of ecosystem exaptation

Ecosystem exaptation occurs when entrepreneurs use the development ecosystems to bootstrap a business ecosystem, thus using the original ecosystem for a different purpose than the one it was adapted for.

difficult to understand because of the co-development between business ecosystems and development ecosystems. The effect is that the ecosystem exaptation does not have five phases, but only deploys during the three central phases where all the business agencies get bootstrapped. During the technology premature phase, the business ecosystem does not yet exist, but, of course, the development ecosystem exists where the networking for the business ecosystem can start.

The full richness of ecosystem exaptation is better described as an emerging wave. To visualize this wave, two figures that were used earlier are combined. In the software simulation, Figure 2.3 describes the serendipitous spillover effect of an action as a hidden wave. The wave on the level of an ecosystem is the successive groups as described in Figure 5.4. The two figures are combined in Figure 8.5. The black dots show the agency of a phase i.e. it shows what guides the emergence. The agency moves from prototype over product to framework, which relate to the central three stages of the phase transition. The ecosystem exaptation is reached by the exaptation of (current) prototypes and the (older) framework. The framework being used relates to the earlier created enrichment for the development. It is visualized in Figure 8.5 by having the framework below the current development arrow. The white dots in Figure 8.5 present the different successive groups and follow the curves of the wave.

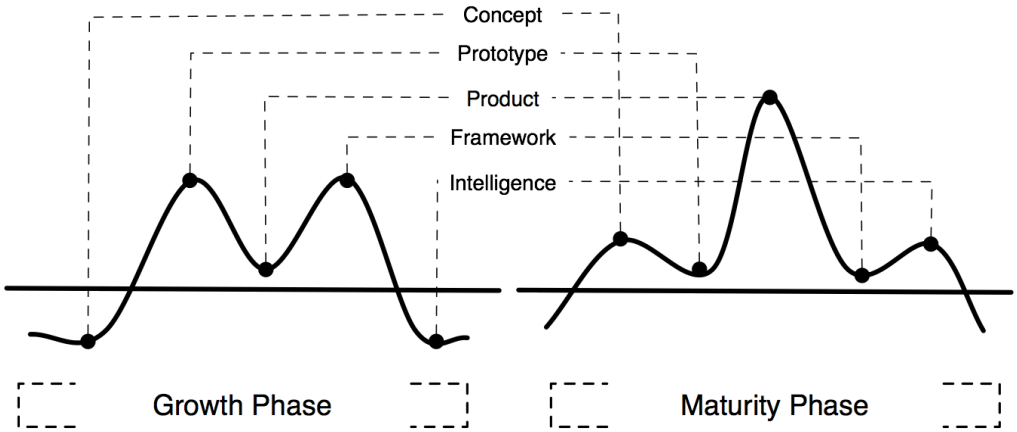
Figure 8.5 Incubation phase of bootstrapping an ecosystem shows the serendipitous spillover effect emerging as a wave.



The successive groups show an interesting relationship to the technology development. The innovators can be recognized when the technology is still a prototype. They are the pioneers of the business ecosystems. The adopters join the business ecosystem even before a clear technological product is realized. The majority are recognized only after the technological product is established.

During the incubation phase, the wave is emerging for the first time. It is a oscillating wave fixed between the prototypes and the framework. The same effect of two forces pushing up the wave is recognized in the next stages of the phase transition (figure 8.6). Four forces now get recognized: two forces from the product pushing in both directions and two new exaptations. The effect makes both the business prototypes and the business frameworks get bootstrapped during the growth phase. For the maturity phase, a spreading in two directions is seen again, creating an exaptation that creates the business concepts, the business intelligence and lifts up the business product. The effect looks like an oscillation standing wave.

Figure 8.6 Next phase transitions arise as an oscillation of the spillover wave.



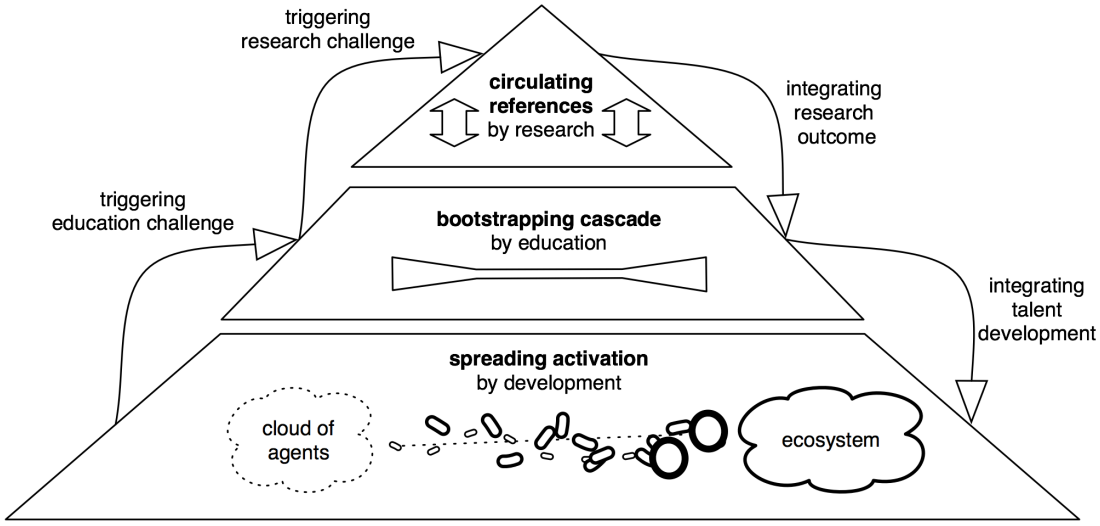
Just like the bootstrapping cascade, the method for the spreading activation also has to get recognized first. The way this works with the participation research is to first have a more abstract description applied to the selection process. For example, it was not clear at the beginning of the PhD which FOSS project was preferred. Instead, we looked for dynamics known from evolutionary studies. A project was selected where the force of both the business ecosystem and the development ecosystem showed a balance. It was expected that such a balance would create a state far from equilibrium and would allow us to observe complex adaptive self-organization around innovation.

In addition to the selection of the project, the activities during the participation research also needed to be better understood. At first, simple participation would allow us to recognize the ecosystem exaptation. Once this was recognized, more directed actions were taken, such as interviewing entrepreneurs, who were active during the incubation phase. The interviews provided details about how the spreading activation in the emerging business ecosystem was deployed. Both the incubation phase and the growth phase have been observed and by interviews the validation became possible. The maturity phase is my own projection of how the ecosystem exaptation is expected to continue, but this part of the method still needs to be verified in future research.

8.4 Institutionalizing the ÆIP architecture

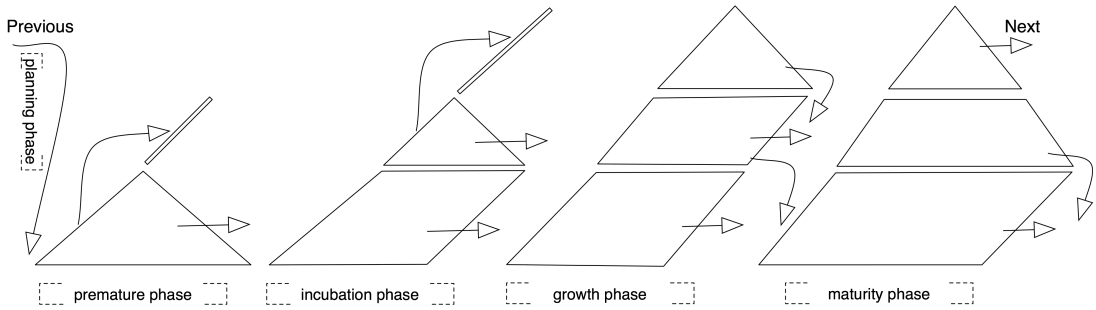
The ÆIP architecture is crucial for spinning off innovation ecosystems. In the ÆIP architecture, the bootstrapping cascade and the spreading activation create a flow for an artificial production of circulating references. The ÆIP architecture is visualized as a pyramid consisting of three layers (Figure 8.7). The base layer is the actual development of the ecosystem where the spreading activation is most dominant. To make a strong ecosystem requires talent development, which is the central layer. The talent development is by project-oriented education with the dynamic of the bootstrapping cascade. The top layer is created by circulating references to the scientific insight of the emerging ecosystem that is used to guide the spinoff of the ecosystem.

Figure 8.7 The pyramidal visualization of the ÆIP architecture consists of three layers



The ÆIP architecture develops through a process of six phases, relating to the five stages of the phase transition. One extra phase is required for planning. Figure 8.8 shows all but the last phases. The last phase is Figure 8.7. The three layers each develop initially by an exaptation process triggered from a lower layer. The base layer comes from previous spinoffs. The feedback of the initial test of each layer then creates an adaption process that develops the required contribution of that layer. The research layer is the last to get involved. This is not to say that the research is less important. The research only gets involved during the growth phase, but it is managing all phases.

Figure 8.8 The schematic steps prior to Figure 9.4, each step is one semester



After a planning phase, the development undergoes an artificial evolution of the phase transition. During the premature phase, the partners meet and interact with each other. It is a penetration test at the level of the ecosystem to better grasp the challenges. From this penetration test, a more adaptive development is expected. The penetration test also provides insight for the required talent development and triggers the central layer to begin its adaptive development in the incubation phase. The talent development is first separated from the ecosystem development. Only

when the ecosystem is getting into a growth phase does the talent become integrated, which is a process that continues during the maturity phase.

The talent development allows for a sprint, as the students can take on prototype development for a not yet fully matured ecosystem. The prototypes of the students emerge in the incubation phase and trigger the research challenges that get taken on during the growth phase. During the maturity phase, the focus is again on the development ecosystem, which is getting ready to spinoff.

After an initial investigation, it became clear that the ÆIP architecture could be considered a next generation Technology Transfer Office (TTO) of a university. Debackere (2010) gives an overview of TTO generations. The first generation was the university's R&D administration for contract research and IP management. The second generation TTO are the so called incubation centers for PhD spinoffs. They can be recognized in almost all universities today. Debackere suggested that the ÆIP architecture can become a next generation TTO (personal communication). Moving from an administrative organ to an incubation center shows how the institutional structure of the TTO grows and how more of the university functions get involved.

Chapter 11 takes on the challenge of building an architectural model (maquette) of an institute using the ÆIP architecture. The growth in institutional structure of the TTO is expected to fully integrate all university functions. In other words, the third generation TTO is a new generation university that we like to call Interversity. A university was about "the whole" (from the Latin "universitas"), indicating that universities were the place for universal knowledge. At this stage of our current social fabric, the concept of universal knowledge is becoming an illusion. Even the large universities do not contain all knowledge. Interversity draws the attention to "what is between us" (from the Latin Inter, as used for internet, interacting, interchange, interdepend, interbreed, etc.). It lets go of the idea of containing universal knowledge in favor of spinning off innovative ecosystems.

While innovation has been mostly the focus for business ecosystems, the Interversity cannot be limited to such activities. The social ecosystems, governmental ecosystems, etc. also have to be possible. The concept of the Interversity fits the vision of the emergence of a Global Brain and the ability of large-scale structures to become stronger agents in the social fabric thanks to the technological progress. How the university functions can be transformed to become an Interversity is the challenge in Chapter 11. The architectural model also helps us to position ongoing research activities. It is therefore a fitting topic to end this PhD.

8.5 Research Question III.1

How can the novelty research be demonstrated and validated in a setting with actual people?

A shift was needed from propositional knowledge that can explain what something is to prescriptive knowledge that can explain how something is done. The CAR method develops the prescriptions needed to validate the novelty research. The CAR

method has two methodological processes, four stages and three dynamics. The CAR processes are penetration and training that envelop around the phase transition like a carburetor. The four CAR stages stand between the five stages of the phase transition. They are: CAR funnel, CAR venturi, CAR horn and ÆIP architecture. The CAR dynamics are: bootstrapping cascade, spreading activation and circulating references. A relatively complicated mapping exists between the dynamics and the phase transition, but during each CAR stage, one of the dynamics is dominant: bootstrapping cascade in the funnel, spreading activation in the venturi, circulating references in the ÆIP architecture and a mixture of all of them during the CAR horn.

The ÆIP architecture institutionalizes the dynamics of the carburetor (funnel, venturi and horn). It is presented as a pyramid of three layers. The base layer is about the ecosystem development by spreading activation; it is the larger part taking the longest time. The base layer follows an artificial construction of the phase transition. On top, the education creates talent, is less restricted and can move faster. The students developing the prototype follow a bootstrapping cascade, while the teachers develop the educational support frameworks. Details become clearer in the next chapter showing how this central layer can be an interface for the research.

Through the structure of the ÆIP architecture, the central layer becomes an interface between the researchers and the development ecosystem, creating the required circulating references for the research. How this can strengthen the ecosystem is examined in Chapter 11, by describing the operational processes of an actual institute that could spinoff ecosystems. Building such an architectural model is described as the third validation method used for this PhD. The first validation method is by creating controlled experiments in education, which relates to the central layer of the ÆIP architecture. Participation research in Chapter 10 shows details of how the spreading activation happens in practice, and how it validates the base layer.

9 Radical change in education

9.1 Introducing the educational experiments

This chapter is about the two experiments on complex adaptive knowledge creation by project-oriented courses. Project-oriented means that the student develops a project during the studies and the evaluation of the student is by the validation of the project. The two courses are given to master-level business students. With the CAR method, the dynamics in the courses are examined, the CAR funnel is used for the first experimental course and the CAR horn is used for the second experimental course.

The first course is called Web Service Development for Business (WSDB) and is about managing software development. The innovation in this course relates to the content of the course, where students become able to develop Internet innovation prototypes. The second course is Operational Risk Analysis (ORA), which is about the complex data modeling of a project. It is not the content of the course that requires innovation but the validation process of the projects.

Because the CAR method is part of the research, the basic validation of the experiments takes place by Action Research. The Action Research iteration cycle follows the academic year. Each year a fresh group of students goes through the system, making the setting optimal for Action Research. The summers were used for the reflection on last year's setup and the planning of next year's setup. The WSDB course has run between 2006 and 2012 and is the setting of the experiment called "Agile Education". Agile education is about how project-oriented education can turn education from knowledge transfer to knowledge creation. The ORA course was the setting of an experiment called "Scalable Education" which took place during the 2011-2012 academic year. Scalable education addresses the intense supervision in agile education by creating a support framework that reduces the validation process by student participation.

It is essential to understand the relationship and differences between training and education of skills. While training allows learning to get a job done, educating is about understanding that there is a job in the first place. In fact, training is only one of the two CAR processes because penetration is also needed in education. Training is about mastering a skill while education is about teaching the student the discipline to become a professional. A relationship between commitment and the duration of the education can be observed. One-year programs have difficulties with incentives. In contrast, specialization like surgical studies or pilot studies have fewer problems with students' incentives. This is because you need to be really committed to start this type of education.

The innovation challenge for WSDB relates to an incentive problem. To understand software development requires some programming. Before WSDB, business students were given a classic programming course. This is not an optimal solution, because it motivates the student to become a programmer and not a manager. For WSDB this creates the wicked problem: *how do you train students in software development, by teaching them the discipline of a manager?* The effect is a radical change in content of the initial course. The ORA course is part of a one-year master program of management. The program had large numbers of students that had low levels of commitment. Because of the low levels of commitment, more individual guidance for the projects development is required, which stands in contrast to the large number of students. So the wicked problem is: *how can one give more personal education to a large numbers of students (with too limited a staff for a classic approach)?*

9.2 Illustrating Agile education with the WSDB case

The main objective of WSDB was educating business students on how to manage software development. In practice, this is not evident. Programmers are often trained to become project managers. To profoundly understand the complex dynamics of software development requires programming. Software developers don't have the same sensitivity for managerial issues that business students have. The challenge exists to educate business students so that they have as deep a technological adaptation ability as programmers. We knew that such a profile exists. The Internet innovators, observed in the participation research, were managers that often had only a limited understanding of programming itself. The way they became expert in programming was by self-education. By observation of the desired profile, some hypotheses arose that were then used to innovate the WSDB course.

The initial course for the business students was a classic programming course. However, a difficult problematic incentive problem existed. From the participation research, the target profile was known. As a result, a gap existed between the current skills (of business students) and the target profile (of Internet innovators). The novelty gap would result in the convergence of the training path and the penetration path of the CAR funnel. For the development of the WSDB course, it is the teacher that undergoes the CAR funnel. Interestingly, the eventual teaching method is also this CAR funnel where the students utilize it for their project development. The reason is simple because both the WSDB and what the students had to develop were prototypes creating novelty regulation. In the subsection, more detail is given. The first subsection elaborates the setting of the Agile Education experiment. The second subsection follows the development during the following six years and shows how three major milestones were reached. The last subsection discusses the dynamics by the CAR funnel.

9.2.1 Agile education by guidelines and targets

To get business students interested in software development, it was transformed into more of a managerial problem. Today, software development is often related to Internet innovation. Business students are very interested in understanding Internet innovations. Using the Internet to teach about software development creates some new challenges. For the WSDB the challenges were articulated as:

1. **Information overload:** How do you learn something that changes so fast that your knowledge is obsolete by the time you learn it?
2. **Complex management:** How can you build a strategy if technology disrupts the target that you are aiming for?
3. **Openness dilemma**: How do you create a scalable or sellable business (mostly a product) if the development has to be Free and Open Source (resulting in a hard to scale service)?

The first problem refers to the problem of information overload and how to still act usefully upon it. The second problem addresses management in a complex adaptive environment. Both problems are generally relevant to the current acceleration of technology development and innovation. These two questions create the fundament of agile education and it results in an educational shift: *from knowledge transfer to knowledge creation*. Agile education is a reference to agile software development. The last question was specifically designed for the target audience of business students who needed to get a sense of how to manage agile software development.

9.2.2 The three milestones of WSDB

During the years that the experiment was fully operation, the milestones became apparent. The general challenge with the WSDB course was set on October 2006. In the first two years the course was known as "programming" and part of the "Business Information Management" (BIM) program. BIM was a master-after-master program, which ensured a great maturity and commitment of the students. The second year was not fully operational, since the BIM program was being discontinued and no new student enrollments were allowed. So the second milestone only emerged in the third year. In the third year, the course was named WSDB and given to "Business and Technology Management" (BTM) students, which was a two-year master program.

Each subsection elaborates on one of the three milestones. The first subsection describes how the co-creation with the BIM students made most of the basic WSDB structure arise. The second milestone revolves around CAR horn and how to overcome the procrastination. Some student projects became prototypes for potential micro-spinoffs in the third year. In the fourth year, we successfully made it the focus of the course, creating the third milestone. The opportunities recognized with micro-spinoff prototypes would become external to WSDB and so could not be pursued. The following years, only incremental innovations for agile education were reached.

9.2.2.1 Basic co-design with BIM students

In the first two years, the course was given to BIM students. The maturity of the students allowed an exposure to experimental settings. An overall course outline was provided, but the details were developed each week. The feedback of one week would heavily influence what would be given the next week. Programmers often show a lock-in effect by becoming an expert in one programming language and not knowing the various alternative languages. In the initial setup, two basic programming languages (PHP and Java) were given to create web applications. The basis was extended with many other script languages (SQL, HTML, Java script, flash) and the integration of third-party applications. Integration of third-party applications is possible by Application Programming Interface (API). The APIs are essential in the development of Internet innovations allowing interoperability between applications.

The diversity was fascinating for the students. However, the one big complaint was that it stayed theoretical. More exercises were created to address their complaints and it became a more hands-on course. By becoming more practical, the use of Java turned out a bridge too far, because the object-oriented language requires advanced understanding of programming. At the start, the course was a rollercoaster of enthusiasm and fear. For example, early posts had titles like "So I am a Belgian, but yesterday's course was a culture-shock". It later became clear that interoperability is the essence and more abstract models were created to allow a better assimilation of agile education.

During the first two years, the course was a one year program, and each week had a two hours class. During the first semester, students were uneasy with the lack of clarity towards the evaluation. This resulted in the setup of midterm informal evaluations. The outcome of the evaluation allowed a reflection on what we were doing. The midterm evaluations defined the three categories of criteria: collaboration, programming and designing code. The three categories were well enough defined to remain stable in the following years. Each category contains four criteria. The first criterion of each category is an instructional scaffold that exists to make the students start the development in that category. Each of the subsequent criteria in a category becomes a lot harder to reach. Details of the criteria were improved in the following years eventually resulting in:

– Knowledge sharing (blog posts, forum posts & comments).
  Collaboration (helping to solve other people's problems)
    + Co-development (students collaboratively programming a project)
      ++ Distributed development (global co-development by tools e.g. git)
– Basic functionalities (some basic, functional program)
  Programming (understanding of a programming language)
    + Integration of external APIs (demonstrating interoperability)
      ++ Prototyping (creation of an Internet innovation prototype)
– Construction of organization (e.g. using functions to clarify the code)

Designing code (abstract code: reusable, uniquely defined, etc.)
+ Construction of architecture (implementation of software design)
++ Construction of APIs (open the design to integration)

In the first year, the course was totally experimental. In the second year, the basic structure was improved. During the third year, the type of student changed by moving to the MBT program, which created a new set of challenges. The course would be given in one semester with slots of four hours. The MBT students are first year master students that cannot be exposed to the same level of experimentation as the BIM students. The shift required a more streamlined course with better exercises. With the new improvements, students lost the overview and the implicitly applied CAR funnel had to be explicitly articulated. In other words, the CAR funnel was mastered during the first two years, but only in the third year did it get modeled. Students regained an overview by showing how the CAR funnel achieves training (by the exercises) and penetration (by project development) simultaneously.

9.2.2.2 Battling procrastination

The best projects would give us insight as to what was possible and why. From the three categories, it was always the programming category that was most developed. To create more attention for the other categories, scaffolds were built (theory, case studies, exercise, instructions, etc.). Students were asked to create a unique project proposal, which improved the incentives. This also created the required diversity needed for students to openly collaborate, while being individually evaluated. The CAR funnel is the milestone reached. Because it is essential to this PhD, I've moved the details about the CAR funnel to Section 9.2.3. In this subsection, I would like to describe how the procrastination was reduced.

Every course has problems with procrastination. For the individual and self-inspired projects, there is little problem with procrastination. However, the autonomy of the students became the main problem. The autodidactic students flourished and by creating better educational support, the problem was reduced. Cases by peers showed a simple way to reduce the procrastination and stimulate the less autodidactic students become more active. For example, in the first year of MBT students, one student, who was advanced, made it clear that he puts extra work into the project because he had a buyer for his e-commerce project. The announcement, made during class, had an instant effect. Several of the students, who were not very engaged until then, changed the topic of their project to e-commerce and became clearly committed. The e-commerce projects were not optimal for the course criteria. Emphasizing more need for interoperability, by API integration, was an improvement. In the fourth year, students where challenged to focus on API integration, resulting in less sellable projects and more educative projects. Surprisingly, the projects had more economic value, as elaborated by micro-spinoffs in the next subsection.

From the first year, it was clear some procrastination relates to a gender problem. In the first years, I have spent considerable time on individual supervision to overcome the fear of female students towards programming. Eventually more projects created by woman would overcome the gender problem. The first examined project in the next subsection is the project that solved this gender problem by becoming a role model. The effect was clearly recognized the next year (the fourth year).

To further reduce the procrastination of less autodidactic students, intermediate deadlines were set in the fifth year. Three such intermediate deadlines were created. The deadlines were presentation periods in class, so the validation was open and students could learn from each other. This was possible because each student was working on a unique project. During the intermediate deadlines each student had 5 minutes of presentation time and 5 minutes of feedback by the teacher. Each presentation was also open to the class. Some presentations resulted in open class discussions that were not restricted in time. In previous years, these workshops were organized, but the workshops were not structured as well as in the fifth year.

The first deadline was two weeks after the first contact. The goal was a pitch about their projects, where no actual development was created. The deadline reduced the time that students spend on selecting an appropriate project. The open class discussions during this first deadline was related to additional clarification on what was expected, where specific cases triggered the questions. The second intermediate deadline was half way through the semester where students had to show some type of implementation, such as APIs tests and the basic programming of the project. The class discussions were more related to actual program challenges. The last deadline was during the last contact hours of the class before the examination period. Some students used it to gain the last feedback. These students would submit during the examination period. Others used it to actually get a validation of their projects and take the WSDB course off their exam roster. The class discussion was focused on questions about the evaluation of the criteria.

Those open evaluation periods became workshops for more than just the students. They allow a debate on Internet innovation. The workshop debate allowed the students to actually assist me in the research on Internet innovation. This becomes relevant for the position of education in the ÆIP architecture (see Section 11.2.2) and also for some of the solutions on scalable education (see Section 9.3).

9.2.2.3 Micro-spinoff prototypes

The third milestone is when the projects became potential micro-spinoffs. It is important to elaborate on what micro-spinoffs are before continuing the description of this third milestone. It is called a micro-spinoff for two reasons. The first reason is that the target market is a niche. The second reason is the low investment. A small investment is enough to get the spinoff going. The micro-spinoffs can be compared to micro-applications available on smartphones and tablets. The micro-applications are much smaller than the classic applications on top of a computer operating

system (e.g. email, spreadsheet, etc.). They also have limited functions and address a niche audience. It is important to note that environmental enrichment is required to make micro-applications possible.

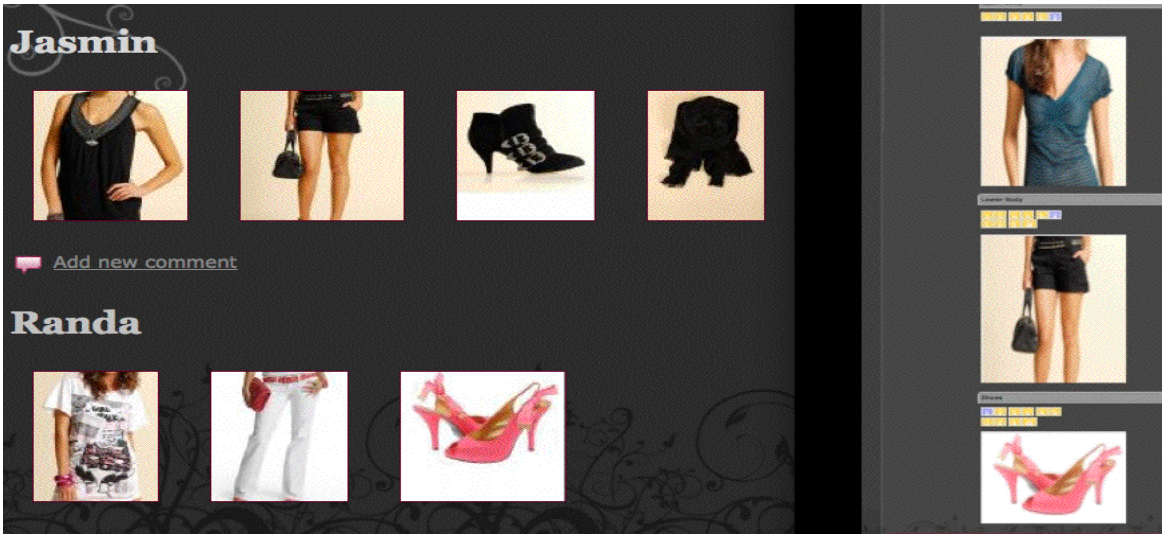
According to the investigation of artificial evolution, both agency and medium are required to create sustainable environmental enrichment. For micro-applications, the device creates the agency and the medium is an online platform called the app-store. The medium for micro-spinoffs relates to the current platforms of micro financing for spinoffs realized by so-called crowd funding (e.g. kickstarter.com). The agency of our Internet Innovation spinoffs relates to the interoperability by APIs and the creation of niche platforms that can stimulate rapid development. In fact, the app-store is such a platform for micro-spinoffs for the niche of micro-applications. Because they are small applications, they allow rapid development.

With the Internet landscape getting more enriched by APIs and niche platforms, the opportunities for micro-spinoffs is increasing. Improved structures can make the micro-spinoffs truly flourish. As an example, current legislation is not optimal for micro-organizations and the crowd funding should become better. The concept of micro-spinoffs fits our current social climate to focus more on (open) innovation as the main competence of the economy. The social climate (the public) is one of the essential roles in the Eventuating model. It is expected that such positive feedback is only improving the environmental enrichment for micro-spinoffs. The student projects explore this trend and use it for an educational purpose.

The student projects are prototypes for micro-spinoffs focusing on a niche business. The first prototypes emerged in the third year. In the fourth year, we made it the focus of the course. Until the third year, all students created a workable project. By the change, some projects would not reach integration and would show only partial functioning of the prototype. Nevertheless, all projects were potential micro-spinoffs. It is during the fourth year that one of the students pursued venturing opportunities with the project, by creating a business plan to present to investors. It is the recognized opportunity for an unreachable fifth milestone. It was unreachable as the opportunity was external to the course and could not be created by the course alone.

Two examples of prototypes were created in the third year. The first project is an "online wardrobe" by Randa El-Ali. This first project is very visual and therefore suitable for a first demonstration. The online wardrobe project has users who would upload pictures of what they have in their wardrobe. The application would then allow them to combine these pictures. Eventually Randa created an interesting interface of different image galleries combining the clothes in your wardrobe in a playful way (see right side of Figure 9.1). During the class demonstration, some students mentioned they had little interest in their own wardrobe, but they still enjoyed the tool and would consider using the system. Clearly, this is a dream for analysts in the garment industry (the niche market).

Figure 9.1 The online wardrobe project. Left the current pictures of two users. Right, a playful way using three image galleries based on the tags put on the pictures (top, bottom, shoos).



The second example is a "personal road trip" by Christophe Cote. Cities on a map could be added to a trip-list. The solution is a lot more technical. The cities were specific content types in the content management system. An algorithm to calculate the shortest distance for the trip-list solves the computationally complex problem known as the "Traveling Salesman Problem" (TSP). To demonstrate the micro-spinoff opportunity, consider how the system could be given as a free service to generate extensive data about trips, which becomes useful for a niche market of traveling agents.

