

SUSTAINING INFORMATION SYSTEMS AS A DISCIPLINE: TOWARDS AN EVOLVING THEORY OF INFORMATION SYSTEMS DISCIPLINE

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Abstract

When designing information systems as complex systems through Information Systems (IS) discipline, researchers and practitioners not only apply models, methods and theories of management and control – they also use the same from engineering, linguistics, cognitive science, environmental science, biology, social science, artificial intelligence, systems thinking and cybernetics and etc. This diversity of IS related disciplines derives from the nature of information systems as multi-faceted, multi-disciplinary entities with interacting dimensions and different design- and evolution concerns. We believe that for the design of large scale complex systems using IS discipline, like any other developing and evolving discipline, there should exist a theory, unified terminology, models and methodology. To model the discipline-as-a-system, we use Beer's Viable System Model (VSM) and introduce three basic components of IS discipline as a viable discipline (system). A 'co-evolution mechanisms' for IS discipline is proposed, and a cybernetic model of co-evolution is applied to IS discipline.

Keywords: Information Systems Discipline, Unified Theory, Viable System Model, Co-evolution Path Model, Cybernetics of IS discipline.

1 INTRODUCTION

For the design of large scale complex systems using IS discipline, like any other developing and evolving discipline, there should exist a theory, with terminology and rules capable of unifying the constituent models and methodologies developed by invoked contributing disciplines. The critical question in this paper is: what is a unified evolving model of IS discipline for the design and evolution of large scale complex systems? By answering this question, we could in fact have an extension of the theory to the design of large scale complex systems.

Cybernetics and General Systems Theory (GST) have previously attacked these types of problems at the same, or similar, level of abstraction and generality. Therefore, to extend the IS discipline for the design of large scale complex systems, we need to incorporate the apport of previously related disciplines and their theories into a unified theory. As this will no doubt be a long-term process we must treat IS as an evolving and developing discipline. This unified theory is indeed to be a developing theory, describing evolution of the IS body of knowledge, therefore it should remain open for further continuous contributions of IS practitioners and researchers. The integrating, or interdisciplinary, aspect of IS manifests when designing large scale complex systems. Here, researchers not only apply models, methods and theories of management and control (and apply the same from engineering, linguistics, cognitive science, environmental science, biology, social science, artificial intelligence, systems thinking and cybernetics), there needs to be a synthesis of these.

Gregor (2002) explored the ‘design theory’ as the fifth type of theory in IS discipline and pointed at the need for more comprehensive research on it as there had been ‘limited understanding and recognition’ of this type of theory in IS discipline. Gregor and Jones later (2007) extended the work of Walls, Widemeyer and El Sawy (1992) on the ‘specification’ of the design theories of information systems invoking design research and theory in order to create a grounding for a more ‘systematic and useful formulation of such theories. Gregor and Jones’ specification of the design theories of information systems complemented Walls et al. invocation of Dubin (1978) and Simon (1969) addressing shortcomings related to the ‘role of instantiations and the specification of design theories for methodologies and interventions as well as for products and applications.’

Given this standpoint many theoreticians can contribute to the development of a unified theory of designing complex systems, taking into account a list of concerns expressed (issues addressed) by different disciplines that are related to ‘designing’ systems. We call these design concerns ‘metaphors’. We can describe the design process as:

- a *Conversation* between the controller of the system, the system’s ‘operations’ and the controllers of environmental ‘entities’ (Conversation Theory (Pask, 1975)),
- a *Decisional & Resource Allocation Process* (using GRAI Grid (Doumeingts, 1984; 1998)),
- *Complex Process* managed to reduce complexity and improve the likelihood of success (applying Axiomatic Design Theory (Suh, 1990; 2001; 2005)),
- an *Emergent and Evolutionary Process* (using Complex Adaptive Systems Theory (Holland 1992; Gell-Mann 1994)),
- a *Planning & Prediction Process* (using Multi-Agent Systems Theory theories (Wooldridge and Jennings, 1995; Wooldridge, 2002)),
- a *Participatory Process* (using models of Participatory Design (Kensing, Simonsen, & Bødker, 1998; Bødker, Kensing, & Simonsen, 2004)),
- a *Change Process* (using Re-engineering Methods and approaches (Hammer & Stanton, 1995)), and
- a *Learning Process* (using Systems thinking and Cybernetics theories (Ashby, 1956; 1960; Senge, 1993; Nonaka and Takeuchi, 1995)).

To develop a unified theory of large scale systems evolution as an extension to the IS body of knowledge, one should therefore review previously developed theories, models and terminologies that study the problem of designing complex systems.

