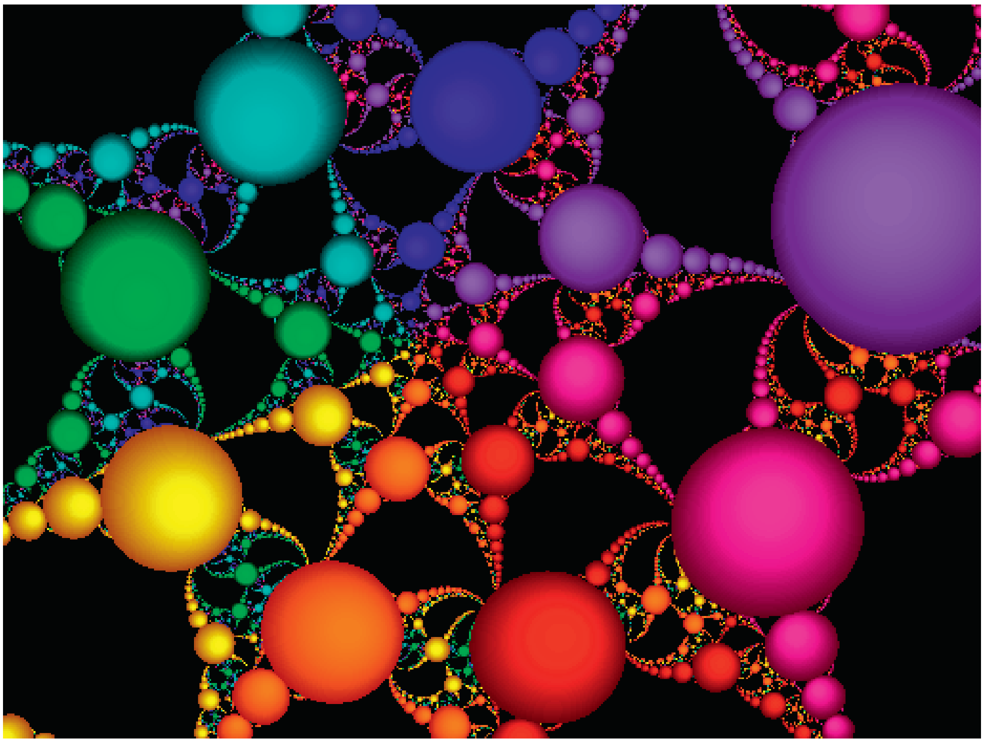
RESEARCH REPORT

Complex adaptive systems

Properties and approaches



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RESEARCH REPORT 2009

COMPLEX ADAPTIVE SYSTEMS

Properties and approaches

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Introduction

This research report is based on a draft theoretical frame of reference from the author's doctoral thesis (working title of the thesis is: "Beyond Process Management"). The research focuses on applications of process management in organizations. The result of the research indicates that the matrix, which appears with the line organization on the one hand and with the process flows on the other hand, creates a complexity in the organization that is challenging to manage. Therefore, the concepts of complex adaptive systems and the possible applications in the management of organizations have been explored.

The report is based on other reviewed literature on systems and complexity recommended from other researchers and practitioners in the field.

The doctoral thesis is planned to be presented in August 2009.

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Content

Complexity – neither simple nor complicated

Traditionally, modern science is preoccupied with independent variables that assume causal relationships. Accordingly, to understand the behavior of a system we need only to address the impact that each independent variable has on that system. However, more and more events occur when the relationship between variables seems to be interdependent. As, Gharajedaghi states: *"increasingly we are finding out that our independent variables are no longer independent and that the neat and simple construct that served us so beautifully in the past is no longer effective."* (Gharajedaghi, 1999, p. 13).

When events are interdependent, the results seldom end up the way we plan them. Many people experience a feeling of chaos, which is rather unpleasant for most people. Tetenbaum (1998, p. 24) describes chaos as a *"complex, unpredictable, and orderly disorder in which patterns of behavior unfold in irregular, but similar forms"*. Like snowflakes, no two alike, but they all look similar. Correspondingly, several authors define complexity in similar ways;

- *"Complex implies diversity – a great number of connections between a wide variety of elements."* (Zimmerman, Lindberg, & Plsek, 1998, p. 8).
- "*Complexity is when something is both orderly and disorderly."* (Norretranders, 2002, s. 96) cited in Augustinsson (2006, s. 17).
- *"Complexity is a perspective that embraces acausal, non-linear interpretations of systems."* (Dent, 1999) cited in (Smith, 2005, p. 24).

