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Co-evolution Path Model: How Enterprises as Complex Systems Survive on the Edge of Chaos

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Abstract

In this theoretical paper, we introduce and describe a model, and demonstrate its origins from the disciplines of Enterprise Architecture, cybernetics and systems theory. We use cybernetic thinking to develop a 'Co-evolution Path Model' that describes how enterprises as complex systems co-evolve with their complex environments. The model re-interprets Stafford Beer's Viable System Model, and also uses the theorem of the 'good regulator' of Conant and Ashby, exemplifying how various complexity management theories could be synthesised into a cybernetic theory of Enterprise Architecture, using concepts from the generalisation of EA frameworks.

Keywords

Enterprise Architecture, Cybernetics, Complexity, Co-evolution, Edge of chaos

INTRODUCTION

The increasing complexity of the IT and business environment and the need to ensure alignment of IT with business goals and operations have given rise to a number of initiatives in information systems research and practice (Luftman & Kempaiah, 2007). Prominent amongst these is the discipline of Enterprise Architecture which is now widely accepted as a requirement for high level and comprehensive management of the IT enterprise (Winter and Sinz, 2007). Despite this acceptance, the field of Enterprise Architecture is still undergoing investigation into its theoretical basis, with considerable work focused on elaborating and harmonising the various frameworks and models. This paper aims to contribute to this work by exploring the application of cybernetic thinking to explain how systems co-evolve with their environments. A 'Co-evolution Path Model' is developed which reinterprets 'System 5' of Beer's Viable System Model (Beer, 1985), i.e., the system which is responsible for strategically steering the organisation.

The purpose of this paper is primarily theoretical – to propose and detail a model and show its derivation from the fields of Enterprise Architecture, cybernetics and systems theory. Since the development of this model is in its early stages, it has yet to be tested in empirical studies. However, it proposes both “testable propositions and causal explanations” (Gregor, 2006, p.620) which may be applied to real cases. In practical terms, such a model might enable organisations to steer away from the 'edge of chaos'. (Note that an extended version of this paper, illustrating the presented co-evolution path model with cases from the evolution of manufacturing enterprises, is to appear in the proceedings of the 46th Hawaii International Conference of Systems Sciences.)

COMPLEXITY AND THE CYBERNETICS PERSPECTIVE

Enterprises are best understood as intrinsically complex adaptive living systems: they can not purely be considered as 'designed systems', as deliberate design/control episodes and processes ('enterprise engineering', using models) are intermixed with emergent change episodes and processes (that may perhaps be explained by models). The mix of deliberate and emerging processes can create a situation in which the enterprise as a system is in dynamic equilibrium (for some stretch of time) – a property studied in General Systems Theory (Bertalanffy 1968). The evolution of the enterprise (or enterprises, networks, industries, the entire economy, society, etc)

includes the emergent as well as the deliberate aspects of system change, therefore we believe that EA needs to interpret previous research in both. Kandjani and Bernus (2011a) summarise this as the main aim of the enterprise architecture discipline and practice, i.e., to explain change in enterprises as complex systems (through theory, models and methodologies).

In response to the problem of managing complexity and rapid change, a number of studies have applied the cybernetic perspective to Enterprise Architecture; for example, the application of cybernetic concepts to EA management (Buckl, Matthes and Schweda, 2009) and to EA principles as, for example, embodied in TOGAF (EsmailZadeh, Millar and Lewis, 2012).

Stafford Beer believed that the dynamics of enterprises is about “the manipulation of men, material, machinery and money: the four M’s”, but also about a fundamental manipulation of systems, which we call the “management of complexity” (Beer 1966; Beer 1985).

Norbert Wiener defined cybernetics as “the science of control and communication in the animal and machine” (Wiener 1948). Ashby (1956) also calls it as the art of “steermanship”, the study of co-ordination, regulation and control of systems, and argued that “truths of cybernetics are not conditional on their being derived from some other branch of science”. Therefore the field embraces a set of self-contained groundings and foundations (ibid). Ashby addressed the complexity of a system as one of the peculiarities of cybernetics and indicated that cybernetics must prescribe a scientific method of dealing with complexity as a critical attribute of a system.

Beer (1959) was perhaps the first person who applied cybernetics to management and defined cybernetics as “the science of effective organisation” (as cited by Jackson (2000)). He was also the first to coin the word “Management Cybernetics” – a field applying cybernetic laws and theories to all types of socio-technical organisations, such as “enterprises” (Ramage and Shipp 2009). Beer elaborates on the relevance of cybernetics to management in ‘Cybernetics and Management’ (1959) and describes his first discoveries and promises in the management discipline. He also characterises cybernetics as “the science of control” and management as “the profession of control” Beer (1966).