In order to ensure that this unified theory has sufficient breadth and depth, it is useful to analyse how researchers previously considered the problems and concerns of this area. This is useful to understand underlying concerns and problems that various researchers have had when designing large scale complex systems, but it could also bring new discoveries via this theory unification process.

When studying information systems as (partially designed and partially evolving) complex evolving systems, many researchers and practitioners implicitly apply methods and models derived from laws and theories of systems thinking and cybernetics. Cybernetics, as an interdisciplinary movement, has formulated multiple laws and theories of complex systems, but each one is presented on a different level of formality, generality and abstraction. Consequently, the application of these laws and theories in Information Systems discipline also lack harmony. Therefore, one should study the Cybernetics of IS discipline with the intention to harmonise, formalise, synthesise and systematise results of multiple disciplines, using systems thinking and cybernetics, for a concerted and coherent application.

Norbert Wiener defined cybernetics as “the science of control and communication in the animal and machine” (Wiener 1948). Ashby (1956) also calls cybernetics the art of “steermanship” which studies co-ordination, regulation and control of systems, arguing that the “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, which Ashby tried to describe in his book (ibid). He addressed the complexity of a system as one of the peculiarities of cybernetics and indicated that cybernetics prescribes a scientific method of dealing with complexity as a critical attribute of a system. Stafford Beer believed that the dynamics of systems is about “the manipulation of men, material, machinery and money: the four Ms”, plus an even more fundamental “manipulation” (from microscopic biological organisms to large scale systems, including information systems): the “management of complexity” (Beer 1966; 1985).

Cybernetics of IS discipline is in fact the re-interpretation of old- and new theories to understand their individual contributions, and to point at the need for genuinely new results when designing and creating complex systems. Cybernetic thinking is a way to unify / relate the apport of multiple disciplines as they explain the ‘architecting process’. Such a synthesis would be the source of a new, unified theory of IS, giving rise to more powerful theories, methodologies and reference models than available today.

2 VIABILITY OF THE IS DISCIPLINE AND EFFECTIVE IS PRACTICE

In this section we propose a viable model of IS as an interdisciplinary discipline of designing, creating and maintaining complex systems.

2.1 Stafford Beer’s Viable System Model

Beer (1979) describes every system as consisting of three main interacting components: Management, Operation and Environment (see Fig.1). Every system of interest (circle in the figure) has a meta-system as its management (represented as a square in the figure) and operates in an environment (represented as an oval shape in the figure), where each component could be further decomposed into more detailed elements. There are communication channels among these three components to keep the operation in homeostasis: these channels are called ‘variety attenuators’ and ‘variety amplifiers’ (Beer 1979; Beer 1981; Beer 1985). Every system of interest (circle in the figure) has a meta-system as its management (represented as a square in the figure) and operates in an environment (represented as an oval shape in the figure), where each component could be further decomposed into more detailed elements. There are communication channels among these three components to keep the operation in homeostasis: these channels are called ‘variety attenuators’ and ‘variety amplifiers’ (Beer 1979; Beer 1981; Beer 1985).

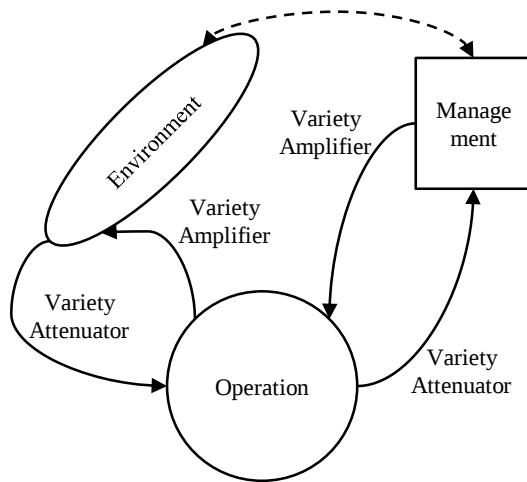


Figure 1. Three components of the Viable System Model (VSM) (Beer, 1985)

According to Beer (1979) the ‘variety’ of the operations is always less than that of the environment, and the ‘variety of management’ is always less than the variety of operations. In contrast, based on Ashby’s law of requisite variety (1956), in order to achieve dynamic stability under change, the variety of operations should be equal to that of its relevant environment, and the variety of management should be at least equal to that of operations. In fact variety attenuation and amplification mechanisms need to be designed in order to keep the system of interest viable (‘evolvable’) in its environment.

However, sometimes the information system’s mission, instead of viability and ‘eternality’ of the system, is a temporary existence, therefore the demolition or deconstruction of the system or system entities is an equally important aspect to consider. Like in construction and civil engineering, a demolition plan is a set of processes to tear down buildings or other structures. The same concept applies in IS.

