New Directions in Design: Five new systems-based design approaches

Dr Terence Love

This paper describes five new systems-based design approaches for use in complex design situations developed by the authors over the last decade. They comprise: a six-level taxonomy of complexity of design situations; the 2 feedback loop hypothesis; the use of variety-based methods for design of dynamically complex socio-technical systems; the use of layered system dynamics graphs for design practice based on integrated design theory; the use of causal loop diagrams in the design of motivational information systems. All of these are new developments at the nexus of systems thinking and design practice.

Keywords – *Systems, design, variety, methods, 2 feedback loop limit, taxonomy.*

Relevance to Design Practice – *The article describes the outcomes of practical research by the authors into the use of systems methods in design practice and design research. These outcomes comprise a new suite of design methods and systems analyses applicable to designing strategies for managing highly complex socio-technical systems with dynamically changing social and technical structures, operational contexts, organisations, ownership and control, including by constituencies outside the system and system design.*

Introduction

The ideas of systems and systems analysis have been used by professionals in many areas of design for several decades. Systems concepts, however, go back at least to Thales of Melitus and the Tao Te Ching of Tzu (Mandel, 2000), are found in many middle eastern writings from the 9th to the 13th century (see, for example, Shah, 1968), and are found in works of Al-Ghazali, Ibn Khaldun, Ibn Sina , Al-Farabi, Naṣīr al-Dīn al-Ṭūsī, Al-Biruni and Al-Balkhi who along with others of the era created the theoretical turn that transformed Greek ideas into what we would regard now as modern science, systems thinking and design theory.

The current wave of interest in Systems and the close discipline Operations Research emerged from research into managing the complexity of military operations in the 20th century. Both are tightly linked conceptually with the field of control theory, in particular, non-linear control theory which again have a history back via the Islamic world and the Greeks. In all of these histories , concepts of systems, government, design, mathematics and philosophy were coincident. Epistemologically, there was little difference made in conceptual terms between the ways these realms were viewed, analysed and designed.

This article follows the same tradition in linking concepts between different disciplines where they are epistemologically coherent . The authors have experience in design and in the, sociological, technical and mathematical aspects of systems as they apply to designing real world interventions and products since the early 1970s. The analyses that follow are influenced by systems perspectives on design in technical and social systems that were common currency at Lancaster university in UK from the 60s; from non-linear control theory through politics and engineering to the studies of operational research and the behaviour of organizations.

This article describes five ‘new’ approaches to systems and design developed by the authors.

First is described a simple *six-level taxonomy of complexity* in systems as they relate to design activity. This taxonomy provides the basis for understanding and delineating differences in professional practices, theories and methods needed for design and systems analysis.

The second section describes a criterion, the *2 feedback loop hypothesis*, that divides systems and design situations into two distinct groups on the basis of whether they can be addressed using traditional design methods or whether they essentially require a modeling step prior to any design work. This new systems tool emerges from ethological analysis of humans’ ability to understand and design complex systems. The limitations of humans ability in this area has been loosely hazarded for the last half century at least ((see, for example, Deming, 1986; Forrester, 1971; Meadows, 1999). The authors during the last decade developed these early ideas into the 2 feedback loop hypothesis via taking an ethological perspective on the application of affective neuro-cognition (emotionally-based design) in understanding design (see, for example, Love, 2009a, 2009b).]. This ‘two-feedback loop limitation hypothesis and related approaches focus on the third and higher categories of the six-level taxonomy.

The work on 2 feedback loop limitations is followed be an outline description of a new *variety-based approach to understanding and managing complex systems and design* that focuses on the use of dynamic variety management in for example the design of strategies for control of dynamically complex socio-technical systems such as airports, global software development, national health systems, digital eco-systems, international agriculture and trade, and global financial markets.

