

Supporting Interoperability for Chaotic and Complex Adaptive Enterprise Systems

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Abstract. Living systems like enterprises and enterprise networks not only want to survive but also want to grow and prosper. These organisational systems adapt to changing environments and proactively change the system itself. Continuous evolution (of parts) of these enterprise systems requires diversity, but this heterogeneity is a source of non interoperability. In this article, interoperability and enterprise systems are analysed through the lenses of chaos theory and complex adaptive systems theory and requirements for continuous adaptation and organisational learning to maintain interoperability are identified.

Keywords: organizational learning, interoperability, complex adaptive systems, chaos theory.

1 Introduction

Thrivability is a concept developed to discuss systems that aim at organic growth [1]. The future is not knowable, and growth, in this view, is not a linear process. The system needs to be adaptive and able to learn when reacting to unforeseen situations [2]. Independent and diverse subsystems provide a basis for adoption [3], in particular in contrast to single large integrated enterprise systems with optimised organisational structures [4]. For organisational systems the most fundamental sub-system are human agents. Since heterogeneity is a source of interoperability problems [5], these agents need support for continuous developing and sustaining interoperability.

General Systems Theory (GST) aims at bridging the gap between different fields of science through abstraction [6]. Due to the dynamics of the environment, recognising organisations and organisational networks as “static” systems is not sufficient [7]. In the following two theories are used to characterise enterprise systems. Chaos theory and complex adaptive systems theory are theories which have their roots in GST and put emphasis on dynamic aspects.

We describe complex and chaotic systems theories, their properties, and aspects of these types of system models. These aspects and properties are linked to required support for organisational systems in order to reach and sustain interoperability.

2 Chaos and Complex Adaptive Systems

A system is chaotic if it contains nonlinear relationships between its parts. Its global state is to a large extent unpredictable. It must be a continuously dynamical system, with its future state not being predicable but evolving over time [8]. For this type of system, it is sufficient that simple, but nonlinear relationships between a few variables (parts) exist.

A Complex Adaptive System (CAS) has active elements, called agents, which interact. The overall system state may not be determined by the sum of these individual agents' behaviours, as non-linear relationships exist. The agents are capable of adapting to the environment and other agents, exhibiting self-organised behaviour.

The literature discusses complex adaptive systems and chaos theory from different points of view (as intended by GST), and has not identified a set of properties for these systems. The properties of chaotic systems and Complex Adaptive Systems are briefly discussed and then used for structuring the discussion of enterprise systems and derive requirements for a supportive environment.

2.1 Dependence on Initial Conditions

Depending on small changes somewhere in the overall system this system's state evolves unpredictable over time. This property is exemplified by the often quoted butterfly effect coined by Lorenz [2,8], where a small change at one part of the system results in significant differences in the behaviour of some distant other part of the system over time. In that particular example, a butterfly causes changes in the airflow in Europe which amplifies over time and causes a thunderstorm in North America months later.

2.2 Self-similarity across Scales

Self-similarity is a property of a system that is similar to a part of itself. Self-similarity may occur along different aspects. For example, coastlines are statistical self-similar, where the same statistical properties exist at different scales.

2.3 Strange Attractors

In a dynamic system, a (strange) attractor is a point, towards which, or around which, particles (parts) of a system are moving. The particles remain independent, however are attracted by the attractor, where the force of attraction is dependent on the distance of an attractor to a particle. Particles getting close to the attractor remain close. The ways along which parts are moving are not fixed or predetermined.

2.4 Bifurcation

A bifurcation point marks a moment in time where a system's part comes under the influence of another attractor. This part will (depending on the strength of the attractor) change “direction” and a qualitative leap may happen at this point [9].

The concept of bifurcation implies that multiple local small changes may lead to unpredictable outcomes in the overall system as the system develops over time. This is due to the assumed nonlinear relationship between the individual system parts.

2.5 Active Agents

In a complex adaptive system, “great many independent agents are interacting with each other in a great many ways” [10, p.11]. The agents themselves follow their individual rules how to interact with other agents. This interaction between agents is a local event. Additionally agents may interact with their (also local) environment. Yet it is important to understand, that there is no global control flow, but there are only local interactions. The overall systems state is not planned and even not predicable due to “nonlinear relationships”.

2.6 Self-organisation, Co-evolution and Emergent Behaviour

The lack of global control enables the agents to act self-controlled and self-organized. As mentioned above, interactions are locally controlled by the agents that take part in a particular interaction. Local interaction with or without taking the higher system level state into account, facilitates emergent behaviour on the higher system level. The global organisation of the system “naturally emerges out of the interaction of individual agents without any top-down control” [11, p.41].

This can be observed on multiple levels, where for example the interaction of brain-cells influences the behaviour of human agents, and interaction between agents influences the behaviour of the department [3].

3 Enterprise Systems

In the following we discuss enterprise systems from the complex adaptive systems and chaos theory point of view. This discussion assumes a structure, where an organisational network's agents are organisations, and an organisation's agents are humans. On all levels these enterprise systems are complex and adaptive systems which exhibit some chaotic behaviour (see for example [12] with respect to Organisations, and [7] with respect to Supply Networks).

3.1 Dependence on Initial Conditions

Enterprise systems depend on their environment, for example market conditions, or other participants in the supply chain like customers and suppliers. From an enterprise

network point of view, the bull-whip effect is used as example where small changes to demand lead to a globally observable phenomenon impacting the overall supply network (from a CAS point of view see [13]). In this particular case, communication delays cause amplifying product orders, which lead to a massive oversupply of products in the overall supply network.