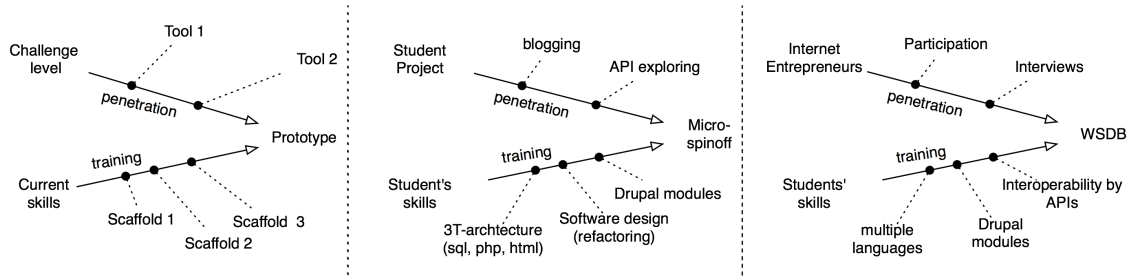
Other projects were about healthcare, fair-trade, interior decoration, emergency services, etc. All created specific opportunities with specific integration and development challenges. Some even needed specific device development. Faisal Nadeem, a student during the fourth year, created a project about personal E.E.G scanning that required a small E.E.G device. The projects together create more abstract patterns useful for research on micro-spinoffs and Internet innovation that was discussed during the workshops. Students would contribute to the modeling about the abstract patterns, while their project allowed the mastering of patterns in the first place. It is further developed for the ÆIP architecture. The students become an interface between the developing ecosystem and the researchers (see Section 11.2.2).

9.2.3 Dynamics of agile education

The WSDB course shows the CAR funnel twice. A CAR funnel is about a gap between existing skills and target skills. The easiest to explain CAR funnel is about students creating their project. By the CAR funnel, students create prototypes that could

become potential micro-spinoffs. The other CAR funnel is the development of the WSDB course itself where a gap was recognized between the skills trained in the old course and the skills recognized with Internet entrepreneurs. The CAR funnel shows convergence by tools in the penetration path and scaffolds in the training path (Figure 9.2). The tools and scaffolds can be examined for both CAR funnels.

Figure 9.2: The CAR funnel: left the general design, center the application by students, right, the application of the teacher



Students would first penetrate their project by creating blogs, which creates more structure than the ideas in their head. It also allows feedback, by teacher and peers, such as creating links, asking for clarification, challenging the idea, etc. A second tool for penetration was the APIs. Each project would have to find their own suitable applications and figure out how to integrate them into their project. The API not only creates leverage to the functionalities of the program. Often the student had to adjust the project because their initial ideas did not take into account the constraints of a concrete application. The integration problems would particularly challenge their managerial skills.

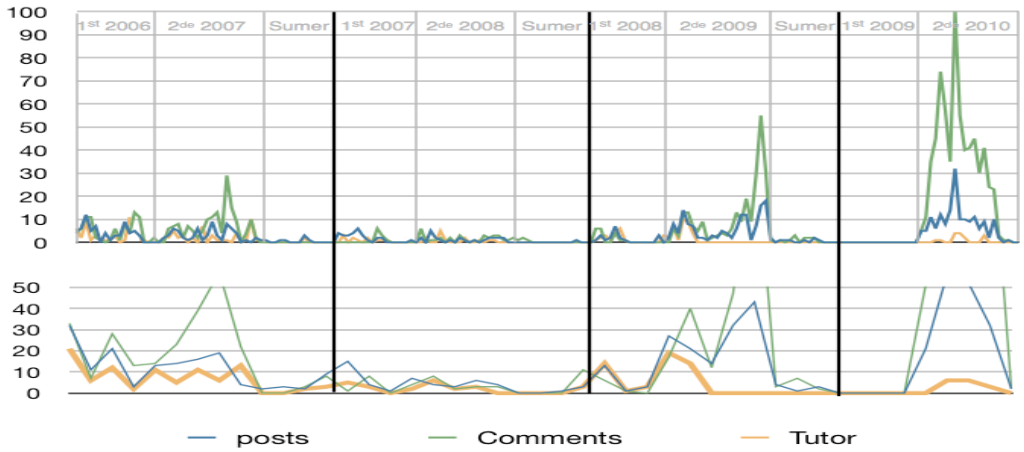
The training would stay relatively independent of the penetration until the third sub-target that allows the integration of the API into a module. The first scaffold for training was a basic 3T-architecture exercise (i.e. database, core and interface, using e.g. respectively sql , php and html), introducing the basic programming and the basic web application. The harder problem of software design becomes the second sub-target where an exercise refactors the 3T-architecture to become more of a Content Management System (CMS). The third scaffold was an exercise on developing a CMS module using API. Drupal was selected because it has a basic level of software design fitting the training path. It is merely coincidental that it is also the topic of the participation research.

The WSDB course has been running long enough to demonstrate how change in Internet innovation was covered in the course. The initial projects were mostly about CMS development. In later years, mobile applications became popular. Since students were allowed to suggest a project, the new developments were integrated into the course naturally. Other self-organizing dynamics can be recognized. For example, student projects of the previous year became scaffolds for the next generation student. To demonstrate this, a simple graph (Figure 9.3) shows the self-

organization. Students were required to blog (blue line), which results in comments (green line). In the first year (2006-2007), the teacher (orange line) had to give feedback on almost every blog. In later years, this feedback was not needed because the student could find answers in the examples of the previous years.

Only data for three years out of the six years can be used to show the self-organization. The first disturbance that is also visible in Figure 9.3 is the end of the BIM program. In 2007-2008, new enrolment was frozen. Many evening students split the workload by moving some of their course to another year, which made the one-year program longer. Only BIM students that still had to do my course were active. A similar problem arose for MBT. In the first two years, no problem existed, but in the last two years students became discouraged from taking the program. The reason had more to do with the inter-university politics of this joint program than with the content of the program. Nevertheless, the three years that can be used clearly show the self-organizing trend.

Figure 9.3: Posting blogs and comments on a weekly basis (top) and a monthly basis (bottom) shows how activity by the students increases in later years (green and blue), without more coordination by the teacher (orange). This illustrates how the coordination becomes self-organizing.



The Agile education does not only create knowledge for the students, the activities of the students become an interface for the researchers, stimulating the dynamics of circulating references, as used in the ÆIP architecture. Let me show how the setting of WSDB creates cases to investigate an Internet innovation strategy. A commonly applied Internet innovation strategy is separating casual users from advanced users. The casual users get basic functions for free while the advanced users need to pay. Two examples are LinkedIn, the professional social media site and newspapers, which restrict some of the news to paying users. This casual-versus-advanced strategy stands in contrast to what I like to call base-versus-target strategy. The base users get an application for free and create data relevant for a target user who has to pay for the data.

The main example of such a base-versus-target strategy is Google search that is free for (base) users. The use generates considerable data useful for specific algorithms (e.g. page-ranking). Access to the output of the algorithms is a strong competitive advantage. Google search allows personalized marketing for (target) users. In contrast, the casual-versus-advanced strategy has difficulties with competitive advantage because of the balancing problem. If too many functions were exclusively for advanced uses only, fewer users would be on the system. If too many functions were given to the casual users, it would make fewer users become paying users. In relation to the completive advantage, the solution is sub-optimal since the business is its own competitor. The base-versus-target requires more creativity and more work to be applied, but from a competitive advantage it is more efficient. By the different setting of the students' projects a variety of base-versus-target applications could be investigated at least in spirit. The actual validation would be the follow-up of the prototypes until they become actual micro-spinoffs, which gets considered in the design of the ÆIP architecture.

9.3 Scalable education: ORA case

A course called "Software for Management" was designed to educate students about the operational complexity of a project. Software tools were used to approach the complexity. With a spreadsheet, a base model implements the constants and variables of the project. The spreadsheet allows an investigation of complex data. Tools like "Sensitivity Analysis" allow an understanding of the interrelationship of the data and tools like "Monte Carlo simulation" allow for non-linear data to become statistically approachable. With these tools, students can learn how to create a good risk assessment of their project. I consider the name of the course misleading and refer to this course as Operational Risk Analysis (ORA).

The teacher's challenges with ORA are very different from WSDB. WSDB had uncertainty in respect to the content of the course. The challenges of ORA relate to the increased student numbers and dramatic cuts in teaching staff. The conservative solution, to deal with the scale problem, would be to stop project development and go to classic exam structures. We believed that the conservative solution would be inappropriate for the ORA course. A risky experiment was preferred instead. The elementary problems and questions we had to work on are:

1. **Cost reduction**: A year ago, three supervisors couldn't service 300 students. How can a support structure and one supervisor service 400 students this year?
2. **Quantity versus Quality**: Last year we had to work with groups of 8 people to manage the workload. It turned out to be impossible to identify who did what, while there were rumors of several people doing no work. How do we ensure the quality of individual evaluations when working with group projects?
3. **Self-regulation paradox:** If students become self-regulating, does the educational institute become redundant?

The first two questions are related to the scalability challenge. In theory, it was clear that self-organization by stigmergy should be able to solve our problem. A design for a support structure was created, but it was clear that the details had to be learned on the job. The last question is a meta-question. It also applies to the previous case of agile education. Technology replacing the tasks of the teacher creates an impression that teaching staff becomes redundant. I demonstrate that the support and methods stimulate self-regulation and allows scalability, where the teacher has an important mediating function.

The general concept of scalable education by self-regulation is simple. It is known that students learn well from each other, but without guidance this can go wrong. The idea is that by support and certain methods, the bulk of the education becomes self-regulating under a 20/80-rule. The 20/80-rule shows how 20% of teaching time goes to 80% of the projects, while 80% of the time goes to 20% of the projects. The best and worst projects require more supervision, while most of the projects only require verification. Which projects require attention and which do not cannot be recognized up front so the teacher needs to see all the projects. It not the validation of a project that takes the time of a teacher, but articulating the feedback is time consuming.

Technology support and methods stimulating coordination between students make it possible to handle the disparities applied by the 20/80-rule. What was only understood after the experiment is how it makes the task of teaching shift from the content of the course to supervising students that became assistants. In the end, 60 so called student-assistants gained the ability to evaluate other students. When the whole system was running optimally, the teacher's main activity was supervising those assistants. The details of the experiment will show how this came about.

9.3.1 Self-regulation in scalable education

The course involves 410 enrolled students. It had two runs with the first run over a period of four months starting in October 2011. The tools and methods were reused during the summer of 2012 (for the re-examination period). Two types of pages were important: issue pages and review pages. The issue was a task of the project that had clear characteristics. The pages have a particular structure that worked as instructional scaffolding for the students. Issue pages had changeable states. Review pages gave a rating to an issue and receive a rating, which was the validation. By recursion, a validation on a review also evaluates the issue.

Let me gives some numbers on the first run. Of the 410 students, a total of 330 of them have actually posted something. However, 30 of them barely did any work. It would be more accurate to represent the student size as 300. During the first term, students posted 4276 pages and 7980 comments on those pages. In the end, 767 issues were reviewed. Students created 1709 reviews, while teachers created 223 reviews. Most reviews of the teachers were so-called dummy reviews. The dummy reviews only contained a rating to correct the score of an issue; about 200 such

dummy reviews were created. The validation was more of a teacher's task, with 1282 validations by teachers and 427 by the student-assistants.

9.3.1.1 Basics by gamification

The design principle was to use "gamification". Gamification is a method of applying the functionalities in games for other purposes. Games have created flow by stigmergy in an implicit and practical way (Heylighen et al. 2013). Exaptation of game functionality for evaluation of projects allows us to gain self-regulation, which is essential for the scalable education. The system challenges students, but the system is just a framework and would have little value if not for the interaction by the students. The gamification leads to automatic score calculation based on feedback given to issues and reviews. In the guidelines, students could read how the calculation of their score was done, which was a complicated relation between different feedback abilities.

Students created an initial score via peer-reviews. The teacher still had control over the final score, ensuring the students that the teacher eventually validates all content. The points were easily enough represented: 10 points on issues and 10 points on reviews (see Figure 9.4). As an extra stimulus, bonus points were given to students creating a lot of useful feedback. It is recognized that such a point should in future applications be part of the review score.

Figure 9.4 Final score table for issues and evaluations, with optional bonus points.

Total score Total Issues Evaluations Meta-evaluators Poor list

Note the score is dynamic, this is just a temporary estimate !!!
The calculations are explained here

* behind an issue means it is not yet meta_evaluated
° after evaluation meens that more evaluations are needed (or pending)
'A' stands for absence, which you get if issues or evaluations is zero

uid	name	issues	evals	bonus	score
2	tester	0	3	0	A
125	fnadeem	2.25	3.3	2.28	8
160	fvgeel	10	4	2.52	17
176	lorenys	10*	4.3	3.27	18
177	mosmenda	5.05*	3.3°	2.38	11
178	Laurens	0	0	0	A
179	EvyVandenSchilden	1.25	0	0.28	A

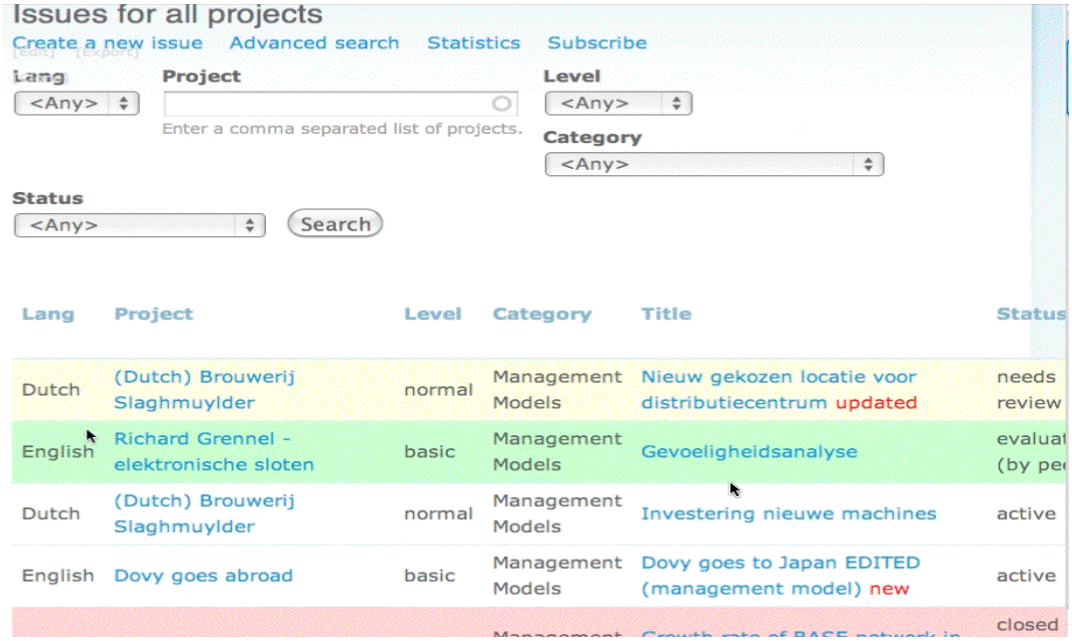
Students had the ability to choose how to earn these points. There were three types of issues that a student could create. In Figure 9.5, the types are indicated as the category: model, sensitivity and MC (Monte Carlo method). The students could decide to create one of each type or go deep into one type.

Figure 9.5 The three issue types creating an issue score table

uid	name	model	sensitivity	MC	score
199	nsleypen	0	8.25	2.3	10
200	eopolot	4.5	0	2.8	7.3
201	irina	2.3	2.3	0	4.6
202	original	2.6	1.8	0	4.4
203	ion	1.75	3.2	1.8	6.75
204	kena	0	0	0	0
205	jmaingu	2.5	0	2.5	5
206	mmontare	2.1	0	3.5	5.6
207	mafoulon	2.6	3*	0	5.6*

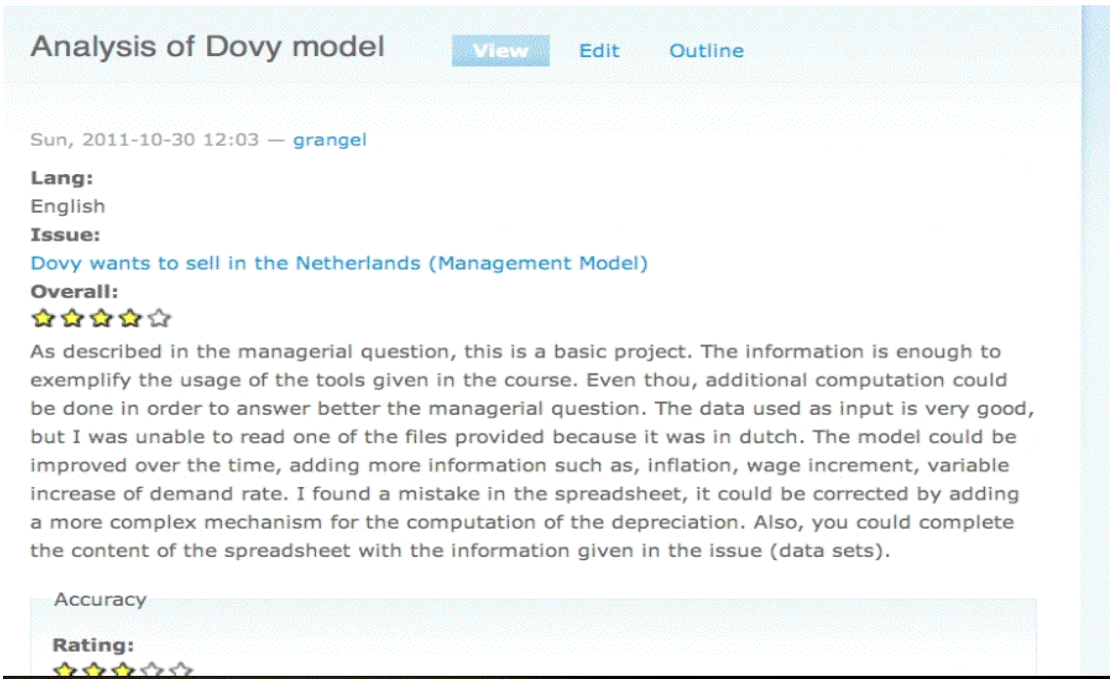
Every issue had a level: basic, normal and advanced. The issue also had a state. The most important states are: active, needs review and evaluated. To get an overview of the issues a queue existed that had filters to easily browse the issues and different colors to visualize the state (Figure 9.6).

Figure 9.6 Issue queue table



Once an issue had the state "needs review", the reviews on the issue could be made. At this moment, the issue has an attachment containing the work of the issue. A review page has several ratings and each rating has a text field to elaborate the rating. An overall rating would exist next to some criteria. In Figure 9.7, you see the first criteria being "Accuracy".

Figure 9.7 Example of a review page



Once an issue had two or more reviews, it would be in a queue for evaluation. In Figure 9.8, you see two reviews related to an issue. Dedicated students could create an evaluation. The teacher selects them after recognizing their ability to do good reviews. In Figure 9.8, the first review only got a 2-stars evaluation, which indicates a poor review. The second review was given 4-stars, which is good review. One star would be bad and would not count, other reviews would weight on the point based on the score of the evaluation. After such reviews, the issue gains the "evaluated by peers" status to pop-up for validation by the teacher.

Figure 9.8 One issue receiving two reviews (with an overall rating) and each review has an evaluation (called meta-evaluation in the figure)

Teachers had to check the issue, review and evaluation to see if the proper feedback was created. In most cases, it would be approximating the teacher's evaluation, but in some cases a "dummy" review was created that allowed the teacher to overrule the score of the students' reviews. A review by a teacher would, of course, need no evaluation. Depending on the level of the issue, the rating of the review and the

rating of the evaluation, a score was generated (see Figures 9.4 and 9.5). Students could improve their issue by simply creating a better one, but the cost of doing so was that the student had to create at least two evaluations for each issue that they submitted.

The review score leads to a more complicated table (Figure 9.9). The score would be higher than the average if students did more evaluations than needed (need and done columns in Figure 9.9) or get a penalty if they did less. To ensure the quality of a review, an evaluation was given. Students contributing to the evaluating could get extra points for doing so (meta columns in Figure 9.9). Pending issues are issues that did not get an evaluation yet and so did not affect the score.

Figure 9.9 Review score table

uid	name	need	done	pending	score	average	meta
195	SvenM	8	10	1	4.8	4.2	0
197	bdiyarov	4	2	1	0.75	2	0
199	nsleypen	4	3	1	7.1	7	0.1
200	eopolot	8	13	0	8.7	5.9	1.2
201	irina	6	10	0	10	6.6	3.1
202	original	4	6	1	2	1.7	0
203	ion	6	8	0	7.8	6.3	1.1
205	jmaingu	6	13	0	8.2	4.8	1.5
206	mmontare	4	5	0	4.5	3.8	0

9.3.1.2 Booting up the system

The whole setting required the teacher to pull the system through an initial start before it would get into a flow. At first, only one simple example was created. Only the most autodidactic students could use it to begin their work. The teacher would review those initial issues. This expands the pool of examples and triggers a next wave of active from students who needed additional examples before they could begin. The process would create a flow of successive groups, such as the groups discussed in Section 5.2, but now groups of students.

Once students got a review for their issue, it was their time to create reviews. The first wave of active students would begin reviewing the issues made by the second wave of students and thus expand the pool of reviews. With the bulk of students joining the review, even the evaluations became a bottleneck. From the reviews it became possible to recognize students doing a good job. Those students were given a role of student-assistant that gave them the right to do evaluations and access to the assistant interface. It is interesting to notice how the feedback process of the teacher shifts from the issues, via reviews and evaluations, to the assistants.

A sub-group of assistants emerged creating evaluations (meta-columns in Figure 9.10). The assistance was not restricted to evaluations. Assistants also identified problems and suggested possible candidates to reinforce the assistant team. The

teacher was now in the position to make the scalable education fully functional. At the end we had 60 assistants, but at the start we had to do the first reviews and evaluations ourselves.

Figure 9.10 Top evaluators and the number of meta-evaluations they have created.

Student radar Total Issues Evaluations Meta-evaluators Poor list

meta	users
41	fgarcia
35	Thomas
31	irina
30	hhenriot
29	achahbou
24	chachoua

During the course, three interfaces were built. At the start, there was only an interface for the students. However, as the dynamics of the system became clearer, an assistant interface and teacher interface were built. First, the teacher interface emerged. As a software developer, I could use the data of the CMS to create functionalities to mediate my teacher responsibilities. To allow the professor to contribute to the mediation, these functionalities were embedded in the interfaces. For example, to get an overview of potential student-assistants, a list was created of students who made three or more good reviews. The assistant interface only emerged later and would stay relatively primitive. It contained some functions for student-assistants to support them in their evaluation activities.

9.3.1.3 Friction by focus on ÆIP grid instead of CAR method

Our setup was good, but our communication was not. Rumors, e.g. that only peer-evaluation would exist without teacher verification, started gaining a life of their own. After a while, much of our attention went to countering those rumors. All of the students also had to follow the new method. In a good change management, we should have a transition period that would give students a choice to work with the new or old system. The effect was that some students worked hard to resist the system. Because of the large number of students, the group dynamics created a vicious cycle, which made their attacks very problematic. The most focal students in such groups filed complaints to the ombudsperson, dean and program chairman. This led to extra overhead, like meeting to discuss the complaints and email traffic.

One aspect that was clearly underestimated was the self-organization of groups by the large number of students. We recognized very late in our work the relevance of communicating with the students' representatives. The concept of a self-organizing group and representatives was examined with the Eventuating model. The setup of the scalable education experiment is a support framework for knowledge creation,

being the focus of the Cohering model. This difference should show why a prescriptive CAR method is needed next to the descriptive ÆIP grid. The mistakes that were made relate to not focusing on the dynamics of the CAR method and being more influenced by the structure of the ÆIP grid.

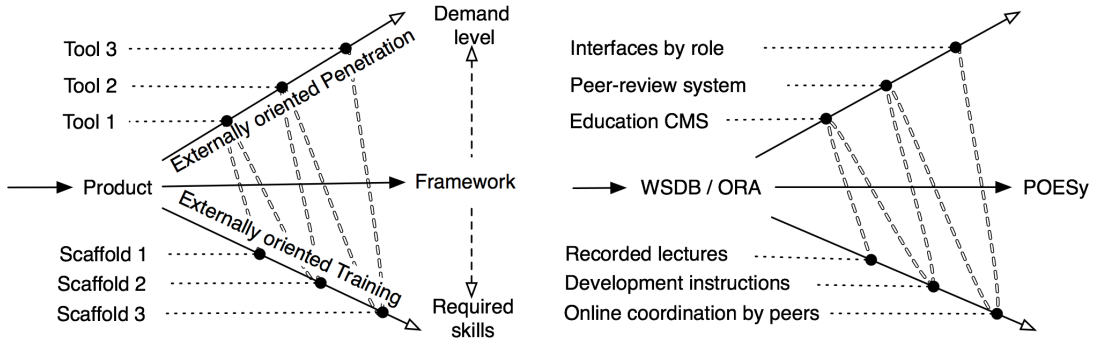
We were aware that the experimental setup would require changes to criteria of the course. This is why only abstract criteria were defined for the course description. The details would change and those changes were within acceptable boundaries. For example, one detail that had to change was the penalty system that turned out to be too harsh and became counterproductive. Other problems were identified, but could not be solved in the available time. For example, there was a simple rule that each issue uploaded required two reviews. However, some students created bad reviews and some issues still did not have good feedback after several reviews. On the other hand, some reviews were so good that everything was elaborated with a single review. It created the insight that the number of reviews to be given need to relate to the quality of the reviews. Some designs were created on how to implement this, but the development would require time, which we did not have. By the end of the project, many such improvements were identified that could increase the operation of the support framework significantly.

9.3.2 **Analyzing the proof-of-concept**

With the WSDB course, some basic instructional scaffolds existed like the content structure, e.g. blogs to express the project progress, forums for questions, etc. Some interface structures allowed the regulation of coordination, e.g. the issue queue. The issue queue is normally a tool for distributed software development. In the ORA course, it was exapted to function as a tool for distributed peer-review. The issues queue's stigmergic ability was transformed for educational purposes. The main extension is the structured reviews. The double check strategy by evaluations is the precondition to ensure the quality. With the teacher as the moderator on top of this structure, the whole system is as good as individual tutoring. The teacher recognizes talent and empowers some students. The empowerment needs tools (e.g. assistant interface) and scaffolds (instructions and examples).

The tools and scaffold are, in fact, part of a development according to the CAR horn (Figure 9.11). With our focus on education, the existing courses are the products. The basic technology developed for WSDB and the extension for ORA transform a course to a Project Oriented Education System (POESy), which is the framework in the CAR horn. The externally oriented training path shows how a more advanced instructional scaffold gets applied to ensure the development of the required skills. The externally oriented penetration shows extensions of our basic technology to address the increasing demands that were requested.

Figure 9.11 Schematic presentation of the how the Project Oriented Education (POE) transforms by the CAR horn



The first development by the CAR horn is recognized in the WSDB. The last functionality was more outspoken for ORA. The last functionality exists in WSDB, but due to the small group size they did not require any framework support. The CAR horn starts by using our current technological abilities to record the lectures (Scaffold 1) and puts them online in a Content Management System (CMS) for education (Tool 1). Instructions are required that guide the student in their project development (Scaffold 2). In case of WSDB, the instruction support was simple because of the small number of students, the instructions were given in class. The only structured support was the blog that the students had to create to elaborate the project development. The instructions for ORA were more elaborate and were about the peer-review system (Tool 2). Development requires coordination (Scaffold 3). In the case of WSDB, the teacher mediated the coordination in class. For ORA, the interfaces per role (student, assistant and teacher) extend the CMS functionalities (Tool3). Due to all of the extensions, the CMS is transforming to POESy.

The framework is being bootstrapped in. In the process, the tools and the scaffolds of the CAR horn become incrementally developed. In the case of WSDB, some of the structure already existed in a marginal form that developed to be stronger for the challenge of working with many students. For example, the issue queue existed, but it was not yet a peer-review tool. The use of the issue queue was marginal in WSDB. The current development of POESy is only a prototype of the emerging support framework. Many improvements are recognized and they would make, what is currently existing in a marginal form, become developed stronger. In order to provide details on this dynamic, Subsection 9.3.2.2 elaborates on the desired improvements.

The development into POESy has more of an effect than moving from knowledge transfer to knowledge creation (WSDB innovation) and the cost reduction of tutoring (ORA innovation). The development is also improving the learning ability. Three levels of learning can be recognized. The first level is the passive absorbing of the required knowledge. Passive absorbing of knowledge is, for example, the ability to understand another language, but being unable to respond. The second level of learning is when the knowledge is active, so that you would be able to respond and apply the knowledge in a different setting. Students are educated to have active

knowledge, which is verified by examination. A third level of learning is only possible for the happy few: the teachers. Indeed, being able to pass knowledge to apprentices requires a mastery of the knowledge that goes beyond the mere applying of knowledge.

Creating the experiment of ORA was itself a challenge that was only possible by the basic insight of novelty regulation. The massive amount of students with far too few teaching staff would normally be a threat, requiring a conservative reaction to stop giving practical courses and go to more theoretic examinations. However, the project-oriented courses exist because practice is needed to gain active knowledge. By the basic understanding of the novelty theory the threat became an opportunity: *willingly undergoing tension to discover the hidden novelty.* The pressure was immense, because there was no room for failing. In the end, all students had to be evaluated. It was a great risk that we took and we were not disappointed. The large amount of students was not only a problem for our course. The next year the program changed significantly, which is why the experiment could not be repeated in the next year even after showing great potential.

Action research was again the main method for development. During the planning phase, issues, reviews, scoring algorithms and one interface were built. During the action phase, different roles emerged and the interface was refactored to the student interface and extended with an assistant interface and a teacher interface. The transformation was a constant movement in the system. For example, for issues that needed more attention because of poor or bad reviews, a "poor-list" was created. First, this poor-list was part of the teacher interface. The teacher interface emerged first and later the poor-list was moved to the assistant interface.