Therefore EA research has acknowledged the relevance of cybernetics for modern enterprises which cannot expect to build ‘ideal’ and one-time systems but must undertake continuous steering and control of their evolving systems (Schmidt and Buxmann, 2011). Such a perspective elaborates on Beer’s ‘system 4 and 5’ to cope with the increasing complexity of organisations and their environments.

ENTERPRISE ARCHITECTURE CYBERNETICS

One common topic of cybernetics is the treatment of complexity (whether it is the complexity of the structure, behaviour, control, management, or other relevant view of the system of interest), raising the question how systems can be managed, controlled, changed, designed, or partially influenced for producing emergent adaptive behaviour. A distinct problem, characteristic of complex systems, is (by definition of what constitutes a complex system) that none of these tasks can be based on a complete predictive model, therefore the involved decisions must be based on incomplete information. Due to this character of complex systems we need theories and methods, or structures, that produce such self-control behaviour (either in deliberate or in emergent way). Whichever way this control is exercised it should be able to be described by an external observer as ‘partial control’ that nevertheless achieves a set of valued system properties (such as sustainability, viability, availability, and so on).

For the above reason, any controller (on any level of a system that is characterised as complex on that level) only has, or can only have, an incomplete model of the system, and sees the system through this model to make decisions to control that system. The complexity of a model like this is the ‘apparent complexity’ of the system from the given controller’s (manager’s) point of view. Checkland warns that theories, frameworks and models with an excessive level of abstraction and general systems principles of ‘wholeness’ could be in danger of not being able to deal with real practice (Checkland 1999). At the same time there exist very specific and context-dependent theories, frameworks and models which sacrifice generality and abstraction and there is little guidance on the limits of their applicability. The optimum degree of generality is somewhere in-between with different levels of abstraction for each purpose. For example, the aim of General Systems Theory (von Bertalanffy 1968) is not achievable by a single science discipline in isolation (Boulding 1956).

EA Cybernetics also must maintain an ‘optimum degree of generality’ to provide the discipline and practice with the ‘right level of abstraction’ for each purpose, whereupon given the abstract theory and a concrete system (and concrete problem), there should exist methods that can be used to solve or explain the problem, and all this within the limitations of available resource and time constraints.

Enterprise Architecture, like any other developing discipline, needs a model for theory development, testing and knowledge creation. Anderton and Checkland (1977) developed a model of any developing discipline to demonstrate the cyclic interaction between theory development and formulation for a problem and theory testing (Anderton and Checkland 1977, Checkland 1996). For EA to be a developing discipline (Fig.1), we consider the real world enterprise problem domains as the source of the development process giving rise to issues to be addressed by theories, models and methods in enterprise related disciplines. These will shape ideas by which two types of theories could be developed (Checkland 1996): a) substantive theories derived from related disciplines to apply relevant models, theories and methods in the problem domains, and b) methodological theories about how to individually apply enterprise related disciplines in the problem domains.

Once we developed such theories, it is possible to state problems – not only existing problems in concrete enterprise problem domains, but also formalised, harmonised and synthesised problem statements by EA cybernetics within this new theory. Based on a new theory, EA cybernetics produces formalised enterprise problem domains which may be represented using the unified cybernetic theory of EA. These unified theories may be used to develop a methodology(ies) to be used in EA practice. Results of such synthesis must be tested in practice (through intervention, influence, or observation) to create ‘case records’, which in turn provide the source of criticism allowing better theories to be formulated (and better models, techniques, and methodologies). The application of the latter methodologies should be documented in case records which provide feedback to improve the individual- and the unified theories.