For this purpose, a cybernetic model of IS discipline must cover the complete life history of the information systems as complex systems (and system of systems), including all significant life events – creation, reproduction, merger, as well as decommissioning / end of life. It is especially this last one, end of life, that has received insufficient attention in literature, therefore we propose the concept of Fatal System Model (FSM) stressing that IS should address the cradle-to-grave aspect of the information systems, from birth (creation of information systems or agglomerations thereof) to decommissioning (states which finally make the information system collapse or dissolve, preserving valuable elements for re-use).

2.2 The IS Discipline as a Viable System

It is possible to map the three components of Beer’s VSM to the IS Discipline itself, and to its surrounding environment. We consider the IS related disciplines as ‘operation’ shown as a circle, and the IS discipline as its integrating and interdisciplinary meta-system (‘management’) shown as a square, with IS discipline’s task being to observe and cross-fertilise IS problem domains as well as to observe the ‘environment’ (Fig.2).

There are communication channels (acting as variety attenuators and amplifiers) among the three components to achieve / maintain the requisite variety, i.e. in order to keep the IS discipline and its related disciplines as a system in homeostasis.

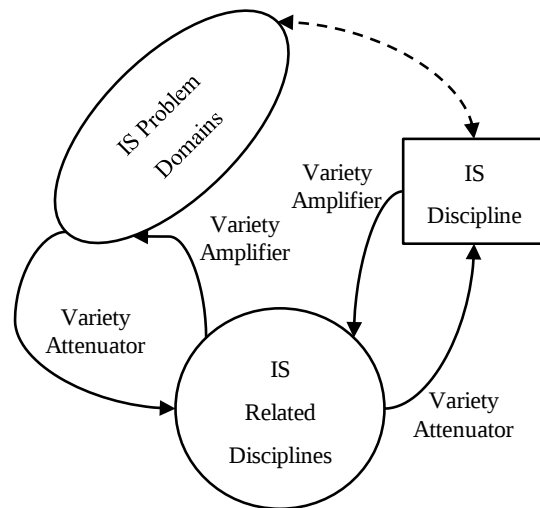


Figure 2. Three components of a Viable IS Discipline

The IS discipline acts as a meta-system that investigates the IS problem domains and using attenuation mechanism, invokes the relevant terminology, models and theories from IS related disciplines (e.g. systems thinking and cybernetics, industrial engineering, management science, control engineering, information and communication technology) to respond to new issues arising in IS problem domains.

Changes in the problem domains mandate the evolution of individual IS related disciplines, so as to respond to the new requirements of the evolving environment. In fact the evolution of IS related disciplines and IS problem domains are coupled and mutually dependent, and the IS discipline should act as a meta-system/ management system regulating the requisite variety between operations and the environment.

In order to harmonise this co-evolution, we need to understand what are the relevant mechanisms to guarantee an effective evolution of IS discipline itself

If we consider IS discipline from a ‘problem solving’ approach, then the step by step stages of co evolution would be: 1) diagnose a significant problem in the IS problem domain, 2) invoke one or more IS relevant disciplines studying the IS problem domain and decide if such multi-disciplinary combined action is adequate, and if not, then 3) provide solutions for IS problems by harmonising and integrating multiple theories, models, techniques and methods from relevant disciplines in a synthesis (new or extended theory), and 4) adopt any ‘new’ case records of IS relevant disciplines and mutual contributions of IS discipline and its relevant disciplines into the IS Body of Knowledge.

The need for a unifying theory clarifies the role of IS discipline as a meta-system (as in Beer’s VSM) that answers the question: a) what IS problems domains would be (or should be) addressed in a specific IS practices?, b) what would be the invoked disciplines targeting the problem domains to solve the problem in combined use?, c) how to formalise and harmonise other disciplines’ contributions and apply them in an IS practice?

As the invoked disciplines are continuously progressing and evolving in their specific domain and field of application, a more effective IS practice could be guaranteed if the evolution of these disciplines were influenced or monitored by the IS discipline and the findings reflected in IS theory and practice when necessary.

We discussed three components of a viable IS discipline, now the question may arise: what are the mechanisms to keep the requisite variety of the IS discipline and maintain and sustain it as a viable system?

3 CO-EVOLUTION MECHANISMS FOR AN EVOLVING IS DISCIPLINE

We discussed three components of a viable IS discipline in Section 2, now the question arises: *what are the mechanisms to keep the requisite variety of the IS discipline as a viable system?*

3.1 Co-evolution Path Model, Dynamic Homeostasis vs. Dynamic Heterostasis

Beer (1966) argues that a key property of a viable system and a “measure of its submission to the control mechanism” is its ability to maintain its equilibrium or homeostasis, which he defines as “constancy of some critical variables (outputs)”. In our model of co-evolution, we define 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”.