With an increase in student-assistants, it became relevant to move the poor list to the assistant interface. Other functionalities emerged by solving conflicts between students. For example, one of my top student-assistants was committed so much that he snapped. In one particular evaluation, he attacked a student claiming that the student played the system. He claimed that the student repeatedly submitted as the second evaluator to avoid any risk. I had no idea where this came from and had to investigate. Some simple data analysis was used and revealed that this student was not playing the system but others were. Just like I did for the professor, this data analysis was embedded in an easy to use interface allowing the student-assistants to create a more informed decision about a particular student. After mending the problem between the two students, I sent a mail to all student-assistants to inform them of this new interface.

The conflict that was just described should show how a method emerged for the action phase. Instead of avoiding the big conflicts, or solving the conflict fast, the time was taken to understand the novelty that was produced. This then results in the development of the interface roles at a moment when the time pressure was high. In some cases, the conflict allowed for a simple solution and so an interface was built. Creating extra instruction for the students solved other conflicts. Some instructions are temporary solutions. After the action phase, a reflection phase has

identified some solutions that could be implemented for a second iteration of the action research. In the WSDB course, several such action iterations were made while for ORA only one run was possible. The following subsections describe the reflection phase of the scalable education experiment. The first subsection plays with numbers to reflect on the scalability. The second subsection describes desired improvements for POESy, which could be implemented in a next planning phase.

9.3.2.1 Playing with numbers

The fact that we have been able to grade every student is itself proof of the scalable education. Some numbers can be discussed, but no control group could be used. In a way, control groups are an academic luxury that simply makes it impossible to do radical experiments. As part of the experiment, I kept track of the hours I spend on the experiment. Totaled 653 hours (in four months), which is roughly 8 hours a day. According to the VUB regulation a PhD student should only spend 40% of total time to teaching activities. Considering that it was only one of the courses I had to teach, it should be clear that the workload was out of proportion. The 653 hours was the total time on all the tasks. An estimate of the different tasks provides a better overview: about 153 hours on overhead (administration, meetings, communication, instruction classes, etc.), about 400 hours on development (software, exercises, videos, etc.) and about 200 hours on the course (reviews and evaluations).

Let me compare the 200 hours with the time that it would have taken with the setup of previous year. There were 450 enrolled students, but only 410 students registered on my site, showing that some of the students never showed up. Using the setup of the previous year, it would be necessary to work with the 450, because the ghost students can only be recognized during the evaluation. Notice that 300 effective students were active during the first run. This is due to the fact that evening students often decide to postpone the course to the second examination session at the end of summer.

Within the department, we stick to 30 students per class. If there are more students, we split them up into groups. The computer rooms have between 15-20 computers allowing two students per computer. With 450 students, this means 15 classes. We also give 10 workshops for the ORA course, thus creating 150 hours of effective teaching and about 50 hours for the teaching overhead, like class preparation, planning of the group formation, email traffic by students, etc. Project development goes with supervision hours and each project requires in the end an in depth evaluation with a report. Each teaching-assistant (PhD students) can supervise 30 projects because of the in depth evaluation of each project. Normally, the enrolment is not so large. For example, if we would have 90 students, we make them work in groups of 3 students per project and split the students in three groups for the classes.

Supervising 450 students with three teaching-assistants means projects of 5 students. With 5 students per group it is difficult to see if all of the students actually

had an active knowledge of the course. For each project, three supervision moments are given with an average of 2 hours per project. Evaluation, reports and related overhead again require 2 hours. For 30 projects and 3 assistants, it gives us 360 hours. There is also the project overhead, like meetings about the evaluations and possible problematic turnouts, administration with the secretary, etc. The overhead needs to be multiplied by 3 for all assistants and 12 hours per person seems a reasonable estimate. In other words, we have 200 hours on effective classes and 400 hours on the projects. These 600 hours would be a recurrent cost each year. In contrast to the experiment where 200 hours are the recurrent cost, while the 153 hours overhead had more to do about this first run and could be reduced to 100 hours. The 200 hours could also be reduced by improvements, so it already stands in strong contrast to the 600 hours, while the benefit of the personal guidance, instead of group projects, is not even considered.

Let me try another approach to give a different insight, by considering what the cost of the individual evaluations was in the system. A teacher took about 45 minutes to create a good review and about 10 minutes for an evaluation. Thanks to the assistants, the checking of an issue (+2 reviews) took an average of about 7 minutes. Consider that 767 issues and 1709 reviews were created. Some issues got more than two reviews when bad issues were created. Let me consider two reviews for each issue. The teacher only needs to give one review, so 767 reviews brings the total time to over 575.25 hours. By the peer-review system each of the 1534 reviews needs an evaluation, bringing the time to 383.5 hours. If student-assistants handled 100% of all reviews, the time is reduced to 89.5 hours. Of course, this is an ideal situation since the system first needs to get into a flow.

The estimated 200 hours is more accurate, which is better than having a system with only peer-reviews. To provide another example, let me apply the 20/80-rule to the 200 hours. Therefore, 240 students (80%) get about 40 hours (20%). This is 10 minutes per evaluation, which is close to the 7 minutes described earlier. For 60 students (20%) about 160 hours (80%) were given, which means a 150 minutes average. The review time of 45 minutes is only a third of the actions needed for the 20%. In some cases, the time was spent on email traffic to supervise the student-assistants. In other cases, it involved meeting with the students to give them more personal tutoring.

The system was booted up slowly. The actual potential for scalable education was only demonstrated during a short period of this experiment. In that moment, the email traffic with the student-assistants became very heavy. During the last month, I would receive 477 emails that needed instant reply. If the course would be given continuously it would make the booting up a one-time cost. The email traffic is therefore a task that needs to be improved. During the whole experiment about 400 hours were spent on development. This is considered to be a one-time cost, since the investment was required to gain scalability. With the simple calculations, it should be recognized that only two years are needed to recoup that investment.

9.3.2.2 Improving POESy for MOOC

At the moment, it was possible to supervise 300 students. This is a ten-fold increase to the 30 projects because the students were evaluated individually. Hundreds of students is a factor ten smaller than the thousands of students in Massive Open Online Course (MOOC). It is believed that POESy could be a support framework for MOOC to enter project-oriented education. However, considerably more investment and experimentation are required to reach such an ambition. Let me examine some of the conflicts and how new functionalities in the next iteration of the experiment could be developed.

During the period of deadlines, I have seen large submissions creating a backlog of issues needing review. The effect was that some students had to wait a month for feedback. The deadlines are essential, but lead to information overload. To actually force the students to spread out the workload better, I like to exapt the concept of "cooldown" in games. In certain games abilities become unusable for a particular duration until the ability has sufficiently "cooled down". In games, a broad variety of cooldowns exist, from seconds related to the primary abilities (e.g. spells) versus cooldowns of several minutes for the powerful abilities. An example of a cooldown of 24 hours is found with "daily quests", while some rare abilities would get cooldowns of weeks (e.g. professions). This diversity of cooldowns may inspire our own improvements.

Two places in our educational system could make use of cooldowns. One place would reserve an issue for review, which is not currently possible and sometimes leads to overlaps and conflicts. In this case, the cooldown helps to regulate the parallel processing of tasks. You could, for example, reserve the right to review an issue for 24 hours. To make sure a student won't block the review of other students, a cooldown of a week would be applied if the student does not deliver the review in that time period. A student may have good intentions, so the student should be able to cancel the reservation within one 1 hour of starting the review. However, once it is canceled, the student cannot select the issue any more. Putting an issue on "need review" could also be improved with the cooldown mechanism. If a student could only put one issue on "need review" each week, it would avoid the explosion we had with the issue-deadline and stimulate them to take on reviews instead of focusing on their own issues first.

Cooldown is only one of the features that could be utilized from studying games. Games are very good at building interfaces. They are simple and easily accessible. In our systems, several problems relate to bad interfaces. For example, a student should be able to create a short list of interesting projects. Another interface aspect not yet developed is the use of alerts. For example, a student-assistant could select interesting issues and an alert would inform them when the issue is put on need review. This is also applicable to evaluation, which would require an alert once a student has created an evaluation for a particular issue.

The simple rule of two reviews for each issue has to be improved. Each issue now requires the creation of two evaluations. The current static and quantitative rule should be replaced by a dynamic and qualitative rule that takes into account how good the review is. The whole principle is that you give as much as you ask. So if your review explains everything, you only need to give one review. When creating poor or only reasonable reviews, it means that you need to do more reviews. A related improvement is to hide a review of an issue requires more reviews, in order not to bias these further reviews. The reviews should become visible after the evaluations have ensured that most of the issue is covered. Of course, the person who creates the review needs to be able to see the feedback.

At the moment, little automation was done for the workflow: activities of the students would not immediately change the state of the issues. This may create misunderstandings. One example is putting an issue automatically on need review once the spreadsheet is uploaded. Similar to the reviews, once a review is given the issue should automatically shift to "need evaluation" and not just stay on need review.

Another interesting opportunity is to open the system to everyone and not restrict it only to enrolled students. A separation between those students can allow the registered students to get certified by ensuring a quality check of the evaluation by a teacher. The difference can be realized by the state of the issue. The issues posted by registered students would shift from "need evaluation" to "need verification" (i.e. evaluation by other students and not by an authority) while issues by unregistered students would close automatically after the evaluation. A time-limited period also needs to exist for the evaluation. In case the student is unregistered, the issue would close with the label "not evaluated" or even "not reviewed". Registered student interfaces need to exist to ensure that the issue is properly reviewed and evaluated. The assistants can also become more open, by having partnering organizations becoming assistants or even teachers in the system. Last, but not least, the system can be open in its development. This has not yet been structured because of limited time and the focus on demonstrating the scalability.

If we consider the practice of MOOC today (Koller 2012), it is clear how big data allows new opportunities for artificial intelligence to data mine the huge activity base. Some of the MOOC machine-learning solutions can be applied to POESy and it is expected to become better as the system is capable of servicing more students. The MOOCs now focus on classic education and POESy can be a way to shift to project-oriented education. Norvig (2013) suggests personal MOOC by one-on-one tutoring and POESy can be a way to reach this. For POESy, another opportunity also exists not related to MOOC, but to the micro-spinoffs. This will be investigated with the ÆIP architecture in Chapter 11.

9.4 Research Question III.2

What insights can experiments in academic education give us?

Starting with simple Action Research eventually the CAR funnel was used to describe how prototypes could emerge and CAR horn was used to describe how support frameworks could develop. For the agile education, several iterations of the experiment have been done. This creates three milestones. The first is a proof that agile education is possible. The second milestone was the explicit use of the CAR funnel for the development of student projects into prototypes. The third milestone is the recognition of how prototypes are potential micro-spinoffs. The development of WSDB not only gave us a better course, it also allowed students to contribute to the research on Internet innovation. This was because the student projects became examples of potential spinoffs and therefore a basis for investigating managerial strategy.

While the agile education experiment was an innovation to the content of the course, the scalable education experiment is an innovation to the support framework and validation method. Instead of validating a project, we validated issues, which were well-defined tasks developable by one individual. In fact, the group size of the project no longer mattered. It could be an individual project or projects with large number of students. For each issue created, a student had to create two evaluations. Students had considerable flexibility to fulfill the criteria of the course. They could create more issues or more evaluations to replace bad issues or evaluations. The score of the course could be reached by creating issues in different categories (model, analysis and simulation) or by using more advanced issues in one category (basic, normal and advanced).

Not all development for the scalable education was developed up front. Many of the dynamics were discovered during the course of the experiment, such as the three different interfaces (student, assistant and teacher). Development solves some conflicts. Other conflicts required extra instructions. Some of these instructions can be replaced by functionalities that could not be created on the job, but are described for future development. During the development, it became clear how a marginal function would become the key function in a next iteration. The issue queue was, for example, marginal in WSDB and central in ORA.

The ORA and WSDB courses were not structurally linked, but they could be. This would improve the development of micro-spinoffs. In fact, several other courses may need to be drastically innovated, such as finance and entrepreneurship. A two-year master program where the goal is not to gain a master degree but to be part of an ecosystem spinoff is envisioned. This two-year master's program will be examined in more detail for the ÆIP architecture (Chapter 11).

10 Participatory Action Research

10.1 Introducing the Drupal case

The education experiments have shown how the CAR dynamic "bootstrapping cascade" comes to be applied. The second validation is about the CAR dynamic "spreading activation". Spreading activation is recognized in loosely connected organization within an ecosystem. The dynamics of spreading activation have been related to the venturing in the CAR venturi (see Section 8.2.1). In the education experiment, the knowledge creation was complex adaptive. Now the motivations become complex adaptive by the alliances that can be forged. The participation research focuses on one project where the dynamics of the ecosystem are consistent with the theory on self-organization. This first section elaborates on the conditions of the ecosystem. The second section presents the interviews done with the entrepreneurs in the ecosystem and the last section considers the CAR method applied in this case.

The self-organizing conditions show a state far-from-equilibrium towards the social dynamic of the ecosystem. Between 2003 and 2005, I have explored Free and Open Source Projects (FOSS) project, mostly during the FOSDEM conference in Brussels. The FOSDEM conference is a place where many FOSS projects meet and provides an open view on what is happening in the FOSS world. In December 2005, our research project (Coenen et al. 2006) on "Knowledge Sharing via Social Software" (KnoSoS) made a "Strengths Weaknesses Opportunities and Threats" (SWOT) analysis of Content Management Systems (CMS). The SWOT made us focus our software development on Drupal and some interesting dynamics of the ecosystem were recognized.

Drupal is not the most popular CMS. It has an environment where the ecosystem is in a state far-from-equilibrium. The state creates a fascinating and rich culture with a strong community. It creates the conditions for the Complex Adaptive Conference Organization (CACO), as introduced in Section 7.2.3. The informal Drupal event during FOSDEM (26th February 2006) allowed me to get involved in the community development. I co-organized the Drupal conference, called Drupalcon, in Brussels later that year. In 2005 and 2006, these Drupalcons were organized in the shadow of larger FOSS conferences, like FOSDEM and OSCON. The 150 places for Drupalcon Brussels were so quickly taken that it was clear that more professional conference organization was needed. After the experience in Brussels, the founder worked on a foundation as a legal structure for later Drupalcons. The size of the conference grew almost exponentially until 2010 when it reached 3000 people with Drupalcon San Francisco.

The emergence of the business ecosystem for Drupal occurred when the CACO was emerging, which was between 2005 and 2010. In late 2009, several signals showed the change of the business ecosystems, which I considered an indication that the ecosystem shifted from the incubation phase into a growth phase. At the

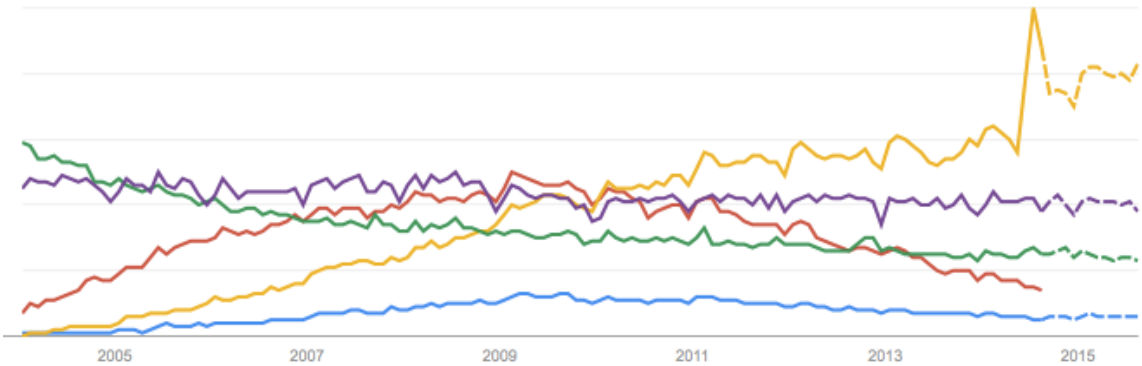
conferences in 2010 and 2011, I interviewed several of the entrepreneurs to capture the narratives describing the dynamics of spreading activation between the different organizations in the evolving ecosystem. The second section investigates the narratives. In this section, I give more detail on the conditions that make this project relevant for our novelty research. The first subsection contextualizes the Drupal project with other CMS. The second subsection elaborates the far-from-equilibrium state and what conditions made this project have such a state.

10.1.1 **SWOT of CMS**

The landscape of CMS is not easy to draw. One reason is that an ambiguous boundary exists between CMS and software development framework. The CMS is typically related to human interfaces to manage users and content. The frameworks are software structures to support the development of such human interfaces. Few projects would make a clear difference between the CMS and framework (e.g. the Plone CMS on the Zope framework). Our interest in CMS relates to a social-technical nature, not purely a technical design and therefore the more technical solutions were not our focus.

To elaborate the social nature, let us look at the trend from proprietary CMS to FOSS solutions. This can be visualized by Google search trends indicating the popularity of one search relative to the other (Figure 10.1). Before 2005, company products would be searched more, in particular the Lotus and SAP search keywords. From 2004 onwards, FOSS solutions would become more popular search terms. The two most popular search terms would become Joomla (formerly known as Mambo) and Wordpress. In 2010, many of the systems became equally popular. Today, Wordpress is the most searched CMS. The trend is but illustrative to demonstrate the larger shift to FOSS CMS applications. Although searching for a CMS gives us an indication of the interest of the (global) public in such CMS, it provides little insight on the effect that the CMS trend has on Enterprises solutions. Let us first examine the CMS trend.

Figure 10.1 Google Trends **Lotus**, **SAP**, **Joomla (+ Mambo)**, **Wordpress** and **Drupal**

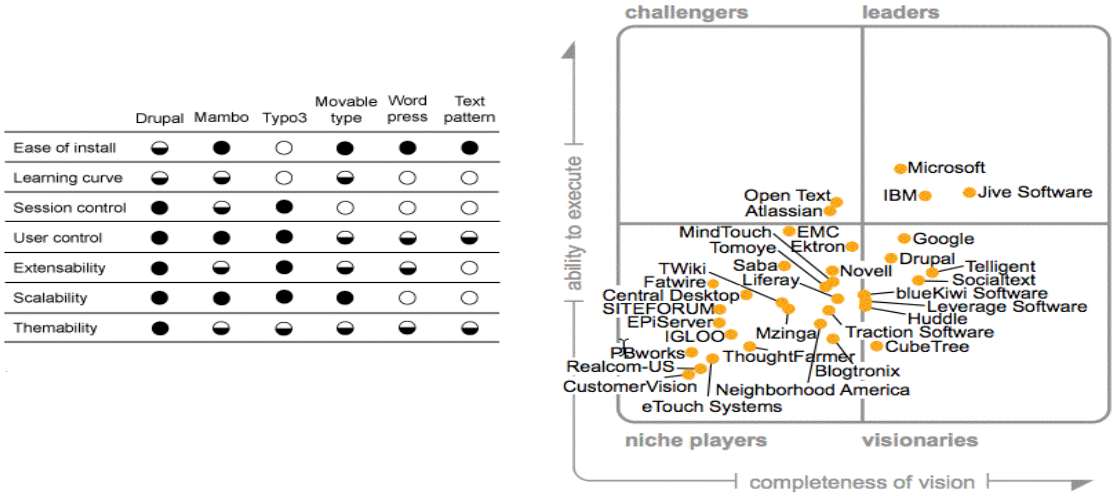


In Figure 10.1 it can be recognized how before 2005 the most searched CMS were Lotus and SAP, two proprietary CMS. While Mambo would become popular, it would have a resulting unstable community and some of the Mambo developers began the Joomla project in September 2006. One year later, Joomla

replaced almost all Mambo searches. In Figure 10.1, both Mambo and Joomla are combined to get a view on how this split, which is called "forking" in the FOSS world, had a negative effect on the overall momentum of the project. Between 2006 and 2011, no dominant search was recognized, but later it clearly became Wordpress. Notice that Drupal is hanging on the bottom of the CMS trend.

Drupal is an enterprise solution that becomes recognized by two other references. The IBM software group revealed in July 2006 a SWOT analysis about existing CMS.[3] Out of the SWOT, the strength of Drupal's extendibility and scalability became recognized (left side of Figure 10.2). This can be compared with the more popular CMS like Mambo and Wordpress that do not score that well. Type3 is another good alternative from a technical perspective, but as a public trend it is much smaller than Drupal. Later another important analysis put the spotlight on Drupal. In October 2009, Gartner produced a report on social software.[4] Drupal was put in the visionaries' quadrant of the "Magic Quadrant for Social Software in the Workplace", while none of the other systems showed up in the Gartner report (right side of Figure 10.2). The Gartner report reflects the emerging interest of enterprises in Drupal. Drupal has become particularly interesting for governmental sites and for large media sites.

Figure 10.2 Left IBM SWOT on CMS, right Gartner on social software



The Drupal ecosystem was in a premature phase from its first development in 2001 until 2005. Between 2005 and 2010 the project was in an incubation phase. In the narratives, some businesses elaborate how they discovered Drupal in late 2004. The first Drupalcon events took place in 2005 and that year is considered the real turning point. Similar to the end of the incubation, some event occurred late in 2009 that created important milestones for the ecosystem, like the first actual acquisition and the announcement of USA governmental involvement. For example, whitehouse.gov and house.gov became Drupal sites. The effect of the events resulted afterwards in a reaction by the ecosystems and 2010 is

[3] http://www.ibm.com/developerworks/ibm/library/i-osource1/index.html

[4] http://www.gartner.com/technology/media-products/reprints/microsoft/vol14/article5/article5.html

considered the transition year to the growth phase. Drupal aligns with the growth phase of Internet innovation wave 3.0 (see Section 5.2.9). As a result, Drupal is a proper environment to examine wave 3.0 in practice. In the case of Drupal, the problem-solving ability of wave 3.0 is related to governance, while the ecosystem has strong problems with education. Before examining why this relationship has occurred, let me first give more insight on the self-organizing dynamics of the ecosystem for the novelty model.

10.1.2 **The balance of the ecosystem during incubation**

The business ecosystem of Drupal is very distinguishable from some of the related FOSS projects. Where other FOSS projects would be community dominant or business dominant, Drupal shows an interesting balance. Some community dominant FOSS projects are the Apache projects and several Linux distributions. Other FOSS projects have one major company behind them. For example, the CMS WordPress has Automatic Inc., while the software platform Eclipse has IBM's RationalDivision. Some refer to the company Acquia as performing that role for Drupal, but the comparison does not hold. Acquia was announced late in 2007, messages of first employees arose early in 2008, but the actually launch of the first business was for September. Acquia became a player late in 2009, which is 5 years after the first emergence of the businesses ecosystem. Acquia is an important company for the growth phase of the business ecosystem, but it was not involved in the incubation phase and that makes all the difference.

To understand why the founder, Dries Buytaert, started up his business so late, requires some insight in his personal history. In 2001, when the project started, the founder was a Masters student and in 2003 he became PhD student. As one of the conditions for his PhD scholarship, he was only allowed to have non-commercial activities. The group dynamics only emerged in 2005, which was halfway through his PhD scholarship. Therefore, he wanted to finish this PhD first. In 2006, when I co-organized Drupalcon Brussels with him, he expressed the restriction that he had as a frustration. The constraint drove him into a particular role of mediator for the business ecosystem.

Drupal's business ecosystem has evolved with this unique balance between business interests and community interests. The hybrid is essential to the self-organizing dynamics. The Drupal project in 2005 was small allowing agile development and was relatively approachable for voluntary developers. By late 2009, Drupal had become very hard for voluntary developers because of the growth of complexity. Most of the developers would be in so-called "Drupal only companies", allowing them to become profoundly involved with the development. Another interesting event at the start of the incubation phase explains why Drupal in 2009 had milestones related to governance. In 2003, Drupal became the tool for the presidential campaign of Howard Dean creating a distribution called Deanspace. The sudden attraction of resources had the potential to break the fragile community between Drupal and Deanspace. The effect is similar to the forking of Mambo and Joomla. Drupal's community diversity allowed overcoming such perturbation and instead of "forking" Drupal

has shown "Spooning", by integrating the diversity of Deanspace into the core of Drupal version 5.

10.2 **Narratives on the business ecosystem**

The pioneering companies were identified first by looking at the sponsors of the early Drupalcons, as well as through networking events that resulted in in-depth interviews with twelve pioneering companies. Not all pioneering companies have been interviewed, but twelve is a fair share that does make a pattern emerge. I talked mostly to founders, but in rare cases also to the business strategist of the company. During Drupalcon Copenhagen (2010) I interviewed: Eric Gundersen of Development Seed, Jeff Walpole of Phase2 Technology, Liza Kindred of Lullabot, Matt Cheney of Chapter Three, Michael Haggerty of Trellon, Mike O'Connor of Commerce Guys, Tiffany Farriss of Palantir, Thomas Barregren of NodeOne and Todd Ross Nienkerk of Four Kitchens.

In Drupalcon Chicago (2011) the interviews included: Aaron Pava of Civic Action, Chris Bryant of Gravitek Labs and Michael E. Meyers of NowPublic (acquired by Examiner). The first two interviews in 2011 were too chaotic and so the cases have not been used. All of the other cases are discussed. Most cases are described in the first subsection. The story of Chapter Three and NodeOne are held back for the growth phase. While the companies emerged in the incubation phase they show some interesting dynamics for the early growth phase. This is described in the second subsection. Considering how fast the ecosystem is growing, it should be clear that the stories are only a moment in time and do not reflect the state of the companies now. For example, some of the companies that I had approached did not exist by 2010 and so I have not been able to interview the entrepreneurs of those startups.

With the participation research, I've noticed how important the business ecosystem is to nurture the whole community. They are doing it in a way that seems to be an optimal open innovation approach. It was my belief this open innovation approach was based on a cultural co-opting by the entrepreneurs, but little did I know of the actual dynamics. To validate the dynamics, I performed qualitative interviews with the entrepreneurs and that revealed a very different force responsible for the open innovation. It was not a cultural issue, but a pragmatic exaptation of technological support that drove the open innovation. Indeed, unintentionally the development ecosystem had created the environmental enrichment that allowed open innovation as a self-organizing phenomenon.

In the interviews, one of the first questions I asked was if they used open innovation intentionally. In most cases, I then had to elaborate what open innovation was. In all of the cases, they answered with "definitely not, what a terrible idea". A qualitative interviewing method was required to retrieve how circumstantial constraints create the conditions of the hidden open innovation. Fontana and Frey (1998) make clear that for qualitative interviewing, questions must be asked person to person. Mason (2002; 2006) sees the interaction as an investigation method that can process the tacit knowledge. She calls it the

creative interviewing method. I have applied this method to find the answers and indeed process the tacit knowledge of the entrepreneurs. Most founders expressed after the interview that they enjoyed the method, giving themselves an interesting reflection on their experience. In all cases, the interviewee were told that the method would be used to discover their relation to open innovation. Let me give the stories now, in an order so as to minimalize repetition.

10.2.1 **A snapshot of the stories**

Liza relates that she was hired in January 2006 since Lullabot needed someone to say "no" to potential customers. In Lullabot, the feeling existed that the demand for Drupal was so large that more shops (development company) were needed. Consequently, they changed their business model from a development company to become more of a Drupal training company. It triggered many of the other development companies to add training to their services.

The story shows how customers are not the scarce resources of the ecosystem but that talented developers are. All of the entrepreneurs would elaborate on how their primary concern was making their developers happy. To understand this better from a business perspective, one needs to recognize the high-end developing that is required, making the developers more software engineering researchers. In other words, the developers had to be gifted to be a useful resource and giftedness is indeed a scarce resource. I've experienced this during my participation research where my Masters education in software was essential to keep up with the discussion that I had with the lead developers. Many developers did not have an academic education and several even openly showed their dislike for it. How they became talented is by being submerged into this enriched environment that shaped their talent to the specific niche. Considering this ability of self-regulated education, makes it fascinating to find that education becomes the biggest problem of the ecosystem (see Section 10.3.3).

The largest of the Drupal shops at that time was Phase2 Technology, with 40 employees, half of them developers. Jeff Walpole explains that Phase2 was a custom Java shop in 2001. He wanted Phase2 to be a "thought leader" in software development. However, the Java market was already mature and the new trend was towards outsourcing. Therefore, the team looked for other projects, and switched to Drupal in 2005. It was not easy to do as a large organization in a new market. The hunger of a 40 person big company did lead to stress. In contrast, most of the emerging companies were below 20 people. During that period it may indeed have been better to be small. The stress does pay off, since during the transition to the growth phase such size was required.

By contrast, Four Kitchens was one of the smallest companies. They just bacome a 12-person company in 2010 but had been a 4-person company in the years before. Four Kitchens focuses on demanding performance and scalability sites, by technical solutions like caching, server architecture, database optimization, etc. While the company was highly specialized at the time of the interview, it did not start that way. Todd Ross Nienkerk explains that in early 2006, the team was working with WordPress on a publishing site. They liked their team and wanted to be creative with the Internet. The switch to Drupal occurred at the end of

2006, yet by 2007, they had large/high-demanding sites, like fundraising for the Wikimedia foundation. It demonstrates how quickly some of the startup companies fit the ecosystem.

Palantir was founded in 1996. Tiffany Farriss explains that it was primarily a consulting firm, but it had a CMS of their own, which had 60 clients in 2006. In 2007, one event changed their approach. They had worked on proprietary software for a number of clients, including one, who had used it to build 120 sites. After the projects had been completed, they discovered that the proprietary software company was stopping its client support without telling its clients. She explains that this was a breaking point, and they decided to focus their attention on Drupal. They have become particularly active in the Drupal Association and core development, which plays to their strength of strategy from their background as consulting firm.

Development Seed is another interesting company. This company has turned their focus away from Drupal with the growth phase, while being one of the most respected pioneers for the incubation phase. Eric Gundersen explains that they were working with non-governmental organizations (NGOs) in Peru on micro-finance when the news of Deanspace reached them. They start working on converting Drupal into Spanish. Gundersen's vision of Development Seed is to be a self-founded R&D company. This is reflected in their actions. They founded Open Atrium, one of the first full Drupal distributions and MapBox, a mapping tool. In February 2011, they sold their Drupal work to Phase2 Technologies to focus on MapBox. As a result, they left the core of Drupal development. It is related to the loss of agility of the Drupal project, which became incompatible with the founder's vision of a self-founded R&D company. Development Seed is not the only company with a strategy towards R&D. Pronovix by Kristof Van Tomme has a similar interest and is still part of the ecosystem, while Development Seed moved away from Drupal when the ecosystem entered a growth phase.