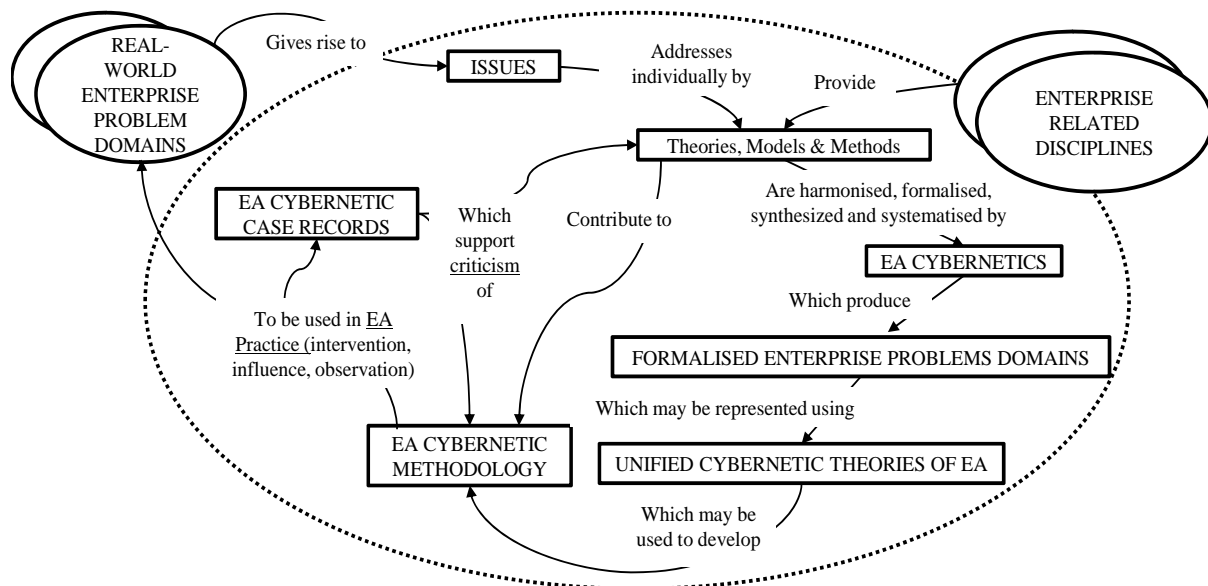


Figure 1. Enterprise Architecture as a Developing Discipline based on the model of activities and results of developing disciplines (Anderton and Checkland 1977; Checkland 1996)

The EA discipline not only embraces the models, methods and theories of management and control – it also uses the same of systems engineering, linguistics, cognitive science, environmental science, biology, social science and artificial intelligence. What cybernetic thinking is able to do is to provide a method of unifying (and relating) the apport of these disciplines: cybernetic thinking can be used to represent the essence of multiple theories using abstract functions and processes (and meta-processes) and their relationships / rules / axioms (likely to be expressed in suitably selected logics). Fig.1., shows the pathway through which the apport of these disciplines is formalised, synthetised, harmonised, systematised and eventually represented as a unified Cybernetic theory of EA. The Co-evolution Path Model introduced in the next sections is an example of a cybernetic model of the control and management of viable complex systems that operate in complex environments.

THE CO-EVOLUTION PATH MODEL: DYNAMIC HOMEOSTASIS VS DYNAMIC HETEREOSTASIS: AN EXAMPLE OF AN EA CYBERNETICS MODEL

A key property of a viable system and a “measure of its submission to the control mechanism” is its ability to maintain homoeostasis, which Beer (1966) defines as “constancy of some critical variable (output)”. In our model of co-evolution, we demonstrate the dynamic sustenance of requisite variety based on Ashby’s law: “only variety can destroy variety” (Ashby 1956), paraphrased by Beer (1979) as “variety absorbs variety”, where

‘variety’ is the number of possible states of a system (Beer 1981), or as recently clarified by Kandjani and Bernus (2011b), the number of relevant states of a system.

In order for a system to dynamically achieve and maintain requisite variety and to be in dynamic equilibrium, the system requires communication channels and feedback loops. These communication channels serve as self-perpetuating mechanism and include both attenuation and amplification mechanisms. (Note that for the discussion below what we call a ‘system’ includes the system’s controller.) Considering the system and its environment as two coupled entities, if one component is perturbed, the effect of that perturbation on the other component is either amplified through positive feedback, or may be reversed (attenuated) through negative feedback. The role of the negative feedback loop is to reverse the effect of the initial perturbation and restore the system’s homeostasis (in which critical variables are stable) while positive feedback can create unstable states (Ashby 1940).