Dee Hock, the founder of Visa, has presented the concept of "chaordic", a combination of chaos and order; *"In chaordic systems, order emerges. Structure evolves. Life is a recognizable pattern within infinite diversity."* (Tetenbaum, 1998, p. 25).

The distinction between complicated and complex is another way to phrase the understanding of complexity. Both Cilliers (2000) and Uhlin (2001) argue that something complicated can be described by its parts, even though they are many (cited in Augustinsson, 2006). A computer, a car or a jumbo jet is complicated, but not complex. When the concepts of cause and effect are used, then something is complicated, according to Weaver (1948), cited in Augustinsson (2006). Senge (1990) uses the same line of argument but uses the categories of; detail complexity (what the previous authors call complicated) and dynamic complexity (what previous authors call complexity). He argues that detail complexity (complicated) is designed to handle many variables, while dynamic complexity (complexity) occurs in situations where cause and effect are subtle.

The concept that deals with interdependent, complex systems has many names:

- **Chaos theory** *"…argue that relationships in complex systems, like organizations, are non-linear, made up of interconnections and branching choices that produce unintended consequences and render the universe unpredictable."* (Tetenbaum, 1998, p. 21)
- **Complexity theory** *"…offers the twin benefits of describing how complex systems can generate simple outcomes while looking at the whole system and not just its components."* (Smith, 2005, p. 24)
- **Complexity science** *"…is the name commonly used to describe a set of interdisciplinary studies that share the idea that all things tend to self-organize into systems."* (Kelly & Allison, 1999, p. 5)
- **Complexity science** *"…provides us with a demonstration of possibility, and with insights into the nature of nonlinear interaction among large numbers of entities."* (Stacey, 2003a, p. 38)

- **Systems thinking** *"… a discipline for seeing wholes. It is a framework for seeing interrelationships rather than things, … a discipline for seeing the 'structures' that underlie complex situations."* (Senge, 1990, p. 68).

There is much literature on complexity and complex systems in the field of quantitative mathematics (Smith, 2005). Gleick (1998) emphasizes the growing number of researchers from the natural sciences who, from the sixties onwards, have developed theories and conclusions on complex adaptive systems, cited in Augustinsson (2006). Ackoff (1999) argues that the work of von Bertalanffy (1968) and his General Systems Theory were major stimuli for the awareness of the nature of systems and the implications of their nature to effective organizations and management.

In his doctoral thesis, Augustinsson (2006) reviewed several fields within which the ideas of complex adaptive systems formed a basis. These ideas are applied in the fields of physics (Marion & Uhl-Bien, 2001; Zohar, 1990). Prigogine (1989) received the Nobel Prize for research into how chemical systems can self-organize through randomness and produce emergent structures (Prigogine, 1997; Nicolis & Prigogine, 1989; Prigogine & Stengers, 1985). Another Nobel Prize laureate, with his work within the field of complex adaptive systems, is the physicist Gell-Mann, (1995; 1997). For research and applications in the field of biology, see Bird (2003) and Kaufmann (1993). Ralph Stacey is a central figure within the social sciences (1995; 2003a; 2003b and Stacey et al., 2000). For studies in the social sciences, see also McKergow (1996) and Mitleton-Kelly (2003). Some examples of studies on leadership, innovation, and learning have been carried out by Fonseca (2002), Griffin (2002), Shaw (2002), Streatfield (2001), Marion (1999), Marion & Uhl-Bien (2001), and Lissack & Roos (2000), cited in Augustinsson (2006).

The development of common concepts and ideas enables the development of cross-disciplinary work within the wide field of complex adaptive systems. Augustinsson (2006) resemble the theories from the second half of the 20th century to a scientific revolution, which has contributed to a new line of thinking in a number of scientific fields. According to Augustinsson (2006), this is also a critique of the modern and the traditional scientific approaches, which is common for researchers within the varying fields of complex adaptive systems.