Trellon has provided important and systematic sponsorship for Drupal conferences. Trellon is a development shop, which began operating in 2003 with another OS CMS project called Scoop. In 2004, Trellon switched to Drupal. At first, it appeared that Trellon was even ahead of the other pioneers. Yet Michael Haggerty explains that although the team's contributions were quite tangible, Trellon was less recognized and disconnected from the other shops. During the interview, we debated where this conflict was coming from. It seems related to the hidden order created by business culture. The lack of connection was identified as a difference in business culture between the shops. It demonstrates how the self-organization depends on similarity in culture. Having a similar culture allows a shop to coordinate more easily, while working under different rules makes it exhausting. During the incubation phase, it seems like a company such as Development Seed with an entrepreneurial culture was admired, while Trellon with a more classic business culture was considered disturbing. Note that for the growth phase, Development Seed is not a player any more. For the growth phase, the tension that Trellon had to undergo may well become an advantage.

The story of Commerce Guys also started with a conflict. It was not a cultural conflict, but a technical one. The company Prima Supply, which was selling restaurant equipment, developed an important e-commerce module, called Ubercart. The business had no strategic interest in Drupal and the apathy resulted in a conflict with key developers over the Drupal e-commerce applications. This conflict resulted in a competing e-commerce module called Drupal Commerce. Both systems co-exist in Drupal. Mike O'Connor of Commerce Guys elaborated on their strategic interest in Drupal development, which led to co-development events such as the feature module with Development Seed. It shows that not all companies adjust to the open innovation model, but if they do not it creates space for a new team to step in.

Several companies in the ecosystem worked thanks to venture capital. NowPublic was the first to get an external acquisition. Some internal acquisitions existed within the business ecosystem, but an external acquisition was truly a milestone. Michael E. Meyers explained the vision of Nowpublic in 2004, which was to revolutionize the editorial workflow model. At first, it was hard to get funding. It was requested that they make a proof-of-concept and Drupal was suggested. Meyers did not think that the Drupal ecosystem was commercially ready. He and his team eventually helped Drupal to become ready. The initial funding in 2004 was by friends and family, in 2005 angel investment and in 2007 investment by venture capital. In September 2009, NowPublic was sold to Examiner for $25 million. This acquisition is one of the milestones in Drupal's evolution, showing the shift from incubation to growth.

10.2.2 **Analyzing incubation phase: talents and support**

One pattern that was evident in all of the interviews is their attention to talented developers. They are the true scarce resource in the business. Talent is always important, but not always the bottleneck. Businesses with clear and challenging goals find it easier to attract and keep the talent. More general businesses require a strong community culture to make talent stick. In many business environments, the business processes ensure the strength of a company.

From the interviews, I conclude that the circumstantial constraints leading to open innovation was a direct consequence of the tension between two aspects: the requests of customers and the exaptation of open data. The requests of customers has been recognized by other scholars as a driving force of the innovation in FOSS projects (Bitzer et al. 2007; West & Lakhani 2008). The creative process by exaptation of open data is the essential discovery from the interviews. Because talent is a scarce resource, the business had to get creative with the development. I will describe this creative process in a bit more detail.

The demands of a customer usually results in a study of what modules can provide the best fit to the needs of the customers. It requires a description of the improvements that are needed to the existing modules. In some cases, their own developers could create the required improvements. The richness of the development and the scarcity of talent makes it likely that the company did not have the talent. Because the study would identify some specific model, and because the model has open data, it can be used to identify the lead developers of

the module. Talent scarcity makes the best developers most likely to be in one of the Drupal companies. The developers would become the bridge between their own company and the company having the custom demand. If the developer was interested or could be persuaded to implement the improvements, then the two companies could work out the business collaboration for the improvements. The tool used by the developer has created the open data. It was exapted by the manager to create business.

10.2.3 **Early stories of the growth phase**

When writing this review, I found that some Drupal companies had the size to cover a large part of a market. Because of the early growth phase, I may not be aware of all the relevant companies. For example, it is known that Phase 2 Technologies was doing many internal acquisitions and was getting ready for the growth phase. While I had the chance to interview the company about the incubation phase, I did not have the chance to interview them about more recent activities. To provide a glimpse of the growth phase, I focus on two companies: Acquia and Wunderkraut. Acquia is a venture capital bootstrapped company by the founder of Drupal. With the founder as lead, Acquia knew the Drupal talent and could attract it. During Drupalcon Szeged (2008), Acquia was first announced. A fear existed that Acquia would absorb the already scarce talent. In terms of developers, the company is smaller than Phase2, NodeOne, Capgemini, and dozens of other companies (Buytaert personal blog sep. 2011). Wunderkraut is the effect of a merger between several Drupal companies, initiated by NodeOne and Krimsom. Insight into Wunderkraut was achieved by interviewing the founders of Krimsom. The insights about Acquia come primarily through the personal blogs of the founder Buytaert.

Acquia's target was to grow the ecosystem by external and internal means. In both cases, the company was trying to use economies of scale, to strengthen partnership relations and to reduce the risk for the smaller Drupal companies. An example of the external growth is found by interacting with big (external) companies like Capgemini. While these companies bring in larger groups of Drupal developers than any of the existing companies in the ecosystem, they do not have the culture of working in such a community. This is not only about giving back to the community, it is also about understanding the benefit of working in a complex adaptive system. To service these large players, Acquia has announced the "Large Scale Drupal" program (Buytaert personal blog March 2012). It is a club only accessible to the large players and helps these companies to adopt the Drupal culture. The expected effect is more efficiency for the partners and more contribution to the community.

For the internal growth, let me consider another company in the ecosystem. Matt Cheney explains that Chapter Three was a consulting firm in the summer of 2006. By 2008, its business was site building, themes and training. Chapter Three became an Acquia training partner. While they provided the curriculum, Acquia was providing marketing and sales for the training. This enabled them to focus more on what they really wanted to do. This approach illustrated the use of economy of scale, while not absorbing the small players in the ecosystem. Acquia is trying to ensure the future of Drupal by growing it in such a way as to preserve

the culture and the diversity of the ecosystem. It has made no secret of their goal to develop an IPO. This is, of course, related to their venture capital investment and it is what makes Acquia very different from the other cases. Other venture capital investment startups exist in Drupal, but Acquia is bold enough to set IPO as a target.

The story of Wunderkraut is revealed by interviewing Jo Wouters and Roel De Meester, the founders of Krimson. Krimson and NodeOne are the first companies of the merger. The founders of Krimson have a background in banking and wanted to get the professionalism of that market for agile software development. For that reason, they went to "Open Source CMS Summit at Yahoo" in Sunnyvale on March 22, 2007, an event that was overrun by people that like Drupal. To reach their vision, fast growth was necessary. However, they were surprised at how large the growth had to be. Their culture would be very close to the community spirit, making them well represented at Drupal events. NodeOne exhibits an even bigger community spirit in the sense that they involve other members of the community by organizing playful events. In Copenhagen, they had a "Drupal the Card Game" and their rock band "Kitten Killers" gave a performance. By interviewing the founder Thomas Barregren at Drupalcon Copenhagen (August 2010), more insight into the company was obtained. For Drupalcon Paris (September 2009), they organized the "Drupalcon road trip". It is with this road trip that the NodeOne team visited the Krimson team in Antwerp. They discovered their similar interest for the future. Eventually it resulted in the fusion of NodeOne, Krimson, Mearra and Wunderkraut, which was announced during Drupalcon Munich (August 2012).

The relevance of small business events for Drupal has been essential for the natural merger. An example was the 2010 Brussels CXO meeting, organized by the company Pronovix that also organized Drupalcon 2008 in Szeged. The contact between NodeOne and Krimson would get stronger during such smaller events, beginning with the Drupal CXO in Brussels (October 2010) and continuing with the Drupalcamp Stockholm (May 2011). During the Drupal Products Meet-up in Rome (February 2012), the plans became more concrete and the details were worked out. At that time Mearra joined. Part of the plan was to have a North-European cover for Drupal, which required expansion to other countries. The small shop Wunderkraut in Germany joined the consortium. A bigger meeting in Amsterdam (June 2012) was created for the legal aspects of the fusion and to prepare for the big exposure. This meeting was no longer during a Drupal event. The meeting dealt with the level of detail for the holding, such as how the companies should transfer the majority of their shares to the holding. After that meeting, the employees were also informed. However, it stayed a secret until Drupalcon Munich (August 2012). At that time, the negotiations with a London startup were finalized, which left Wunderkraut holding a large North-European coverage.

The coverage of North-European is important to create websites for enterprises that play on this market. For example, banks would only work with development companies that have revenue above 5 million dollars a year. Wunderkraut aims to be for the European market what Acquia is for the U.S. market. However, their approaches are radically different, which relates to the circumstantial

constraints. Wunderkraut has 140 employees and in 2012 was the largest company in terms of Drupal developer staff. For Wunderkraut less than 10% of the staff is in sales, in contrast to Acquia where sales account for over 50% of the staff. The differences are related to the type of companies that they try to be. Acquia is a service company, creating products by external partnership. The Wunderkraut partnership is internal. The holding stays in the hands of the founders, giving them autonomy, but with shared goals and risks. Both companies do make an effort to promote the Drupal culture. The example also shows how a large difference between big players is expected in the growth phase, just as it was with the agile companies during the incubation phase. This strengthens my belief that I should continue the participation research.

10.2.4 **Waves of Internet Innovation**

In Section 5.2.9, I've speculated that open governance is related to the wave 3.0 of Internet Innovation and that the growth phase of the wave happens between 2010and 2020. Based on the two earlier waves, it is expected that some understanding should currently be emerging about what identifies wave 3.0. For wave 1.0 it was just one tool, namely the browser. While some options existed, the differentiation was limited. For example, FTP clients also made some of the file sharing easier. For wave 2.0, it is a family of tools called social media. Based on the early insight, I assume that wave 3.0 could be described as a family of platforms that are used to build mobilization systems. Heylighen et al. (2012) elaborate how mobilization systems stimulate people to act towards specific and common objectives. For example, the application frameworks for smartphones are mobilization systems for the development of micro-applications.

Drupal is one of the projects on wave 3.0 with its growth phase starting in 2010. How relevant Drupal is for the development of wave 3.0 is impossible to say since we are in the middle of this process. A short insight on some of the emerging technology that may be at the base of wave 3.0 is possible. First, a trend needs to be recognized. Web 1.0 was purely technical, Web 2.0 became more social and Web 3.0 is more organizational. For example, the event "Apps for Democracy" was a mobilization system where organization was central. The event was a contest in 2009 to create the best use of open data produced by Washington DC's government. The contest triggered a code sprint and the development of 47 web, smart phone and social media applications. It is the whole event that is important, showing how the organization of a contest triggers the mobilization of developers for open governance.

The "Apps for Democracy" event demonstrates constructive co-creation between politicians and the open movement (e.g. FOSS culture). Destructive competition is also recognized, such as the arms race around the open data movement versus the emphasis on secrecy by national secrecies agencies. The public sympathizes with the digital rebellion against such secrecy, with projects like wikileaks, which emerged in 2003. The digital rebellion in the music industry (see Section 6.1.3.1) was to fight the artificial scarcity. The digital rebellion against the national secrecies agencies is about the corruptive effect of secrecy. Both artificial scarcity and secrecy are incompatible with the culture of the open movement. It

is again an argument to consider the public as an autonomous and separate force in the innovation process, as expressed with the Eventuating model in Chapter 5.

WikiLeaks stands in strong contrast to DeanSpace. DeanSpace was the vision of a presidential candidate and shows the deep root of the project from within existing governmental thinking. The involvement of top-level decision makers shows a fast adaptation of the technology. With the establishment of the Obama administration ".gov" sides became powered by Drupal (e.g. whitehouse.gov, house.gov of representatives, etc.). One project adds an interesting dimension, demonstrating how Drupal is a framework for development of open data governance solutions: itdashboard.gov. The IT dashboard is a co-creation of several companies. The tool visualizes the money flow of USA government spending on IT projects. In particular, 27 government agencies had to implement this in 2010, making clear how $78.9 billion was being spent. [5]

10.3 Institutionalizing self-organization.

The limited participation makes it harder to find the essential variables. By shifting to a controlled experiment, as done with the previous chapter, the features can be better understood. The use of participation research as a source for developing controlled experiments makes it clear why it is important to have both validations at the same time. The goal is eventually to provide validation of the ÆIP architecture. The ÆIP architecture is about institutionalizing the self-organization recognized in the participation research. To prepare for the next chapter, this section provides a more structural view of the participation research and connects it to the CAR venturi. The first subsection generalizes the policy from the pioneering companies showing how the spreading activation dynamics come to be applied through organizational policy. The second subsection includes studies of strategy management and shows how the institutionalizing self-organizing stands in contrast with managerial institutions. The third subsection focuses on the CAR venturi, showing how the standing wave is recognized in the Drupal case. The fourth subsection considers where Drupal is failing to institutionalize self-organizing. The failure can give us a better understanding of the model of institutional self-organizing and it is an introduction for the next chapter on the ÆIP architecture.

10.3.1 Guided self-organization in business ecosystems

Two policies, implemented by all the pioneering companies, can be recognized. The policy is so general that it should get recognized in other FOSS projects as well. The first policy is "community first" and the second "community contribution". The "community first" policy is: hurt the company before hurting the community. The "community contribution" policy allows employees to spend part of their time working on their own pet projects (in the community). Both policies may seem like strange, noble and selfless gestures. It is, however, plain business logic to attract the talented developers.

[5] http://www.whitehouse.gov/sites/default/files/omb/budget/fy2013/assets/topics.pdf

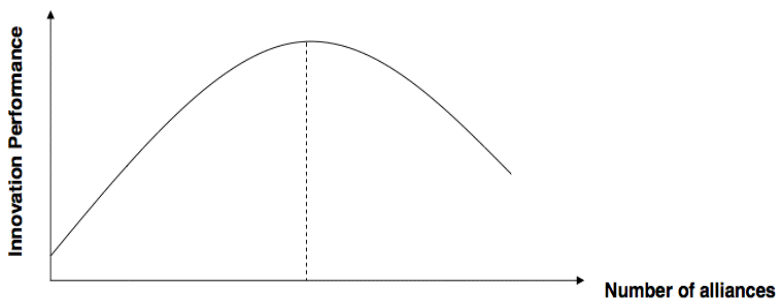
To be competitive, the companies need to specialize on one FOSS project and when the FOSS project matures, the companies should focus only on some niche within the ecosystem. Examples of such higher-order specialization are found with the business narratives. The interdependency of the agile organization with the ecosystem interlocks the companies' fate with the FOSS project. In that case, it is better to allow the business to fail than the community. After all, they can start up a new business or go work for the other companies in the ecosystem. This made the "community first" policy a common strategy under the agile companies. The policy also increases their reputation drastically in the community, which allows them to attract the talented developers.

Attracting talented developers is one challenge, keeping them is the other and for that the "community contribution" policy is essential. From a business perspective, it is considered the cost to operate in the FOSS market. It is my understanding that the "community first" policy forces organizations to fit the ecosystem. The "community contribution" is actually creating soil to grow on. For business to behave smart in the ecosystem requires optimizing the use of talent. The different business narratives show how a variety of solutions exist to optimize the organization within the ecosystem. Because the ecosystem is itself in a phase transition the fitness is a moving target. For example, what was fit and not fit during an incubation phase is very different from the growth phase.

10.3.2 **Management influenced by self-organization**

The collaborating dynamics recognized in the participation research are very different from the collaborating dynamics of other open innovation projects. For example, Deeds and Hill (1996) explain the relationship between innovation performance and the number of alliances for biotechnology firms (Figure 10.3). Once the threshold is reached, more alliances are counterproductive, because they become too difficult to manage. In a decentralized self-organizing setup there is no need for management and so the threshold does not exist.

Figure 10.3 Relationship between innovation performance and number of alliances Source: Deeds and Hill (1996)



O'Reilly and Tushman (2004) argue for ambidextrous organizations that can combine opposite cultures within one company. Ambidextrous organizations need top-level management to regulate the conflict zones where the different cultures meet. The Drupal ecosystem is clearly ambidextrous and the interviews have shown some of the conflicts. However, no management of the conflicts is needed, since they are simply part of the evolutionary process that the

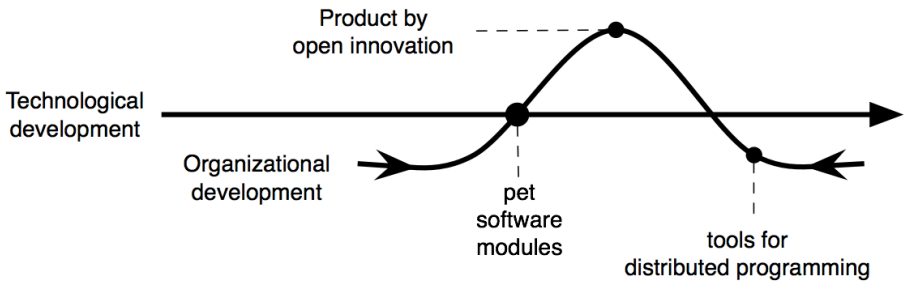
organizations undergo. The organizations can decide to change and find a better fit with the ecosystem or accept the friction that goes with staying in the same situation. Because the strategy is a moving target, some conflict during the incubation phase could become a competitive advantage during the growth phase. In other words, the complex adaptive ecosystem makes it simply unlikely to have certainty about which decisions are strategically sound and which decisions are not. Consequently the diversity of the ecosystem keeps getting recognized while the phase transition is deploying.

The difference between the Drupal case versus the biotech case and the ambidextrous studies can be explained by recognizing how the technology support has created the enriched environment, making many of the managerial needs become self-regulating. In other words, *self-organizing and distributed* methods replace the more classic managerial methods. To go to an ÆIP architecture will require the building of an Enterprise Architecture based on self-organizing and distributed methods. That challenge gets examined in the next chapter.

10.3.3 **Recognizing the standing wave of CAR venturi**

The CAR venturi is about how a business ecosystem gets bootstrapped from a development ecosystem. The bootstrapping is a standing wave between the prototypes developed for the current innovation and the frameworks of the enriched environment. From the interviews, it became clear how the serendipitous wave of open innovation happened by the development of the pet modules. From a business perspective, those pet modules have no economic value yet; they are the cost to operate in a FOSS market. They have the potential to evoke serendipitous events, so they are the soil for future economic activities. The frameworks are the tools used for distributed and self-organizing development. Examples are the distributed revision control (e.g. Git) and the issue queue. These tools create open data that gets exapted by entrepreneurs to create business. The open data is generated by the tools for distributed programming, and the pet software projects create serendipitous events that have opportunities for product and service development by open innovation. The serendipitous effect on top of the technological development shows the application of the CAR venturi method (Figure 10.4).

Figure 10.4 The self-organizing development of a product as serendipitous spillover effect by exaptation of technological development.



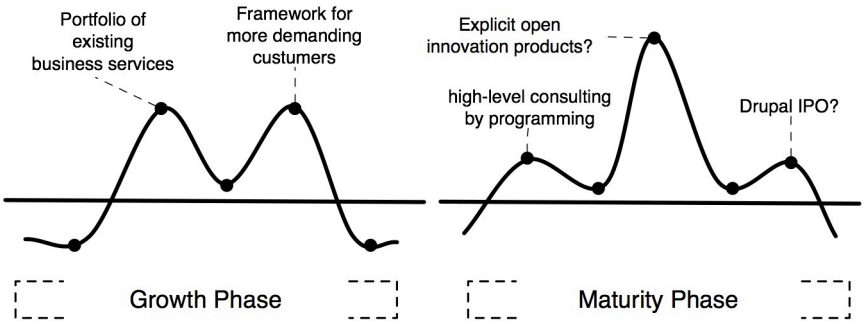
The prototypes (pet projects) come from the currently emerging development ecosystem, while the frameworks come from deeper in the environmental

enrichment. Prior FOSS projects required a system for managing distributed software development and the improvement of the frameworks continue. For example, Drupal first used a "Concurrent Versioning System" (initial released in 1990), in late 2009 it was replaced by "Git" (initially released in 2005).

With the participation research around the early growth phase of the business ecosystem some premature description of the growth phase can be given. The players of the growth phase are explicitly developing business prototypes and business frameworks, as described by CAR venturi. Now more technology exaptation for business can be recognized. Many companies have created lists of portfolios to describe their focus of the development in Drupal. While the portfolios are a summary of existing products, they create a prototype of what this business is focusing on. Just like the business product that arose by adjusted agencies (development prototypes and older frameworks), the business prototype arose by adjusted agencies: development concepts and business products. The development concepts like "agile development" are being exapted by business creating concepts like "agile management". So with the exaptation of development concepts and the abstraction of the existing product portfolio, the business prototype is being bootstrapped.

To service more demanding customers, adjusted agencies for business can now be recognized: business concepts, business prototypes, business products, business frameworks and developmental intelligence. While the business prototypes are creating an internal focus, trying to understand what the core competence of the business is, the business frameworks use economies of scales for more demanding customers. Three types of more demanding customers enter the ecosystem. One type of more demanding customers is the occasional user who likes to pay little and needs simple interfaces. An integrated solution is created for them. By giving such a solution for many customers makes up for the investment of the integrated solution. The second type of more demanding customers are enterprises who require custom built frameworks to support their operations. A third type of more demanding customers comes from within the ecosystem, being the agile Drupal companies, as elaborated with the case of Four Kitchens. The Acquia partner program is one example of such a support framework. In addition, specific development frameworks get built to service these agile development companies (by e.g. Acquia and Pantheon). The business prototypes and business frameworks show how the standing wave of the spreading activation arises (left side of Figure 10.5).

Figure 10.5: Next phase transitions make the spillover wave of spreading activation oscillate.



We can speculate on how this trend of bootstrapping the business ecosystem can behave during the maturity phase. The goal of business prototypes and business frameworks is, of course, to increase the revenue for the business, reached by the amplification of the business product (right side of Figure 10.5). Some high-level consulting is expected to become the main focus for the core developers during the maturity phase. Some pioneering cases already exist in the ecosystem today. One case of high-level consulting is given by Chapter Three, where the developers had to try and hack the security of an airport to identify the weaknesses of their system. The example shows how programming can be a high-end consulting service. For such high-end consulting service, profound theory building and conceptualization is expected, which is the left end of our standing wave, creating unique business concepts.

The right end of our standing wave relates to enterprises. With the growth phase, enterprises have entered the business ecosystem, but they are not part of the ecosystem. If proper interfaces can be built they can become part of an ecosystem, like the "Large Scale Drupal" program by Acquia. Wunderkraut's merger is another way of putting enterprises on the table, now by bundling internal resources to service the enterprises. If the trend of aligning with enterprises becomes effective during the growth phase, it can be a trigger for the development of actual Drupal enterprise during the maturity phase, which is after all the goal of Acquia with the IPO.

10.3.4 **Blockages on exaptation for education**

With the Drupalcon Brussels event in 2006, the concept of talent starvation was already an issue. So far, it is an issue without a solution. The talent starvation is the increasing gap between the available talent and the demand for talent. The experiment on agile education relates to this talent starvation, but the effects of the experiments have never influenced the ecosystem. The main reason is that I've been educating business students and not developers. Therefore, my students would learn how to use Drupal, but not how to contribute to the ecosystem.

In respect to media organization and political organization (e.g. open governance), the Drupal project can successfully show how the self-organization works. The project fails to create a bridge to educational organization, although talent starvation was one of the most persistent problems with the ecosystem. A bridge has two sides, so two blockages need to be explained: from the Drupal community toward education and from the academic community towards the

FOSS community. After describing the blockage, I consider how the test done in my participation research (around CACO) overcomes the issue. The test provided insight, but failed to have an effect. The solution requires an architectural innovation to CACO, which I describe in the third subsection.

10.3.4.1 Drupal's Blockage: training is not education

Drupal's ecosystem shows a good balance between FOSS community and venturing businesses, but has little relation to educational institutes. This explains why business fills the talent gap by training services. Training is not education (see Section 9.1.1). The need for education is so far not answered effectively. To solve the education problem, a complex alliance similar to the existing alliances around open governance is needed, such as "Apps for Democracy" and Deanspace. Examples are alliances with an open university. Instead, business interests dominated the sub-community and no balance with educational interests is recognized. The only educational force recognized came from a larger player in the IT market providing a benefit for the FOSS community: Google's "Summer of Code" (SoC) program. SoC stimulates young potentials to use their talent in a summer job with one of the FOSS projects. Google provides SoC with the funding for student summer projects, while the organization is left to the FOSS community.

During the incubation phase, the Drupal SoC has been essential in creating lead developers for the community. In the early days of Drupal, SoC worked fine enough to provide talent for its slow growth. In the later years, the talent became scarcer because the learning curve became a lot steeper, while at the same time the growth of the community required larger number of such talents. It led to a talent starvation and a change in the culture of the ecosystem. In contrast to 2006, the conference in 2012 showed me how little patience people had. I relate this to the pressure created by the talent starvation. It is a clear breaking point and makes even the most open-minded developer become more protective to avoid burnouts.

10.3.4.2 The academic Blockage: the absence of EduLabs

Academic change goes slowly, since it has to undergo long procedures of checks and balances. In a complex adaptive world, the slow change is becoming a problem, which was indeed a topic for the agile education experiment. IT support for education can be in conflict with the educational institutionalization. Today, some changes can be recognized, like the creation of the Massive Open Online Course (MOOC) by universities like Stanford and MIT. The MOOC is creating IT support of the classic courses where existing knowledge is transferred. The relevance of MOOC becomes less important in a complex adaptive world where knowledge changes rapidly. A more hands-on education is needed with learning on the job using educational projects. The concept of Project Oriented Education System (POESy), as examined with the scalable education experiment provides an alternative.

Other education innovation projects help to build an ecosystem around educational innovation. In particular, it is seen with engineering domains, like the fab-lab. The fab-lab is a small-scale workshop where IT support can allow rapid fabrication by e.g. 3D printers. Other educational workshops, focusing on a particular education, can be recognized, like a language-lab, which are computers filled with software to learn a foreign language. Other education labs are big mobile trucks to bring education to remote areas. We can generalize all the niche labs to "EduLabs", indicating a specific workspace mediating education by IT support. MOOC and POESy should also be considered EduLabs, where the workshop is much more virtual. Even more virtual workshops exist, like virtual labs for chemistry.

The EduLabs are new building blocks transforming education by a phase transition, but this ecosystem of EduLabs is only in an early incubation phase. It is, in fact, part of the Internet innovation wave 4.0, with an expected growth phase in 2020-2030. The actual institutional reform is expected for the growth phase and it may change how education is done (in the social fabric) significantly. Our application of the ÆIP architecture is directed to the educational reform and investigates how the institutional structure of a university may change (see next chapter).

10.3.4.3 The CACO Blockage: nurturing guided self-organization

Based on my own interest in bringing the insight of Internet innovation to the students, I became involved during the conferences in education related topics.

In Drupalcon Szeged (2008), some meetings discussed training services and CMS for educational institutes. During Drupalcon Chicago (2011), I noticed the education being the dominant topic in the BoF sessions and how some interesting diversity was found, like a BoF specifically about using Drupal for research and several BoFs on specific educational challenges (e.g. inclusion). This stimulated me to organize an open space called "DrupalEdu" for Drupalcon London (2011).

The event had 40 participants. My intent was to guide the otherwise self-organizing process, as seen with the multilingual issue during Drupalcon Brussels (see Section 7.2.3.3). Those 40 people would mean 26% of the participants in 2006, which would have an effect. In 2011, 40 people would only be 2% of the participants and may explain the diffusion of momentum. I am guessing that at least 10% is required, so in London it would be 180 participants, which would have been a separate conference all together. So while the pressure of talent starvation is building to a breaking point, the growth of the conference has created circumstantial constraints now making it less likely for self-organization to arise.

Let us get back to Drupalcon as an example of Complex Adaptive Conference Organization (CACO) and speculate how the CACO can create systemic support to nurture the self-organization from the BoFs. Consider the Wunderkraut story and how events helped to discuss the merger. The story shows how a smaller

group can use larger events to get organized. Businesses have the resources to organize this themselves, which is seen in the story. However, other more community-oriented concepts do not have the resources. To work with the available resources the effect needs to be designed differently as a parallel track during the conference, between the unstructured BoFs and the structured tracks. One exceptional part of the Drupalcon can be used as example: core conversations. Core conversations focus the discussion on the core development of Drupal. The core conversations have a dedicated room during the whole conference and protect core developers as a sub-community within the large conference.

Consider the CACO structure of Drupalcon. It is a five-day event with a three-day conference. A pre-event day is used for training and other small meetings. The post-event day is the code sprint (see Section 7.2.3.5). The three days conference has three keynote speakers. The pre-event and post-event have a significantly lower number of participants, about 10% of the main event. My suggestion is to enlarge the number of participants to about 25%. The 25% would consist of participants experienced with CACO and interested in developing more structures for sub-communities. For those people that like to work on the sub-communities a structure is needed that is between the totally fixed track slots and the open BoFs slots. A method would be applied that allows people to mingle with the other activities, but have a protected workspace comparable to the core conversations. Maybe it can be called the "conversation tracks". It must be emphasized that the conversation-track is a constructive group effort that needs to deliver clear targets to allow the process to continue.