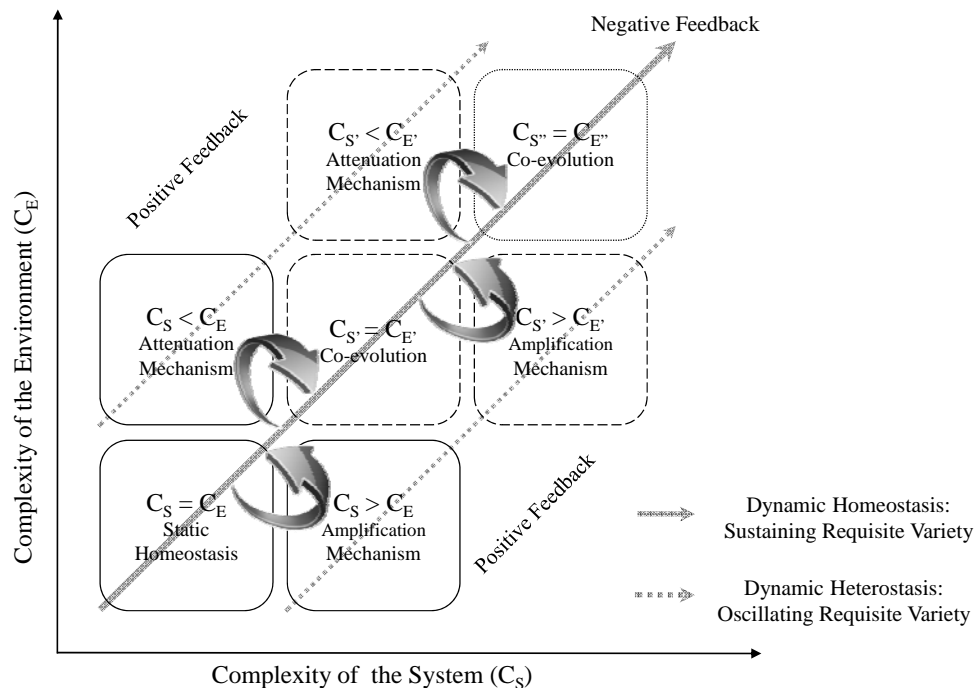


Figure 2. The Co-evolution Path Model

We observe that both a system and its environment (including systems in that environment) evolve, and such change can create an imbalance between the requisite variety (maintained by the controller) of our system of interest and the variety that would be required for it to maintain homeostasis. In other words, systems that want to live long must co-evolve with their environment.

More formally: we consider the environment an entity with a possible set of observable states and if two such states require different response from the system then the system must be able to differentiate between them (thus they are two different relevant states). (Note that we may not necessarily be able to describe the environment as a system, although it may contain one or more systems.) Consequently, in Fig. 2, the complexity of a system (CS) is defined to be the complexity of the model that the controller of the system maintains (appears to be maintaining) in order to manage the system’s operations, which includes the need to interact with the environment.

The complexity of the system’s environment (CE) is a relative notion and is defined to be the complexity of the model of the environment that the controller of the system would need to maintain the system’s homeostasis; – although it is sufficient if in the eyes of an external observer the system’s controller appears to be maintaining such model.

Specifically, such an ‘environment model’ must have predictive capability, so that the system, while interoperating with the environment, can maintain a homeostatic trajectory in time (and space). An environment model would thus include as components a) models of external systems with which our system interacts (including models of their controllers and operations), and b) a model of the rest of the environment, so as to be able to represent and predict the states of signals and resources among the system, the external systems and the

rest of the environment: based on the theorem of the ‘Good Regulator’ (Conant and Ashby 1970), a good controller of a system must have a model of that system with an equal complexity at its disposal as the system to be controlled has. In Fig 2, notice that 1) If the complexity of the system (CS) equals to that of its environment (CE), then the system has the requisite variety and is in static equilibrium. However, any change in the complexity of the environment should be sensed by the system’s self-perpetuating mechanism to restore the system to its initial state or to create a new equilibrium state; 2) If the complexity of the environment is greater than that of the system, then the system should attenuate the effects of this complexity, i.e., change and co-evolve with its environment (in other words, the environment produced, or is recognised to have the potential to produce, some states in which the system can not function as expected); 3) If the complexity of the system is greater than that of its environment, then the system can potentially create a set of different states and perform behaviours which are not differentiated by its environment. The system can identify this extra complexity as undesired, or use an amplification mechanism to create new differentiations in the environment (e.g. marketing of new goods / services).

If a new enterprise lacks co-evolution mechanisms then it may be viable in the short term, but is doomed in the long term. Such failure of enterprises is attributable to the inflexibility of their business models, due to the lack of attenuation and amplification mechanisms to sustain dynamic stability: according to Badalotti (2004) the new economy’s most successful start-ups have changed their business models several times in the first few years of their existence. A successful example is America-on-line (AOL) that initiated its business and grew as an Internet Service Provider, but re-identified itself as a content provider, re-designing its business model and market positioning (ibid).

CO-EVOLUTION MECHANISMS: ORDER, COMPLEXITY AND THE EDGE OF CHAOS

In this section, we demonstrate the transitions caused by changes in the complexity of a system (CS) and the complexity of its environment (CE), and relevant mechanisms to keep the system in equilibrium.

Co-evolving/viable System states

Consider the system in state 1 as its initial state where $CS = CE$, i.e., the system is in a homeostatic state. If there is an increase in CE from state 1 to state 2 (such as introducing a substitute product or service to the market by a rival company) then this makes the company move into the vulnerable zone.

