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Digital Eco-systems Pre-Design: Variety Analyses, System Viability and Tacit System Control Mechanisms

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Abstract—**This paper reports research into the application of Ashby's Law of Requisite Variety to assist with identifying optimal choices of design solutions at the pre-design stage of designing digital ecosystems. This study of the application of Ashby's Law is a component of a larger research program investigating the application of classical systems analysis tools in pre-design optimisation processes in designing digital information systems.**

The paper describes three extensions to Ashby's Law of Requisite Variety developed by the authors that extend the analytical role of Ashby's Law in diagnosis of unintended design outcomes from changes in control of variety in complex, multi-layered and hierarchical systems (such as digital eco-systems) that have multiple stakeholders or constituencies.

The paper demonstrates this application of Ashby's Law of Requisite Variety and the three extensions in a pre-design role in relation to digital learning object eco-systems. Analysis of variety generation and variety control is used to investigate how choice of software systems such as XML influences the control of system variety. The research draws attention to ways this leads to weaknesses in eco-system viability necessitating additional variety controlling measures that offer opportunities for hegemonic control of the eco-system by constituencies providing the additional variety controlling infrastructures and standards.

Index Terms—**digital eco-systems, design optimisation, pre-design, systems analysis, Ashby's Law of Requisite Variety.**

I. Introduction

This paper describes part of a research program undertaken by the authors in the realm of pre-design, exploring the application of classical systems analysis tools in the pre-design phase of system design. This paper demonstrates how Ashby's Law of Requisite Variety and three extensions to it developed by the authors can be used as a pre-design tool for the design of digital eco-systems.

Many design methods and methodologies have been developed from design practice and from design research. In the main, these focus on improving the outcomes of design as a result of changes to design activity. In contrast, pre-design research focuses on the development and application of analytical tools used to support design optimisation decisions undertaken prior to the design phase proper. The role of pre-design research is to provide conceptual and analytical tools for identifying which regions of a solution space of potential designs are likely to be more optimal and worthy of more design effort and explaining why this is so. Pre-design research investigates the physical, theoretical and conceptual characteristics of design contexts and potential solution spaces and sets in a more abstract way than that found in the conventional design phases to identify, for example:

- areas of optimal solution
- bounds on likely areas of solutions
- changes in physical, social, political and informatic attributes of design solutions varying across the multiple dimensions of design contexts and solution space
- design principles, heuristics and guidelines
- analytical approaches that provide design solution optimisation

In a simplified linear model of system design activity, pre- design research and analyses typically occur after problem-setting and prior to the conventional design processes (e.g. the design of program architectures, patterns, aspect identification, programming) (see Fig 1).

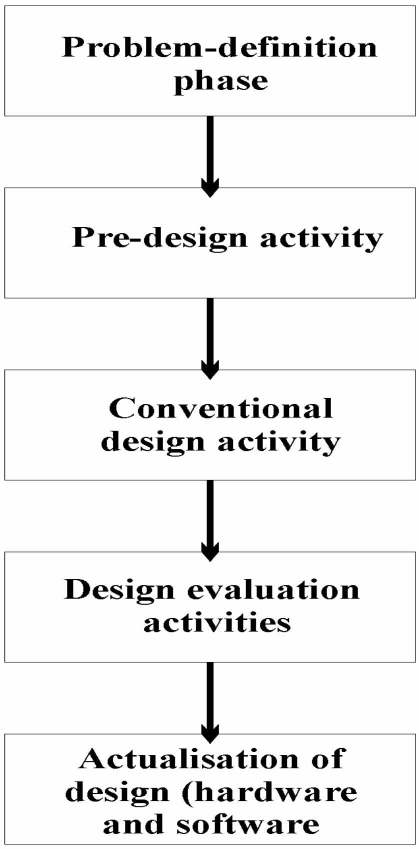

Fig 1: Pre-design in simple linear design process

Pre-design research and analyses most commonly comprises three stages: abstraction of problem characteristics; abstraction of typological characteristics of potential regions of solution space; and development and application of analytical tools to identify which regions of the solution space/classes of solutions are likely to be most successful/problematic and why (see Fig 2).