3.2 Self-similarity across Scales

Here organisational systems are seen as collaborations of independent, cooperative organisational units, which are composed of sub-systems, which themselves are composed of sub-systems. Depending on the scale, organisational networks consist of organisations, which consist of departments which consist of agents.

3.3 Strange Attractors and Bifurcation

Qualitative leaps on micro level lead to small gradual changes on the macro level. “We call this “scale invariance” or the fractal dimension of growth: gradual change on a macro-level may be interpreted as a series of small qualitative leaps on a micro-level.” [9, p 433]. With respect to enterprise systems, such decisions might be a change of the production technology used by a company. This change allows the company to grow over time. This rather “dramatic” change on lower levels of aggregation is visible at higher levels only as gradual growth.

3.4 Active Agents

The agents in supply networks are the firms and suppliers taking part in these organisational networks [7]. Within organisations these agents are organisational units, which themselves consist of human agents [12] However, all agents (independent on the observed system scale) act independent and interact with other agents.

3.5 Self-organisation, Co-evolution, and Emergent Behaviour

In a social system, an agent’s behaviour influences the environment and vice versa, the environment influences the agent [14]. Over time, the agents learn from each other, through copying successful behaviour. However, 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 [9,7]. Learning and improvement are results of self-organisation of individual agents and of groups of agents. Depending on the level observed an agent may be a learning organisation, which is member of several supply networks [7], or a human agent working in an organisation [12].

4 Supporting Interoperability

So far we have discussed properties of chaos theory and complex adaptive systems theory. We have conceptually established a mapping between enterprise systems and these theories. From a chaotic and complex adaptive systems point of view, in the following implications for a system to support interoperability is discussed.

4.1 Dependence on Initial Conditions

The butterfly effect is often used to explain, why models don't work (see above). A model is intentionally a reduction of the complexity of the reality and there are too many influences which a model would need to integrate in order to deliver a picture close to reality. This has consequences for Enterprise Modelling for integration approaches. Enterprise modelling projects face the challenge that the enterprise system permanently changes, requiring to continuously adapt the model [7]. Models consisting of independent, but interoperable parts have the advantage to provide more stability as not all systems are influencing each other and changes may be limited to sub-parts. A support environment would allow continuous contributions to the model.

4.2 Self-organisation, Co-evolution, and Emergent Behaviour

To maintain a continuous evolution of an enterprise model, a distributed and decentralised approach to enterprise modelling is needed. Taking a CAS point of view, management (being responsible for organisation of the enterprise system) should “[i]nstead of acting as a central authority and exerting top-down control, the manager's role should be facilitating and geared towards creating an open environment, where people are allowed to question rules and procedures” [15, p 345]. Management should encourage self-organisation and emergent behaviour. Enterprise models should provide support for self-organising agents, who contribute to a single enterprise model in a decentralised and distributed fashion. A support environment needs to support these dynamic changes.

4.3 Active Agents

The price for the above described freedom of and for agents is responsibility. It is the responsibility of the agents to maintain interoperability, if there is no centralised top-down management. The environment is needed which allows responsible agents to communicate, coordinate and adapt to emerging interoperability problems.

4.4 Self-similarity across Scales

An “interoperability support environment” supporting responsible agents to collaboratively adapt to changing circumstances requires to support agents on different scales. An interoperability environment needs to support modelling of self-similar systems to

support agents to conceptualise and understand the model on different levels of abstractions and scales. This allows agents to receive feedback on local and global level by other agents. A learning environment needs to support both, the local interaction between agents, as well as an overall enterprise model to support making interfaces interoperable. Agents should be enabled to interactively contribute to the enterprise system model with respect to different aspects, depending on the situation at hand.

4.5 Strange Attractors and Bifurcation

As discussed above strange attractors might emerge and provide opportunities for bifurcation points. Both is needed, support for a-priori and a-posteriori interoperability support. “A priori solution consists in negotiation and homogenisation actions before the beginning of an interoperation. A posteriori solution takes place after collaboration starts. It consists in a domination, an adjustment or an exclusion.” [5, p 848]. In both cases an environment is needed which allows participating agents to collaboratively “jump” to the next attractor or not. This might be planned a-priori or the need for adjustments might be learned a-posteriori.

5 Conclusions

Due to the dynamic and evolving environment, agents need a learning environment which supports them in understanding the changing requirements for maintaining interoperability. Using chaos theory and complex adaptive systems theory as lenses for discussion, we have identified a few requirements for a learning environment that supports active and responsible agents:

- modelling enterprise systems on different scales
- support for self-organisation and negotiation of interoperability solutions
- collaborative learning about new attractors and possible bifurcation points

Existing interoperability approaches like Enterprise Modelling provide building blocks on which an overall learning environment may be build. Enterprise Models for example may serve as attractors for discussions.

However, in addition to the existing work, the proposed learning environment supports a continual process where learning and work related activities are no longer separate [16]. It aims at enabling adaptation, organic growth, and thriving of the enterprise system.

This article is only a first attempt to identify learning support features and requirements for interoperability from a dynamic process point of view. It provides a conceptualisation of interoperability from complex adaptive systems and chaos theory point of view. Similar to the learning theory of connectivism [16], which acknowledges the dynamics and technology enhancements in today’s learning environments; the conceptual work presented here is an attempt to bring together technology and organisational learning. In this context, interoperability is a key issue for learning.

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