The fourth systems contribution to design by the authors is an approach developed in 2000 in which characteristics of theories of design are mapped into a new system dynamics structure: *multi-layered systems dynamics graphs of design theories and phenomena*. This is a radically new approach as it works with the characteristics of theories rather than the theory elements or contents themselves. The ‘system’ that is the focus of attention is ‘the whole body of design theory’ and the ‘dynamics’ that is modeled comprises the dynamic changes in theory relationships. In effect, the system dynamics modeling structure and software tools are being used as a convenient complex ‘entity-relationship’ representation tool and this is being focused on the entities (concepts) and relationships (theoretical connections) of the theory world relating to design. The approach is potentially applicable across a wide variety of complex design situations and design fields. The technique builds on the work of the author in mapping the epistemological and ontological characteristics of coherent design theories. Conceptually, the approach it is similar to ideas expressed by Hesse in the 'Magister Ludi' (the 'Master Game' or 'Master School' often called 'The Glass Bead Game').

The fifth system approach that is described in the article comprises a new class of systems - *'Motivational Information Systems'* and a practical description of their use in Design and their analysis using causal loop diagramming.

Six level taxonomy of complexity in systems and designs

One of the significantly problematic issues in the application of systems approaches in the Art and Design fields has been the relatively naïve way in which the term 'complex' has been applied to any design issues to which a designer does not have the necessary knowledge to address competently. In the terminology of the Art and Design world, any issues in this class have often been referred to as 'Wicked Problems'. It is commonly assumed that anything so labeled is impossible to understand and the designer is exempt from responsibility for failure of designed outcomes. In parallel, however, designers also strangely commonly competence to be able to design in areas for which the necessary information and understanding is not available or not known to them.

One way of clarifying this issue is via the following six-level taxonomy of complexity of design situations. The list is below is a composite of mathematical definitions of systems in informal use in the 70s and common systems concepts of this decade.

The focus of understanding or designing any system or design is to be able to predict and prescribe the behaviour of the designed outcome. Five defining factors that separate designs and systems into usefully different categories are: the *number of variables in the system* that can be perceived, measured or managed; the *number of degrees of freedom* of the system, i.e. the variety of types of changes that are possible; the *number of feedback loops* between variables; and whether the *structure* of the system or design remains *constant* (always has the same elements) or is *dynamic* (the elements of the system or design change, e.g. in type, behaviour or number); and what is known about the stability of the *behaviour of the outcomes*.

For example, a chess piece on a chessboard can be considered to have two *degrees of freedom* in its position (forward/ backward and left/right). If the *number of variables* that was used to describe the position of the chess piece was only one (say its position forward/backward) this would be insufficient to describe its position. Similarly, if the number of variables that was used was more than two (say, forward/backward, left/right and up/down) there would be a redundant variable. Any aspect of a system and a design can be regarded in these terms, other variables and degrees of freedom might include but are not restricted to colour, shapes, behaviours, functions, emotional responses, choices, etc.

In the above case, there are no feedback loops. Commonly, elements of many everyday designs are managed by a single feedback loop that tends to stabilise the behaviour of the system. Examples include temperature management (e.g. the temperature of water from a hot water heater); sound (e.g. audio volume of a phone or radio); light (e.g. light levels in a digital camera).

Using these five factors enables an easy and relatively comprehensive categorisation of systems and designs into a six-level typology that usefully separates systems and designs that require different sorts of approaches (see Table 1).

Table 1: Six level typology of complexity in systems and designs

Type	Degrees of freedom	Number of variables	Number of feedback loops	Structure	Behaviour of outcomes
Simple	Low	Equal to or higher than degrees of freedom	None or one feedback loop	Constant	Constant
Complicated	High	Equal to or higher than degrees of freedom	None or one feedback loop	Constant	Constant or very simple dynamic behaviour
Complex	Low or high	Equal to or higher than degrees of freedom	Two or more feedback loops	Constant	Dynamically changing but predictable behaviour of outcomes depending on multiple variables whose states depend on each other
Dynamically complex	Low or high	Equal to or higher than degrees of freedom	Two or more feedback loops	Dynamic	Dynamically changing behaviour of outcomes in a partially predictable manner
Chaotic	Low or high	Equal to or higher than degrees of freedom	Feedback loops interlink such that multiple different behaviours are possible at any point and cannot be predicted which will occur	Constant or dynamic	Dynamically changing in an unpredictable manner
Under defined	Low or high	Lower than degrees of freedom	None or many feedback loops of any type	Constant or dynamic	Unknown