Several authors agree that it is premature to call the above-mentioned concepts a theory (Smith, 2005; Cohen, 1999; Lissack, 1999). However, there is an increasing number of results, models, and methods that give us insights into the interdependent dynamics of systems that can be found in a variety of domains (Cohen, 1999). These insights and tools embody a distinctive point of view and suggest new types of questions (Cohen, 1999).

The concepts of systems and complexity can be a helpful metaphor when observing organizations (Smith, 2005). Lissack (1999, s. 112) calls it "*a collection of ideas that have in common the notion that within dynamic patterns there may be underlying simplicity that can, in part, be discovered through the use of large quantities of computer power; Horgan (1995), Casti (1997) and through analytic, logical, and conceptual development…*". Finally, Senge (1990) defines it as a language to help restructure how we think.

In the literature, many authors from different disciplines differently describe the components of complex adaptive systems; no overview has been found that describes these components. In the following sections, classifications are suggested: (1) properties of complex adaptive systems, see Figure 1, and (2) approaches for managing complex adaptive systems, see Figure 2. The elements of each, i.e., the properties and approaches, will be presented.

Properties of complex systems of interdependent agents

According to Zimmerman et al. (1998) a system is a set of connected or interdependent agents, where an agent may be a person or an organization. It is by contemplating the whole, and the relationships and interactions between agents, that one understands a system; not by the absolute knowledge about each agent (Richardson, 2008; Senge, 1990; Zimmerman et al., 1998). Augustinsson (2006) presents the ideas of the physics Nobel laureate, Murray Gell-Mann (1997) who argues that we need to cherish the people who dare to look at "the big picture" because organizations are not just the sum of their components (agents), but also the intricate relationship between the components (agents).

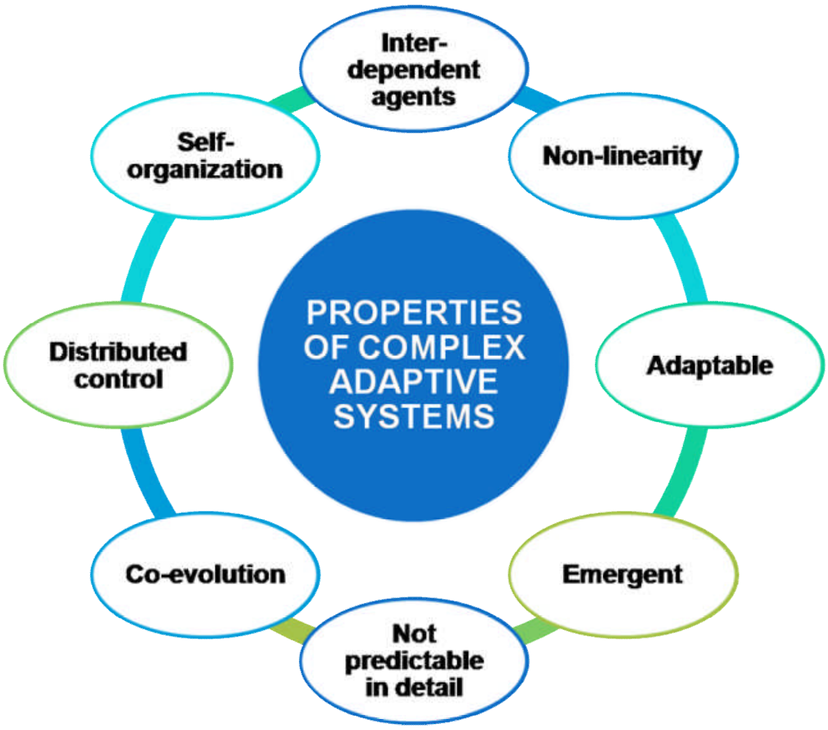

Figure 1 – An overview of the properties of complex adaptive systems (CAS) assembled by the author

Interdependent agents: only understood in their context

If you look at an organization as a complex adaptive system (CAS) the departments, teams or individuals are interdependent agents who act in that system. It is termed interdependency because each part in the system can affect the behavior or properties of the whole (Ackoff, 1999). Deming (1994, p. 50) argues that *"a system is a network of interdependent components that work together to try to accomplish the aim of the system"*. Each agent is seen as a CAS (Richardson, 2008). Kelly & Allison (1999) argue that agents in CASs are autonomous – thinking, conscious, decision-making individuals who make decisions and take responsibility for their decisions. Richardson (2008) defines the autonomy of each agent as the local memory of agent, the ability to learn from their experience and to generate new responses.

