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Learning for Sustainable Organisational Interoperability

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Abstract. In contrast to non-interoperable and fully-interoperable systems, *interoperable systems* have qualities that the former can not fulfil. A system of loosely coupled and interoperable parts is more resilient and sustainable than a system of fully integrated parts since a failure in one part halts the integrated system. In a system where its parts are non-interoperable, the individual parts do not work together, and the full desired functionality is not available. For organisations, which are in a constant flux, support is required to maintain interoperability and keep the organisations' parts from falling towards the above extreme sides. The same is true for organisations as part of an ecosystem, an economic system and a social system to maintain resilience and sustainability. In this paper we derive requirements and conceptualise a multi-faced learning environment to support organisations to keep pace with the permanent changes in their environments, helping to reach a level of sustainability that allows organisations to survive in their environment on the long run.

Keywords: Enterprise Interoperability; Learning; Education; Sustainability

1. INTRODUCTION

Sustainability needs a holistic approach (Espinosa et al., 2008). Complex and non–linear relationships between multiple heterogeneous systems of (at least) three types "environmental systems", "industrial systems", and "societal systems" have to be addressed in order to maintain sustainability (Fiksel, 2012). Organisations are placed in the industrial system, interacting with the environmental system through the use of resources and their employees are part of the societal system.

"In today's globally networked environment, one cannot achieve environmental, social/ethical or economic sustainability of any artifact ... without achieving ubiquitous ability of the artifact and its creators and users to exchange and understand shared information and if necessary perform processes on behalf of each other in other words, interoperate. Thus, sustainability relies on interoperability, while, conversely, interoperability as an ongoing concern relies on ... sustainability" (Dassisti et al., 2013, p. 2).

To support an understanding of sustainability from a holistic point of view, a theory that is capable of modelling the high number of complex relationships between independent system parts, is needed. Complex Adaptive Systems (CAS) theory is one such theory (Espinosa and Porter, 2011).

In CAS theory many independent agents interact with many other agents in great many ways (Waldrop, 1992). Taking a CAS point of view interoperability between system parts becomes a necessity, which, if not met, might bring the overall system to a halt. Support for active agents in organisations is required to meet resilience and sustainability criteria. To permanently adapt to a changing environment, and changing demands from the environment, the active agents need to learn individually and the organisation needs to learn as a whole.

This paper is organised as follows. First systemic views, interoperability and organisational learning as basic requirements to handle dynamics of enterprise systems are discussed. This allows to establish a conceptual support environment for organisations aiming being sustainable in a dynamic environment.

2. ORGANISATIONAL SUSTAINABILITY

In the following an introduction to a broad range of related literature is provided. Due to space constraints no in depth analysis is made.

2.1 Organisational Interoperability

Chen (2006); Ducq et al. (2012) and others have created an interoperability matrix for detailing the problem space, having the following two independent dimensions and categories:

- *Enterprise Interoperability Barriers:*
  Conceptual — Technological — Organisational
- *Enterprise Interoperability Concerns:*
  Business — Process — Service — Data

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2.2 Interoperability for Sustainability

The systemic approach to sustainability requires many different system parts to be interacting. The dynamics requires a system where parts may be changed without effecting the whole system. It is important to differentiate between the integration and interoperability of systems as "integration is generally considered to go beyond mere interoperability to involve some degree of functional dependence" (Panetto, 2007, p. 731). This dependence implies less flexibility and less resilience since it combines the involved systems in order to form a single whole (Dassisti et al., 2013). In an integrated system the number of system parts and the probability of a part failing determines the overall probability of the whole system to fail. The probability of the overall system to fail gets higher if the number of system parts becomes higher (Weichhart et al., 2002).

Interoperability, requires a more loosely coupled approach compared to integration. Here system parts remain independent, coordinated to allow collaboration to take place. Changes to system parts are less crucial as long as the interfaces defined for interaction between parts are not changed. For interoperability heterogeneous system parts are required (Dassisti et al., 2013). The concept of interoperability of systems is of importance for sustainable development, and is an ongoing concern for meeting the demands of sustainability of an overall system.