Pre-design analytical approaches are typically situated two levels of abstraction (meta-levels) above the level of concepts and theories used to describe and program the everyday functionality of a digital eco-system and its subsystems. That is, they operate as reasoning about the abstract characteristics of the solutions space properties, attribute typologies and typological environments of which digital systems are instances.

The research outcomes described in this paper are part of a trilogy of systems-based pre-design research involving:

- System Dynamic modelling
- Viable System Modelling (Beer's VSM)
- Application of Ashby's Law of Requisite Variety and its corollaries and extensions.

Each systems tool provides specific insights for pre-design. System Dynamic modelling identifies multiple causal loops and is especially useful to identify counter intuitive links between causes and outcomes. Stafford Beer's Viable System Modelling (VSM) [1, 2] is useful for identifying structural and informatic sub-system design characteristics necessary for overall system viability. Application of Ashby's Law of Requisite Variety provides insights into how, where by whom system variety (of state changes and ranges) is controlled and managed and the likely outcomes. Together they provide the pre-design basis for:

- Assessing whether systems (in this case digital eco-systems) with their sub-systems are potentially viable
- Optimising digital eco-systems in terms of managing complexity and interoperability
- identifying essential properties of digital eco-systems at element and network levels
- Identifying key information pathways between digital eco-system elements and environments
- Identifying the factors that shape the appropriate balance and location of complexity and standardisation in digital eco-systems and their elements (this in turn identifies types of software environment likely to be most effective/problematic, and why and in what ways)
- Identifying and predicting digital eco-system pathologies and identifying changes necessary for restoring or creating viable digital eco-system functioning.
- Conceptually linking digital eco-systems, digital business digital eco-systems, business engineering, virtual organisation development, real world business practices and real world social and economic development processes.

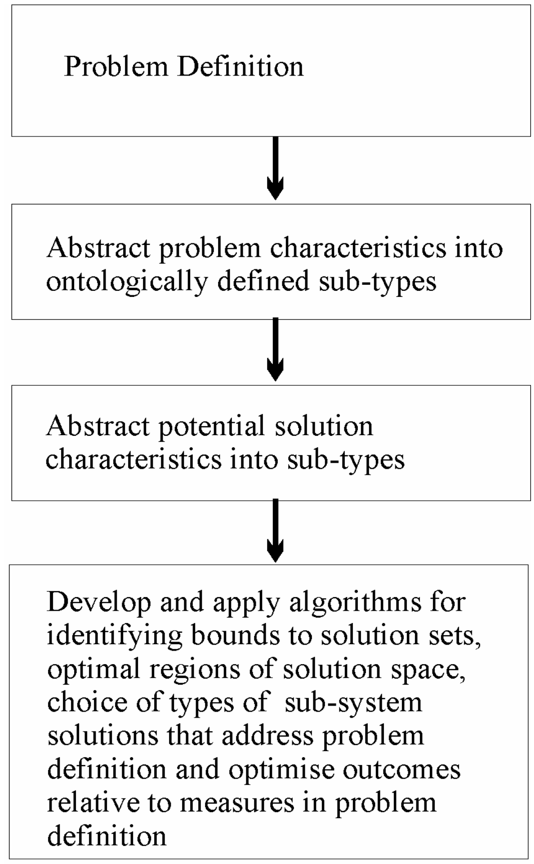

Fig 2: Pre-design processes

A recent European Union discussion paper regarded Stafford Beer's VSM as central to understanding digital eco-system development for small to medium enterprises (SMEs) [3]. Beer's VSM has been successfully tested over 45 years across a wide variety of complex real world systemic situations involving people, machines, organisations and computerised systems ranging from Business Process Reengineering[4] managing cooperative ventures[5], information warfare[6], to the national economic management of Chile[7]. VSM concepts draw heavily on Ashby's work and both are derived from Shannon's early work in communication theory[8].