Further, organizations are seen as open systems, by that, Gharajedaghi (1999) means that the system can only be understood in the context of its environment. An example of an open system is illustrated by Kelly & Allison (1999) by looking at the human cell. Clearly, the cell membrane defines the boundary of the system, while at the same time enabling nutrients, information (electrical impulses) and waste to pass through the membrane.

Non-linearity: how small changes can make a big difference

A central property of CASs is their non-linearity. Between the agents of a CAS exists dynamic, varying and non-linear connections and interactions (Augustinsson, 2006). The effect of the non-linear connections is that the size of an outcome from a CAS cannot correlate with the size of the input (Zimmerman et al., 1998; Richardson, 2008). *"A large push to the system may not move it at all."* (Zimmerman et al., 1998, p. 11) or as Senge (1990, p. 58) states: *"The harder you push, the harder the system pushes back."*

Gharajedaghi (1999) takes it further, calling the property "counterintuitiveness", which he defines as actions intended to produce a desired outcome that may, in fact, generate opposite results.

Adaptability: adaptable to new conditions in the environment

CASs are seen as adaptable, which means that they have the ability to learn from their own experience and adapt to new, unexpected conditions (Zimmerman et al., 1998).

Emergence: to develop capacity that is more than the sum of the capacity of the parts

Emergence is a property of a CAS that comes out of the interaction of many participants (agents) (Lissack, 1999; Gharajedaghi, 1999). It is a property of the whole, not of the parts (Gharajedaghi, 1999). Emergens is *"the creation of attributes, structures, and capabilities that are not inherent to any single node in the network."* (Tapscott & Williams, 2006, p. 44). Richardson (2008) states that emergence is often portrayed as a process whereby the properties of the whole emerge from the properties of the parts.

Self-organization: creating order out of chaos

Some argue that self-organization is the cause of emergence (Tapscott & Williams, 2006). Independent agents acting together will unwittingly create something new. Self-organization is a self-enhancing process that aims to construct and retain current structures (Augustinsson, 2006).

For self-organization to take place it takes a state of bounded instability, this state is often described as "the edge of chaos" (Kelly & Allison, 1999). In this state, organizations (CASs) have the ability to create order out of chaos (Gharajedaghi, 1999). Organizations use their cultural codes in the same way as biological systems use genetic codes to self-organize (Gharajedaghi, 1999).

Distributed control: order without central control

The property of distributed control is opposite to hierarchical central authority, which directs all agents (Zimmerman et al., 1998). *"Just because no one is 'in control' does not mean that there is no control. In fact, all healthy organisms have processes of control."* (Senge, 1990, p. 292).

An example of a distributed, self-organizing system from biology is the Physarum polycephalum, a slime mold that is a cross between single-celled and multi-cellular organisms, often referred to as the "many-headed slime". It lacks a nerve system and no central part controls the whole organism. Toshiyuki Nakagaki, Professor, at the Japanese Hokkiado University, has studied the slime mold for over fifteen years. Even if the molds are presented with something entirely new, they have the ability to adapt to the new conditions. Through his research (Nakagaki *et al.*, 2000), he has shown that the slime mold will choose the shortest and safest route through a labyrinth. A slime mold searching for food first covers a surface and when part of it has found food, it creates thicker threads between the places where the food was found in order for it to use it effectively.

In organizations managed by distributed control vision dialogues are kept all around (Sandberg & Targama, 1998). The dialogues happen in the network of densely-connected interacting agents, each operating from its own schema or local knowledge (Zimmerman et al., 1998).