2.3 Evolving Dimensions of Sustainability

With respect to sustainability, which system-parts are of relevance is a matter of debate in the scientific and political community. There is no doubt that models of sub-systems and linkages will evolve. The analysis of sustainability trends and causes takes the dynamic nature of modelling into account. Models for analysis of sustainability are not finite, once build. Any model forms a basis for exploration and provides input to the next future model.

Even if the relevance of systems and their structures are a matter of debate, it is still of importance that a holistic and systemic view is taken (Fiksel, 2012). Besides the required overview, special attention is required to handle the dynamics of the system and of the modelling process.

- *Dynamics in the system* (to be modelled) means that the system will evolve, because non–linear relationships between subsystems are part of the system. The system's global behaviour is not pre-determined, but will emerge from the interactions.
- *Dynamics of the modelling process* here means that the system will evolve, because modellers change the system's structure and parts (over time). (cf. Espinosa et al. (2008)).

Theories that pay attention to dynamics on both of these levels are used in the following.

2.4 Evolution of Models and Knowledge

Systemic models for sustainability represent the *current* abstract knowledge about relevant parts and linkages between parts of systems build for gaining better understanding of real world aspects and effects. Educational theorists hardly speak of models and modelling but of "organized bodies of information" (Dewey, 1938, p. 18) and knowledge acquisition. For this article, it is not distinguish between knowledge and models, and take a look on a particular class of approaches that support explorative learning facilitating the evolution of models.

Progressive Education theory has developed particular interesting approaches to support self–organisation of learners, through the careful design of a learning environment. The approaches appreciate the evolution of knowledge rather than the reproduction of existing knowledge (Dewey, 1938). Progressive education follows the following principles (Stary and Weichhart, 2012; Weichhart, 2013a):

- *focusing on the individual learning styles of the learner*: active responsible agents, knowledge acquisition paths are individual processes
- *situated, complex, challenging problems are provided in a prepared, motivating learning environment*: learning through creative exploration of the problem space using authentic activities; teachers are coaches, facilitating learning
- *emphasizing self–organized, social learning*: facilitated through the environment, the individual agents interact and knowledge is actively constructed in groups, new knowledge is emerging during the process

Complex Adaptive Systems Theory and Chaos Theory have been used to inform the creation of learning environments which enable (human) agents to self–organize their learning (Davis et al., 2008; Englehardt and Simmons, 2002; Hite, 1999; Siemens, 2005; Weichhart, 2013a,b; Firestone and McElroy, 2005).

3. COMPLEX ADAPTIVE SYSTEMS

Complex Adaptive Systems (CAS) Theory gives special attention to the dynamics in systems. The borders of CAS to Chaotic Systems and Cybernetic Systems are blurry. These bodies of literature have a common root in General Systems Theory (GST) (von Bertalanffy, 1969). It is the intention of GST to abstract scientific fields for describing systems, subsystems and relationships. These theories will provide a holistic approach taking dynamics into account.

Different views exist on the distinguishing properties signifying Complex Adaptive Systems and Chaotic Systems (Espinosa et al., 2008; Norman, 2011; Weichhart, 2013a). For the purpose of this paper it is not distinguished between these. Most importantly the theories take non–linear relationships between system parts into account.

Complex Adaptive Systems Theory has been applied to a number of applications relevant for the work described in this paper. In addition to using CAS Theory in the field of sustainability, CAS theory has been applied to organisations, enterprises, innovation projects, and organisational networks like supply chains (Anderson, 1999; Espinosa et al., 2008; Espinosa and Porter, 2011; Firestone and McElroy, 2004; Pathak et al., 2007; Weichhart, 2013b; Harkema, 2003). For the design and realisation of educational environments as CAS, especially progressive education strategies support the emergence of solutions to interoperability problems that evolve from within the system and are constructed by active learners. CAS theory and progressive education theory inform both the learning organisation (Firestone and McElroy, 2005; Weichhart, 2013a).

In the following selected CAS elements are discussed from an organisational learning point of view. Learning is used as an instrument facilitate the evolution of models and knowledge. Interoperability is required to sustain interaction between system parts.