In design terms, digital eco-systems are a natural product development in the trajectory of increased complexity of computerised systems. The locally networked mainframe-terminal architectures of the 1960s and 70s made the transition into internationally networked client server architectures of the 90s using the Internet and the World Wide Web. The combination of peer-to-peer networking has enabled individual workstations to be internationally linked in real time to allow individual machines to access the information and spare hardware resources available across the network. In the last 10 years in areas as diverse as business and education, suppliers and consumers are linked in increasingly complex ways through brokered middleware systems of Web services and learning object systems. On the software side, during the 80s, a transition was made from procedural to object-based programming.

During the 1990s, increasing use has been made of software agents, particularly beneficial are those capable of autonomously acting across networks. On the human side of computer systems, since the 1990s there has been increasing attention to aligning hardware, software and network systems with real world human systems and organisations, leading to the development of virtual organisations and systems software such as UML for creating code to represent the organisational and information management processes. Since the turn of the millennium, the human aspect of computer-based relations has been enhanced by a focus on social and emotional relationship aspects of human computer interfaces (see, for example, [9]).

Taken together, the above evolution of computing and networking systems and environments have lead to proposals that some highly linked high complexity networks can be regarded as a digital ecosystems: in the case of business environments, digital business eco-systems. The latter follows naturally from 90s theory developments in business ecology relating to the modelling of interactions and development of mixed economies of SMEs and larger enterprises.

The main design criteria of a digital ecosystem include:

- Its elements are networked
- Individual computers consume resources and provide resources (i.e. act as both servers and clients)
- Participants vary in their scale, roles, purposes and expertise
- Participants have differences in needs and the resources they can supply
- There is some autonomous activity in the system (perhaps by autonomous agents or by system-based automated learning)
- The system manages collaboration and competition in such a way as to preserve system integrity and to encourage growth in positive outcomes system-wide.

Underlying the re-envisioning of networked information-based interactions as digital ecosystems is the assumption that, by echoing natural systems, computer systems can gain the benefits perceived to accrue to natural systems, i.e. system stability, system transformation over time, system evolution, improved systemic functioning, improved interaction between digital eco-system members and digital eco-system ecological environment etc. Pre-design research and analyses of the sort described in this paper identify in detail the design factors and solution typologies most likely to achieve this agenda; identify the likely bounds on design solutions; and identify the specific system pathologies associated with particular design choices.

The following sections will outline Ashby's Law of Requisite Variety and three extensions to it developed by the authors. It will then describe how these apply to digital eco-systems using as an example the instance of digital learning object eco-systems. The concluding section will outline the implications of these analyses for designing digital ecosystems with improved interoperability, improved viability, reduced pathologies, and improved understanding of hegemonic influence by proprietary business interests on the evolution of a digital eco-system and preferential distribution of financial and other benefits generated by it.

II. ASHBY'S LAW OF REQUISITE VARIETY

William Ross Ashby was a psychiatrist involved in the earliest stages of the study of complex systems and cybernetics. His work has influenced most researchers involved in systemic analysis to the present; through his contributions to systems thinking, cybernetics, control theory and operations research, particularly his law of requisite variety. This law is stated in short form in many different ways, e.g., 'only variety can absorb/control variety' or 'every good regulator of a system must be a model of that system itself' [10]. In essence, his law of requisite variety states that to control a complex system requires that the subsystem(s) doing controlling must be capable of a similar variety of states as the system itself. In terms of Ashby's Law of Variety, variety comprises *anything* about a system that can be different or changed. Examples of systems attributes that can have variety include: information, organisational structure, system processes, system activities, inputs, outputs, functions, participants, control mechanisms, ownership, opinions, judgments and emotions. Each of these attributes is capable of multiple 'states'. In short, Ashby's Law states that to control any system, the amount of variety (i.e. the number of possible states) of the controlling process has to be at least the amount of variety (number of different states) that the system is capable of exhibiting. Ashby's Law is perhaps the only 'Law' that is held true across the diverse disciplines of informatics, system design cybernetics, communications systems and information systems.

Many corollaries and extensions to Ashby's Law of Requisite Variety have been identified. The primary focus of these extensions and of Ashby's original proposal have, however, been from a functionalist perspective which has excluded many aspects of systems that relate to wetware, e.g. issues of hegemony, management control, constituent orientation, distribution of power, ethical management, control of system evolution, struggles for control and ownership. Many of these factors are issues central to envisioning digital systems as digital eco-systems.