Senge (1990, pp. 287-288) calls this property localness:

> *moving decisions down the organizational hierarchy; designing business units where, to the greatest degree possible, local decision-makers confront the full range of issues and dilemmas. … Localness means unleashing people's commitment by giving them freedom to act, to try out their own ideas and be responsible for producing results.*

Co-evolution: acting and reacting in cooperation and in competition with other agents

In the connected world of today, no agents act on their own. An agent's actions affects other agents in its system. Organizations act and react in cooperation and in competition with other agents. Kelly & Allison (1999, p. 16) state:

> *Evolution is the theory that those species survive that are most capable of adapting to the environment as it changes over time. …. In a rapidly changing global market, for example, the actions of one company (departments or teams) trigger actions and reactions in other companies (departments or teams), whose actions trigger responsive actions in the first. … Co-evolution is the reason companies today must run as fast as they can just to maintain their current positions.*

Regarding the combination of cooperation and competition, Tim Bray, director of Web Technologies at Sun Microsystems states in Tapscott & Williams (2006, p. 27) that:

> *we genuinely believe that radical sharing is a win-win for everyone. Expanding markets create new opportunities." … Contributing to the common is not altruism; it's often the best way to build vibrant business ecosystems that harness a shared foundation of technology and knowledge to accelerate growth and innovation.*

Not predictable in detail, but with structures and patterns

When analyzed in detail, CASs are not predictable because of their interdependencies and non-linearity. However, it is still possible to find inherent order in the mess or chaos. Senge (1990, p. 290), makes the case that *"The art of systems thinking lies in seeing through complexity to the underlying structures generating change."*

The concept of these underlying structures is inspired by fractals in mathematics, as Kelly & Allisson say (1999, pp. 15-16):

> *Fractal structures are those in which the nested parts of a system are shaped into the same pattern as the whole. This is called self-similarity. … We can build on the nature of the fractal structures and generate an organization that can change direction quickly. In a business in which self-similarity of values and beliefs has emerged at all levels and in all geographic areas, effective teams can be assembled very quickly to take advantage of sudden opportunities or handle unexpected threats.*

A complex system cannot be controlled – but there are approaches for management

A number of authors strongly argue that CASs cannot be controlled, see: Cilliers (2000) cited in Augustinsson (2006) and Stacey (2003a). They argue that a system cannot be designed to predict a certain result. According to Tapscott & Williams (2006), even though a CAS cannot be controlled, as is assumed in the approach of the traditional management of hierarchical organizations, a CAS can be steered. Deming (1994) states that a system must be managed, and that it is the job of management to direct the efforts of all components towards the goal of the system. The literature presents a number of approaches regarding the management of an organization as a CAS, which will be presented below, see also Figure 2.

Figure 2 – An overview of approaches for managing a complex adaptive system (CAS) assembled by the author

Creating a vision that generates a shared picture of the future

"If any one idea about leadership has inspired organizations for thousands of years, it's the capacity to hold a shared picture of the future we seek to create." (Senge, 1990, p. 9).

Traditionally, in organizations, visions are broken down into strategic plans and action plans that describe how the vision should be realized. Gharajedaghi (1999, pp. 104-105) calls this "reactive planning", which, according to him, is *"concerned with identifying deficiencies and designing projects and strategies to remove or suppress them"*. Further, he describes "proactive planning" as consisting of prediction and preparation with the objective to *"forecast the future and then prepare the organization as well as possible"*. Finally, he describes an interactive-type of planning, where the future is assumed to be created by what we and other agents do between now and then. Using an interactive-type of planning *"the objective is to design a desirable future (idealization) to invent or select ways of bringing it about (realization)"*. (Gharajedaghi, 1999, pp. 104-105).

Within the same scope as interactive planning, Zimmerman et al. (1998, p. 27) suggest that *"intricate strategic plans be replaced by simple documents that describe the general direction the organization* *is pursuing, and a few basic principles for how the organization should get there"*. That is, to build a good enough vision to provide a minimum specification that generates a shared image of a desired future of the system. This should encourage the flexibility, adaptability, and creativity in the systems and enable individuals (agents) to become more active (Zimmerman et al., 1998).