Here, ‘variety’ is the number of possible states of a system (Beer 1981), or as recently re-interpreted and refined by Kandjani and Bernus (2011), the number of relevant states of a system.

For a system to dynamically achieve / maintain requisite variety and to be in dynamic equilibrium, the system requires communication channels and feedback loops. These 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).

We observe that both a system and its environment (including systems in that environment) evolve, and the change can create 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.)

Fig. 3 demonstrates an effective IS Practice which is the result of the co-evolution of IS discipline with IS Problem Domains (ISPD) through invocation of relevant theories, models and methods from the IS-Related Disciplines

Consequently, in Fig. 4, the complexity of a system (C_S) 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, and to maintain adequate interaction with the environment.

The complexity of the system’s environment (C_E) 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, yet again, 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 include a) models of external systems (including models of their controllers and operations), and b) a model of the rest of the environment.

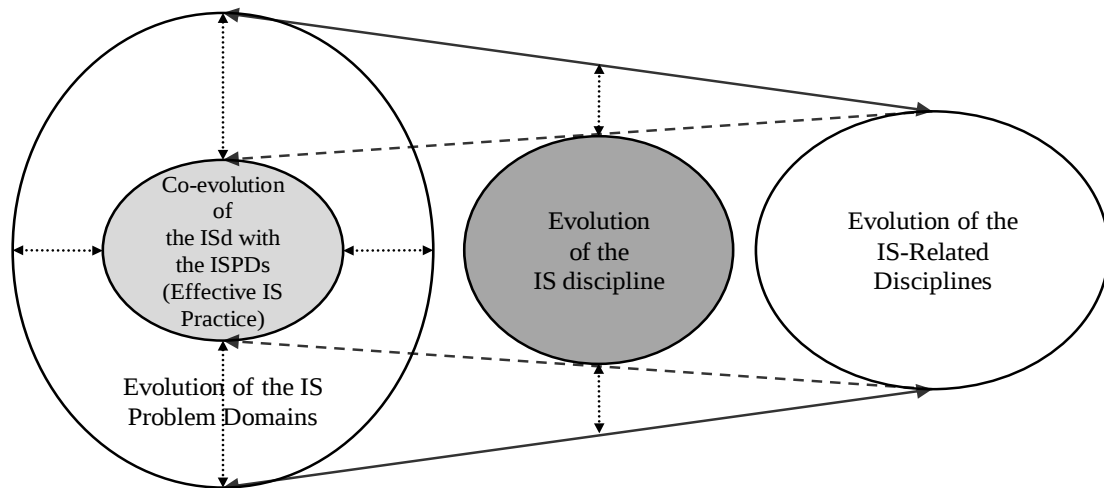


Figure 3. *An effective IS Practice: Co-evolution of IS Discipline with IS Problem Domains (ISPD) through invocation of relevant theories, models and methods from the IS-Related Disciplines*

These models are needed 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. This because 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.

Notice (Fig.4) that 1) If the complexity of the system (C_S) equals to that of its environment (C_E), 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 adequately); 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).

Information Systems 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 critical success factors measured by 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 parametric modifications and corrections to the system. As opposed to this, the second loop changes the structure or architecture of the system and operates if the tolerance of essential is predicted to fall outside the limits of survival. If the system’s second feedback loop does not respond to the changes in complexity of the environment, then the system will be on a 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 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.