The authors of this paper have applied Ashby's Law in the area of complex subsystems combining social, political, ethical, environmental and technical factors and identified the following three extensions:

1. *For complex, layered and hierarchical systems involving multiple constituencies in which the distribution of variety generation and control is uneven across the system THEN the differing distributions of generated and controlling variety will result in structural basis for differing amounts of power and hegemonic control over the structure, evolution and distribution of benefits and costs of the system by particular constituencies.*

2. *For complex, layered and hierarchical systems, the type of outcome in terms of stability depends on the relative locations of subsystems generating variety and the control subsystems able to use variety to control system variety.*
3. *Where differing sub-systems of control are involved in the management of a system and some sources of control are able to increase their variety to accommodate the lack of requisite variety in other control systems then the overall distribution of control between sub-systems and constituencies will be shaped by the amount and distribution of transfer of control to the accommodating control system.*

These extensions of Ashby's Law of Requisite Variety by the authors apply in particular to five areas of systems design:

- Designed systems which are under development
- Systems and activities involving rework
- Systems with evolving/emergent social dynamics
- Situations to which standards apply in which the standards do not completely define solutions
- Complex, evolving, autonomous and semi-autonomous systems

The more variety is controlled in the earlier stages of system development, the more the product is similar to what was conceived and intended. As the variety exceeds the variety provided by the internal control sub-systems, then if the outcome is to be controlled, it must be done so by the application of additional variety later. Often, in practical situations, this later application of control of variety is ad-hoc, inefficient, has knock-on adverse outcomes, and offers opportunity for control of whole-of-system outputs by stakeholders outside the system.

A practical example from outside the digital field is where system variety is insufficiently controlled in vehicle design. The design team for a new motor car apply what they perceive to be the requisite variety to control the design and production of a vehicle that is safe, can be manufactured as specified, and will function as intended. Typical variety-controlling activities used by the design team include using a well-tested design process, applying design checking and validation, utilising engineering research and market research, prototyping and user testing to ensure the intended design outcome. Any outstanding variety relating to the vehicle after these activities, however, will be accommodated through alternative variety control mechanisms such as in-production design modifications, rework, repairs, product development modifications (often incorporated into a later version of the vehicle), and sometime litigious product recalls. These latter methods 'mop up' excess variety of possible system states uncontrolled by the requisite variety offered in the design stages in order to result in the intended output of a safe reliable car for the customer. As variety is 'mopped up' through sub-systems outside the design process, the control of the system and solution becomes transferred in parts to constituencies outside the design team. In the limit, unmanaged distribution of control of variety across the system can result in primary design decisions being taken outside the official design process and design outcomes being shaped primarily by external factors.

Similar conditions apply in the design and evolution of digital eco-systems. Changes to the distribution of environmental, system and controlling varieties in a digital eco-system changes the distribution of the different loci of control of participating eco-system sub-systems and constituent individuals and organisations: including those who provide internal information flow management (e.g. network services, middleware, database management services, brokerage and coordination, access, authorisation infrastructure, financial management etc).

Ashby's Law of Requisite Variety with the extensions above offers significant insights into digital eco-systems development and management. The digital learning object eco-system example below shows how distribution of power and control, establishment of hidden hegemonies by players, and the structure and form of the digital eco-system are significantly dependent on something as simple as standardisation of underlying software; through its role in changing the distribution of system variety and control variety across the digital eco-system.

III. Controlling Variety in Digital Learning Object Eco-systems

Learning object systems are instances of digital eco-systems. The main typological characteristic of these digital learning object eco-systems is their transmission, storage, and exchange of reusable learning content and for tokens of other forms of value (mainly financial but also status, power, control etc). Discrete 'chunks' of learning content are labelled, packaged and served digitally as 'learning objects' that can be combined in different ways with other learning objects for different teaching and learning situations [11].