Here, the basic idea is to leave behind the principle of managing through detailed instructions, which decreases the freedom of the individual agent, and instead, lead by making people embrace visions and by stimulating individual agents to use their inherited abilities (Sandberg & Targama, 1998).

The risk of managing through visions and boundaries is that if people do not share a common vision and common mental models, *"empowering people will only increase organizational stress"* (Senge, 1990, p. 146). Tetenbaum (1998, pp. 28-29) even states that *"To enable individuals and small groups to pursue the learning and innovation that leads to self-organizing behavior, they must be allowed autonomy. But autonomy cannot be allowed to dissolve into anarchy."* To avoid organizational stress and even anarchy, Dee Hock, the founder of Visa, refers to the use of purpose and principles to provide directions, cited in Tetenbaum (1998).

Simple rules to enable complex behavior

Chaos is constrained by the rules and boundaries that govern it (Tetenbaum, 1998, p. 25). In 1986, Craig Reynolds was trying to program a computer simulation of a flock of birds. With the available computer capacity, it was difficult to make the calculations, since the birds expressed such a complex behavior when flying. Instead, he created a simulation of autonomous agents (boids) who's behaviors were governed only by three rules (steering behaviors), which described how an individual boid maneuvers, based on the positions and velocities of its nearby flockmates (Reynolds, 2001). His three rules were:

1. **Separation**: steer to avoid crowding local flockmates
2. **Alignment**: steer towards the average heading of local flockmates
3. **Cohesion**: steer to move toward the average position of local flockmates.

The remarkable thing was that, governed by these three rules, the flocks of boids could handle varying environments, which were filled with obstacles, without being controlled or steered. As Zimmerman et al. (1998, p. 26) states: *"it does show that simple rules – minimum specifications – can lead to complex behaviors. These complex behaviors emerge from the interactions among agents, rather than being imposed upon the CAS by an outside agent or explicit, detailed description."*

Or, as Dee Hock, founder of Visa states: *"Simple, clear purpose and principles give rise to complex intelligent behavior. Complex rules and regulations give rise to simple, stupid behavior."*

Attractors – there is no such thing as resistance, there is only attraction

It is argued that there is no such thing as resistance – there is only attraction. To make something happen, all one has to do is create stronger attractors than the ones in place. Senge (1990, p. 95) states, *"do not push growth, remove factors limiting growth"*. Zimmerman et al. (1998, p. 12) suggest that it is important *"to move the natural energy in the system rather than to fight against it"*.

Diversity and tension – to challenge instead of simplify

Just because the approach of simple rules is suggested above, it does not mean that everything should be simplified, in fact, just the opposite is required. Traditionally, in the industrial era, stability was a success factor among organizations. Today, with the pressure to remain innovative and flexible, managers instead need to create an environment of tension and instability.

Theoretical studies of complex adaptive systems suggest that creative self-organization occurs when there is jut enough information flow, diversity, connectivity power-differential and anxiety among the agents. Too much of these can lead to chaotic system behavior: too little and the system remains stuck in a pattern of behavior. (Zimmerman et al., 1998, p. 31).

In a CAS, creativity and innovation have the best chance to emerge precisely at the point of greatest tension and apparent irreconcilable differences. Rather than smoothening over these differences – the typical leadership intuition from the machine and military metaphors – we should focus on them and seek a new way forward. (Zimmerman et al., 1998, p. 33).

Tension is a necessary ingredient of creativity, but it will take particular skill on the part of the manager to keep the tension level at a point where it generates dynamic imagination without exceeding people's ability to handle stress engendered. (Tetenbaum, 1998, p. 30).

One approach to create tension is to see to that the organization is diverse (Zimmerman et al., 1998).

Homogenous groups tend to produce homogenous ideas. … To achieve a high level of creative thought, it is necessary to bring together diverse groups of people: people with different levels of expertise …, employees at all levels of the organization …, people outside the organization …, and, above all, people representing a broad spectrum of ideas. (Tetenbaum, 1998, p. 28).