3.1 Active Agents

Agents in CAS may follow simple rules (behaviours). The interaction may happen (locally) between individual agents, or between agents and their (local) environment. In contrast to many other (organisational) systems, there is no actively designed global control flow in agent based organisation. Social learning of self–organised agents facilitates self–directed learning (Bandura, 1989) leading to emergent behaviour. In a learning environment populated by active agents, learning processes may be influenced by the environment, the collective behaviour of a group of agents and the individual agents themselves. These system parts influence each other, leading to social dynamics triggering learning (Bandura, 1989).

3.2 Memory

Not only active agents, but also other sub–systems may have a memory. Ecosystems, for example, "memorize" waste of factories for a long time. Organisations that have been part of a network may memorize the behaviour of a partner for some time. Memories influence an agent's current and future behaviour.

3.3 Dependence on Initial Conditions and Feedback Loops

A model is an intentional reduction of the complexity of the reality. However, in a non–linear system, small changes in initial conditions may amplify and lead to unpredictable results over time (cf. Butterfly effect Hite (1999)). There are too many influences which a model would need to *integrate* in order to deliver a picture close to reality.

Amplifications are made possible to some extend by (feedback) loops in the system. These feedback loops contribute to the non–linearity in the overall system.

3.4 Emergent Behaviour and Self–organisation

Missing control facilitates free flowing self–organisation and social interaction. The interaction is maintained locally by the participating agents. In a social system the learners behaviour influences the environment, and the in the other way around the environment influences the learners (Bandura, 1989). Local interaction, with or without taking the higher system level state into account, facilitates emergent behaviour on the higher system level. The global organization of the system "naturally emerges out of the interaction of individual agents without any top-down control" (Englehardt and Simmons, 2002, p. 41).

Individual and group learning paths, and learning results, are not predictable. The performance of a group does not only depend on individuals, but also on the interaction between individuals. Emergent learning takes place, and through multiple qualitative leaps on lower levels the overall system develops (van Eijnatten, 2004). However, learners have to self–organize their doing. Reflection and Meta-learning (learning about one's learning) facilitates this and support improving learning paths. Additionally, agents following their own learning paths and strategies for problem solving, opens the potential of a diverse set of innovative results to meet interoperability and sustainability criteria.

3.5 Attractors and Bifurcation

An attractor is a point, towards which parts of a system are moving, where elements getting close to the attractor remain close. Attractors do not control the paths taken by attracted particles, only influence the path.

A bifurcation point occurs when a small change in a system causes a dramatic change in the overall behaviour of the system. This may be triggered by an attractor coming into the sphere of influence of some particles or because of feedback loops building-up.

4. SUPPORT FOR COMPLEX ADAPTIVE ORGANISATIONAL SYSTEMS

So far we have argued that from an complex adaptive systems point of view that organisations in order to ensure sustainability, require active agents who are loosely connected, collaborate, continuous learn, and adapt to changes in the environment. Interoperability and organisational learning are two important aspects allowing organisations to become sustainable systems.

4.1 Supporting Organisational Learning

Below features to support organisational learning from a CAS point are briefly discussed. This discussion provides examples how the above discussed elements of a complex adaptive system may be supported through a web–based e–learning environment. These CAS elements are marked using *italics* characters in the following. This section serves as a demonstration that support is possible by using existing features and tools. However, no evaluation of the quality of the support is currently available.

In the following, again, no sharp distinction between knowledge and models is drawn. Models are explicit representations of knowledge. Knowledge takes additional different forms, including tacit knowledge. In the context of enterprises both conceptual elements are used for decision making.

To construct and maintain a continuous evolving model of the environment and/or organisation, a distributed and de–centralised approach to modelling is needed. Models consisting of independent, but interoperable parts have the advantage to provide more resilience. Not all model changes are influencing all other system parts. But changes may trigger local or global "disturbances". Additonal support is needed to maintain an overall model that suits the decentralised character of a CAS and where all parts are interoperable. Not a central manager distributes different model parts to different groups (departments), but an *enabling space* is required, allowing agents to contribute to the knowledge creation process.