Let me elaborate how I see the general process of such conversation tracks. The sub-community would have a dedicated slot for the full five days if they can deliver the targets. The first day would be an open space that allows the people to recognize the concerns. The target of the open space is to create the planning for the third day, when the concerns are shared in a track-like presentation setting. The second day is to do actual work and transform the abstract descriptions to actual presentations and demonstrations. By the end of the day, a short pitch is prepared. The pitch is given to the organization committee who decide if the conversation-track can continue. In the morning around the keynote, the pitches are given to create awareness to the broader audience. The third day is for the presentations and discussions. The fourth day is to integrate the feedback of the presentation and to plan work. The fifth day is dedicated to the code sprint to ensure the work is started in such a way that the participants can continue working as a sub-community after the conference. If at any moment, one of the conversation tracks gets abandoned, the space can become normal BoF rooms again. In this way, the conversation tracks are a hybrid between the well-structured tracks and the fully self-organizing BoFs. The conversation tracks are just a suggestion of how to institutionalize the guided emergence of CACO and some pilots would be needed to figure out if it can work.

10.4 Research Question III.3

Can participation research help to gain more insights into the self-organizing nature of development ecosystems on Internet innovation?

The participation research should have shown how circumstantial constraints allow self-organization to arise often without much conscious involvement of the people and more often as a side effect of their activities. I have shown how the circumstantial constraints have worked when a balance between forces is recognized. The balance between business interest and community interest for software development shows self-organization for the ecosystem. The balance creates a state far-from-equilibrium and requires profound environmental enrichment. For example, while recognizing how Drupal already has technology for open innovation, it was not evident to extract the mechanism for any experiment since the technology is deeply embedded in the fabric of the ecosystem. Applying it for different development ecosystems requires the people in that ecosystem to use similar distributed tools and understand the nature of working in such a fashion.

The self-organization created open innovation. The open innovation is directed by the alliances that can be forged. It was successful for innovation around open governance and media sites. No such open innovation existed around education, which results in talent starvation. The open innovation is by the CAR dynamic spreading activation, which is a relatively simple dynamic to understand compared to the bootstrapping cascade. Still the application of the bootstrapping cascade by CAR funnel and CAR horn is relatively easier, while the application of the spreading activation is deeply rooted into the ecosystem.

The method of CAR venturi needs more research. Only the incubation phase has been examined enough. The growth phase has not yet finished. For the methodology to become reliable, it should at least require a full investigation of the growth phase and the maturity phase, while it should be examined by at least two different development ecosystems. To be sure, the created study is but the beginning of the studies of CAR venturi. For future research, it may also be relevant to interact with a more experienced anthropological researcher to see if the fieldwork is applied properly. After all, I've been trained to validate using experiments and learned the anthropological part along the way. Some more professionalization seems relevant.

The participation research has been more an observation research than committed participation. To be truly committed, I need to be part of a development company, which clearly does not fit with my research interest. A new emerging ecosystem may give us the opportunity to become truly committed, with the ecosystem emerging around EduLabs. Trying to develop POESy more as an academic spinoff may bring us this opportunity. It would also be a new ecosystem just starting an incubation phase. It would be a second test for the CAR venturi. The spinoff needs to get contextualized in the bigger research vision, which is created in the next chapter.

11 Design of the Interversity

11.1 Next generation university: distributed and self-organizing

The Interversity is the envisioned transformation of universities. The university was about "the whole" (from the Latin "universitas"), indicating that universities were the place for universal knowledge. Due to the information overload and the acceleration of innovation, the concept of universal knowledge is becoming an illusion. Even the largest universities today have specialized research performed by specialized research institutes. The Interversity emphasizes the change towards a complex adaptive reality. Interversity draws attention to "what is between us" (from the Latin Inter, like used in Internet, interacting, interchange, interdepend, interbreed, etc.). The Interversity is distributed and self-organizing where IT has enriched the environment drastically. A university is often divided in three pillars: education, research and public service. The Interversity is expected to affect all three pillars. The trend of Massive Online Open Courses (MOOC) shows how the education pillar is affected. To understand how all pillars get affected requires educational experiments.

The agile education experiments investigated how research and public service can become distributed and self-organizing, while the scalable education shows how it can become massive. The research in the agile education is achieved when students start to act like assistants of a PhD researcher. The public service relates to spinoffs, where the agile education experiment has shown how students can create micro-spinoffs. In both cases, the students do research and validation (by spinoffs). In other words, the students utilize methods and technology that make the pillars of a university more accessible. In fact, it relates to the transition created by the Eventuating model, making what was scarce (i.e. university for the happy few) abundant (university for the masses). The first section models how such a transition can occur, which is described as the open Interversity.

The three pillars of a university are presently working separately. In respect to the professors, the three pillars are even in competition, since they need to divide their attention on it. Another opportunity exists for the Interversity to create synergy between the pillars by focusing on the spinning-off of innovation ecosystems. I call this opportunity the integrated Interversity and it requires more institutionalization of the dynamics described by the ÆIP architecture. Where the open Interversity relates to the further development of the POESy framework to support entrepreneurship, the integrated Interversity relates to the integration and expansion of the courses towards a master program for entrepreneurship.

For both type of Interversities, the education is an interface between the development by the ecosystem and the research to create the CAR dynamic of circulating references i.e. both can get described by the ÆIP architecture. The open Interversity focuses on micro-spinoffs and is a support structure for the entrepreneurial ecosystem of small startups. The integrated Interversity is about the spinning-off of ecosystems where research labs are spinning-off of their research by partnering with more mature organizations pursuing entrepreneurship.

The open Interversity relates to how current academic activity can become part of Life Long Learning. The transformation makes some of the dynamics normally only seen in universities become part of the social fabric. This relates to the transition of the Eventuating model. The integrated Interversity is about approaching radical change systematically. It is going to create a much harder challenge and requires much more research. In relation to the description of Internet Innovation waves (see Section 5.2.7), the open Interversity can be part of wave 4.0, now in an incubation phase and it requires a prototype to participate in the emerging ecosystem. We have that prototype through the educational experiments. The integrated Interversity is part of wave 5.0, which is still in a premature phase and therefore the research is on concept building. The integrated Interversity concept relates to the ÆIP architecture as a control structure, while the open Interversity can use the ÆIP architecture to describe the self-organizing coordination.

In a way, the open Interversity is the foundation of the integrated Interversity. This can be explained by considering how the open Interversity relates to the default flow of the meta-model, while the integrated university requires a constructive flow. The default flow of the meta-model only requires the Cohering model and the Eventuating model. The constructive flow also requires the contribution of the Strategizing model and the Establishing model. The open Interversity increases the environmental enrichment and the spontaneous development of radical change is expected to become more likely. The integrated Interversity relates to the artificial construction of the phase transition and the spinning-off of ecosystems. Let us now build models (maquettes) of both the open Interversity and the integrated Interversity to gain some information.

11.2 **Open Interversity: advances for the POESy framework**

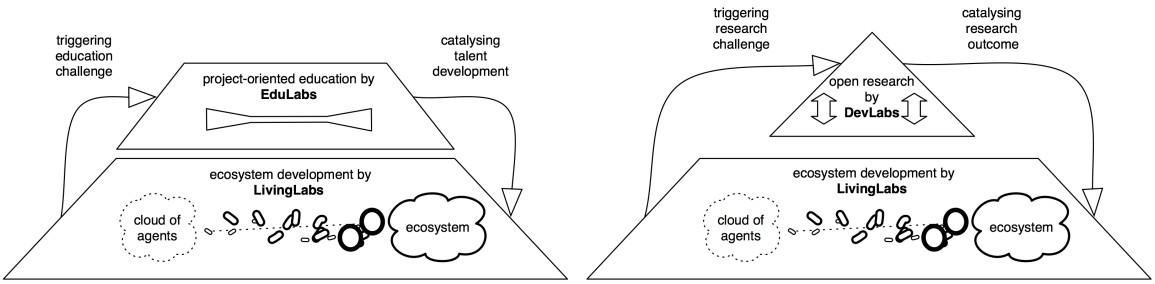
Because MOOCs already address the first pillar, let us give more detail. MOOCs use smart algorithms to automate many educational tasks and make interesting patterns become visible in the big data. The University of Manitoba created the first MOOC in 2008, with 24 credit-bearing students and 2200 online participants (Mackness et al. 2010). The MOOCs became even larger when Stanford University created MOOC courses in 2011 with over 100.000 online participants. The largest MOOC so far involves 300.000 students. The ongoing development of MOOC has already proven how academic education can become massive. For an open Interversity, research and public service also need to become massive. The experiments in Chapter 9 are a proof-of-concept on how project-oriented education creates micro-spinoffs. The scalable education

experiment is a proof-of-concept of how project-oriented education can become massive. To understand how the rare spinoff event can become abundant requires the retrofitting of the concept "lab". A lab is normally only considered part of universities or the R&D facility of larger companies. For the open Interversity, labs become part of our public sphere.

The three layers of the ÆIP architecture all introduce a type of public lab. The base of the ÆIP architecture is about the spreading activation and the development of the ecosystem. It is described by the already established LivingLabs. LivingLabs are user-centered open innovation spaces, which are elaborated on in the first subsection. The second subsection considers how project-oriented education, which addresses the central layer of the ÆIP architecture, can become more generally applicable. This relates to the EduLabs introduced in Section 10.3.4.2. The EduLabs are modular entities to achieve a particular education goal. Such modular entities are expected to become more common by the co-development between the current educational innovation projects.

The top layer brings me back to the participation research and to recognize that software development is a pragmatic and public kind of research, which brings us to the top layer of what I like to call DevLabs. The DevLabs are different from normal research labs since they focus on Action Research and development. The DevLabs have a relationship with the ecosystem that functions as a LivingLab. However, as elaborated in the Drupal case, no bridge exists to education. In other words, the base of the ÆIP architecture with the LivingLabs shows a connection with the two other layers in the ÆIP architecture, but coordination between EduLabs and DevLabs is not recognized (illustrated with Figure 11.1).

Figure 11.1 The ÆIP architecture behind the open Interversity



In the last subsection, I argue how some of the core FOSS development is very similar to the research that I perceive in software engineering labs. It brings me to a discussion on how to understand the difference between the two. The focus of the former is to have a workable code and to make this more efficient they develop software architectures. The focus of the latter is to understand the nature of coding and to make this possible they develop software architectures. Therefore, in a way they do exactly the same, while their methods for validating the software architectures is very different. The core developer has an ecosystem where its software architecture needs to make sense. The researchers need to publish about the software architectures and demonstrate to their peers what the software architecture is about. The latter is, in fact, a much weaker form of validation and so a focus exists on methods to back up the claims. Understanding

how these methods can become part of the core developers practice is investigated in the last subsection. The last subsection also investigates how to make such core development practice applicable for other development and not just software engineering, which will yet again focus our attention to the ecosystem.

11.2.1 **Spreading activation by LivingLabs**

LivingLabs are described as user-centered open innovation ecosystems to test technology. In a first subsection, I elaborate the need for LivingLabs, emerging from a European paradox with innovation. The growing interest for the method has made the research focus on better defining what LivingLabs are, which I consider in a second subsection. In a third subsection, I describe what I consider the essential variables of LivingLabs and in the fourth section, some cases are used to demonstrate them.

11.2.1.1 The need for LivingLabs

The concept of LivingLabs was introduced to study ubiquitous technologies in home settings (Intille et al. 2005). LivingLabs allow experiencing technology in a real environment context, that creates feedback for the validation of the technology. Ballon et al. (2005) recognize that LivingLabs challenges the European paradox. The European Commission released a green paper on innovation (December 1995), in which the European paradox was articulated:

> Compared with the scientific performance of its principal competitors, that of the EU is excellent, but over the last fifteen years its technological and commercial performance in high-technology sectors such as electronics and information technologies has deteriorated.

The complex cultural and national landscape of Europe is a challenge for industrial technology development. This landscape created a meta-workspace for the industrial age (see Section 5.2.4), but now it creates this European paradox. The European context made the need for LivingLabs greater. As a result, in 2006 the European Network of LivingLabs was founded and has grown to just under 300 member organizations in 2012. LivingLabs have rapidly become an entrenched part of the innovation landscape in Europe.

11.2.1.2 LivingLabs research

As practically driven and pragmatically operating organizations, LivingLabs have often been diagnosed as lacking in theoretical and methodological rigor (Ballon et al. 2007). This has led to a research focus that is trying to get a sense of its own identity. Følstad (2008) has done a literature review to identify the characterizing purposes of LivingLabs (Table 8.1).

Table 8.1 Survey created to identify the character of a LivingLab. The survey was given to the member of the European Network of LivingLabs (from Følstad 2008)

High-level issues	Identified characterizing purposes	Common purpose?
Living Lab contributions to the innovation and development process	*1. Context research* (To investigate the context of use)	No
	2. Discovery (To provide insight into unexpected ICT uses and new service opportunities)	Yes
	3. Co-creation (To involve users as co-creators)	No
	4. Evaluation (To evaluate or validate new ICT solutions with users)	Yes
	5. Technical testing (To conduct technical testing in a (semi)realistic context of use)	No
The Living Lab context	*6. Familiar context* (To experience and experiment with ICT solutions in contexts familiar to users)	Yes
	7. Real-world context (To experience and experiment with ICT solutions in real-world contexts)	No
Characteristics of Living Lab studies	*8. Medium- or long-term* (To conduct medium- or long-term studies involving users)	Yes
	9. Large scale (To try out ICT solutions with large numbers of users)	No

During the ISPIM conference (2012), a special track on LivingLabs showed how most contributions were about identifying what LivingLabs characteristics are (Krawczyk et al. 2012; Veeckman et al. 2012; Svensson 2012). To add another dimension to the LivingLabs research, I consider a system review instead of interviews to give a different view of the essential variables of LivingLabs.

11.2.1.3 Essential variables of LivingLabs.

The essential variables are the features that need to have a certain value for the system to exist. These variables allow categorizing conditions for the system's existence (Ashby 1964). For example, living systems are fragile to temperature, but less ao to large changes in pressure. In this respect, temperature is an essential variable and pressure is not. After examining LivingLabs cases, it seems that three essential variables can be identified: level of scale, degree of regulation and novelty ranking. The LivingLabs relate to guided self-organization where agents are added to guide the innovation. The smallest possible scale for LivingLabs is when only one agent is creating the guidance. The prototypical example would be a classroom where the teacher creates the guidance. The larger scale is when the guided emergence happens by the ecosystem. One of the best examples is the Industrial Revolution where several countries were agents in an ecosystem. The scale mostly used by Living Lab institutes relates to a small size ecosystem around a single technology.

The variable "degree of regulation" lies between spontaneous and controlled. The degree of regulation demonstrates that LivingLabs is a hybrid between these two extreme states of full self-organization and full control. For the degree of regulation, a wide variety of the variable is observed in LivingLabs. For many Living Lab operators, the variety is exactly a concern, making it hard to consider the different LivingLabs as being similar. The last variable "novelty ranking" makes innovation vary between incremental (little novelty) and radical (a lot of novelty).

11.2.1.4 Living Lab cases

Examples of different essential variables are visible in Living Lab projects and initiatives. First of all, they include LivingLabs as advanced open spaces. Guidance is often limited to the provision of physical or virtual spaces that facilitate interaction between creative groups and individuals, yet without very specifically stated objectives, guidance or roadmaps, and with a focus on the spontaneous processes of creativity. One example is the Manchester Digital Laboratory or MadLab, which describes itself as "a community space for people who want to do and make interesting stuff - a place for geeks, artists, designers, illustrators, hackers, tinkerers, innovators and idle dreamers; an autonomous R&D laboratory and a release valve for Manchester's creative communities" (http://madlab.org.uk).

There are LivingLabs, which, despite their emphasis on user-driven open innovation, rely on a central authority that issues a number of rather specific guidelines and frameworks to steer the overall direction of innovation. One example is the European SmartIP pilot project, in which citizens in selected urban neighborhoods are given easy-to-use software tools and are being actively solicited by local social workers to invent, prioritize and develop their own neighborhood applications (http://www.smart-ip.eu/). Such LivingLabs are closely related to more classic laboratory practice, but the Lab has been replaced by the city, allowing all kinds of unanticipated effects to influence the phase-gate process of deployment. The process divides the project in phases by gates, where the gates have checks to verify if the project can enter the next phase.

Some LivingLabs are systemic in the sense that all Living Lab activities directly relate to a central management entity. One example is the now defunct Kenniswijk Living Lab in Eindhoven, the Netherlands. This was a meticulously planned and fully managed implementation project that was orchestrated by the national and regional public authorities. Their goal was to use a Living Lab approach in order to develop and commercially roll out a large-scale Fibre-To-The-Home infrastructure as well as a range of related services. Interestingly, the lack of dynamism that surfaced after a number of months of operation, was attributed by several observers to the centrally managed approach, and eventually, a bottom-up, cooperative initiative in the nearby village of Nuenen had to be co-opted into the Kenniswijk project in order to save it from failure (see e.g. http://www.novay.nl/publicaties/lessons-learned-from-two-dutch-LivingLabs-freeband-and-kenniswijk/64764).

Related to the different degrees of scale, micro LivingLabs comprise, for example, a classroom in which teachers and students may experiment with new educational tools and processes, or a small number of households where homecare technology is installed so that its real-life use may be observed (Van Den Eede 2011; Verbeek 2011). Regular-scale LivingLabs include e.g. current 'smart cities' projects, in which several tens to up to a few thousand users are involved in user-driven innovation processes (see e.g. http://www.epic-cities.eu/). Finally, macro LivingLabs have a scale that is similar to the European Commission's Future Internet Public Private Partnership (FI-PPP), which aims at the European-wide implementation of a Future Internet technical platform and a

number of 'generic enablers', which SMEs, non-profit organizations and citizens throughout Europe may use to test and develop new services related to a range of application domains, including energy, agriculture, transport, and media (www.fi-ppp.eu/).

11.2.2 **Opening the project-oriented education**

Central to the experiments was project-oriented education. Project-oriented education is particularly fitting for a broad range of engineering studies (e.g. design studies, business engineering, …). Project-oriented education, enriched by IT, enables knowledge creation rather then mere knowledge transfer (see section XXX). The framework to support the project-oriented education is now a pioneering product. It can be compared to how the atmospheric engine was a pioneering product that was only used for mining. It required Watt's improvement to make the steam engine an open product applicable to a wider range of applications (see Section 5.2.4). By first investigating different engineering studies, such as industrial design studies, software engineering studies and business engineering studies, the workspace for project-oriented education became understood. In particular, IT support mediates the project-oriented education, which gets examined in the first subsection. From these "niche" educations, a more general description seems possible allowing the project-oriented education to become applicable to a wide range of educations. For example, it can shift from a pioneering product (limited to the niche of engineering studies) towards an open product (wide range of educations).

The second subsection continues by describing EduLabs, which are like LivingLabs scaffolds in the enriched ecosystem that stimulates self-organization. The LivingLabs change a cloud of agents to an ecosystem of coordinating agents by spreading activation. The EduLabs need to stimulate the bootstrapping cascade. In the third subsection, one case is examined, showing both a clear relationship to both LivingLabs and EduLabs. The last subsection builds a model based on that case.

11.2.2.1 Mediation by IT workspaces

It is my understanding that the workshops, as environmental enriched workspaces, are the essential mediator for the project-oriented education. For industrial design studies, the workshops are clearly visible, since the education relates to manipulating materials with machinery. In a way, many of the more practical schools have already advanced workshops (e.g. garages, kitchens, etc.) where they allow students to experience the tools and methods. In workshops, resources are transformed to products (e.g. cars, food, etc.). The differences between educational workshops and actual workshops are not so great. Until recently, the workshops were only a part of practical education that were created to prepare people for work. I will now argue that development around workshops has become a tool for more general education and how it envisions that any education can gain an engineering equivalent of the current education by creating advanced workshops.

For software engineering, the IT frameworks function as the virtual workshops. For example, without computers, programming languages and systems to run such languages (compilers or interpreters), the software engineering would not exist. Next to the core of the IT workshop many enhancements exist, such as Integrated Development Environment (IDE, e.g. Eclipse), communication media for peer learning (IRC, forums, etc.), and distributed version control system (e.g. Git). The tools and scaffold for software engineering are codified. It allows for the development of codified validation tools. For example, compilers and interpreters may tell you where an error is located and provide more info about the error of your code.

The codified nature of software engineering stimulates self-regulation. If an error occurs, hints can be created. If the code works, the program can run creating feedback about the code. Business engineering is not codified, while it does contain clear artifacts to support the engineering practice, like financial tools and statistical tools that can be supported by IT (e.g. spreadsheets and statistical programs). In contrast to the software engineering, the human validation is needed even at the beginning. Software engineering is simply much more self-organizing and distributed thanks to the codification. Self-organizing and distributed is reachable for business engineering but it needed exaptation of the software engineering artifacts as was demonstrated with the scalable education experiment. In other words, the IT workshops were still too much of a pioneering product that had to be improved to become more open.

11.2.2.2 Transforming every education to engineering

Shifting from physical workspaces to codified workspaces should create the understanding of the improvements required to make project-oriented education more commonly applicable for a wide range of domains. Just like "labs" is becoming part of the public sphere, I claim that by making "engineering" part of every education, those education domains can become more self-organizing and distributed. Such a claim may become more acceptable now that the social abilities of IT are recognized (e.g. Facebook and Twitter use for social protest). Concepts like social engineering, political engineering, legal engineering, etc. are already used, but environmental enrichment by IT support is marginal.

Transforming education domains, like moral studies and history, is simply considered harder and require much more development of IT tools before such education can gain an engineering alternative. For example, the structure created in the scalable education experiment around reviews and validations are scaffolds for structured debate. It should get improved which will allow the artifacts for structured debate to get improved. How much more improvement is needed before the scaffold for structured debate would become developed enough to be a valuable tool for fields such as moral studies would be an interesting investigation for future research.

The IT support, creating educational workshops, should not be confused with virtual simulation environments like a virtual classroom. The workshops we are interested in require exaptation. It is helpful to compare it to other technology

tools. For example, the drill engine gained a wider range of applications e.g. screwing. In the same way, the tools to support software development can gain a wider range of applications e.g. a tool for structural debate. A tool for structural debate can benefit any education. It is by using this philosophy that many of our current educational tasks can become enriched, stimulating self-organization, as demonstrated with the scalable education experiment.

11.2.2.3 From blended universities to EduLabs

Innovation around academic education creates an argument for blended universities. Blended universities are a hybrid between the online open universities and the classic campus universities. While the open universities allow an improvement of many educational aspects, the campus has some undeniable benefits that should not be lost. Consequently, a blend is emerging.

Open universities have explored more organizational support for the distributed and self-organizing education. An example is the Accreditation for Prior Experiential Learning (APEL) protocol, which allows the prior knowledge of a student to become credits for a particular education. The APEL protocol is an administrative innovation that improves the workspace of education and is elaborated on in Section 11.2.2.5. There are other types of educational innovation, like Social Inclusion and Integration (SII). For SII educational innovation focuses on why a particular group falls behind and designs solution to overcome such problem. The focus of SII requires more organizational and social innovation to bring education to those who need it the most. With both APEL and SII the innovation focus brings us back to the need for Enterprise Architectures, which involve technology, as well as the organizational, administrative and operational parts of an organization.

11.2.2.4 Design for (every) one, a case for the internal interface

To give a practical example of SII innovation by EduLabs, I consider the project-oriented education by HoWest's Industrial Design Centre (IDC). The bachelor program of IDC-HoWest has high standings with the industrial partners and is considered a good practice for modern education. The SII innovation IDC-HoWest is called "Design for (every) one" (http://designforeveryone.howest.be). The aim is to develop assistive artifacts for meaningful daily occupations to allow disabled people more autonomy in maintenance of their own physical, mental and social well-being. This case can illustrate how an educational project can also be a useful development.

Disabled people and their caretakers become committed actors in the design process and create the LivingLab for the student's prototypes. Once the prototype is created, it changes the needs of the disabled person, which makes the bootstrapping cascade dynamic become recognized. The clear social engagement solves an actual need, while the solution remains a prototype so that the disabled person can easily maintain the solution.

By combining the IDC-HoWest case with the business engineering studies around prototyping in my experiment, it can be possible to make the prototypes be used in a different setting where prototypes for economies of scales can be created. Let me give one specific project to support my case. The case of Fred's prism glasses was documented by De Couvreur et al. (2013). Fred has ankylosing spondylitis. This disease mainly affects joints in the spine and causes rigidity. Because of this disability Fred cannot lift his head entirely upwards. The design to improve Fred's condition is a prism glass, which are glasses that use a prism to see at a 90° angle. While the market for ankylosing spondylitis may be small, the prism glasses can be used for other applications.

In fact, the prism glasses are familiar to me in a very different context. I am a climber and the company "Power'n play" sells prism glasses to climbers. The glasses allow for securing a person on the wall without a need to look upwards all the time. Frequent climbers like me know the pain in the neck from all the looking up. The glasses create a huge increase in comfort, and although the glasses are not cheap, I own a pair, just like most of the climbers I know. The argument I am making is that while a design for a particular disability can solve an individual need, the design can become exapted for other markets.

11.2.2.5 Enriching the educational environment

Finding economic value for the assistive artifacts requires out of the box thinking. Another case of IT support can extend our story. The company CREAX uses a categorization tool to classify a patterns database with the AULIVE methodology. The AULIVE methodology combines methods like TRIZ, QFD and FA that create patterns of innovation. Patent databases are then harvested (using software algorithms) to build databases and those patterns are then used in a tool that allows for a problem to find solutions in different domains i.e. exaptation.

It would be an interesting future research to combine the prototype development by IDC-HoWest students with the tool created by CREAX and to provide it as IT support for business-engineering students to build interesting business prototypes. Such an EduLab would stimulate the features of the education layer in the ÆIP architecture (to be the interface between the ecosystem and the research). It requires the connection of diverse tools and diverse profiles of students. Combining design students and business students may not be enough. Other disciplines like legal studies, political studies, social studies, media studies, etc. should also get involved. The diversity increases complexity, which allows for self-organizing dynamics to deploy.

The classifying of patterns is not a task of the research or teaching staff, but of the administrative staff. It shows that the Interversity requires an enterprise-architecture. To illustrate how the administrative staff can fit an open system, let me consider two of the administrative cells at my university: the R&D cell and the career center. The R&D cell is concerned with legal aspects and may adopt what CREAX does to their own IP databases. The career center is a job agency that creates an interface for graduating students with the industry. The career center has different databases containing the needs of the industry and the

availability of human resources (the graduated students). What both the R&D and the career center have in data can become enrichment for the project-oriented education. With the movement of open data, other carrier agencies and innovative companies may also contribute to the data landscape that used to be internal to the administration.

In the case of assistive artifacts, caretakers form a fascinating contribution to the environmental enrichment related to the roles of the Eventuating model. Remember the roles are: the developer, the delegate, the allies and the peers. In both my approach and IDC-HoWest's approach, students are allowed to define their own project, which makes them the main developer, while the other students become peers. The case on assistive artifacts also has a delegate and allies, making their approach align better with the novelty theory. The caretakers are the delegates, be it professional or volunteers. The ally is the disabled person that is in need of the assistive artifacts.

11.2.3 **DevLabs running simulations**

From interacting with both the researcher in software engineering and with the core developers of the Drupal project, it became clear how similar the actions of the two are and how they are improving by becoming more similar. To improve the validation, the core developers are increasingly making the validation methods easier to apply by means of IT support. In the research lab, we see how the lab is creating a network with partners to make spinning-off of the research easier. For the Interversity, the improvements of both are needed to make the DevLabs possible. In that process, the essence of research becomes part of the public sphere.

Because it is IT that enables the development, it is necessary to consider software engineering as the niche to understand the first DevLabs. To move out of this niche requires other domains to create artifacts for that domain. It is in particular the synergy between the different artifacts that is relevant. For example, in the ORA case financial artifacts existed (e.g. Net Present Value calculation for cash flow) next to algorithmic artifact (e.g. Monte Carlo methods), that were combined by simple interfaces. Separately the artifacts have value, but combined that value becomes more than the sum of its parts.

One of the key features of DevLabs is to have simulation environments. For the software engineer, this is by running the code. In the ORA case, applying the Monte Carlo method onto the complex data set creates simulations of possible scenarios. The simulations can analyze the complex data with statistical tools. Without the simulation, that would be impossible. To clarify what a simulation is, let me consider an extreme example of simulations found in archeology. Experimental archaeology aims to understand what ancient societies were doing by reliving it (Coles 1979). Experimental archaeology is a (re-)engineering approach to archaeology. In this case, the simulation is exactly to downgrade the technological development in our social fabric to understand how people could have lived in that period. It requires effort to ensure that the resources of that time are provided in a most authentic way. This case of archaeological engineering shows how DevLabs can exist in very different domains. Another

case of artificial environments where the social fabric gets downgraded is wildlife preservation (see Section 4.3.4).

The experimental archeology and wildlife preservation show the artificial construction of historical environments. In order to not create any confusion that it is only about upgrading or downgrading technology, let me consider how arts is embracing the concept of public labs in a very different way. The performance art group "Improve Everywhere" has created an event (Muse 2010). Big marketing groups later pick up the event after they became a YouTube sensation. The event was later called "flash mobs". The original setup involves a group of people dispersed across the central station hall that had the task to freeze simultaneously in place for five minutes. The normal train station users react with surprise and fascination on this art performance, as can be observed in the video of the event. Later marketers more commonly use the flash mobs where the freezing is mostly replaced by dancing. The FoodRevolution project (Slocum et al. 2011) is another application of a flash mob, where the crowd is cooking collectively. The essence is, however, that it is a coordinated and artificial collective action, so it is a simulation.

11.3 Integrated Interversity: institutionalizing innovation

In case of the open Interversity, the ÆIP architecture describes a self-organizing process. For the integrated Interversity, the ÆIP architecture is the mechanism to artificially create a phase transition. The self-organizing process is already an improvement, however, some highly needed development for society is not likely to develop naturally. Many reasons for a blockage can exist and they are most likely complex.

The attempt to concentrate radical change in a hub is not new. In fact, this PhD is inspired by the experience in such a hub. In a first subsection, I consider details of a case called STARLAB. STARLAB was a pioneering company that was able to emerge during the dot-com bubble. It has only existed briefly since it was not stable enough to survive the dot-com downfall.