In its simplest forms, digital learning object eco-systems comprise learning objects (LOs) attached to pre-defined 'learning object meta-data' (LOM) indexed and queried by a learning object management system (LMS). Typically, LOs, LOM and LMSs are distributed across a variety of constituencies, organisations, servers, networks and systems. Digital learning object ecosystems involve multiple constituencies that:

- Provide resources (learning content converted into learning objects),
- Access learning object resources
- Access related meso-system resources (e.g. servers, networks, information management services, applications, standardisation systems, market and financial exchange management processes, organisational processes, legitimation and governance processes) provided by others
- Provide supporting services such as the meso-system resources above

The transfer of learning object resources and the processes of management and distribution are undertaken under a variety of economic mechanisms, e.g. some resources are free, some are public goods, some proprietary, some pre-paid and some bought on demand.

In current systems, the digital meta-data by which learning objects are labelled and identified are usually incorporated into or wrapped around each digital learning content object using mark-up language. At the simplest, meta-data for digital learning object content expressed directly as an html web page would, e.g. use Title, Keyword and Meta tags. More commonly, codification and management of digital learning object meta-data has focused on XML-based approaches in which digital learning objects combined with their meta-data are located in digital learning content databases or repositories.

Systems analysis of XML-based digital learning object ecosystems via Ashby's Law of Requite Variety (with extensions and corollaries) suggests there are significant systemic structural problems associated with the use of XML and other mark-up languages in codifying meta-data because of their influence on the relative distribution of system variety and its control . These problems emerge as poor eco-system viability, poor interoperability at all system levels, system inefficiencies, the needs for additional supporting system structures, and problems of hegemonic control of the whole digital eco-system by propriety interests. These latter gain control by their role in supplying sub-systems that control unaddressed variety and thus repair problems with digital eco-system viability. Broadly, the overall problem with using XML and similar mark-up language approaches is they control variety by attempting to create system standardization and interoperability of meta-data and data at lower system levels.

From the perspective of Ashby's Law of Requisite Variety, it is problematic to attempt to manage a system by attempting to attenuate system variety through propagating standardization upward from page content level via mark-up languages such as XML, which is essentially a page description formatting language whose role has been extended. In variety terms, it is limited in its management of containers (meta-data). It assumes a singular and fixed relationship between a particular element of data and its meta-data container. This is on one hand over restrictive for situations in which different information providers and different readers will have different interpretations about what sort of meta-data characterisation is appropriate for a particular piece of data. For example which meta data should a film be characterised by - the fact it is a comedy, a farce, set in Mexico, filmed in Spain, has a certain leading actor, uses a certain rhetoric device….? Each of these options is potential system variety that must be matched by controlling variety. Other potential variety accrues from a wide variety of other sources elsewhere in the system, e.g. choice of server, network systems, database management structures, database types, data organisation, organisation structures, and business structures. Variety is generated at many system levels in ways not addressed by lower level standardization. Attempt at control at lower system levels by standardisation using XML is essentially 'back to front'. In digital learning object eco-systems (as in many other digital systems) such an approach is insufficient for maintaining system viability because it does not fully control the variety across and between different learning objects, courses, learning designs, software systems, disciplines, organizations, networks, and other technical, virtual and real institutions. Where standardization attempts are focused on the lower levels of the system, improving interoperability between units, courses, servers, networks and institutions requires strategies that are difficult to implement. Not only are they difficult to implement but structurally they add to the overall problem by increasing variety overall, which in turn needs to be absorbed. An additional problem is that coding meta-data via inline XML and html mark-up requires learning object content and page elements have meta-data applied in consistent pre-defined and pre-structured ways to be consistently and meaningfully machine-parsable. This depends on pre-specified, pre-defined and accurately applied meta-data vocabularies. All of these are problematic in a digital learning content eco-system whose meta-data classification is emerging as time passes and where learning objects are classified by meta-data in a variety of different ways. This lower level approach to controlling system variety contrasts with alternative approaches such as W3C's Resource Definition Framework that focus on propagating control of variety from the level of over-arching system framework downwards.

From a superficial perspective, the transition in the late 90s to XML from html appeared an improvement because it increased control variety. At a whole of system level, however, the gains offered by using XML (and XHTML) are limited. XML was designed for simple business transactions systems with already tightly controlled variety of objects types, which are transacted in strictly limited ways with transactions undertaken close to page level. In contrast, digital learning object eco-systems and other forms of complex digital eco-systems are high variety systems.