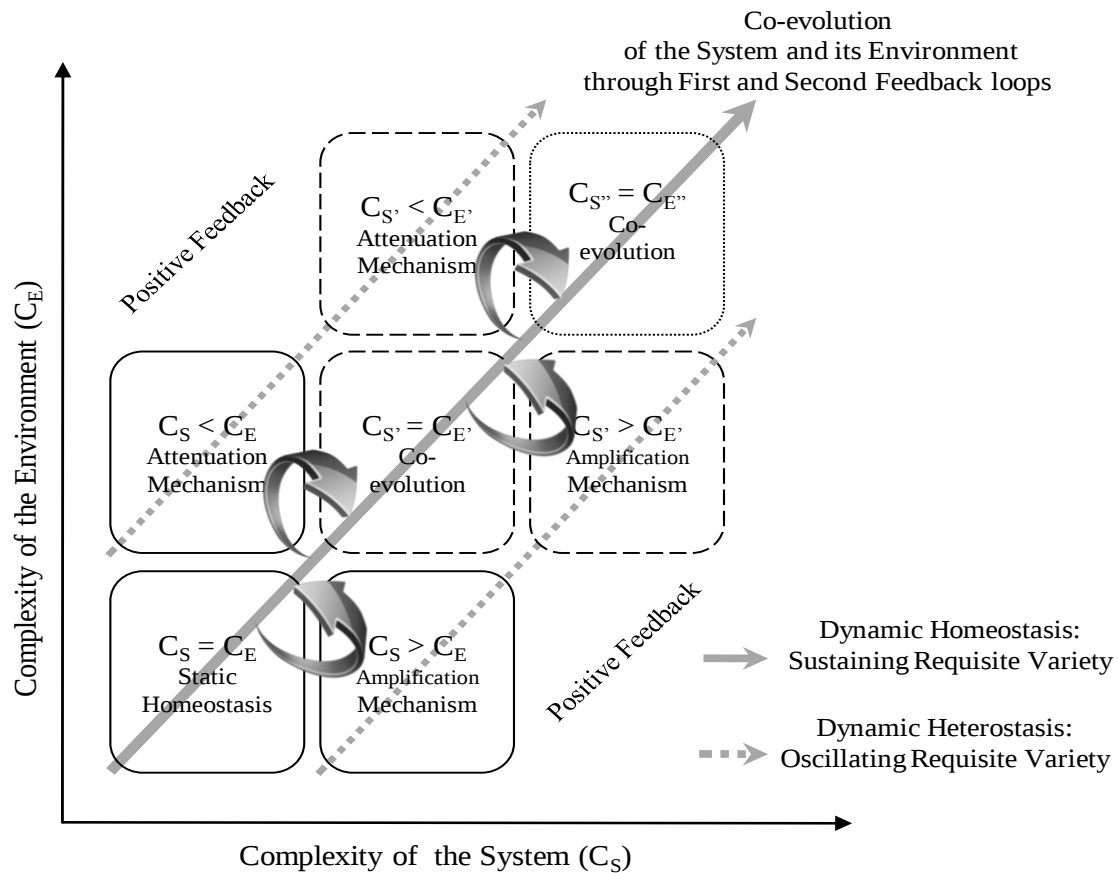


Figure 4. Co-evolution Path Model (Kandjani, Bernus, and Nielsen 2012; 2013)

If there is a dramatic increase in complexity of the environment on which the system is not prepared to act (due to scarcity of resources, lack of dynamic capability, inability to create new structures / adapt its architecture in a timely manner), then the lack of an appropriate second feedback loop makes the system non-viable and the system is doomed to fail.

3.2 Co-evolution Path Model of the IS Discipline

Looking at IS discipline as a system (the 'discipline-as-a-system') the co-evolution model of Section 3.1 applies to that system too, therefore the question: *what are the co-evolution mechanisms through which the IS discipline can maintain its requisite variety to remain relevant in light of changes to evolving IS problem domains?*

IS discipline as an integrating discipline invokes models, theories, and methods of related disciplines, an effective co-evolution is only guaranteed by:

- invoking the right theories, models, and methods from IS related Disciplines (IS-RD) to address new and emerging IS Problem Domains (ISPD) in a combined use (attenuation mechanism), and
- promoting new synthesised IS terminologies, reference models, and methods to provide solutions in IS problem domains using a holistic approach (amplification mechanism).

Thus, if at any one time the variety of the unified IS theory is less than the variety of the IS problem domains, then IS discipline can not respond to the evolution of information systems and therefore IS

as a discipline must increase its variety by attenuating the relevant variety through adopting new elements from relevant IS-related disciplines.

On the other hand, an information systems researchers or practitioners should also formulate and execute a promotion mechanism if the variety of IS models methods and frameworks is more than the variety of the IS problem domains. In this case, system managers, users, and stakeholders would not be able to comprehend these complex IS models, methods and etc. and would probably avoid using them in the evolution of information systems; therefore an information systems researchers or practitioners should decrease the variety of the models by amplifying the variety of the models, or promote the use of more complex models to invent solutions for the information system's extended 'new action domains'.

By using these mechanisms (invocation and promotion), it would be possible to sustain the co-evolution of the IS discipline and of IS problem domains, to ensure that IS discipline is adaptively and effectively addressing issues of its problem domains.

The evolution of IS related disciplines should therefore be closely monitored so as to be able to perform the mentioned 'invocation' and 'promotion' to provide IS problem domains with relevant combined discipline-contributions in any IS practice (Fig.5).