The spinning-off of an ecosystem requires time. I will suggest that an optimal development process for spinning-off of an ecosystem would require three years. By creating a pipeline process or assembly line the spinoff can happen twice a year. The pipeline process or assembly line make the artifact move from workstation to workstation to add parts. In case of the Interversity a workstation takes one semester, which is why an ecosystem can spinoff twice a year, while each ecosystem takes three years of development. The speedup of the process is not the most important reason to create a pipeline. The educational needs require that students who fail be given a second chance. If only one ecosystem every three years is created, it would create problems for a sustainable education. With the pipeline, students that fail during one semester can retry with the next ecosystem in the pipeline. For the pipeline to work requires an alignment between the spinning-off (in three years) of the master education (in two years) and the PhD research (in four years). How these different needs and requirements line up is examined in the second subsection.

To demonstrate a case of spinning-off of an ecosystem, the participation research around the Metropolitan Food Security (MFS) project is examined in the third subsection. The MFS project is about creating a whole supply chain of food production to increase food security. A supply chain is a special kind of ecosystem. The case shows how spinning-off of an ecosystem can solve some of the larger problems in society. The case opens a debate about the effect of globalization, which brings us to the last subsection with the development of the Global Brain Institute (GBI) and is the next step in the proof-of-concept for an integrated Interversity.

11.3.1 **Blue sky research: STARLAB case**

STARLAB nv operated briefly between 1997 and 2001 as a company venturing on very long-term research projects, which no company would consider. The company was described as a "blue sky" research lab and had the slogan "where 1000 years means nothing". The concept of a business operating on such timescale was radical. STARLAB is an important pioneering case for the ÆIP architecture and one that I have been lucky to experience firsthand. Let me first describe the organization and then consider my personal experience.

11.3.1.1 Pioneering work

Walter De Brouwer, the CEO and founder of STARLAB nv, elaborates that the idea of the company came about by discussions, among others, with Professor Nicholas Negroponte of MIT Digital Life. Digital Life is a radically rethinking of the human-computer interactive experience and the vision of that lab has been resonating in STARLAB. The co-founder of STARLAB was Paul Allen, who also was the co-founder of Microsoft. Allen (2011) explains how his contribution to Microsoft was much inspired by what went wrong in Xerox PARC and that he wanted to use it for STARLAB. Notice that Xerox PARC was also the inspiration for open innovation (see Section 6.2.1.3). Ironically it seems that STARLAB had the same fate as Xerox PARC: many radical inventions (prototypes), but no innovations (products). The short operation of STARLAB can explain why the prototypes did not develop into products. The big question is what we learned from STARLAB.

STARLAB nv is very different from Xerox PARC. It was set up by venture capital and did not have a large enterprise as its backbone. The lack of such enterprise support made the organization agile, while more fragile for external perturbations. The company went bankrupt with the dot.com crisis. As an agile organization, STARLAB nv has created some creative projects, with clearly radical features, like iWare and KidCam. The iWare was a proof-of-concept on intelligent clothing. The clothing had sensors all across its surface. Some interesting creative solutions were explored to reload the device. Using chemical energy, the heat during the washing process allowed the recharging of the clothes. The KidsCam has been elaborated in Section 2.1.3.4. It was fundamental to the novelty research since it demonstrates how proper interfaces can create collective intelligence.

11.3.1.2 Firsthand experience

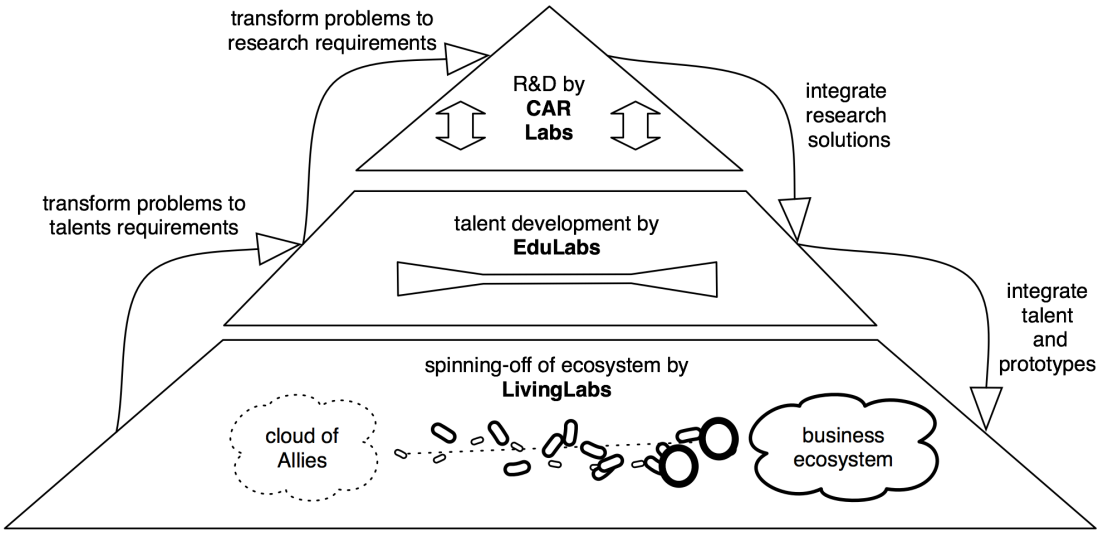
Considering the unique design of STARLAB, I find myself very lucky to have worked in the facility as a student during the summers of 1997 and 1998. While I was not involved in any of the scientific activities, I at least saw them develop and got to experience the enriched environment firsthand. When the organization went bankrupt in 2001, the CTO, Prof. Walter Van de Velde, returned to his former AI lab as guest teacher for two years. In 2001-2002 he gave an advanced AI course, which was a scientific reflection about STALAB's innovation ability by examining the projects created in the facility. In the summer of 2002, he became my master thesis supervisor. Between 2003 and 2004 he was part of a new organization. I have participated and worked in that organization until it ceased to exist in 2005. For a brief period of one year, the CTO was my PhD advisor. However, with his new function at the EU Commission he was not allowed to continue this supervision.

To continue the reflection and learning from STARLAB, I became more involved with the ex-CEO between 2005 and 2009 around some entrepreneurial ideas, in particular around Braingym and Pajamanation. The Braingym project was based on the book "minds wide open" (Knight 2011), which suggests how attention could be trained by neuro-feedback. Pajamanation was the vision of a nationwide population working from home in their pajamas. Both projects never left the ground. It did give me considerable insight into the complications around venturing and to better position the institutional studies in STS, making clear how important environmental enrichment is for innovation.

11.3.2 **Synergy between the three pillars of universities**

The three dynamics in each layer of the ÆIP architecture align with the labs described for the open Interversity. What the universities can do more is to change the self-organizing coordination of a phase transition to the controlled execution of an artificial phase transition to work on large problems in society that do not have a self-organizing solution. With the open Interversity, the enrichment of the environment is by coordination between LivingLabs and EduLabs (Section 11.2.2) and by coordination between LivingLabs and DevLabs (Section 11.2.3). For the integrated Interversity, the EduLabs need to become a bridge between LivingLabs and DevLabs, as described by the ÆIP architecture (Figure 8.3).

Figure 8.3 The ÆIP architecture behind the integrated Interversity



The setup of the integrated Interversity makes the administration staff become a larger entity and more directly involved with the different pillars to proactively work on ecosystem development. The involvement of administration next to researchers is not seen in Figure 8.3. The first subsection describes how different roles and different tasks can be aligned. It involves spinoff ecosystems for the base layer, running a master program for the central layer and developing PhDs for the top layer. The ÆIP architecture can explain the synergy between the layers. A synergy also exists between the concurrent and parallel development of ecosystems, which involves the administration of the Interversity and illustrates how the solution requires the involvement of many departments over different faculties. The diversity by many departments is examined in the second subsection.

11.3.2.1 The pipeline of spinning-off of ecosystems

In Section 8.4, the ÆIP architecture describes a process of artificially creating a phase transition by six stages, being the five stages of the phase transition and a planning phase. For the modeling of an integrated Interversity, we assume that each stage is a semester. Therefore, spinning-off of an ecosystem requires three years. Three different control agents exist, each of them is responsible during one year. The control agent is not creating the development, but managing it. The participation agent is developing the innovation with three types of participation agents.

The first control agents are the administration that is in charge during the last year. The administration should have an overview of the distributed and parallel developing ecosystems. The role of the administration is to macro-manage the ecosystem development and prepare for what comes in next. During the first semester of the third year, they prepare the spinning-off. During the last semester they diffuse the research from different ecosystems and create a selection process of the new ecosystems, which is all part of the preparation for the planning phase of the new ecosystem.

The second control agents are the professors who have the responsibility for ecosystem development. During the first year, the professors are only indirectly involved. During the second year, when the development requires the most expertise, the professor is in charge. The first year requires a fresh look, provided by a final year PhD student.

The PhD student is a participation agent for the first three years and only becomes a control agent in the fourth and last year. The other two types of participation agents are the master students and the stakeholders in the ecosystem. The stakeholders truly carry the ecosystem development and have to be committed. The students are only involved. They challenge the ecosystem development, as part of their education. Each of the three participation agents each get involved for a different duration. The PhD takes four years, which means that the PhD is part of more than one ecosystem development. The stakeholders are committed for three years, which is the time required for one ecosystem development. The students are involved for two years of a master program. They are not part of the planning phase or the enrichment phase. Table 8.2 provides an overview for each of the six stages. For the control agents, it shows how each year one has the lead. The PhD student is for the three years interacting with the stakeholders and carries the responsibility for supervising the students. The two years for the students are marked by dotted lines, showing how the students are separated from interactions with the stakeholders in the first year. During the first semester of the second year, all participation agents are interacting; while during the second semester the master students are left on their own to write out the thesis.

Table 8.2: Activity diagram for the three years of ecosystem spinoff

		1st stage Planning phase	2nd stage Prematurity Phase	3th stage Incubation Phase	4th stage Growth Phase	5th stage Maturity Phase	6th stage Enrichment Phase
Control Agents	Administration					Institutionalization	PhD workshops
	Professors			Ecosystem coordination	PhD coordination		
	Last year PhD	Operating	PhD defence				
Different semester experiences between spinoff years and master years		1st semester 1st spinoff year	2nd semester 1st spinoff year	1st semester 2nd spinoff year	2nd semester 2nd spinoff year	1st semester 3th spinoff year	2nd semester 3th spinoff year
			1st semester 1st master year	2nd semester 1st master year	1st semester 2nd master year	2nd semester 2nd master year	
Participation Agents	PhD student	Observation	Teaching	Tutoring	Negotiating	Consolidating	Designing
	Master student		Basic training	Individual project	Group project	Thesis	
	Stakeholders	Networking	Positioning	Developing	Cross-fertilization	Validating	Legalizing

A recursion exists and the task of the administration is to prepare the next stage. Let us first focus on the last task by the administration, which is described in Table 8.2 as "PhD workshops". During the first two years, the PhD students are assisting in the cultivation of the ecosystem. Because the PhD student has been involved in all of the various parts, the PhD student becomes the expert in the third year. During the first semester, it involves consolidating the ecosystem. During the second year, the PhD student becomes part of the co-design process for new ecosystems. It is the task of the administration to create PhD workshops in order to allow PhD students of different ecosystems to share their knowledge and collaborate on the challenges of new ecosystems. The administration

organizes open spaces, appoints the selection committee and creates awareness around existing challenges in the social fabric. However, the administration is only macro-managing and cannot get involved in the actual content. For university administration, such macro-management is well known, such as in the management of PhD defense.

A diffusion of knowledge is reached by getting all the PhD talent from the different ecosystems together in one big pool. Several milestones should exist in this last semester, like presenting the ecosystem to the other PhDs, ideation around the social challenges, building markups, co-creation with lead stakeholders and finally having a selection commission decide on the final form. All this preparation is needed to ensure that the planning phase of the new ecosystem can start properly. Because the PhD students were involved in the development of the new ecosystem, they become the best control agents during the first year of the ecosystem development, being the planning phase and the premature phase. It is expected that the PhD student may become an agent of the ecosystem after that year in one form or another (e.g. a spinoff in the ecosystem or working for a lead organization in the ecosystem).

The last year PhD student takes the lead in the planning of the ecosystem, which means preparation of open spaces with the stakeholders. Because the last year PhD is a control agent, a new PhD student now becomes a participation agent. Notice how this is different from PhD positions in universities today, where one PhD positions only becomes free after the PhD defense. It is, however, a terrible loss of knowledge when no diffusion is possible from one PhD student to the next. By having two PhD students simultaneously active for a year that knowledge transfer becomes an inherent part of the organization. During the first semester, the new PhD student is participating and taking up all this knowledge. During the second iteration, the new PhD student is still learning most from the last year PhD student who is now wrapping up her/his PhD. The new PhD student is responsible for teaching the basic training for the project-oriented education. Notice that this second stage is, in fact, the first semester for the students. During this phase, the open spaces with the stakeholders should show the opportunities and threats the ecosystem is facing. The stakeholders are taking in the position of the ecosystem during this prematurity phase to focus on the actual development planned for the incubation phase.

In the incubation phase, the ecosystem needs to gain coordination. This is very important and requires the involvement of the most expert control agents, being the professors. The new PhD student is now providing the individual project development, as demonstrated with the agile education experiment (see Section 9.2). The student may observe the ecosystem development for inspiration about their project, but they are not allowed to interact yet. The interaction between students and the ecosystem happens with the growth phase. It is an artificial growth created by bringing the students into the ecosystem. The students now learn how to work as a group. No specific control is executed. Students may form their own groups or become part of existing organizations of the stakeholders. Consider that the PhD student has followed the students for the past year and a half makes them the expert. Therefore, during the incubation phase, the PhD student is assisting the professor. During the growth phase, the PhD students

take more responsibility towards the ecosystem under close supervision of the professors.

It is during the incubation phase that stakeholders create the actual development of their prototypes for the ecosystem. During the artificial growth phase, cross-fertilization between stakeholders' prototypes and students' prototypes is expected. The interference can be direct, by students teaming up with the stakeholders, or indirect as other prototypes in the ecosystem can create coordination with the prototype of a stakeholder. The artificial growth phase is expected to be turbulent and during the artificial maturity phase a validation has to be done to take in the feedback of the turbulent growth phase. After the validation, the ecosystem is close to spinning-off of and only the legal aspects needs to be finalized during the artificial enrichment phase.

While the professionalism of the control agents should ensure a proper execution of the method, it is not expected for the students. Therefore, let me consider what is expected when a student fails and cannot pass to a next iteration. Because of the pipeline process, it is expected that each semester a new ecosystem is started. If the student cannot pass, it can fall into the next ecosystem. It means that the theme would be different, but many of the skills should be similar. The student has already experienced the iteration, creating a benefit that compensates for the problem of working on a new theme. It is also expected that some student may fail during the earlier semesters, which makes it easier to transform to a new theme.

11.3.2.2 Regulating the agency and mediation of the phase transition

For each different faculty, different labs should be involved, providing different PhD students and academic staff. The exposure to such complex and adaptive development requires some concrete examples to elaborate the phase transition. To give a different case than the latter mentioned participation research, let me elaborate a venture currently being developed by the former CEO of STARLAB called "scanadu". The project is about a smart phone for medical devices and is in competition for the $10 million reward of the "Qualcomm Tricorder X Prize". Assume that developing such a tricorder was the focus of an ecosystem development. It would involve the medical faculty for the domain application, the engineering faculty for the device development and the faculty of human sciences for more social development (legal, economic, psychology, etc.). They would at the start not even be interacting and shift according to the workspace stages from interaction, over coordination to control. This happens by the agency and mediation described in Section 6.2.

During the premature phase, the agency is the grounded concept developed within the laboratory (mediator). The different research labs get involved with the different stakeholders in open space to get to know each other. This defines in more detail what prototypes and workshops need to get developed, which are indeed the agency and mediator during the incubation phase. During the incubation phase, students create their individual projects. The students' projects create more naïve prototypes than the prototypes emerging in the

ecosystem. A diversity of student projects exist from simple to very ambitious. The project for each individual student relates to the skill of the faculty that the student is coming from. Notice that several features developed in the agile education and scalable education experiments are applicable to any domain, like the tools and scaffolds for structural debate.

Exaptive development is expected. For example, engineering students take cases from other domains to build technological prototypes. Conversely, medical students may consider the integration of existing technology to their domain. These processes can be supported by the IT alignment method described in Section 7.2.1.2. The students base their projects on what exists in the ecosystem and less on what other students are developing. More interaction with the other students is expected along the way and in the first semester of the second year this becomes the target indicated in Table 8.2 by "group projects". The interaction between stakeholders and students brings cross-fertilization of prototypes. It is expected to create turbulence in the ecosystem that provides novelty that must be validated in the next semester.

11.3.3 **Participation in the Metropolitan Food Security (MFS) case**

For large problems in fast growing regions, the need for integral innovation can stimulate the shift from individual spinoffs to spinning-off of ecosystems. For this reason, I have participated in the Metropolitan Food Security (MFS) project. The MFS project has the challenge of building a supply chain for food from scratch as a centralized hub: the metropolis. The metropolis can be visualized as a hybrid between a university campus, a high-tech industrial park and a small city.

While the MFS project can be relevant to many fast growing regions, I have been involved in one particular development for the Chinese province of Hebei. The project leader for the MFS-Hebei is Ir.Th.M.Lohman who was joining the province Z-Holland on a trading mission to Hebei. It is thanks to Lohman that innovation on the inter-organizational level was explored. I participated in the Hebei trading mission of 2012, which was for the ÆIP research an incredible learning experience.

The Hebei province is a rural area surrounding Beijing city. During the trading missions, we visited greenhouses, which were to Z-Holland standards outdated. The focus of the trading mission was exactly to find opportunities for improvements. I have also learned that the province Hebei is in need of improving the universities levels. Most Hebei universities operate at the bachelor-level and during a high-level meeting with the university representatives (mostly rectors) it was recognized how they are all interested in creating master-level education. The interest to innovate food production and uplift the education as a general trend in the province is an opportunity unseen in any of the SMS studies. Hebei has by its current state, the proper incentive for the niche construction that can help develop the integrated Interversity.

The high-level meeting with the universities was focused entirely on student exchange. The best students would be sent by partnership programs to the Dutch universities. They call it the 3+1 program, meaning 3 years in their own

university and one year abroad. It is an expensive program only available for a few students. With the experience of my scalable education project, I suggested an alternative, with a full master program in Hebie where professors from Dutch universities would ensure the expert education. It is an adaptation of the scalable education model by replacing many of the technological processes by a bureaucratic organization, in this case, consisting of assisting PhD students. The assisting PhD students would be bilingual students, who are able to bridge the language problem.

My suggestion is ambitious and just a wild insight that arose spontaneously. To investigate the possibility of a pilot project, on the 20th of September we visited with representatives of Shijiazhuang University of Economics. The meeting showed much appreciation of the idea and even resulted in a brainstorming on how to overcome some of the problems the representatives saw in the plan. I was expecting some skepticism. Instead I was pleasantly surprised to see the plan becoming detailed by their input. It is with great anticipation that I am waiting for Lohman to take the plans a step further and actually start a pilot. The whole development does need to fit into Lohman's bigger plan for creating the MFS and so it is taking time before we are able to get back to the proposal.

The trading mission gave me a taste for what it means when government backs up a proposal. During and after the mission, we consulted with embassies and departments of education. Those activities allowed for some insight on what I consider the conversion pattern of the strategizing model during the enrichment phase. It is interesting to see that a project as radical as MFS requires the involvement of government as strategy before any pilot can be created. The reason is, of course, the scale. The project is a province-to-province collaboration that automatically requires the involvement of government. In Europe, we have less of a tradition of governmental involvement, showing us how the game of innovation changes by scale, it may actually be the more bureaucratic nations that gain a competitive advantage.

11.3.4 **The Global Brain Institute (GBI)**

The Global Brain has been an important concept for the PhD. In resent years some promising progress is reached thanks to the creation of the Global Brain Institute (GBI). The GBI is focusing on simulations to research the Global Brain. Software simulations for the Global Brain are not evident at all. The interest in Chemical Organization Theory (COT) is finding more interest in GBI. Section 4.1.5 shows a very simple implementation of COT to investigate the emerging of coordination. Other applications of COT involve the modeling of the Global Brain model to investigate the emerging of a meta-system development of intelligence. It is with the research in GBI that a connection can be recognized between the theoretic research on novelty and the research in ÆIP architecture with the Integrated Interversity. As current research is showing us, it might be possible to approach innovation differently by mathematics, which can help the ambition to reach a science of innovation.

In relation to the participation research on integrated innovation, ongoing research in GBI examines the possibility to simulate cases like Metropolitan Food

Security (MFS) by COT. Moving from COT to stronger science for innovation is a future research challenge that can be approach by organizations like GBI. This brings me to my final remark that this PhD is a proof-of-concept for a research path with many opportunities and it is my ambition to continue the research within GBI.

11.4 **Research Question III.4**

> *How can research on ÆIP architecture continue by planning pilots for an Interversity?*

This chapter has explored the design of an Interversity by considering how events become more approachable. The open Interversity is about academic activity becoming massive. While MOOC is already showing how this is happening for education, I have used the experiments around micro-spinoffs to describe the ÆIP architecture based on public labs. Labs are expected to become increasingly more a part of the public sphere. The LivingLabs, as user-centered open innovation have already shown some of this development. The EduLabs are now getting more developed. I have argued it can make project-oriented education more applicable to other disciplines. The DevLabs is a design based on observations with the participation research. The software engineering with the development ecosystem is an evident case. To demonstrate how it can be general, I have considered the experimental archeology and argued how it creates a very different meaning for simulations.

The integrated Interversity is about the systematic development of radical change by the spinning-off of ecosystems. It is different from the open Interversity in regards to the regulation. The open Interversity is about coordination and self-organization, making radical change more likely. The integrated Interversity requires the full structure of the ÆIP architecture. It is about artificially creating the phase transition to control the radical change process. In respect to the open Interversity, the biggest change is that EduLabs becomes a bridge between LivingLabs and DevLabs.

Just as with the first proof-of-concept created with this PhD, the Interversity needs a combination of controlled experiment and participation research. For the open Interversity this seems approachable by creating a spinoff around the POESy framework and becoming a committed member of the ecosystem emerging around EduLabs. The integrated Interversity requires more research to become acceptable. Participation research is possible around a large-scale project, like the Metropolitan Food Security (MFS) project. Controlled experiment requires top-level support of universities to create experimental programs. It is expected that simulations by Chemical Organization Theory (COT) can improve the understanding of an integrated Interversity. The goal of this chapter was to create more detail on how the ÆIP architecture can become applicable. The models of the Interversity (open and integrated) are plans for future research. Only time will tell what parts of the suggested plans can be put in motion, since it requires forging the alliances to do the research.

12 Conclusion

12.1 The fundamental research of novelty regulation

The introduction of this PhD started with an inability to forecast innovation. Failing to understand innovation creates the impression that innovation happens by chance. However, chance requires us to observe random distribution for innovation. Instead innovation appears to be concentrated in particular locations, i.e. innovation does not happen by chance, but in an unfamiliar order. It is evident that knowledge creation is important for innovation. The local concentration of innovation also draws our attention to environmental enrichment. The problem with forecasting is that it starts with what exists. What exists is, however, a barrier to novelty. To get to the core of the unfamiliar order of innovation requires a stronger novelty theory. The novelty research is about the feedback that allows us to create the required knowledge and environmental enrichment in an efficient way, which is the novelty model. The novelty research is broader than innovation in the social fabric. It is, in general, related to artificial evolution.

Two key structures exist to study artificial evolution in general, and innovation in particular: the novelty models and the phase transition. Both have a high level of abstraction. To create a bridge to actual cases requires us to create intermediate concepts. In the case of the novelty model, we recognize six actual implementations of the abstract model. The phase transition was divided into five stages and the elements undergoing the transition are assigned a different name during each stage to emphasis what happens during that stage. When we combine the novelty models with the phase transition, we get an explosion of intermediate concepts that were helpful to understand the details of what is happening, but can cloud the essence of this PhD. For this conclusion, it is better to remain on a more abstract level in order to understand the abilities gained by the introduced structure. In the first section, we focus on the novelty regulation as a fundamental research topic. Because the phase transition is central to the innovation, it is examined in the second section on innovation.

For the artificial evolution, the most general concept relates to the artificial variation and artificial selection that change during the phase transition. By the artificial variation eventually agents arise, which is why the intermediate stages are called agency. The artificial selection makes mediation emerge and weaker forms of mediation are recognized in the intermediate stages. Let me first discuss the artificial evolution and the concept of workspace. While workspaces are best known to us for their interaction between people, the specific definition given to workspaces in this PhD is broader so that it can become a key concept for our evolutionary study. The workspace used by people is just one of the possible concrete implementations. The workspace becomes the central element in the novelty model.

12.1.1 **Artificial evolution and workspaces**

Evolution is a process of variation and selection. Both natural evolution and artificial evolution make use of variation and selection. At first, no distinction exists between natural evolution and artificial evolution. To find the origin of the artificial evolution requires a deeper investigation on how variation and selection are reached. Heylighen introduces energy as a potential variation to understand the distinction between thermodynamic entropy and information entropy (Section 3.2.3). Based on convergent evolution (see Section 3.3.1), it is argued that a medium creates actual selection, when no interaction exists (i.e. a collective) it would be potential selection. By moving from potential variation and potential selection to actual variation and actual selection, we get the process of evolution.

Natural evolution is only about variation and selection. The artificial evolution has a slightly different focus where artificial variation becomes agency and artificial selection becomes mediation. The distinction between natural evolution and artificial evolution increases with more advanced stages of agency and mediation. Artificial evolution is the evolution of an artifact that evolves, but not by its own means. The simplest example is recognized with technology, but as the evolutionary study shows, humans are not the only agents that create artificial evolution. Natural evolution and artificial evolution are so entwined that it is sometimes hard to separate them.

By introducing novelty, it becomes easier to separate natural evolution from artificial evolution. In fact, other scholars have been introducing the concept of novelty to make sense of evolution, in particular the evolution of science and technology (see Section 5.1). From a purely evolutionary study, Barbieri (2008) introduces the concept of relative and absolute novelties (see Section 3.3.5). Natural evolution produces relative novelties by adaptation. Artificial evolution produces absolute novelties by exaptation. Gould and Vrba (1982) introduce exaptation, as the utilization of a structure or feature for a function other than that for which it is developed through natural selection. Technology is one absolute novelty, but proteins and feelings are also absolute novelties according to Barbieri.

One of the contributions of this PhD is to connect the different studies that have some relation to novelty. In some cases, novelty is actually used by the scholars, but other relevant studies do not express the relation explicitly. One such relevant study is about Meta-System Transition creating major transitions in evolution (Turchin 1995; Heylighen 2004b). By Meta-System Transitions, a distinction is made between relative novelties (by natural evolution) and radical novelties by a phase transition. Section 3.3.3 examined major transitions in the origin of life and Section 5.2 elaborated on some of the major transitions in the history of technology. Such major transitions are applied to a broad context. If we focus more on a local context, it becomes possible to see many smaller, but still radical novelties, like the Internet innovation waves that are described (Section 5.2.9).

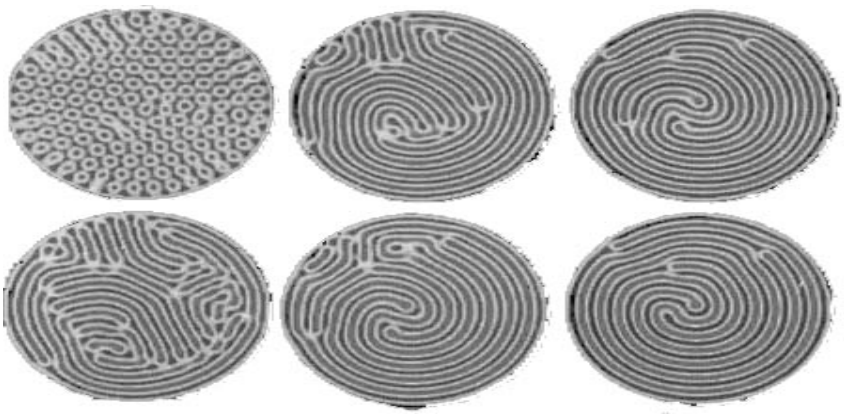
Interestingly, the radical novelties often make absolute novelties become dominant. While proteins have some function for the regulation in single cells

(e.g. metabolism), they become more dominant for the regulation of multi-cellar systems. For a single animal, feelings improve the regulation ability in respect to the cybernetic brain (see Section 3.3.5). Feelings become a more dominant regulation for the social dynamics between animals. The same concept holds for technology that gives some improvement for the individual, but becomes a more dominant regulation for the social fabric.

Investigating the Meta-System Transition brings us to the stages of artificial evolution. While Heylighen has described the stages of mediation, I have extended it for stages of agency (see Section 4.1). The first stage of agency is the fabrication of artifacts. To elaborate on the second stage of agency, a distinction is made between artifacts improving the agency and artifacts improving the mediation. Artifacts improving the agency are amplifying a function and become tools. Artifacts improving the mediation are restraining a perturbation and become scaffolds. When features of tools and scaffolds are coupled they form machines that create advanced manipulations of the natural world. When machines start using information for regulation and become able to learn that information (i.e. knowledge), they become autonomous agents, which is the last stage of agency.

The stages of agency stand in a bootstrapping relation with the stages of mediation. The first such mediations are recognized as mediums. In a medium, the self-organization of some spreading activation can result in patterns. The mediation by a simple medium creates only one self-organizing pattern. More advanced mediation is reached with a workspace. A workspace is a medium where dynamic boundary conditions exist creating dynamic patterns. The most primitive version of a workspace is the advanced Bénard cell. In this case, the difference in heat on the side creates different patterns of fluid motion in the workspace (Figure 12.1). The advanced Bénard cell can demonstrate the basic structure of a workspace, showing how input (the heated sides) can create information (the patterns of fluid motion).