In digital learning object eco-systems other sources of system variety include, for example, variety due to differing uses of the same learning object, differing higher-level learning object classification systems, different forms of machine-parsing engines with different parsing approaches, differing learning object data structures in different organizations and different computer systems, and even differing interpretations of the XML standards. From experience in digital learning object eco-systems and many other digital systems, the limitations of XML to attenuate system variety requires additional sub-systems as means to control variety in the system. For example, the problems of lack of adequate management of variety in meta-data has required development of multiple schema language alternatives to the Document Type Definition such as XLS, and the family of schema languages under ISO DSDL. Managing interoperability between different LMSs, different networks and different institutions has required ongoing development of multiple middleware, database and communication standards, many of which are proprietary.

Naturally, organisations prefer addressing these upper system variety problems by producing proprietary middleware solutions tied to proprietary standards that offer those who own them potential for commercial or national advantage. These additional means of controlling excess variety are the focus of current intensive and expensive efforts by e.g. ADI, IMS, IEEE, and OSPI to create multiple mid-level standards such as SCORM.

Whilst providing the means to attenuate excess system variety, these 'additional' system control strategies also add to the problem by increasing the amount of system variety overall that needs to be absorbed. That is, attempts to resolve the structural problems by using XML plus additional systems tends to result in increased system variety, increased complexity, weaker interoperability and increased dependence on incompatible proprietary formats. Each approach to addressing different problematic aspects of variety management will in turn require more variety controlling subsystems until eventually the complexity from the variety controlling sub-systems matches the variety in the whole system. In many digital eco-systems, this is potentially an unconstrained problem in cases where system variety is effectively unrestrained at upper systems levels. In essence, the underlying structural weaknesses of XML-based digital learning object eco-systems is likely to continue to produce problems of incompatibility between systems, continue the problems of lack of flexibility in responding to change and to new insights, and continue a lack of scalability in meta-data management processes.

These problems of poor variety attenuation of XML and mark-up languages are substantially resolved by the Semantic Web infrastructure such as the Resource Description Framework (RDF). Using RDF as the basis for a digital eco-system management offers improvements compared to XML in eco-system viability and reductions in eco-system pathologies because RDF controls variety from the top down. RDF specifies standards and interoperability at network level, and as a framework for interoperability propagates standardization via simple graph-based 'triple' protocols downwards to the page level, where it can be efficiently actualized via, RDF/XML an RDF-based variant of XML that integrates well with existing XML page descriptions. It attenuates system variety and offers increased control variety by increasing the variety of the system and its communication channels. This enables the management of higher levels of variety at page level. In practical terms, RDF also allows separation of metadata describing learning objects from the objects themselves. It allows the integration of different forms of meta-data; provides a smooth transition to consistent vocabularies as and when they are available and appropriate, and provides graceful resolution of inconsistent meta-data and relative avoidance of incompatible meta-data. Significantly, for all digital eco-systems, RDF also supports better integration between digital and real world eco-systems. A limitation of XML mark-up approaches to labelling digital objects with meta-data is it restricts digital eco-systems to virtual or digital objects that can be stored digitally with their meta-data and be network accessible. In contrast, the ability of RDF's URIs to refer to *anything* means that RDF-based digital eco-systems can also be easily integrated with real world eco-systems.

IV. Conclusions

This paper has reported the application of Ashby's Law of Requisite Variety to improving choices of design solutions at the pre-design stage of designing digital ecosystems. This application of Ashby's Law is one component of a larger research program investigating the application of classical systems analysis tools in pre-design optimisations processes in designing digital information systems.

The paper described three extensions to Ashby's Law of Requisite Variety developed by the authors that extends its analytical role in the diagnosis of outcomes of changes in control in complex, multi-layered and hierarchical systems that have multiple stakeholders or constituencies.

The paper then demonstrated the use of Ashby's Law of Requisite Variety and the three extensions of the law in exploring the role of XML in controlling system variety in digital learning object eco-systems.

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