Designers and design educators in conventional Art and Design design fields, typically are only involved in design work in the first two categories 'Simple systems/designs' and 'Complicated systems/designs'. The design tools taught in design schools and in university degree and postgraduate courses in design (including PhD) typically focus exclusively on these first two categories of simple and complicated systems and designs. In part, this is because the design structures and the design outcomes remain fixed and stable. Graphic representations of the differences between simple, complicated and complex systems and designs are available at http://www.love.com.au/PublicationsTLminisite/2010/CEPHAD-TL-AA.pptx

Design and systems methods appropriate to *simple* and *complicated* systems and designs are, however, insufficient for the other four higher levels of categories. More importantly, they commonly give the wrong predictions of the behaviour of outcomes particularly in systems and designs that involve people and technology together.

Elsewhere, the authors have identified that a significant problem of Art and Design design education and design practice is the widespread and incorrect assumption by designers that the tools and skills applicable to simple and complicated design are sufficient for complex and higher levels of design situations in the above table (Love, 2009b, 2010). This is because these approaches do not apply to systems that have dynamic outcomes dependent on multiple variables whose states depend on each other, i.e. they have 2 or more feedback loops

2 Feedback Loop Limitation hypothesis

Viewing human behaviour and being through an ethological lens reveals that we are compromised by cognitive biases, biological limitations and fallacies (see, for example, Fernandez-Armesto, 2004; Gilovich, 1993; Klein, 1996; Knight, 1999a, 1999b; Labossiere, 1995; Schacter, 1999; Stroessner & Heuer, 1996; Warren, 1976) linked to our evolutionary development (Damasio, 1994, 1999; Fernandez-Armesto, 2004): in which our cognition and equip us to respond quickly to direct, simple, causally-obvious challenges close in time and space and with obvious causes (e.g. touch a fire and your finger gets burned). We can also learn to deal with situations with a **single feedback loop** (someone runs, you chase them, they run faster, you run faster- or not). Our cognitive and emotional process are not suited to enable us to envisage, understand or predict behaviours of situations where causes of outcomes are complex, multiple, interlinked and hidden, especially when outcomes and causes are remote in time and location. In these situations, our basic human biological processes can delude us into erroneous understanding and decisions.

The absolute limit of human thinking and intuition seems to be biologically limited to predicting the behaviour of situations with **less than two feedback loops**.

Quick Test: Mike has $1.10 and buys two items. The first item costs $1 more. How much is the second item? Most people answer 10 cents. This is a very simple uncluttered single feedback loop problem shaped in arithmetic. The answer is $1.05 and 5 cents. Another example is http://web.mit.edu/jsterman/www/Bathtub.pdf .

The ***2 feedback loop limitation*** hypothesis of the authors is:

Humans unaided ***CANNOT*** *predict behaviour of complex situations*
with ***2 or more interlinked feedback loops***

If correct, and practical review of a variety of design situations across a number of design fields supports it, this biological limitation of human thinking, intuition, feeling and understanding apply to everyone – designers included.

The 2 feedback loop limitation hypothesis has a number of interesting ramifications:

- It suggests that modeling must be the primary method of design understanding and systems analysis in complex and higher levels in the six-level taxonomy. Designers can then simply observe the outcomes of the modeling without understanding how the situation behaves. This circumvents the human biological limitations.
- Design methods of intuition, feelings, creativity and related methods do not workfor design activity and systems analysis in complex and higher levels in the six-level taxonomy.
- Participatory, collaborative, stakeholder-based or other group-based multi-person design methods do not work for design activity and systems analysis in complex and higher levels in the six-level taxonomy.
- Fixed visual diagrams and representations of designs, contexts, and design do not work for design activity and systems analysis in complex and higher levels in the six-level taxonomy. This is because the design outcomes are dynamic and cannot be represented by a fixed visual, and, because people are not able to infer the dynamic behaviour from the relationships, fixed visual representations of the relationships are also useless.
- Current claims by some design professionals that design methods suited for the first two levels of the above taxonomy (simple and complicated design situations) are suitable for complex design situations are false.

The visual representation in Figure 1 below is of a complex design situation. It shows the relationships between factors necessary to develop a health promotion strategy to reduce obesity. As such, it refers to all the factors and relationships that a graphic designer might need to create public informational material.