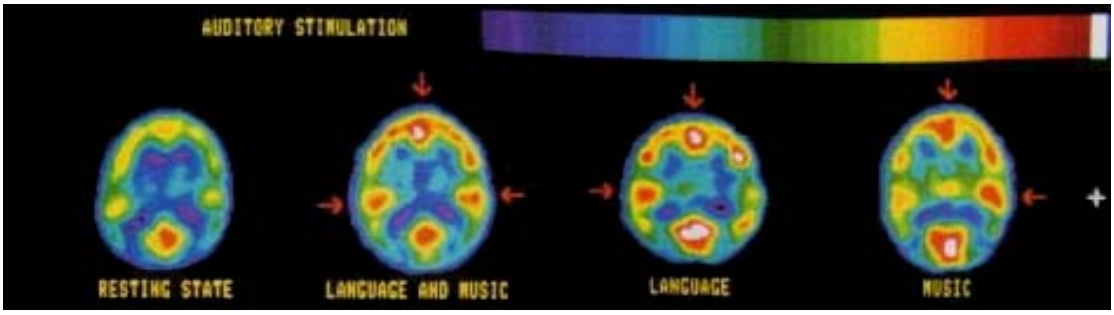
Figure 12.1 The advanced Bénard cells show patterns in a workspace, repetition of Figure 3.5



The brain is a more advanced workspace. PET scans can show the energy consumption patterns of neurons, showing a relation with a mental state (Figure 2.12). The brain has an intrinsic similarity with the advanced Bénard cells: it

creates a relation between inputs and patterns. The human brain is, however, more advanced than a simple workspace. It is a meta-system where control over a workspace (or workspaces) allows advanced manipulation of the natural world.

Figure 12.2 The brain as a workspace, repetition of figure 3.20.



Two types of meta-system workspaces are recognized. The easiest to understand is when agents exist in the meta-system and produce the advanced manipulation. It is the utilization of a workspace that we know best, i.e. people or other animals collaborating though the workspace. When agents produce control over the workspace, I call the meta-system a meta-element. Exceptional cases of meta-systems show how the control can come from environmental conditions. It gets recognized in what I call a meta-workspace, which is a workspace constructed of multiple workspaces. The central workspace is surrounded by workspaces creating the first artifacts. The advanced manipulation by the central workspace is because it gets artifacts to start from. In a way, it is part of a fabrication chain. Thus, the advanced manipulation is the effect of the environmental conditions.

The separation of two types of meta-system workspaces is relevant in order to understand how a novelty model can emerge. The novelty model is an advanced meta-workspace. The advanced meta-workspace may have emerged when a system has internalized a meta-workspace to gain more advanced regulation (i.e. a brain). To optimize the control produced by the meta-workspace, the meta-workspace can undergo natural evolution towards the novelty generating mechanism described by the novelty model. In the human brain it leads to a novelty model around the global workspace (see Figure 12.3). While my description may be only one of many descriptions, it allows for a specific investigation that could be done in future novelty research. By examining more primitive brains, the less optimal meta-workspace could be recognized. It could validate this claim and help us to better understand the dynamics leading to a novelty model.

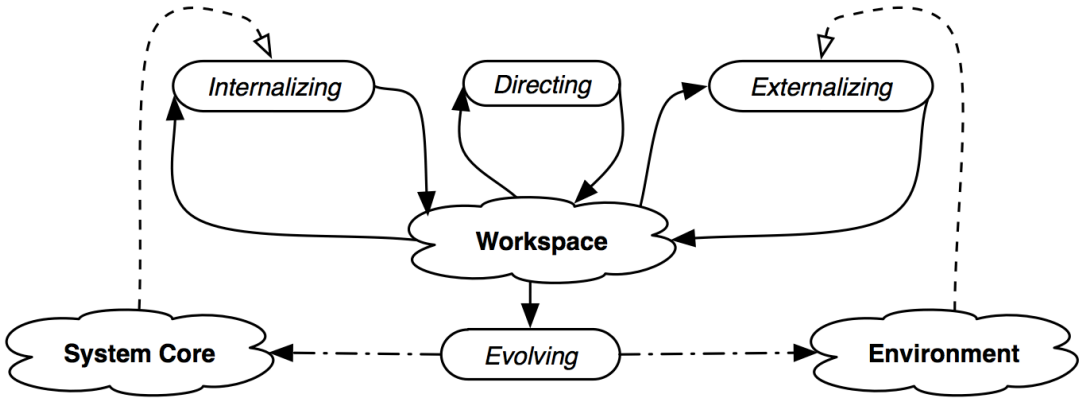
The study of artificial evolution can also give us new tools to continue the fundamental research. In particular, the Chemical Organization Theory (COT) can be enhanced to study the stages of the artificial evolution. A very simple case to examine the evolution of mediation by COT was given in Section 4.1.5. This case shows how much research is still needed, since it only is a case to investigate coordination. A case of how COT can be used to describe novelty regulation by a novelty model has been made, but it is not developed enough to be part of this PhD. This is another way that future research can continue the investigation of novelty regulation without the need to get into the more

complicated case of innovation. Innovation is a particularly complicated case of novelty regulation since it involves several novelty models.

12.1.2 **Six applications of the novelty model**

The study of artificial evolution can help us to understand novelty regulation. We can also define the novelty model so that it becomes independent of the studies on artificial evolution: *the novelty model is a mechanism to overcome conservation by bootstrapping*. Understanding the novelty model is difficult. It is fundamental research that requires altering our worldview. This becomes clear by considering the six actual applications of the novelty model. It is indeed strange to see a similarity between sailing against the wind, knowledge creation, environmental enrichment, strategy management, agile development and systematic innovation. In all six applications, the novelty model overcomes conservation and has a cost. To understand the cost and the conservation requires the details of the novelty model (Figure 12.1).

Figure 12.1: General design of the novelty model, simplification of figure 4.14



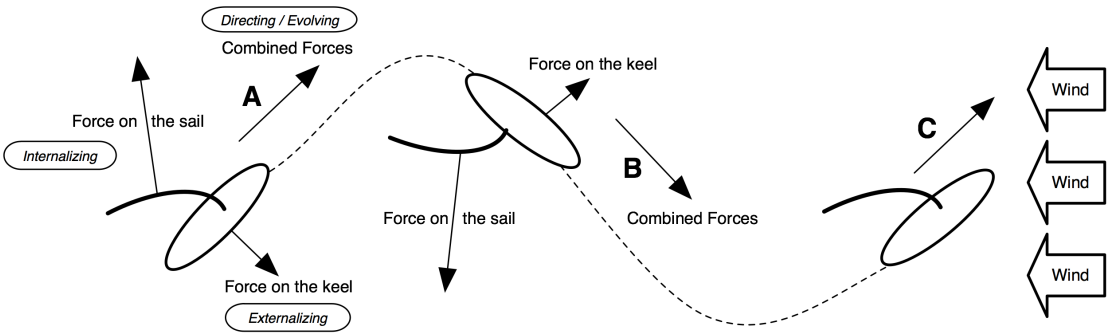
The novelty model consists of three mediums (clouds in Figure 12.1) and four anchors that together can create two opposite directions of development. These two directions stand in a bootstrapping relation to overcome the conservation. The mediums and anchors are abstract and become concrete with an actual implementation. The mediums are relatively easy to understand. The central medium is the workspace where all the work happens. The work can affect the external medium, which is the environment or create the internal medium described as the system core.

The anchors make connections. The internalizing anchor connects the system core to the workspace and the externalizing anchor connects the environment to the workspace. The third anchor connects what is emerging with goals and challenges by manipulating the workspace. It is therefore named the directing anchor. The fourth anchor creates a connection to evolution by transforming what emerged in the workspace into one of the two other mediums. The medium depends on the manipulation of the directing anchor. Finally, it is the

evolution of the system core and the evolution of the environment that create the bootstrapping process of novelty regulation.

Sailing against the wind can give us a clear view of the novelty regulation mechanism by the anchors. It is, however, an exceptional case because the type of environment is fluid-based (wind and water), where no storage of information is possible (see Section 3.2.3). The effect is an absence of construction and therefore also the absence of a system core. Because of this absence, the directing anchor and the evolving anchor become the same. The anchors become forces and the workspace is the boat that all forces are working on. The boat cannot move in a straight line against the wind. The solution by a zigzag motion shows how a bootstrapping process solves the constraint by moving in two opposite directions with a 45° angle against the wind (directions A & C versus B in Figure 12.2). The cost of the mechanism is the reduction of the force on the sail with the reaction by the environment (force on the keel). This cost overcomes the conservation of momentum. Details on how the forces relate to the novelty regulation are given in Section 4.2.1 and a repetition of the central figure is given here.

Figure 12.2: Mechanism of sailing against the wind, repetition of Figure 4.10

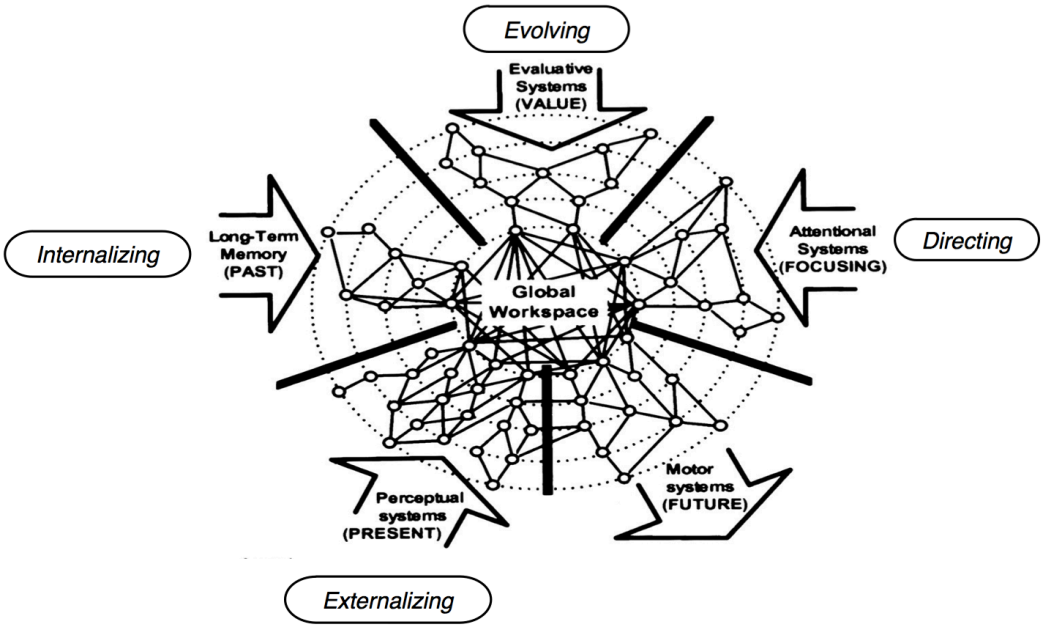


Knowledge creation is the first case of novelty regulation where an actual system core is developed. This application of the novelty model is called the Cohering model. Just like sailing against the wind, the energy is subjected to a conservation law. The energy is now knowledge and the bias of knowledge is the conservation to overcome. A cost is again recognized. Now more can be imagined than realized, but by implementing in reality we do get the fundamental novelty that may be in contradiction to our existing knowledge and that forces us to master the novelty by actions and model the novelty into knowledge. It is the mastering and modeling that now stands in a bootstrap relation creating a path of development comparable to the zigzag motion of sailing against the wind.

For knowledge creation, the mediums are memories, while the anchors are anticipation processes. The three required memories for novelty regulation are all recognized in cognitive studies. The extended mind gives us an insight into how the environment itself becomes memory (see Section 2.2.3). Brain studies describe the global workspace (Section 2.3.3) and the system core is the long-term memory. One cognitive study, in particular, describes the novelty model around the global workspace (Figure 12.3). The novelty model in the brain needs

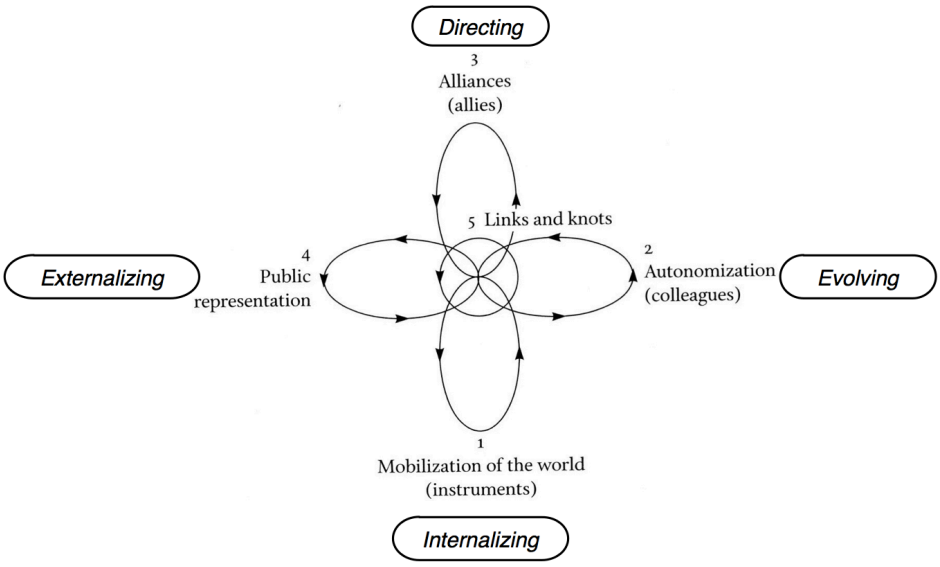
to create a motoric response, so one output is also described. In other novelty models, agents working on the workspace can create the output.

Figure 12.3: The workspace memory in the brain and the anchors of the novelty model, repetition of Figure 2.21



In cognitive studies a mechanism similar to the novelty model is observed. Implementation of other novelty models are described by scholars from a particular domain that adapt their tools to become complex adaptive. The first of these domains is the Science and Technology Studies (STS) that investigate the environmental enrichment. The mediums are now part of the environment, where the workspaces become workshops for technology development and laboratories for scientific development. The system core now becomes the social fabric. The anchors are roles that people take in the development. One STS study has described a novelty model (Figure 12.4 from Section 5.1.5). The conservation that this novelty model overcomes relates to the scarcity of a resource, where environmental enrichment allows for this resource to become abundant (e.g. electricity). For that reason, the novelty model is called the Eventuating model. In this case, the workspaces are distributed in the environment (described as links and knots in Figure 12.4).

Figure 12.4: The development of environmental enrichment by science and technology, repetition of Figure 5.3



The cost is recognized as the constant human involvement to maintain the infrastructure that makes the resource abundant. By economies of scales, it seems as if the cost decreases, but the cost is real and huge. The benefits are even larger, which creates the cost reduction. Economies of scale and cost reduction are concepts that are more critical in Strategy Management Studies (SMS). An interesting paradox again is recognized, now around organizations.

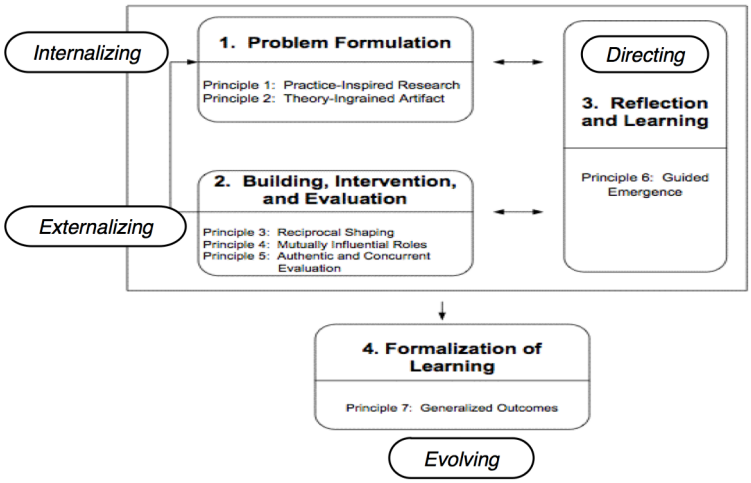
The organization creates by definition limitations, but the organization also creates leverage. The conservation of this novelty model, called the Strategizing Model, is related to the organizational design. Studies like disruptive innovation (see Section 6.2.2) show how the organizational design constrains the innovation and organizations with new organizational designs can overcome the conservation. This process is described in SMS as creative destruction (see Section 6.1.1). Creative destruction emphasizes how creation requires the destruction of the old system by new organizational designs, which is the cost of the novelty regulation.

The mediums of the Strategizing model all relate to organization: organization workspace, organization core and organization environment (e.g. market for businesses). One study again shows many of the anchors of the Strategizing Model. This study is based on the competitive advantage principle. Competitive advantage is reached when an organization implements a value not simultaneously being implemented by other organizations. Studies of competitive advantage in complex adaptive environments show how the anchors are the capabilities of the organization (see Section 6.1.3). The capabilities define the organizational design and the capabilities are the anchors of the novelty model.

Each novelty model shows some basic novelty regulation, but the advanced regulation brings us to the next novelty model. The advanced regulation for knowledge creation requires environmental enrichment, the advanced cases of environmental enrichment require organizational strategy and the advanced cases of organization require design thinking. Studies on design thinking have

been investigating designing for complex adaptive problems. They again described a novelty model where anchors are now principles (Figure 12.5, from Section 7.1.1).

Figure 12.5: The development method for complex adaptive problems, repetition of Figure 7.1

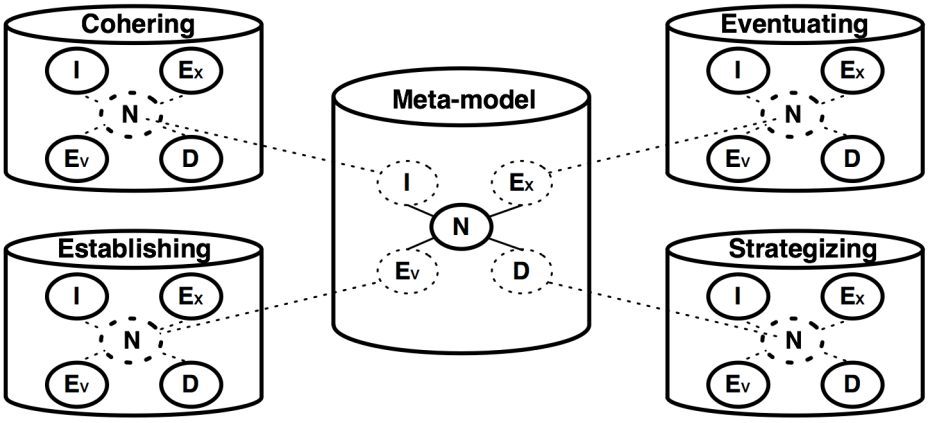


Principles are used in design thinking as guidelines to establish the development. This new novelty model is called the Establishing Model for that reason. The conservation the Establishing Model overcomes is procrastination. Procrastination is a natural effect of information overload, which is inevitable for complex adaptive problems. The cost to overcome procrastination is now the acceptance that no total comprehension is possible. In classic development, the design had to incorporate all possible scenarios. A design was only implemented after intense studies to understand all of the constraints and variables. In a complex adaptive environment, this becomes impossible and instead of having a full picture, the development becomes agile, meaning that it can rapidly adapt based on the feedback it is getting.

The Establishing Model is again a special case of a novelty model, described as a meso-model. The model is intermediate since it works on the other novelty models. The three other models require development and that development can indeed be produced in an agile way. While the absence of separate mediums makes understanding the Establishing Model harder, it creates the opportunity to gain a meta-level novelty model, called the meta-model. It also creates closure as the more advanced case of design thinking brings us to the basics of knowledge creation.

The meta-model is a novelty model, were the anchors are the described novelty models. The Cohering Model creates knowledge and is therefore considered the internalizing anchor. The Eventuating Model creates environmental enrichment and so it is the externalizing anchor. Organizations are the patterns developed in the workspace of the meta-model and the Strategizing Model is manipulating those organizations, making it the directing anchor. The Establishing Model is about the coordination of all the development. It is, therefore, the evolving anchor of the meta-model.

Figure 12.6: The meta-model is a novelty model where the anchors are four novelty models, repetition of Figure 7.1



When they are combined, all of the models create innovation. The meta-model is only an observation of dynamics. The challenge of this PhD is how to use the meta-model for systematic development of innovation. The fundamental research of novelty regulation is able to produce paths for further research by being specialized, like the mathematical modeling with Chemical organization and the brain research to investigate more primitive forms of novelty regulation. The larger opportunity is, however, to create systematic innovation. To pursue this opportunity requires additional investigation into the dynamics of the phase transition.

12.2 Planning Radical innovation

The focus for systematic innovation is about the development of radical novelties. Radical novelty emerges by a phase transition. During the phase transition, the agency and the mediation of the radical novelty change. The stages of this phase transition should not get confused with the stages of agency and the stages of mediation. The radical novelty has a relatively stable stage of agency and mediation. The agency is mostly related to the development of machines, meaning it involves the coupling of different artifacts (tools and scaffolds). The mediation happens by agents in an ecosystem working on the workspace and creating the advanced manipulation of the natural world. During the phase transition, something that was marginal in the ecosystem becomes central to the ecosystem, which is the major change by radical novelty.

The phase transition follows in theory an S-shaped curve. To investigate the process of major change, a separation is made into five stages for the phase transition related to the symmetry of the S-curve: premature, incubation, growth, maturity and enrichment. To gain control over the phase transition, a method is developed that focuses on the four transitions between the five stages. The first three transitions can help us grasp the major transition. We will now discuss this transition in more detail. The validation turned out to be a challenge and was one of the reasons this PhD took more time than average. Because of the ambitious challenge of an ÆIP architecture, an equally ambitious validation is needed that became possible by combining three different validation methods.

12.2.1 **The phase transiton of radical innovation**

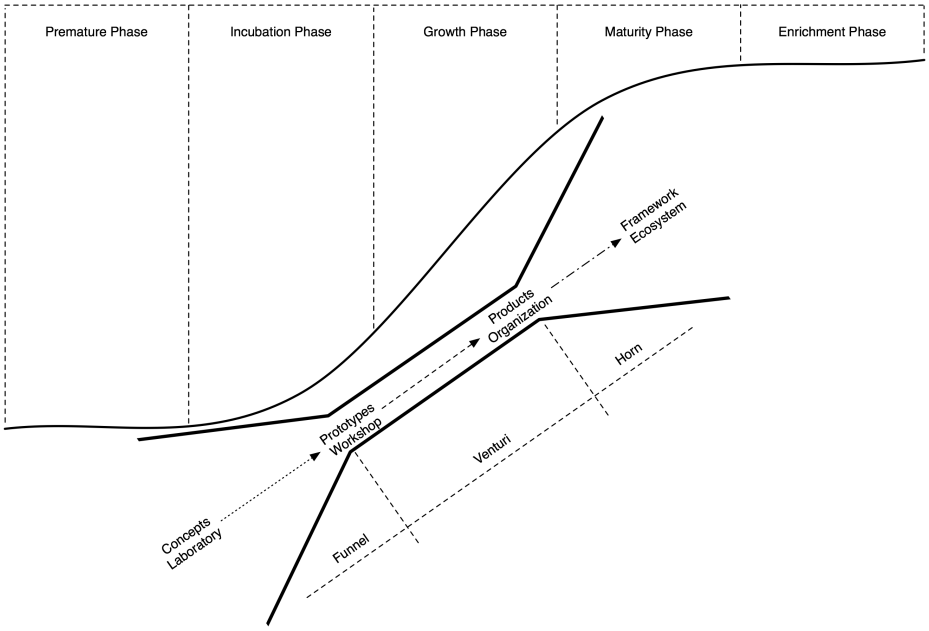
To understand the radical change requires a description of the agency and the mediation of the novelty. The agency starts as a marginal aspect of the ecosystem. During the premature phase, the laboratories allow the development of artifacts to measure and approach the novelty, creating the fundamental concepts for the phase transition. During the incubation phase, the workshops mediate the development and artifacts are created that embody the novelty. The agency transforms from concepts into the prototype of the emerging machine. These prototypes are inventions and require more support to become innovations.

During the growth phase, it is the organizations that mediate the innovation making the agency transform from prototype into products. With products, the novelty has become a useful aspect of the social fabric. However, the cost of operation is high. During the maturity phase, another transformation is recognized that reduces the high cost by the mediation of the ecosystems and now the agency transforms into a framework to support the ecosystem. Not all innovations reach this stage of maturity. Even less common is the transition to the enrichment phase that automates the novelty, making it an intrinsic part of the social fabric.

Because intelligence is still a mechanism with yet unknown features it is difficult to fully understand the enrichment phase, where intelligence is the agency. Some of the automatization is reached by the creation of knowledge. This can be understood as the enrichment of the agents. Other automatization is reached by environmental enrichment, which opens an interesting discussion about intelligence being part of the environment. A topic that is also appears in studies of the extended mind (see Section 2.2.3). The enrichment phase is clearly a fascinating phase holding many mysteries for future research on intelligence and in particular about the mediation by the Global Brain.

The enrichment phase still requires more research to resolve the mysteries. The stage is, however, less essential to our aim of systematic innovation. Innovation is something that to an extent has always been part of evolution and it is not essential to gain control over the whole phase transition. In fact, the control seems to be strongest around the central growth phase. Gaining more control over the incubation phase and maturity phase is already a big improvement. To reach this goal, a method is developed called Carbureted Action Research (CAR). The name of the method is a reference to how two development paths envelop the agency and mediation (see Figure 12.7).

Figure 12.7: The description of the phase transition, repetition of Figure 8.1



The CAR method has two development paths: training and penetration. During the premature phase, a gap is recognized between the current skills and the challenge. This gap requires both the training of skills and the penetration of the challenge. The training relates to knowledge creation and requires scaffolds to bridge the gap. The penetration requires measuring to approach the novelty and requires tools. In the CAR funnel, a bootstrapping process between training and penetration allows the narrowing of the gap. The scaffolds and tools in the CAR funnel reduce the gap until it becomes possible to build prototypes. During the incubation process, it is then the prototype that guides the development.

Once prototypes are maturing, another dynamic is recognized which happens in the CAR venturi. The CAR venturi produces spreading activation, by pumping venture capital into the ecosystem, thus making a cloud of prototypes transform into a business ecosystem. Venture capital allows for organizations to emerge and is essential for the transformation to the growth phase.

An essential difference between radical innovation and incremental innovation is recognized. Where incremental innovation can emerge in an existing ecosystem, the radical innovation co-emerges with the new ecosystem. Indeed, no single invention can produce a major transition, but many related inventions can create a breakthrough allowing for a whole new ecosystem to arise. When the different organizations mature, we see products arise.

Once products have proven their use in a particular niche, they can become multiple purpose products. This creates a new kind of bootstrapping relation between penetration of different markets and the training of skills that goes with it. The penetration and training now form the shape of a horn, increasing the demand for a support framework. Actual strategies with support frameworks as part of a product development are recent innovations seen with e.g. smart phones. With the emergence of the Internet of Things (a wider adaptation of

many yet unconnected objects to the Internet), it is expected that a support framework will increasingly become an aspect of the product development.

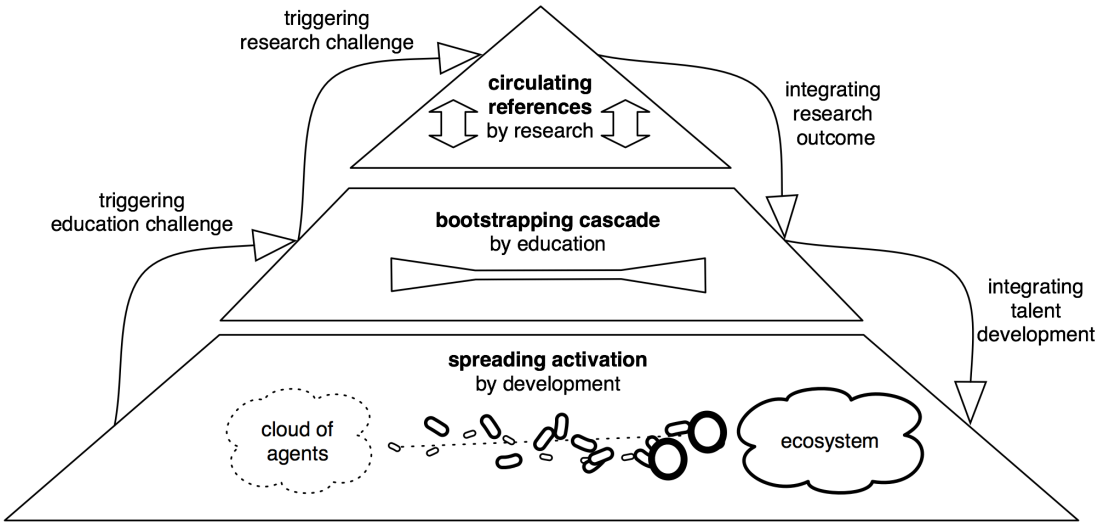
12.2.2 Agile-Enterprise Innovation Planning

The last part of the CAR method is a special case where the whole phase transition gets created artificially for spinning off ecosystems. Another description is more appropriate to describe it. Considering the scale of ecosystem spinoffs, it requires an Enterprise. However, Enterprises are too slow for developing radical innovations. A need exists for a new kind of organization that can combine the features of an Enterprise and a startup. This type of organization has been called Agile-Enterprise and organizational studies on these structures have been described (see Section 7.2.1). By use of the novelty theory, a new organization structure is proposed called the Agile-Enterprise Innovation Planning (ÆIP).

With a study to combine the novelty models and the phase transition, an ÆIP grid is proposed. Nonaka describes the first conversion patterns about knowledge creation (see Section 7.2.) Knowledge creation is only one of the four novelty models in the meta-model. We had to consider conversion patterns for all aspects of innovation. Each novelty model has five conversion patterns, one for each stage, resulting in the twenty conversion patterns. Conversion patterns for environmental enrichment, strategy management and agile development have been proposed. The names of the conversion patterns are not that important. What is relevant is that the ÆIP grid shows how a staircase of activation gets recognized where each next stage in the phase transition requires the activities of another novelty model. The ÆIP grid can help us understand the dynamics of the radical innovation better, but it is not yet practical.