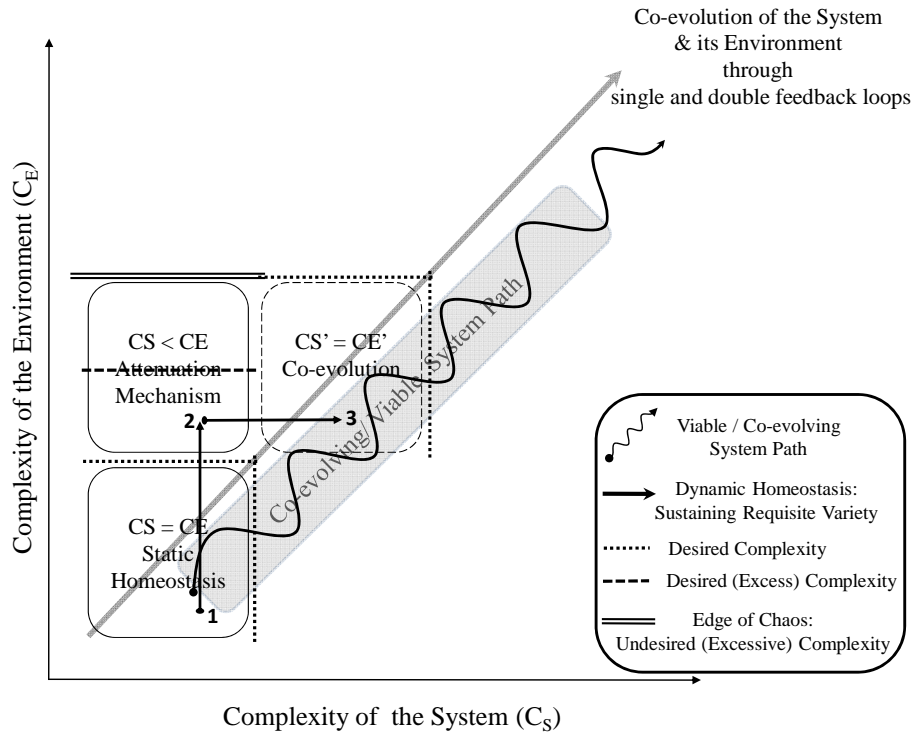
In order for the system to adapt to the changes in the environment and achieve the requisite variety and to remain the viable path, it actually always needs some excess (but not excessive) complexity. There are two different complexities here: the variety of the system and how the system achieves that variety. For instance, by the reconfiguration of its structure, acquiring more resources, creating new capabilities, reducing the cost of production of the current product or service, or innovating a new product or service. Such adjustment which takes into account new differentiations (and thereby variety) in the environment will move the company from state 2 to state 3 where CS equals CE and the company remains on the co-evolving / viable system path.

Inefficient System states

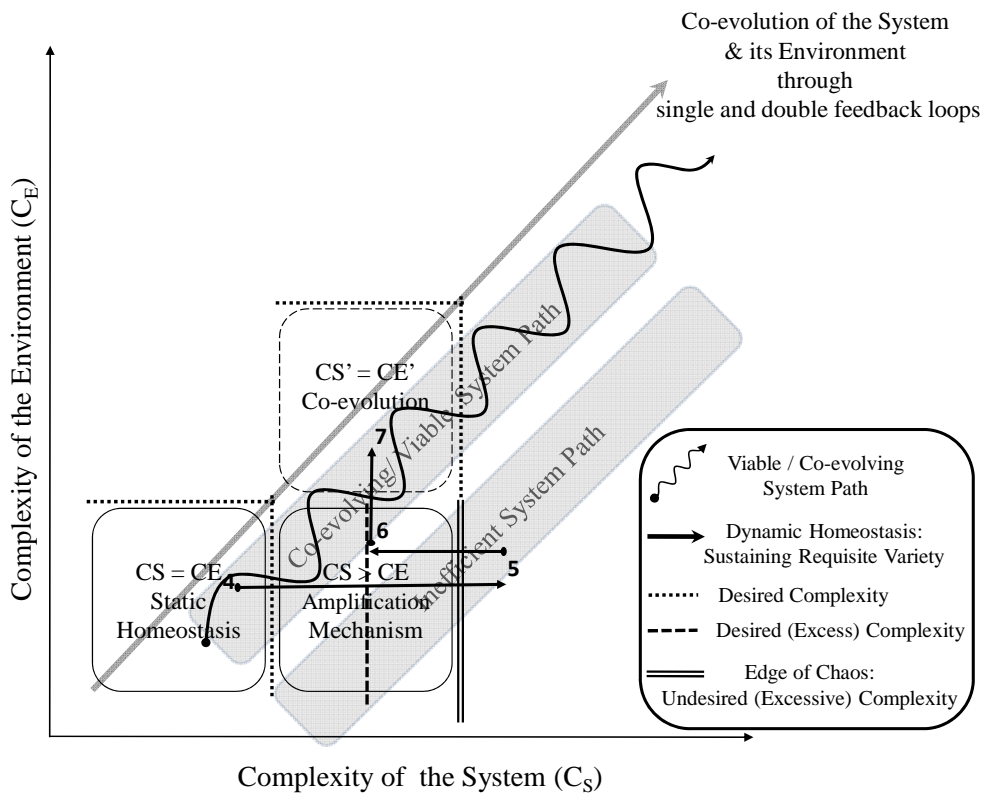
Now consider the state where the system has, or acquires, excessive resources and capabilities (a set of potential structures and ability that could perform functions that are not ‘completely’ invoked by the system’s environment). This transition from state 4 to state 5 creates undesired or unnecessary (excessive) complexity. For example, a manufacturing company (in state 4) with leading R&D department designs a new product, the inbound logistics provides necessary goods and materials and finally the company establishes its production line (state 5), where the company has excessive, and therefore undesired, complexity.