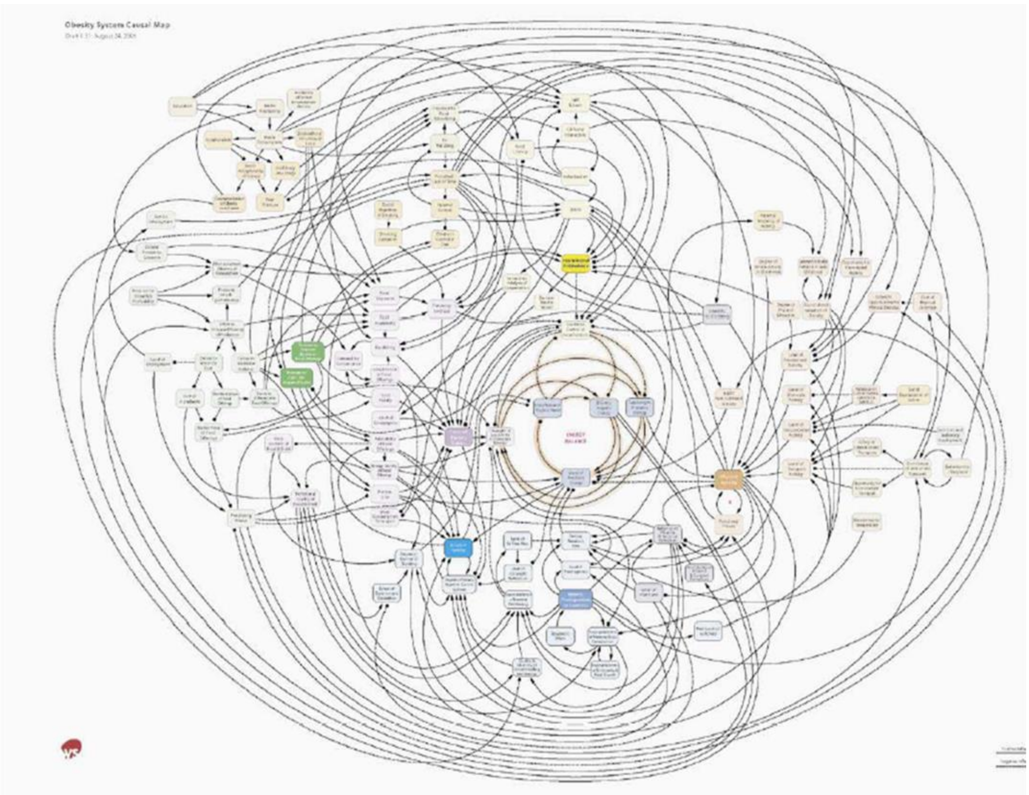
The visual representation in Figure 1, however, is useless for helping a designer understanding the behaviour of the effects of any graphics they produce. The only purpose of the system representation in Figure 1 is to identify the factors and feedback loops so that a suitable system dynamics model can be created. It is the active behaviour of the system dynamics model that will show the designer how the behaviour of the system will change as a result of their graphic designs for public information material.

By implication, design failures occur as a result of lack of awareness of the 2 feedback loop limitation; , the false assumption that design approaches for simple and complicated designs apply to complex design situations; and failure to use modeling of design situations prior to and as the basis for design activity in complex design situations. Experience has shown that when people try to create interventions to manage complex situations and use tools only suited to simple situations then many will produce results *opposite* to those intended. This is reflected in a quote attributed to American humorist Henry Mencken,

'For every complex problem, there is a solution that is simple, neat and wrong.'

A further failure mode, that is common and easily observed is when designers undertake designing in complex design situations and do so by deliberately ignoring the complexity and 'simplifying' the situations by removing any feedback loop effects. The result is design outcomes that fail because the dynamic effect of the feedback loops will change the design outcome and this will obviously be different for much of its time to any intention of the designer that assumes the outcome would be fixed.

This combination of forced simplification and an assumption that designers and understand complex multi-feedback situations explains much of the theory 'mess' in many areas of design theory and research that involve people and technology together, e.g. the Design and Emotion field.