Another approach to create tension is through, what Zimmerman et al. (1998) call, wicked questions. These types of questions have no direct answers; instead they aim to expose our assumptions. A third approach to create tension is to mix cooperation and competition: *"A good leader would be one who knows how to, and prefers to, cooperate, but is a skillful competitor when provoked to competition (that is, a nice, forgiving, tough and clear person). Note that this strategy rejects both extremes as a singular strategy."* (Zimmerman et al., 1998, p. 42).

Experimentation and reflection – let direction arise

While the traditional approach of problem solving is to start with an extensive analysis of the problem, the problem-solving approach when managing complex adaptive systems is to experiment. To act and learn, instead of planning, try to analyze until a certainty is reached, and then act.

Zimmerman et al. (1998, pp. 35-36) suggest that one should aim for multiple actions at the fringes, and then let direction arise:

when we find ourselves in situations far from certainty and agreement, the management advise contained in this principle is to quit agonizing over it, quit trying to analyze it to certainty. Try several small experiments, reflect carefully on what happens and gradually shift time and attention towards those things that seem to be working the best (that is, let direction arise).

Tetenbaum (1998, p. 31) emphasizes that: *"if experimentation, risk-taking, and trial-and-error modes of problem solving are to compete with the overused rational, analytic modes, then the culture must tolerate failure, refrain from placing blame, and reinforce nontraditional thinking."*

If an organization is going to start to experiment in order to solve problems, an important principle would be to reflect on the results of the experimentation. *"Reflection is, therefore, a key skill for anyone in a CAS. Good leaders in a CAS lead not by telling people what to do, but by being open to experimentation, followed by thoughtful and honest reflection."* (Zimmerman et al., 1998, p. 32).

The reflection should aim at learning from the experimentation. What will work when we try it on a small scale? The challenge is to shift the attention to the things that seem to be working the best. The good thing about learning is that

> *Social learning is not the sum of the isolated learning of each member. It is the members' shared learning as manifested in a notion of shared image and culture. … But unlike energy, knowledge is not subject to the 'laws of conservation´. One does not lose knowledge by sharing it with others. The ability to learn and share knowledge enables socio-cultural systems to continuously increase their capacity for higher levels in organization.* (Gharajedaghi, 1999, p. 86).

It is suggested that a leader can increase an organization's and an employees' ability to learn and create understanding, by institutionalizing the questioning of everything and by using interpretation instead of analysis (Sandberg & Targama, 1998).

Chunking – to build on what works

When agents have experimented on a small scale to try something new or to solve a problem Zimmerman et al. (1998, p. 39) suggest that, instead of planning an implementation or a "roll out" of the new solution, managers should use the approach of chunking: *"Chunking means that a good approach to building complex systems is to start small. Experiment to get pieces that work, and then link the pieces together. Of course, when you make the links, be aware that new interconnections may bring about unpredicted emerging behavior."*

The approach is to start with an issue that is overwhelmingly complex and start quickly with small, simple experiments. Perform the experiment and reflect carefully. Adopt the good bits by dropping what clearly will not work and continue by linking the pieces that work together, and allow the solution to emerge.

Feedback – a key factor affecting learning

Feedback is the action of feeding or reporting back the results of an action to the people performing that action (Kelly & Allison, 1999). According to Eurat (2006) feedback is accepted as a key factor affecting learning, cited in Augustinsson (2006). It is the concept of feedback that allows for emergence, self-organization, adaptability, and learning in CASs (Richardson, 2008).

There are two kinds of feedback, given slightly different names by different authors: amplifying and balancing (Kelly & Allison, 1999); reinforcing and counteracting (Senge, 1990); and positive and negative (Augustinsson, 2006). Normann (2001) calls the second kind correcting, cited in Augustinsson (2006). If, to create control and predictability, a system is managed by a majority of balancing/counteracting/negative/correcting feedback, innovation may not occur (Augustinsson, 2006).

It is suggested that there should be a prerequisite for healthy CASs to contain both types of feedback; Bird (2003) cited in Augustinsson (2006). With both types of feedback, the system will have little equilibrium and will be sensitive to its surroundings. The existence of both types of feedback results in the whole system speeding up, according to Wood (2002), cited in Augustinsson (2006).

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