4 CYBERNETIC MODEL OF IS AS AN EVOLVING AND DEVELOPING DISCIPLINE

Information Systems discipline, like any other developing discipline, needs a model for theory development, theory 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 IS to be a developing discipline (Fig.6), we consider the real world IS problem domains as the source of the development process that give rise to issues that are addressed by theories, models and methods in IS 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 IS problem domains, and
- b) methodological theories about how to individually apply IS related disciplines in IS problem domains.

Once we developed such theories, we can state problems – not only existing problems in concrete problem domains, but also formalised, harmonised and synthesised problem statements by cybernetics of IS discipline within this new theory. Based on a new theory, one could express new problems and find new solutions / models never before contemplated.

A unified cybernetic theory of IS may be used to develop a corresponding methodology (or rather, methodologies) for use in IS 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 which allow better theories to be formulated (and as a result, better models, techniques, and methodologies). The application of the latter methodologies should be documented in case records which could provide feedback to improve the individual- and the unified theories. The IS discipline not only embraces models, methods and theories of management and control – it also uses the same from 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 appert 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).

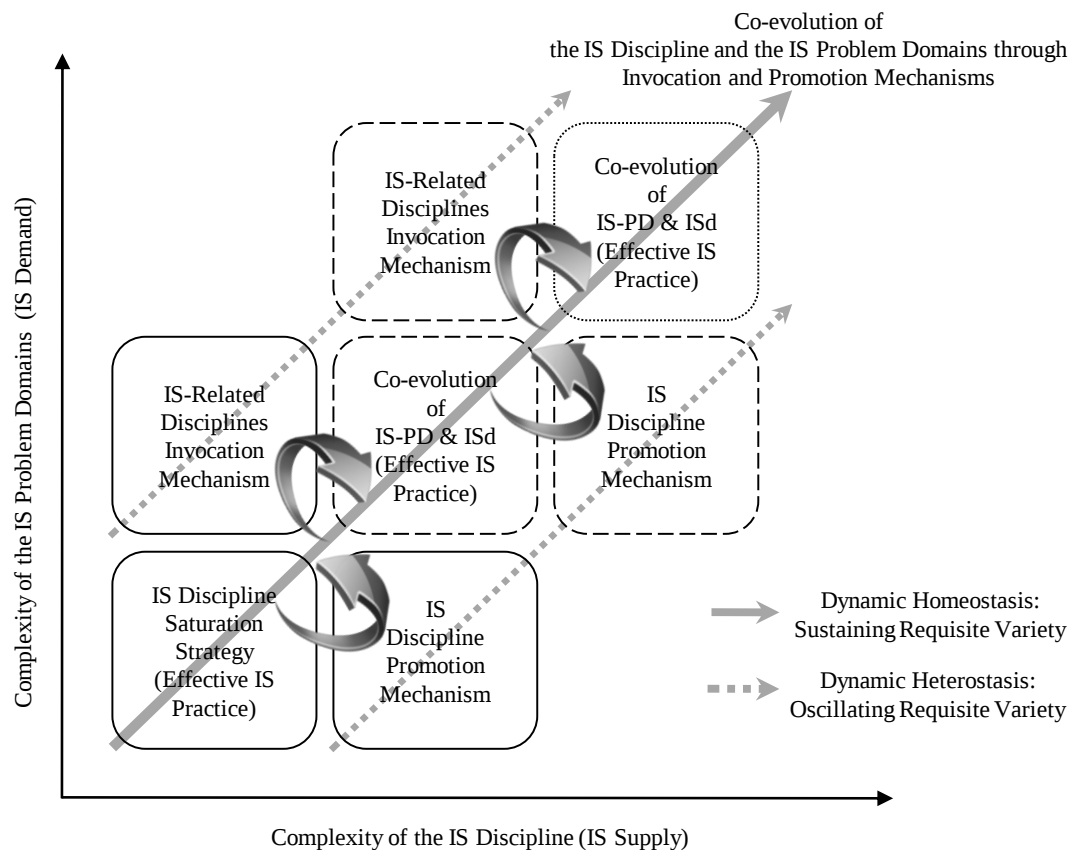


Figure 5. Co-evolution Path Model of the Information Systems Discipline

Following the systems thinking diagram of Fig.6., the contributions of these disciplines needs to be formalised, synthetised, harmonised, systematised and eventually represented as a unified Cybernetic Theory of IS.