Direct support for organisational-learning using internet–based environments is limited. However modern web–development frameworks allow configuration and creation of learning platforms that facilitate collaborative modelling and knowledge exchange (Weichhart, 2010; Stary and Weichhart, 2012). Features like collaborative process–modelling and negotiation support may be combined and used to facilitate learning for supporting the construction of a–priori and a–posteriori interoperability solutions.

Per se a web–based environment which provides communication and coordination features support human *agents* working in a distributed environment. Shared calendars and scheduling application allow coordination on a group level. Message Boards, Discussion Forums facilitate peer-to-peer communications.

Web–based learning environments linking content and communication allow to make learning paths transparent (Stary and Weichhart, 2012; Weichhart, 2013a). Web–based tools allow to share some *initial conditions* with a group, followed by discussions in a forum, which leads to an updated model. The overall process (learning path) is available on–line. The learning environment serves as an organisational *memory*, and the tools allow to point new group members to the reasons and arguments that lead to a particular model. The history of decisions and hence the paths taken by the group is documented on–line. A *feedback loop* is realised by working on models, discussions in the forum and based on this modifying the content again.

Similar to the approach used in progressive education, managers should act as coach and mentor, encouraging *self–organisation* and *emergent behaviour*. This allows to acquire multiple points of view and provides the necessary heterogeneity to cover many necessary aspects for supporting sustainability of organisations.

A manager aiming at influencing discussions of a group of learners, may introduce a threshold concept to a discussion. Initially it may serve as an *attractor* around which the discussions evolve (Meyer and Land, 2005). Threshold concepts are "gateway" concepts in a domain, where an understanding of these important concepts leeds to a significat deeper understanding of that domain. An example is depreciation in the domain of accounting (Meyer and Land, 2005). When discussing such concepts, new topics may emerge, around which the discussions cycle. And the topics take many forms like ideas, theories, and approaches (Davis et al., 2008). These concepts influence the discussions and serve as *attractors*.

4.2 Creation of Interoperability Solutions

From the CAS point of view, it must be assumed that knowledge relevant for business is distributed within the enterprise and even across multiple enterprises. This (naturally) leads to situations where it is not possible to establish a global integrated model. But even stronger it is not desirable to construct a single, integrated model, as this constraints the autonomy of different agents.

Any support to overcome interoperability barriers has to consider support for reaching interoperability *a–priori* and *a–posteriori*. Possible types of solutions may be classified in negotiation, homogenisation, domination, adjustment, exclusion. These actions have to address barriers on conceptual, technological, organisational level (Naudet et al., 2010; Ducq et al., 2012).

In the following exemplify support for the creation of interoperability solutions through the use of learning technology. Again CAS theory informs the particular point of view taken in this section.

Conceptual Barriers. Comprehand (Oppl and Stary, 2014) supports negotiation of solutions to bridge conceptual interoperability barriers. This approach enables groups of users to explore physical models of work. This table is equipped with sensors and a graphical user output. It is primary designed to facilitate knowledge transfer through the collaborative, physical construction of work-models like task-networks or S–BPM models. A limited set of boxes are used to represent elements of work. These boxes are related to each other using digital connections between the boxes. Among many other features, it provides an organisational memory of digital representations of the physical models. For each model a history is recorded, which may be used to explore the paths taken.

In web–based learning environments a glossary build using wiki technology is often used to facilitate the organisation's *agents* in clarifying terms related to the daily work. Another possibility which allows better automation for overcoming conceptual problems on data level are ontologies. Some initial work has been done to construct an ontology for the interoperability domain. An ontology in this context provides a unified meta-model (Naudet et al., 2010). This is also useful for software agents for reasoning over the domain of discourse.

Organisational Barriers. Organisational *a–priori interoperability* requires an environment that allows participating agents to collaborate and come up with problem solutions. Solutions should not hinder future developments and organisational sustainability. Due to the (assumed) complexity of the overall system, multiple groups need to have access to the solution creation process in order to take their individual views on the problem at hand. The learning environment has to support provision of models (content) and discussions (negotiations). Advanced support for voting on issues might be of additional help. Merging different views (eventually expressed as models) supports unification of ideas. Sharing ideas and models has to be balanced with organisational security and access policies in a perceivable manner.