Design of obesity reduction: simplified model of multiple interrelated feedback loops
http://www.foresight.gov.uk/Obesity/12.pdf

Figure 1: Complex multiple feedback loop model typical of addiction reduction management

Variety in Dynamic Complex Systems and Designs

Many design and systems situations are dynamically complex in that their structure and management systems, feedback loops, delays and behaviours all change dynamically in a highly-interlinked manner. The problem with designing interventions in this kind of dynamically changing scenario is that any modeling (which takes time to create) can easily be outdated by system changes before there is the opportunity to design interventions based on these models.

During the 80s, the authors developed crude approaches for measuring the effects of community development interventions in approximately real time (they would perhaps now be called real time social capital evaluations). Building in these in the 90s led to an exploration as to what could be reliably and justifiable used in designing interventions in a variety of highly complex socio-technical organisaitonal situations. The authors defined the category of these dynamic socio-technical situations as having the following characteristics:

- Multiple constituencies – changing over time
- Multiple sub-systems
- Mixed ownership of sub-systems
- Changing technologies
- Learning
- Irregular reflective connections between technology change and related sub-systems and socio-dynamic sub-systems
- Varying purposes and roles of system and sub-systems
- Complex and dynamic distribution of formal and informal power and control

Examples of such dynamic complex socio-technical systems include: media, transport systems, global retail and manufacturing, construction, religion, political systems, education, computerised information systems, asymmetric warfare, and legal systems.

The authors have so far developed twelve axioms for creating design interventions in such dynamic complex socio-technical systems of which six have been published so far (refs). The authors' approach is epistemologically and ontologically driven. Put simply, it starts from the perspective of asking' At what level of theoretical abstraction is it possible to identify characteristics that represent systems behaviour and enable the identification of guidelines as to ways to design strategies and interventions that will result in preferred system behaviour outcomes?'. The authors identified that this was possible to undertake by focusing on the dynamic distribution of system *variety'* (level 8 in Table 2 below).

Table 2: Abstraction levels of theory analysis for dynamic complex socio-technical systems design

Level of theory abstraction		
1	Level at which things happen	Daily life
2	Level at which people ordinarily plan what happens	Design
3	Level at which people analyse about how people ordinarily plan what happens	Design research
4	Level of systems models and systems thinking (situations are seen as systems and systems thinking and analysis tools are applied)	Systems design
5	Level of thinking about the variety in systems and the balance between control variety, system variety and environment variety	Systems – Ashby's Law
6	Level of thinking about the distribution of control, system and environment variety across sub-systems and their conceptual representations (especially important in terms of thinking about information systems)	Control theory
7	Level of thinking about the time and location distributions of control, system and environment varieties	Non-linear control theory
8	**Level of thinking about the dynamic shifts in power and control that result from the dynamics of change in time and location of control, system and environment varieties.**	**Variety-based design and analysis for dynamic complex socio-technical systems**

One of the first projects in which these approaches were applied was to explore the way that the design of variety distribution in international Learning Management Systems influenced how the dynamic balances between system variety and control varieties would shift giving advantages to some stakeholders and reducing the power of other stakeholders. This provides a prediction of which players would eventually control the industry. The analyses led to the identification by the authors of axioms to guide the design of interventions that would change the relative distributions of system and control variety to influence the dynamics of system behaviour in order to change the relative advantages and balance of power. For those interested, the analyses suggested the open source movement needs to prioritise RDF over XML and deprecate XML to the role of page descriptor management. It appears, however, that developers seem to prefer to regard RDF as a secondary subset of XML. It will be interesting to watch the variety distribution behaviour unfold.

Other axioms for designing variety-based interventions to change system behaviours were developed and published for use by environmental activists and change agents in large scale organisations such as universities who were in positions with relative low power.

The authors categorized dynamic complex socio-technical systems into different types as this reflected the dynamic distribution of different forms of variety and the effects of variety distribution on system behaviour.

An example of one of the core axioms developed by the authors is:

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.

Another axiom developed by the authors that offers design guidance for interventions is:

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 a shortfall 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 and its owners.

This new variety-based theoretical foundation for the design of systems interventions is unusual in that it does not require complete causal information to predict behaviour. Instead, it offers a way of defining the likely effect of influence, i.e. changing the power and control mechanisms. The epistemological level at which it is addressed means this approach can be applied to design situations at all six levels of the systems and design typology, including systems whose behaviour is chaotic or undefined.