The last part of the CAR method contains the practical part, called the ÆIP architecture. While the ÆIP architecture looks more like a classic Enterprise-Architecture, it is in fact a process that artificially creates the five stages of the phase transition, with one extra planning stage. The dynamics of bootstrapping and spreading activation from the CAR method get extended with a last dynamic called circulating references. Circulating references is a dynamic observed in STS (see Section 5.1.2). Circulating references give authority to the novelty. The ÆIP architecture allows a level of control over the circulating references and a level of control over the radical innovation.

Figure 12.8: The description of the ÆIP architecture, repetition of Figure 8.7



The ÆIP architecture is presented as a pyramid to emphasis the size, relevance, sequence and hierarchy of the structure. The spreading activation is the base layer showing how a cloud of agents becomes an ecosystem. It involves many resources and is in development before the other layers get active and after the other layers end. To let the research gain control over the ecosystem development requires the education as an interface. While the research is guiding all the development, its actual involvement by circulating references is only a part of the central stage of the artificial phase transition. The insight that education can be such an interface emerged by the experiments to validate the novelty research.

12.2.3 **Different types of validation**

Three types of validation are used and each provides different insights. We needed three types of validation because of the ambitious nature of the research. It is clearly impossible for a PhD to do experiments on a structure as large as an ÆIP architecture. Creating a maquette of the ÆIP architecture without any stronger scientific investigation would not suffice. The way to create the stronger scientific investigation is by applying stronger methods for a more limited context. The participation research is stronger than the maquette since it replaces the virtual construct by an actual ecosystem that allows observation of some of the yet unfamiliar dynamics of self-organizing innovation. With the participation research, we became able to better elaborate on how the base layer of the ÆIP architecture is possible. Even more powerful are controlled experiments, but they again restrict the application. With the controlled experiments, the central layer of the ÆIP architecture gains a level of detail. The validation around the base layer and the central layer reinforce the maquette. Only the top layer of the ÆIP architecture is yet untested empirically. By this triple method we believe that a strong argument has been offered that an ÆIP architecture is indeed feasible.

Two experiments have been done. The first is called agile education and deals with the knowledge creation in a complex adaptive environment. The second experiment is about scaling the project-oriented education by peer-evaluation enhanced with many checks and balances. The focus of the experiments was to ensure agile and scalable education. During the experiments, the actual CAR method (funnel and horn) became clear giving us a stronger method to describe the bootstrapping cascade by education (central layer of ÆIP architecture). We also understood better how education could be an interface between the development ecosystem and the research. It required the education to be about projects and knowledge creation instead of the more classical education that only deals with knowledge transfer.

The educational experiment cannot be disconnected from the participation research. The insights of the participation research explain many of the setups in the experiments. The participation research did more than inspire the experiments. Some dynamics, like the spreading activation by an emerging business ecosystem (base layer of the ÆIP architecture) could only be retrieved from such participation research. The participation research has mostly been about interaction. Some attempts at coordination have been undertaken, but without much effect. Interactions are weaker than coordination and coordination is weaker than control, so the participation research is a weaker form of validation than experimentation, but it does allow us to approach the self-organization in a complex adaptive environment in a way not possible by experiments.

Moving from the observation of self-organizing dynamics in an emerging entrepreneurial ecosystem to the actual control of ecosystem spinoff by an ÆIP architecture is still difficult . The scale and complexity of the Enterprise were an ÆIP architecture would be useful is huge. After a long investigation it became clear how the enterprise can be seen as a radical innovation on the current structure of a university. The history of the Technology Transfer Office (TTO, see Section 8.4) can give us an idea of the prematurity phase of this radical innovation. In a way, TTO has been a marginal activity of universities that is gaining more recognition. The maquette made for the ÆIP architecture is a next generation university called interversity where the TTO has become the core of the university, including all academic activities.

The Interversity is an architectural innovation of the existing university structure creating a synergy between the three pillars: research, education and public service. Eventually a fitting description was given showing how a three year period is needed to spin off an ecosystem, how it can fit with a two year master program and how it relates to a four year PhD program. The solution is a pipeline where multiple ecosystems get spun off each year. It involves hundreds of control agents (research & administration) and thousands of participation agents (students & developers).

12.2.4 **Limilations during the validation**

When I took on the position of teaching PhD students at the faculty of economics (2006), the plan existed with the professors on IT-management to develop an

experiment for the ÆIP architecture. When we believed the architecture to be concrete enough we took up contact with the companies, IBM, Toyota and Recticel. While the companies were very interested, any concrete experiment failed to develop. In particular Recticel was interested in executing an experiment, but this was late 2009 and the economic crises resulted in major layoffs. So the plans broke down. The failure to do an experiment on the ÆIP resulted in a big crisis for the research and a search for new validation. Clearly this disruption is part of the reason why the PhD took way longer then anticipated. Notice that the eventual validation by experiments and participation research started in 2006, in other words, we were developing the education and participating in Drupal initially of other reasons then for the PhD validation. Indeed the educational development and the participation became exapted as validation for the PhD. In 2010 the educational development and the participation got more directed for this new goal. For the educational development the planning of the scalable experiment in 2010 and running it in 2011. For the participation research the essential interviews began in 2010.

To grasp better the problems with the ÆIP architecture the maquette was build and it showed us that part of the problem with the validation is the scale. We were focusing on companies who had a large R&D (i.e. about 150 researchers), but the scale was not even close to what is eventually considered for the ÆIP architecture. The scale is so large it seems unlikely that any experiment can get started soon after the PhD. More intermediate steps are required. This can involve related experiment dealing with some aspect of the challenge, like the knowledge creation with large groups (i.e. the scalable education experiment). Other ways to work around the limitation is to consider a more organic growth by getting more involved with change management. In particular change management for large organization to adopt agile development and address complex adaptive challenges.

12.2.5 **Future research on ÆIP architecture**

Thanks to the participation research and the experiment it has become possible to create a stronger maquette for the ÆIP architecture. In the last phase of the PhD, other projects have been recognized that are moving in the same direction as the Interversity. It seems possible that a new entrepreneurial ecosystem can emerge. Universities have now taken up the trend of Massive Online Open Education (MOOC) for classic courses and many experiments are known that make education become EduLabs. The EduLabs are modular entities for a particular education effect (see Section 11.2). In other words, a whole new participation research seems possible and this time we could become a more active agent creating coordination in the ecosystem. This is a great improvement over the more passive involvement in the emerging ecosystem during this PhD. In fact, this ecosystem may be closely related to the required change management to create an Interversity. So it seems we may get closer to understanding the ÆIP architecture. The process is however a guided emergence, indeed we are blind for the novelty and this guided emergence seems to align with the phase the ÆIP architecture is currently in (late premature phase or early incubation phase)

The new ecosystem revolves around the Internet innovation wave 4.0 that is expected to show a growth phase in the 2020-2030 period. The Internet innovation is expected to be about Agile-Enterprise. The ÆIP architecture is a concept that created the agency for our development during our own premature phase. This phase began in 2002 with the first experiments on exaptation (see Section 2.1.1) and lasted until 2012 when the reflection about the experiments of the scalable education took place. We introduced a prototype currently called Project-Oriented Education System (POESy). Attempts to get venture capital to back up the prototype and let it develop into a product are happening at this moment. What remains to be seen is whether we will be able to become a coordinating agent in the emerging ecosystem.

Another way to reinforce the research and create opportunities for future research is the fundamental theoretical development. Within the GBI we are currently spending much attention to Chemical Organization Theory (COT). The spirit exists that some extension of the COT theory to focus on the problem of self-organization and coordination can become a tool to more effectively investigate innovation. In other words even if experiments turn out more difficult then anticipated we still can develop the theory independent of it. So enough paths exist to continue the research, which one will be most fruitful is simply impossible to know without investigating those paths more firmly. This expresses again that this PhD is a proof-of-concept, opening research paths more then solving existing research questions.

Abbreviations

Æ: Agile-Enterprise

ÆIP: Agile-Enterprise Innovation Planning

ADR: Action Design Research

API: Application Programming Interface

CAR: Carbureted Action Research

CACO: Complex Adaptive Conference Organization

CMS: Content Management System

COT: Chemical Organization Theory

DSR: Design Science Studies

FOSS: Free and Open Source Software

GBI: Global Brain Institute

ORA: Operational Risk Analysis

POESy: Project-Oriented Education System

MOOC: Massive Online Open Education

MST: Meta-System Transition

SMS: Strategic Management Studies

STS: Science and Technology Studies

WSDB: Web Service Development for Business

Glossary

Absolute novelty: Novelty that is produced by a process of exaptation (in contrast to relative novelty).

Agency: The ability of a system to gain control over fabrication, i.e. the ability to manufacture artifacts. When artifacts get coupled into a machine we gain advanced manipulation of the natural world, which is a higher state of agency. When such machines gain autonomy over the regulation (by knowledge) they become the highest state of agency, being agents.

Agile Education: Education in a complex adaptive information landscape where the need exists to develop without understanding the whole. Well-designed methods guided a concrete development (in the form of projects). The education shifts therefore from knowledge transfer to knowledge creation and students become more like researchers.

Agile-Enterprise: A wicked concept trying to combine the flat management of agile development with the hierarchical structure of an enterprise structure.

Agile-Enterprise Innovation Planning (ÆIP): The application of the novelty theory to design an Agile-Enterprise. The ÆIP concept is used to create propositional knowledge with the ÆIP grid and prescriptive knowledge with the AIP architecture.

ÆIP architecture: The Enterprise Architecture that is capable of producing radical change by spinning off ecosystems. The architecture makes a process possible that creates the phase transition for radical change in an artificial way.

Agile development: A method of development that uses different speeds of feedback to regulate the development instead of a fully planned regulation. The method is particularly useful for complex adaptive environments where fully planned regulation is difficult or impossible.

ÆIP grid: A grid of twenty conversion patterns. The conversion patterns are for each of the novelty models during each of the stages of the phase transition. Those conversion patterns can give a better insight on what a novelty model is contributing during a particular stage in the phase transition.

Agile management: The agile development applied to management.

Allies: A type of agent that contributes in a complementary way to the development. By the aligning between developers and allies, the direction of the development gets set.

Autonomizing: The process of gaining autonomy. For people this relates to knowledge creation to become more independent of external control (so more intrinsicly regulated). For organizations this relates to the ability to become more independent of people, which happens by organizational processes to train

people for a particular task in the organization, legal rights of the organization, etc.

Architectural innovation: in contrast to modular innovation in large companies. Where modular innovation only changes an aspect (e.g. the engine of an airplane), the architectural innovation changes the whole product (the airplane) without changing the parts. In the case of both the parts and the overall architecture change it becomes radical innovation.

Artifacts: Simon (1969) defines the artificial as man-made, in contrast to natural. This is generalized to include other systems that fabricate things that did not evolve naturally, e.g. ribosomes producing proteins, brains producing emotions, bees building hives. The artifact can be a tool or a scaffold.

Breakthrough innovation: The most recognized form of innovation when inventions become broadly used in the social fabric. The invention may have been used in a niche and now breaks through into different markets and different applications.

Bootstrapping cascade: The process of iterative bootstraps producing a co-development path. The dynamic is particularly relevant for the CAR method where the bootstrapping cascade can close a gap for development by having convergent bootstrapping iterations and open space for development by divergent bootstrapping iterations.

Carbureted Action Research (CAR): An extension of the Action Research (AR) method. The AR works by repetitive iterations of a three-stage development process: planning, acting and reflecting. The CAR method makes use of two parallel developments (learning and penetrating) with two stages (modeling and mastering). A mapping between AR and CAR is possible: AR planning becomes CAR learning-mastering, AR reflecting becomes learning-modeling and AR acting becomes penetrating (both modeling and mastering). The more complicated CAR method is important as a method to guide the phase transition. The learning and mastering envelops around the agency during each stage in the phase transition (i.e. concept, prototype, product, framework). The CAR method makes two dynamics possible: bootstrapping cascade and spreading activation. The bootstrapping cascade makes the learning and penetrating converge or diverge. When it converges, it makes a prototype emerge, when it diverges, it makes a framework emerge. The spreading activation occurs when learning and penetration happen in parallel and it reinforces the coordination between the elements in the workspace, which makes the ecosystem emerge. With the two CAR dynamics it becomes possible to develop the ÆIP architecture.

Circulating references: Latour's description of how references are made and how references give science authority. He emphasizes how the references need to be traceable back and forth from the world (the thing itself) to the form (the written representation). When the chain of relation is broken, the "circulating" stops and the authority dissolves. Circulating references is an important dynamic for the ÆIP architecture, which requires environmental enrichment by software development. Software development can automate the chain of relation. For example, transforming data from sensors (the world), by complex programs, to

gain simple presentations (the form), e.g. using a camera with face recognition software to identify a person in a picture. For more complicated research challenges not all can be automated, but with synthesizing collective intelligence it is expected that more autonomization of the circulating references will become possible.

Conversion pattern: The pattern that allows the transformation of one state to another. The Conversion pattern is an extension of Nonaka's four knowledge conversion patterns. With the ÆIP grid, twenty conversion patterns are described: one more knowledge conversion pattern for the Cohering model and for each other novelty model (Eventuating, Strategizing and Establishing) again with five conversion patterns.

Cohering model: The novelty model for knowledge creation that exists through anticipation processes working on memories.

Competitive advantage: Occurs when an organization acquires or develops an attribute or combination of attributes that allows it to outperform its competitors.

Developer: The lead agent in the development.

DevLab: a hypothetical future lab structure based on the IT enrichment found in today's technology environment. For example, the software development by FOSS has an environmental enrichment that allows for self-organizing innovation to arise (see Section 10.2). By exaptation of the IT enrichment, a hypothetic structure is proposed where research has more refined circulating references.

Delegate: The type of agent that is the spokesperson for a group or for the public sphere in general. The delegates can give more insight on how favorable or unfavorable a development can be. It is by interaction with the delegates that some minor adaptations of the target can have a huge impact on the development.

Disruptive innovation: Innovation by creative destruction (destroying the old system to gain a new system) and transforming markets by value exaptation. The innovation happens by the guided emergence produced by the prototypes.

Domestication: Domestication, of plants and animals, is the replacement of natural evolution with artificial evolution. Other species, in a similar manner to humans, domesticate, e.g. ants also grow farms and maintain cattle.

Directing anticipation: The anticipation process that uses challenges to prioritize and guide the other anticipations, creating regulation (by coordination) in the workspace.

Directing capability: Capability relating to the historic path that an organization has created. Such a capability can create the momentum required for the development of innovation. Because of the path, the innovation is driving in a particular direction.

Directing model: see Strategizing model.

Directing principle: The principle recognized in the process of alignment, where the fitness of the element in the whole defines the direction that the development is going.

Directing role: The function that allies add to the development. Through the use of allies, particular resources become available and the value of the allies creates the direction of the development. The allies' values are complementary to the developers' values. This can be a financial interest, strategic interest, social interest or any other value.

EduLabs: The currently emerging environmental enrichment that is transforming the education system. It makes a new kind of building block emerge improving the ability to provide project-oriented education. While the classic system would be organized around classes and courses, the new system is more distributed and self-organizing, revolving around projects. The classical courses become more like labs where students experiment with the subject instead of being instructed. The EduLabs can exist in many forms, such as pure virtual laboratories and actual workshops. In all cases, the enrichment works as a scaffold for the education, allowing students to learn more easily and deeply.

Enrichment phase: The fifth and last stage in the phase transition that develops very slowly, while the impact is very large. The stage is characterized by the automatization and autonomization of the novelty. The mediation and agency of this stage require more research to become clearly understood. The agency relates to the autonomization of the novelty. It can be knowledge (enriching an agent) or environmental enrichment. The innovation allows for Meta-System Transition to arise that can be studied by the origin of life and the history of technology. How such innovation can be managed is for future research to investigate.

Enterprise Architecture: The holistic design of a support system to improve enterprise.

Environmental Enrichment: This was originally recognized by Renner and Rosenzweig (1987). In the original experiments, mice in dull cages and cages rich with toys showed a significant difference in intelligence. Environmental enrichment is a fundamental aspect of understanding intelligence and shows how intelligent tasks (e.g. innovation) can become supported externally.

Establishing model: The meso-level novelty model that exists of principles for agile development. The model is intermediate because such principles can be applied to the other novelty models. This makes the Establishing model an essential part of understanding systematic innovation by the meta-model.

Eventuating model: the novelty model for environmental enrichment. The novelty anchors are roles (of agents), developing the social fabric.

Evolving anticipation: The anticipation process that uses experience to model the long-term memory or master actions in the environment.

Evolving capability: The capability allowing organizations to become more independent from the talented people that build the organization in the first place. For example, the process of training and recruiting creates an inflow of talent and restructuring creates an outflow. Such inflow and outflow shows how the organizational processes can gain regulation of the talent in the organization.

Evolving model: See Establishing model.

Evolving principle: The principle of transforming tension into synergy, creating a state of flow for the developers.

Evolving role: The function that peers have on the development. In the process of knowledge creation, no authority exists and peers evaluate each other to create the required feedback for progress. The development can progress by parts of the solution given by those peers.

Evolving system: A system that increasingly improves its regulation. It is an abstract description of more specific descriptions like: living systems (Miller 1965), Autopoiesis (Maturana & Varela 1980) and Complex Adaptive Systems (Holland 1996).

Exaptation: The utilization of a structure or feature for a function other than that for which it was developed through either natural or artificial selection.

Externalizing anticipation: The anticipation process that uses tags to align the concepts currently in the workspace to observation in the environment.

Externalizing capability: The capability to use externally developed values. It is similar to perceived values (e.g. the brand) that define the position of a business in a market. By using the position, an organization can more easily reach certain goals than others.

Externalizing model: See Eventuating model.

Externalizing principle: The principle decomposing the development and creating visible tags for a particular task. This allows for stigmergy to arise and make the development self-organizing and distributed.

Externalizing role: The function that delegates add to the development. The delegates represent part of the public. This role shows how goals that are consistent with the public needs are easier to reach and goals that are opposed to the public needs require more effort. It is important to note that the public values are dynamic and can change over time.

Fabricating: The action of a system to use energy and an internal structure to transform resources. The most basic fabrications are recognized with physical reactions where energy is added externally and the system is nothing more then a medium. Examples of physical fabrications are cyclones and whirlpools. With chemical reactions, the catalysts are recognized as fabricators. In both physical and basic chemical reactions, the transformed resources are still natural. With more advanced biochemical reactions, we recognize the development of absolute novelties by fabrication.

Framework: A support structure for a system. In the phase transition, the framework is a support structure for an ecosystem of organizations.

Flow: Generalized from the psychological description of flow, it is the mental state where a person is optimally engaged in an action. Flow is sometimes referred to as "being in the zone". The generalized use of flow in this PhD also considers environmental flow (a healthy ecosystem), chemical flow (a continuous running reaction), etc. I.e. flow is the optimal condition for circulating operation. In the Establishing model, it is the evolving principle, which means that flow can be applied to each of the novelty models. For the Cohering model, it relates to psychological flow. For the eventuating model, it is the environmental flow. For the strategizing model, it is the organizational flow (the ability of an organization to operate autonomously).

Gamification: The use of the game mechanism in a non-game context. Games have been under considerable pressure to create flow for players by well-designed user interfaces, mysterious storylines, esthetic media, self-actualization learning paths, etc. The ability of the game mechanism to create flow is now exapted for other applications. An example is education, where the factor entertainment of the game must be replaced by a stronger focus on learning.

Global Workspace: A workspace that is utilized for many processes. The Global Workspace in cognitive studies refers to a part of the brain where all other brain modules get together. When something is in the global workspace, all of the other brain modules work on that focus. In this PhD, the concept of Global Workspace is generalized. Considering that description, the Global Workspace is considered to be the workspace of a meta-system. The Global Workspace in the brain is one example of a meta-system on a neural scale. The Internet seems to be the Global Workspace on a social scale, which brings the concept of Global Brain to the debate.

Growth phase: the third and central stage in the phase transition that is identified by the investment in the development. The process transforms the prototype into a product by breakthrough innovation. By the proof-of-concept delivered from the pioneering products, the development is now focusing on scale increase by bringing the product to more customers and by using the product for different purposes. The open product is now the agency, mediated by organizations.

Guided emergence: A development process where the developers do not have all the knowledge. However, the interaction with the prototype guides the development.

LivingLab: A user-centered open-innovation ecosystem for the co-creation of innovation. It stands in contrast to the classic "testbed" where no major change to the technology is possible. In the LivingLab, the technology is more of a prototype and the development of the product happens in co-creation with the users.

Incubation phase: the second stage in the phase transition that is identified by the accelerating development and disruptive innovation. The acceleration is

reached by the mediation of workshops and the agency of prototypes. The workshops create artifacts to manipulate the novelty and gain more control over the prototypes. The prototypes create a guided emergence allowing pioneering products to arise.

Instructional Scaffolding: The support given during the learning process. Instructional Scaffolding is a temporary structure to help the student begin the learning and often is replaced by the student's own learning strategies.

Internalizing anticipation: The anticipation process that uses associations to retrieve concepts similar to the concept currently in the workspace, from the long-term memory.

Internalizing capability: The capability to use resource bundles that make particular values tangible.

Internalizing model: See Cohering model.

Internalizing principle: The principle to tackle wicked problems, shaping new knowledge connections and developing abstract concepts so that a coherent model of knowledge can arise.

Internalizing role: See developers.

Intelligence amplification: Introduced by Ashby (1956) who argues that intelligence, like physical power, can be amplified. It can be reached for individuals by technology that transforms input to digestible information by more evolved sensory systems. It can be reached for collective intelligence by environmental enrichment.

Interversity: The construction of a distributed self-organizing university that shows advancements around the three pillars of the university (education, research and public service). The open Interversity is the change of making all university activities massive. The integrated Interversity shows how a synergy can be reached between the three pillars and the spinning-off of ecosystems for radical change.

Innovation: The action of an organization to create new products and services (significantly different from existing products and services).

Invention: The ability of an individual to develop new artifacts (significantly different from existing artifacts).

Machine: A system made of various tools and scaffolds.

Mastering: The process described by the novelty model that develops the enriched environment. With the Cohering, model, for example, it is the process of applying knowledge and developing artifacts. The novelty mechanism produces mastering by a particular state of the anchors. The directing anchor focuses the input to the external anchor and reduces the input of the internal anchor, allowing the evolving anchor to develop the enriched environment.

Maturity phase: The fourth stage in the phase transition that is identified by the slowdown of development and the focus on cost reduction. The wide variety of product applications makes the need of a support framework arise, which is now producing the agency. The mediation comes from the coordinating organizations that make up the ecosystem. For a large organization, the ecosystem can be internal and architectural innovation becomes possible.

Mediation: In general, mediation is the action of capturing elements and creating coordination between the captured elements. In this PhD, mediation is used to describe the selection of the artificial evolution (in contrast to the variation by agency). The reason for this specific definition is that mediation only affects some elements. For example, electrons could be captured by an atom (the mediator), while neutrons are unaffected. Similarly for people, the waiters may be mediated by the numbers on a table, while the customers are unaffected. Therefore, the mediation creates some form of selection, but it is indeed an artificial selection relating to some system.

Meta-element: A meta-system where agents execute the control over the global workspace. Because of the global workspace, the agents become one system, while they can be distributed and self-organizing. The main example is the brain where autonomous brain modules use relay neurons to transport signals to the workspace, allowing a distribution of brain modules to connect with each other though the global workspace. A similar distribution and self-organization is recognized between people where the Internet is the global workspace. This brings up the debate about Global Brain as a meta-system transition binding us into one big system.

Meta-model: A novelty model where each of the four anchors is again a novelty model. It is the novelty model capable of regulating radical innovation.

Meta-system: In general, a meta-system is a system composed of multiple systems. In this PhD, a more specific meaning is given, being the system where the workspace is controlled in contrast to the simpler coordination of all workspaces. The meta-system is a general description that does not say where the control is coming from. If the control comes from agents, it becomes a meta-element. If the control comes from environmental conditions, it becomes a meta-workspace.

Meta-Workspace: A specific environmental situation of multiple workspaces in close proximity, allowing the creations from the workspaces to interact before they break down. This dynamic is mostly recognized as a laboratory. The meta-workspaces are essential for creating higher-order regulation of a system. They are proposed next to the meta-elements. While a meta-element is a permanent structure bringing the elements under control, the meta-workspace can become redundant after the phase transition. By internalizing a meta-workspace, as seen with embryonic development and the brain, a novelty model can emerge by a natural evolution of the meta-workspace.

Micro-spinoff: These are spinoffs with little need of investment. In particular, software spinoffs, using many available online resources, can be cheap, while having high added value. This is possible because many online programs have an

API and the integration of several programs may easily bring new constructions, like using existing music to mix up new sounds. Examples of possible micro-spinoff are given in Section 9.2.2.3.

Modeling: The process described by the novelty model that develops the system core. With the Cohering model, for example, it develops knowledge. The novelty mechanism produces modeling by a particular state of the anchors. The directing anchor focuses the input to the internal anchor and reduces the input of the external anchor, allowing the evolving anchor to develop the system core.

Novelty: Novelty is what did not exist before, but emerges into existence by artificial evolution. Artificial evolution is a bootstrapping process between medium (which defines the novelty) and agency (that embodies the novelty). Novelty is what lies beyond the horizon. By the feedback mechanism, the entity emerges. In the novelty model, the type of novelty that emerges depends on the concrete implementation of the model.

Novelty anchors: These are the connectors defining the feedback mechanism. In concrete implementation, the novelty anchors are of one type. For knowledge creation, the anchors are anticipation processes. For environmental enrichment, the anchors are agents. For organization, the anchors are capabilities. For development processes, the anchors are principles.

Novelty model: a model describing the mechanism that can overcome conservation. The kind of conservation depends on the concrete implementation of the novelty model. It consists of four anchors connecting three mediums. By the anchors, feedback can flow. The internal anchor connects the workspace with the system core. The external anchor connects the workspace with the environment. The directional anchor connects regulation to the workspace. The evolving anchor connects the invariant pattern emerging in the workspace to the development of the system core and the development of the environment.

Niche construction: The development of an agent to change the environment, making the environment fit better with the agents needs.

Open product: A multipurpose product or a product that is open to custom development by interfaces (e.g. API). The open product is the later stage of a product in contrast to the early stage (pioneering product).

Peer: A peer has the same knowledge and interest as the developer and can be involved in the project, just not committed to the development. For example, peers and developers are interchangeable, but peers are often committed to other development. Peers are the best way to evaluate the developer, which is how peers function as the evolving role for the development.

Phase transition: major change that slowly emerges, accelerates and eventually slows down, which creates the typical S-curved shape of the transition. The S-shape is a theoretical model of a more chaotic development where accelerators or blockages can disturb the shape. The phase transition is separated into five stages: premature phase, incubation phase, growth phase, maturity phase and enrichment phase.

Pioneering products: The first application of a product into a niche market.

Premature phase: The first stage in the phase transition that is identified by the very slow development. During this phase, worldview innovation emerges altering the knowledge radically. The mediation during this phase comes from laboratories, while the agency comes from wicked concepts, used to build artifacts that allow the measuring and capturing of the novelty.

Radical change: the ability to overcome conservation by a phase transition.

Radical novelty: The novelty developed by the radical change of a phase transition (in contrast to relative novelty).

Relative novelty: The novelty emerging from an adaptive and incremental development process (in contrast to absolute novelty and radical novelty).

Regulation: the ability of a system to control the environment. The classic example of regulation is the functioning of a thermostat, which approximates the goal temperature by switching on and off the heating.

Scaffold: An artifact reducing perturbations from the environment.

Scalable Education: Project-oriented education is hard to scale because of the intense feedback required by a supervisor. The scalable education is an experiment to replace many of the tasks of the supervisor by peer evaluation, according to the principle of synthesizing collective intelligence.

Spreading activation: The dynamic recognized in a medium that allows for an activation to spread over the elements in the medium. In a fluid medium, this is a force, in a neural medium this is a charge. For people, the spreading activation can happen by viral concepts or by a challenge appealing to the person to get into action. The dynamic of spreading activation is particularly relevant in the CAR method where a cloud of prototypes transforms by the spreading action to an ecosystem of products.

Strategizing model: the novelty model creating organizations. It consists of capabilities that define the organization.

Succession: the process of change on an ecosystem. Two types of ecological succession exist, primary and secondary. In this PhD, the concept is generalized so it is not only about ecological succession, but can explain technological succession and succession of the social fabric.

Synthesizing collective intelligence: This stands in contrast to the aggregated collective intelligence. The aggregated collective intelligence shows simply how the whole is more than the parts. The synthesized collective intelligence brings more refined feedback structures and enables more refined applications of collective intelligence. For example, aggregated collective intelligence would give the average solution of a group of amateurs. The synthesized collective intelligence would use a moderator to filter the solutions first. Using a moderator is one simple example. More refined systems are the topic of current research.

Social fabric: The society constructed by the agents that contains institutions, technologies, processes of operation, etc.

Tool: an artifact that amplifies a feature. An agent uses the artifact to simplify an action or reach into domains that are out of reach. For example, if an ape uses a stick to capture termites, it has fabricated a tool. In this example, the physical fabrication is trivial. The internal knowledge that makes a stick a tool is the real fabrication.

Value exaptation: values that exist in a particular context get exapted for another context. An example is when values about public goods get applied to private goods, like the Free and Open Source software development in contrast to the IP protected software development. In a more local context, the value can exist in one market for a particular product and get exapted for a different market and/or a different product.

Wickedness: abstracted from the concept "wicked problems", which refers to problems that can only be clearly defined after the solution has been found. The concept is generalized so that it can be applied to: wicked actions, wicked organization, etc.

Workspace: a medium with sensory input creating invariant patterns. In the most basic workspaces, the pattern regulates the motoric response, as seen with the advanced Bénard cells. In more advanced workspaces, as seen with brains, the motoric response is decoupled allowing more advanced operations on the patterns and creating intelligence by knowledge.

Worldview innovation: the transformation of a worldview by a society based on new observations and changed values. In the process, a rare event becomes easier to manipulate and understandable.

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