To reduce the potential risks and inefficiency of this new venture as a new potential structure and to increase the probability of success when designing change projects, this company should apply complexity reduction techniques such as , Axiomatic Design Theory and Techniques (Suh 1990; 2001; 2005) to reconfigure its functions, structures and architectures to shift from the inefficiency zone and achieve effectiveness and efficiency in state 6 where company has some desired excess complexity but expels undesired (excessive) complexity.

At this stage, the company still has excess complexity which should be amplified to the market (‘the environment’), therefore the marketing department should apply effective marketing strategies in order to introduce the new product to the market and promote its sales. Having developed and implemented a successful marketing strategy and plan, the manufacturing company amplifies its excess desired complexity caused by new structures and ends up in a new homeostatic state (state 7).



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Vulnerable System states

Let us consider the state where there is an increase in the complexity of the environment (state 8 to 9). For the system to respond to the changes in CE and achieve requisite variety (and a new homeostasis), and remain viable, it needs to attenuate more complexity and co-evolve with the environment.

For example, rival companies reduce the company’s market share by introducing new substitute products and therefore company is at the risk of losing its competitive advantage. The company has no choice other than reconfiguration of its current resources and structures, or acquiring more resources and potential structures to create new capabilities / competencies and revitalising its competitive advantage or perhaps merging with other companies to survive (state 9 to 10).

Unfortunately, state transitions from state 9 to state 10 usually imposes excessive complexity to the company. Therefore for the company to avoid potential inefficiency and mitigate the risks of establishing a new production line as a new set of structures and capabilities (that creates undesired excessive complexity) the R&D department / the design authority should apply complexity reduction methods and techniques such as ‘Extended’ Axiomatic Design Theory (EAD) (Kandjani and Bernus 2011b). EAD deals with reducing and possibly avoiding the complexity of the change process that designs and implements necessary changes (such as the establishment of a new production line). Using this method, the company may avoid the inefficiency zone and remain in the viable zone. The spiral arrow in Fig.3 demonstrates the viable system path in which the system dynamically sustains its homeostasis and avoids or rectifies inefficient and vulnerable states by invoking relevant attenuation and amplification mechanisms.