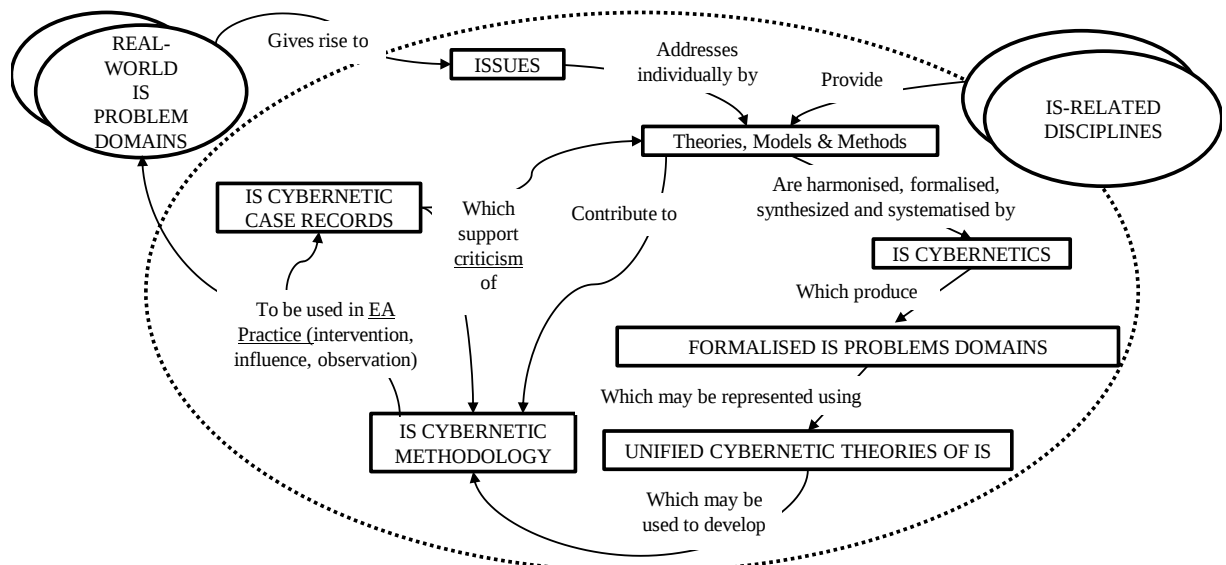


Figure 6. A Cybernetic Model of Information Systems Discipline as a Developing Discipline based on the relationship between activities and results in a developing discipline (after Anderton and Checkland 1977; Checkland 1996)

5 CONCLUSIONS

In this paper we focused on the viability of IS as a discipline and discussed it using Beer's Viable System Model (VSM), and correspondingly introduced three basic components of a viable IS discipline using VSM.

We also proposed the concept of a co-evolution mechanisms for an evolving IS discipline based on VSM and a companion theory (Ashby's law of requisite variety, but with a new, refined definition of the complexity measure for the model(s) of the environment, that takes the relativity of this term into account).

We also proposed a cybernetic model of IS as a developing discipline using Checkland's system model for a developing discipline and introduced Cybernetics of IS discipline that harmonises, formalises, synthesises and systematises the results of systems thinking and cybernetics to enable their concerted application in IS practice. Future work will concentrate on the application of this model, whereupon testing and validation of this theoretical model is to be performed.

We expect to propose to flesh out the details of the article, and illustrate the evolution of the IS discipline (using current model which has already been developed in current paper) with significant events in the history of the IS discipline, significant changes / developments in problem domains (technological and political/ economic changes), and changes in contributing domains (such as cognitive science, IT, social science, management science and etc), as well as the threats to the current IS discipline establishment and its consequences.

References

- Anderton, R. H. and Checkland P. B. (1977) On learning our lessons. Internal Discussion Paper. Lancaster, UK, Department of Systems, University of Lancaster. 2/77
- Ashby, W. R. (1940) Adaptiveness and equilibrium. *The British Journal of Psychiatry* 86(362) pp478-483
- Ashby, W. R. (1956) *An introduction to cybernetics*. London : Chapman & Hall
- Ashby, W. R. (1960) *Design for a brain; the origin of adaptive behavior*. New York : Wiley
- Beer, S. (1966) *Decision and Control: The Meaning of Operational Research and Management Cybernetics*. New York : Wiley
- Beer, S. (1979) *The Heart of Enterprise: the Managerial Cybernetics of Organization*. New York : Wiley
- Beer, S. (1981) *Brain of the Firm*, 2nd Ed. New York : Wiley
- Beer, S. (1985) *Diagnosing the system for organizations*. New York : Wiley
- Bertalanffy, L. (1968). *General System Theory-Foundations and Developments*. New York: George Braziller, Inc, 10.
- Bødker, K., Kensing, F., & Simonsen, J. (2004). *Participatory IT design: designing for business and workplace realities*: The MIT Press.
- Boulding, K. E. (1956) General systems theory-the skeleton of science. *Management Science* 2(3) pp197-208
- Checkland, P. (1996) *Systems Thinking, Systems Practice*. Chichester, UK, John Wiley & Sons.
- Conant, R. C. and Ashby W. R. (1970). Every Good Regulator of a System Must be a Model of That System. *International Journal of Systems Science* 1(2): 89-97
- Doumeings, G. (1984). *La Methode GRAI [PhD Thesis]*. Bordeaux, France: University of Bordeaux I.
- Doumeings, G. (1998). GIM, Grain Integrated Methodology. In A. Molina and A. Kusiak and J. Sanchez (Eds.), *Handbook of Life Cycle Engineering, Models and Methodologies* (pp. 227-288). Dordrecht: Kluwer Academic Publishers
- Dubin, R. (1978) *Theory Building*, revised edition, London: Free Press.