In the case of agents trying to re–establish interoperability, an *a–posteriori interoperability* solution is required. Something has happened which breaks interoperability of system–parts. Here first a notification facility (like a discussion forum) is required to be able to contact agents that cover different aspects of the problem at hand.

In both cases negotiation between actors and exchange of different views is required. Any negotiation facility requires to store the history so other agents are able to explore the initial solution and the paths that have been taken to come up with a solution. By providing this service, the environment provides an organisational memory functionality.

To support individual and independent agents, these must be enabled to change their expected behaviour. As autonomous changes may lead to non–interoperability on process level it must also be possible to study the impact of changing behaviours autonomously. An approach to support this, is agent–based simulation (Fleischmann et al., 2013). Software components (called agents) represent users and their behaviour. A new approach to business process management, provides a possibility to link processes and agent based modelling. Instead of aiming to provide a single map of all processes of an organisation, Subject–oriented Business Process Management (S–BPM) provides an agent–based conceptualisation (Fleischmann et al., 2013). This, in principle, allows independent interaction of users with a virtual environment which is build on actual process models. However, a subject in S–BPM is similar to a role for an agent.

A particular type of support has been exemplified in the SUddEN project (Weichhart, 2010). Here, in the context of forming Supply Networks, *Performance Indicators* have been used to support organisational learning. Performance measurement models are collaboratively build and organisational interoperability on business level is measured in terms of supply chain performance along the individual model. In this particular approach a "network" of indicators is used to find suitable collaboration partners, agree on a target performance for a project and monitor the performance. A violation in the performance with respect to the target is a signal for non-interoperability. The e–learning environment facilitages further exchange of knowledge. A Multi Agent System based simulation environment used "historical" performance data to help users in finding interoperable collaborators. The SUddEN system combines an e-learning and multi-agent-systems technology to address interoperability barriers concerning the overall business level. To some extend also the service level is addressed. However, no support on process level is given.

While S-BPM execution environments exist which allow the use of Performance indicators, sofar an agent–based simulation and exploration environment for S–BPM is missing. From a CAS and learning point of view, this would be a substantial feature, enabling users to explore the impact of changing a behaviour by running an agent–based simulation of the organization in order to identify the impact of the (proposed) changes. This (currently missing link) between agent–based simulation and business process support, facilitates bridging interoperability barriers on business, process and service level. Solving issues of service and process non-interoperability are supported solved by existing S–BPM tools that facilitate cooperation and coordination based on business processes.

Technological Barriers. The existing S–BPM suite (Fleischmann et al., 2012) may be used as a middle layer to facilitated data exchange on technical level. Different legacy–systems may be connected to the suite in order to allow data exchange. Each system would be represented as "agent" and this way the internal behaviour of individual agents may be changed autonomously potentially, without affecting global workflows. S–BPM in this case provides the possibility to reach a unification type of interoperability (Weichhart, 2013a).

5. CONCLUSION

In this paper several theories have been combined using complex adaptive systems (CAS) theory as underlying principle. The overall goal was to conceptualise a web-based environment that supports organisational users in adapting within dynamic environments. For organisations to be sustainable interoperability and learning are key elements. However, currently no integrated support for learning and interoperability is given.

Following the CAS theory, support for independent (human) agents is needed. In the last years, technologies have been created that support this paradigm concerning business, service, process and data level.

While learning environments, S–BPM suits and agent–based frameworks do exist, these have not been used so far together to facilitate the development of organisational interoperability solutions that allow to overcome conceptual, organisational, and technical barriers.

Tool support needs to be combined and streamlined. The S–BPM approach is a good starting point in the middle. It addresses the process concern level. S–BPM provides a conceptual model that is matches the Multi-Agent-System conceptualisation given in CAS which is suitable for the service and data level of concerns.

However, further research is needed to extend S–BPM in a manner that supports business performance, process design, service execution and exchange of data within a Complex Adaptive Organisational System.

From the business concern level point of view, further research is needed to understand if the individual agent/subject versus global business behaviour point of view is informative to users. The individual agent/subject views provided by the Multi-Agent-System and S–BPM frameworks allows individual users to focus on selected tasks. But with respect to business performance, a simulation of the overall system is needed to answer questions about the impact of changing individual behaviours.

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