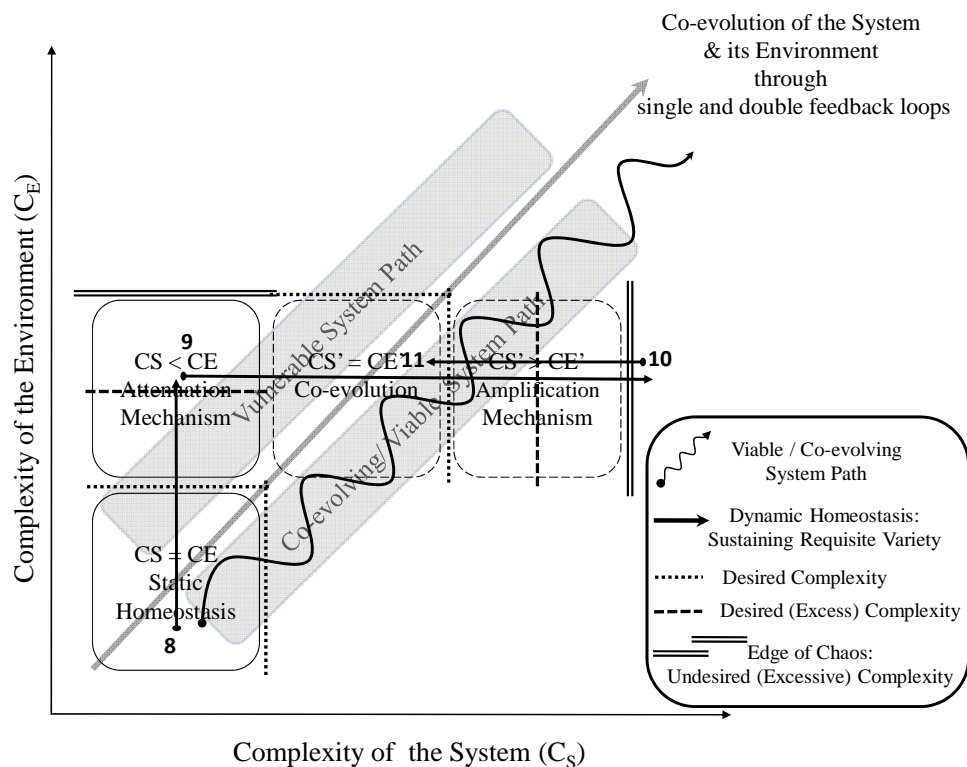


Figure 5. Traces of Vulnerable System states

Non-viable System states

Let us now consider the states where the company will not remain viable. Enterprises as live systems have a number of variables characterising essential survival properties. Ashby (1960) refers to these as ‘essential variables’ (crucial to a system’s survival) – modern literature would refer to these as strategic ‘key performance indicators’. Ashby (1960) defines survival as: “... a line of behaviour [that] takes no essential variable outside given limits” (Ashby 1960; Geoghegan and Pangaro 2009). Therefore, by definition, any line of behaviour outside limits of essential variables is on the non-viable system path and is fatal to the system’s lifeline.

For a system to be regarded as adaptive, and therefore viable, Ashby introduces two necessary feedback loops (Ashby 1960; Geoghegan and Pangaro 2009; Umpleby 2009). The first frequently operating feedback loop makes small modifications and corrections to the system. The second feedback loop in fact changes the structure

and architecture of the system when the tolerance of the essential variables (invoked by dramatic changes in the system's environment) falls / is predicted to be falling beyond the limits of survival. If the system's second feedback loop does not respond to the changes in complexity of the environment, then system will be on the non-viable path. Based on Ashby's theory of adaptation (1960), Umpleby (2009) indicates that the first feedback loop is necessary for a system to learn a pattern of behaviour which is necessary for a specific environment, while the second feedback loop is required for a system to identify the changes in the environment and design and create new patterns of behaviour.

In case there is a dramatic increase in complexity of the environment (as in states 11 to state 12) it is possible that the system is not prepared to react due to the scarcity of necessary resources, lack of dynamic capability, inability to create new structures in a timely manner and adapt its architecture to the change in the environment. The lack of an appropriate second feedback loop makes the system a non-viable and the system is doomed to fail. If in this state, the company may save itself by establishing a partnership or merge (a reactive move, where the system relies on another system for rescue).