- Gell-Mann, M. (1994) Complex adaptive systems. in Complexity: Metaphors, models, and reality. G.A. Cowan, D. Pines, and D. Meltzer (Eds) Reading, MA : Addison-Wesley. pp. 17-45.
- Geoghegan, M. C. and Pangaro P. (2009). Design for a self-regenerating organisation. *International Journal of General Systems* 38(2): 155-173
- Gregor, S. (2002) A Theory of Theories in Information Systems in S. Gregor and D. Hart (eds.) *Information Systems Foundations: Building the Theoretical Base*, Canberra: Australian National University, pp. 1-20.
- Gregor, S. (2002) "Design Theory in Information Systems," *Australian Journal of Information Systems*, Special Issue, pp. 14-22.
- Gregor, S. (2006) "The Nature of Theory in Information Systems," *MIS Quarterly*, (3)30, pp. 611-642.
- Gregor, S. and D. Jones (2004) "The Formulation of Design Theories" in Linger, H. et al.(eds.) *Constructing the Infrastructure for the Knowledge Economy: Methods and Tools, Theory and Practice*, New York: Kluwer Academic, pp. 83-93.
- Gregor, S., & Jones, D. (2007). The anatomy of a design theory. *Journal of the Association for Information Systems*, 8(5), 312-335.
- Hammer, M., & Stanton, S. A. (1995). *The reengineering revolution: A handbook*: HarperBusiness New York.
- Holland, J. H. (1992). Complex adaptive systems. *Daedalus* 121(1): 17-30.
- Kandjani, H., Bernus, P. (2011) Engineering Self-Designing Enterprises as Complex Systems Using Extended Axiomatic Design Theory. *Proc of the 18th IFAC World Congr. Milano, Italy, IFAC Papers On Line*, 18(1). Amsterdam : Elsevier, 11943-11948
- Kandjani, H., Bernus, P., & Nielsen, S. (2012). Co-evolution path model: how enterprises as complex systems survive on the edge of chaos. In *ACIS 2012: Location, location, location: Proceedings of the 23rd Australasian Conference on Information Systems 2012* (pp. 1-11). ACIS.
- Kandjani, H., Bernus, P., & Nielsen, S. (2013). Enterprise Architecture Cybernetics and the Edge of Chaos: Sustaining Enterprises as Complex Systems in Complex Business Environments. In *System Sciences (HICSS), 2013 46th Hawaii International Conference on* (pp. 3858-3867). IEEE.
- Kensing, F., Simonsen, J., & Bodker, K. (1998). MUST: A method for participatory design. *Human-Computer Interaction*, 13(2), 167-198.
- Nonaka, I; Takeuchi, H (1995). *The knowledge creating company: how Japanese companies create the dynamics of innovation*. New York : Oxford University Press.
- Pask, G. (1975) *Conversation, Cognition and Learning*. Amsterdam : Elsevier
- Senge, P. M. (1993). *The Fifth Discipline: The Art and Practice of the Learning Organization*: Book review.
- Simon, H. (1996) *The Sciences of the Artificial*, 3rd edition, Cambridge, MA: MIT Press.
- Suh, N. P. (2005) *Complexity: Theory and Applications*. New York : Oxford University Press
- Suh, N.P. (1990) *The Principles of Design*. New York : Oxford University Press
- Suh, N.P. (2001) *Axiomatic design: advances and applications*. New York : Oxford University Press.
- Umpleby, S. A. (2009). Ross Ashby's general theory of adaptive systems. *International Journal of General Systems* 38(2): 231-238.
- Walls, J. G., Widemeyer G. R., and El Sawy O. A. (1992) "Building an Information System Design theory for Vigilant EIS, *Information Systems Research*, (3)1, pp. 36-59.
- Wiener, N. (1948) *Cybernetics or Control and Communication in the Animal and the Machine*. (2nd Rev. Ed 1961). Cambridge, MA : MIT Press
- Wooldridge, M. J. (2002). *An introduction to multiagent systems* : Wiley.