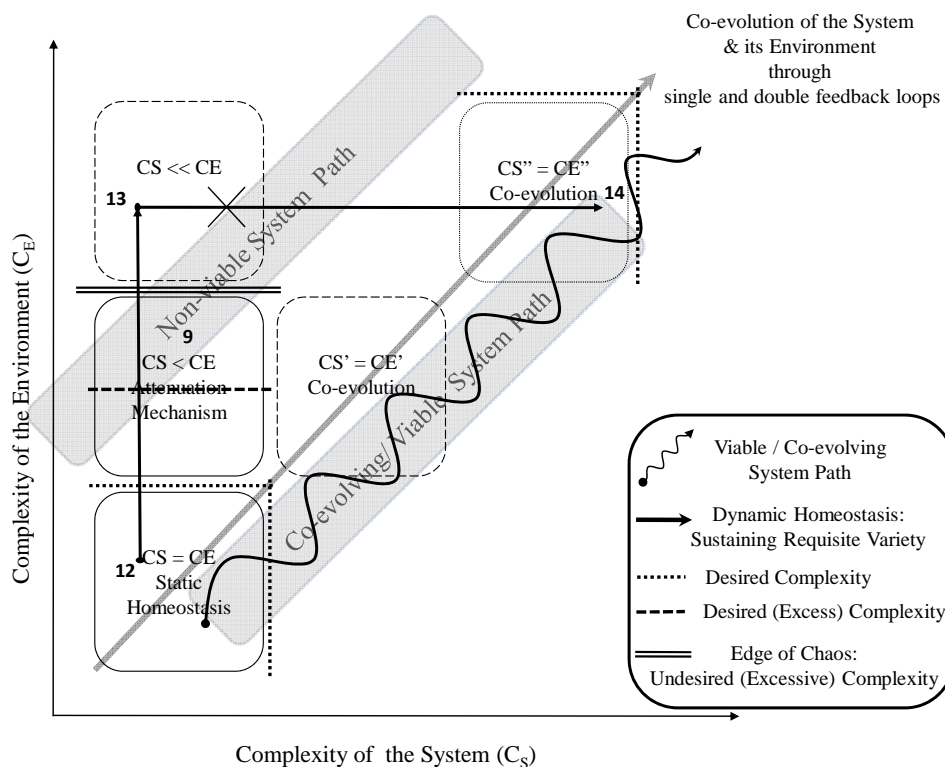


Figure 6 Traces of Non-viable System States

The Co-evolution Path Model has a level of abstraction that makes it applicable to any change and co-evolution of a complex system in its environment. In this paper we use GERA concepts and its Modelling Framework (Fig.7) with a comprehensive coverage of viewpoints through which no change in the environment would be neglected. Using GERA concepts and viewpoints, the controller (manager in charge of the system) could a) model and steer in light of change in the environment by taking into account relevant viewpoints of the environment's model, and b) design a co-evolution mechanisms to change or manipulate the system's operations, using a relevant combination of models, viewpoints and life cycle processes, and design a change trajectory in the system's life history. For example, one could use the Strategic Alignment Model (SAM) by Henderson and Venkatraman (1999) and map it to the Co-evolution Path Model: SAM as a change/co-evolution model of the enterprise and its environment, using IT- and Business related viewpoints of our adopted modelling framework.

In summary, we can classify system states into four groups in terms of co-evolvability/ viability:

- Non-viable System states (States: 12-13-14)
- Vulnerable System states (States: 8-9-10-11)
- Inefficient System states (States: 4-5-6-7)
- Co-evolving/viable System states (States: 1-2-3)

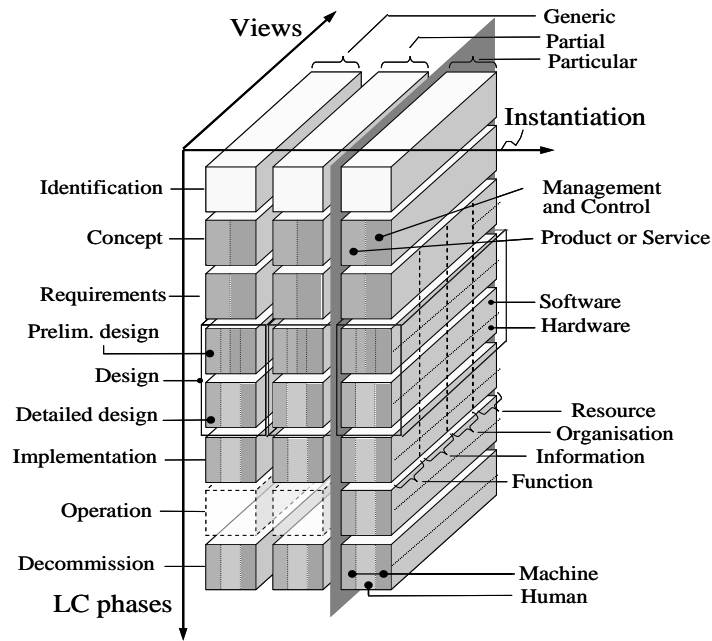


Figure 7. GERA Modelling Framework [source (IITF, 1999), used with permission]

CONCLUSION

This paper has proposed a Co-evolution Path Model using cybernetic principles to explore and map how organisations might manage complexity in light of changes (anticipated changes) in the environment. In proposing this model, it is understood that it is not possible to create complete models of large scale complex systems (such as an enterprise) or of the environment, and use them to fully control the system. This would deny the very complexity which we are attempting to address. It is clear that we must accept that we can only have incomplete models of the complex systems that we want to control. Secondly we accept that when living organisms (such as people) are part of a system, their actions are not completely dictated by the system they are part of, nor are they necessarily guided by logic. Power relations, survival, self-interest, group-interest, value systems, culture, etc are all participating in determining how a system ‘plays out’, in other words, however logical the design of a system may be, relying on the logic of processes is insufficient. We believe that future research that explores the human and organisational implications of the cybernetic perspective would be useful.

When studying enterprises as complex systems, Enterprise Architecture (EA) researchers not only apply models, methods and theories of management and control – they also rely on systems engineering, linguistics, cognitive science, environmental science, biology, social science and artificial intelligence. Cybernetics developed fundamental theories of complexity, therefore the authors propose ‘EA Cybernetics’ as a sub-discipline of EA, aiming to synthesise and harmonise pertinent models developed over the past fifty years to apply them in EA.

The aim of EA cybernetics is the re-interpretation of old- and new theories to understand their individual contributions, as well as to point at the need for genuinely new results. What cybernetic thinking can do is to provide a method of unifying / relating the apport of multiple disciplines. We expect that a synthesis would yield a new, unified cybernetic model of EA, more powerful theories, reference models, and methodologies than we have today, both in the problem domain and meta level (discipline development). We used cybernetic thinking to explain how systems co-evolve with their environments so as to remain viable, and characterised change processes that navigate systems in the plane stretched by the axis of system complexity and the axis of environment complexity. For this purpose, we developed as an example an EA cybernetic model called the ‘Co-evolution Path Model’ that re-interprets ‘System 5’ of Beer’s Viable System Model (based on Ashby’s law of requisite variety and first and second feedback loops) to dynamically sustain the viability of a system.

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