More detail on these approaches is available from papers on www.love.com.au and direct from the authors.

Complexity in Design: Layered System Dynamics Graphs

The approach described in this section following was developed by the author in relation to design theories, particularly relating to design management: a complex issue encompassing individual human creative cognition; communication between stakeholders; designing enterprises, social and economic systems; interactions with business processes; decision making in situations of limited knowledge; cultural considerations; technical issues; and national policymaking. The usual application of system dynamics would be to model phenomena directly (see, for example, Belyazid, 2002; Forrester, 1998; Wolstenholme, 1990). In design, however, there are multiple bodies of contradictory theory and piecemeal research findings and the challenge is to create a coherent contiguous whole theory picture. The initial development of this approach was reported at the ANZSYS 2002 systems conference. Further development is waiting funding.

In this approach, the System Dynamics method was refocused so the System Dynamics (SD) model represents interactions between theories rather than between the characteristics of phenomena as in classic causal loop diagrams or stock-flow models. That is, the SD focus is redirected to *theories as phenomena*. In essence, the role of SD ‘technology’ of software and graphics as a complex ‘entity-relationship’ method of dynamically modeling situations was retargeted at design theory rather than design activity.

Using System Dynamics modeling in this new role required moving on from 2D representation, and led to the use of epistemologically interlinked layers of SD graphs separated and linked via epistemological criteria. This layered form was discovered to have additional benefits and aligned with the approach of Barros, Werner and Travassos (2002) that structured SD graphs through discipline domains.

The problem is to create a system that brings together all this existing knowledge rather than creating a new systemic model of all these phenomena and their relationships from scratch. The systemic approach, therefore, focused on building a *system of theories* that apply to the phenomena rather than on the *phenomena themselves*. This makes sense because epistemologically, there is topological congruity between an integrated system model of theories that individually describe phenomena, and a system representation of the phenomena: in the limit, as theories and systems are decomposed into elemental abstractions.

Some design management theories are intrinsically incommensurate but many do not fit together simply because of inconsistent definitions and conceptualizations. The epistemological process assumed here is that the mix of design theories can be converted to a single coherent theory frame by deconstructing core meanings of theories into primitive, elemental abstractions and relationships, and reconstituting them into a single coherent theoretical whole using a holistic systemic framework. This process is similar to computerised voice transcription in which sounds are turned into phoneme elements and remapped into an alternative conceptual modality (words, sentences and punctuation). This approach builds on the axiomatically-based meta-theoretical hierarchy for decomposing design theories into basic theoretical elements and relationships developed by the author for decomposing design theories and their relationships (Love, 2000; Love, 2001; Love, 2002). The System Dynamics modeling provides the basis for bringing together the decomposed theory elements into an epistemologically coherent whole. Figure 2 shows this process.

Incommensurate, inconsistent and incoherent design theories used in Design Management

↓

Apply meta-theoretical decomposition process

↓

Theories decomposed into elementary abstractions and relationships

↓

Apply SD method using elementary abstractions and relationships

↓

SD model of interactions between theories expressed in terms of above elementary abstractions and relationships

Figure 2: Decomposition and systemic recomposition

Epistemologically, such a systems model of a coherent holistic theory structure is a model of the phenomena themselves because it includes all the theory representations and relationships in a similar topological relationship as would be found in a theory model of the phenomena. Incommensurability between theories, however, is a stumbling block, and the problem is to find an appropriate representational graph. The usual 2-dimensional SD representation is problematic for three reasons (as found by Barros et al (2002)):

- A single picture (graph) is simply too big and complicated
- The problems with the lack of epistemological coherence become more significant
- It is not possible to use many of the classical validation checks that can be used on epistemologically consistent 'groups'

Separating decomposed theories onto different SD 'layers' offered a means of resolving this issue and echoes Newell's (1990) levels-based architectures for representing software, intelligence and cognition. It offers the opportunity of placing incommensurate theory elements on separate layers, but with links between the layers representing correspondences between incommensurate representations. Using layers offers the following benefits:

- Object count in individual SD graphs is reduced making the graphs easier to read and interpret in human terms
- Separation of information processes from physical processes. Most physical systems consist of at least two incommensurate subsystems: one comprising the physical resources and flows that result in the physical actualization of the end behaviour of the system, and the other comprising the information states, flows and transformations that guide the modification of states and flows in the physical system. These, in many systems, are highly interactive but are actualized differently.
- In models of cognition that take into account human affective experiencing can be

more easily represented through the use of multiple 'layers' because it helps conceptually separate the number of similar phenomena that are part of physically different subsystems. These include for example: emotion processes that are different from the feeling processes giving rise to emotions; the 'perception and feeling' processes that precede emotions; multiple parallel processes by which all of these latter processes interact with imagogenic 'thinking' processes; homeostatic processes underpinning sense of self and consciousness; embedded memories in the individual's bodily viscera, musculo-skeletal and fine touch systems, automated reactions at imagogenic and conceptual levels embedded in brain systems such as the basal ganglia, and the valuing and closure processes making use of other brain regions such as the amygdala and anterior cingulate cortices (see, for example, Damasio, 1994, 1999; Love, 2002; Sloman, 1998).

Layered System Dynamic graphs *also represent the phenomena* because the systems representations of theory structure also map structurally as graphs of real phenomena (designing

Incommensurate, inconsistent and incoherent design theories used in Design Management

↓

Apply meta-theoretical decomposition process

↓

Theories decomposed into elementary abstractions and relationships

↓

Apply SD method using elementary abstractions and relationships

↓

Layered SD model of interactions between theories expressed in terms of above elementary abstractions and relationships

↓

Transform layered SD model of theory into layered SD model of phenomena

↓

Layered SD model of physical phenomena

and associated activities). The whole process is outlined in Figure 3.

Figure 3: Transformation to a System Dynamic graph of phenomena

This process essentially depends on transformation of representations and in theory (!) there is no loss of information as theories are decomposed and recomposed. In fact, the increased ordering as a result of bringing the decomposed theory elements into a coherent whole would be expected to reduce informatic entropy. Theories brought together are not, however, bound to be deterministic or contiguous.

To summarize, unusually, this research approach applies layered Systems Dynamics graphs to *theories about phenomena* rather than the phenomena themselves. The approach has four benefits:

- Theories from different domains and addressing different topoi are located in an epistemologically coherent system theory frame
- The method draws on and integrates existing theory and research findings
- The method helps identify inconsistencies and conceptual weaknesses in existing theories and research findings
- The method helps identify valuable but previously unnoticed relationships between theories and findings that were either incommensurate or located in disparate and poorly connected disciplines.

To this point, the approach has been lightly tested across a small range of relatively idealized scenarios.

Motivational Information Systems

The term and concept of '*motivational information systems'* design was coined by the author to refer to information systems whose purpose includes motivation of individuals towards preferred behaviours (Love & Cooper, 2008). Others have referred to this similarly in terms of 'motivational affordances' of information systems (see, for example, Jung, Schneider, & Valacich, 2010).

A central consideration of management is the motivation of staff (Reeves, 2007; Rowley, 1996; Smith, 1999) and organisational information systems are utilised by management for motivational purposes in which the measures of performance are used to encourage improved performance.

Typically, management use the information and metrics gathered via information systems in a carrot and stick motivational manner to control, typically via other motivational information systems, individuals' access to resources (pay, promotion, power, perks etc). In general, information systems are used to provide distillations of such figures to management and employees and to relate these to access to resources or implementation of penalties to motivational pressures to increase performance and improve outputs. Deming (1986) has been highly critical of this approach.

What has been missing for designers of information systems is an understanding of the myriad of ways that these systems can be intentionally or accidentally co-opted by groups within an organisation to control the organization and/or direct benefits to themselves. Analysis of this aspect of the design of motivational information systems was undertaken as part of an ongoing investigating the application and extension of traditional systems tools such as Beer's, Viable Systems Model, Ashby's Laws of Requisite Variety, Checkland's Soft Systems, Critical Systems Analysis, System Dynamics and Causal Loop Diagrams on systems to which these tools are not commonly applied, either because the systems are peculiarly complex or because these classic systems tools have not been normally considered applicable.

The example below uses causal loop diagrams to reveal the influences of groups in the uses of motivational information systems within a university setting. The motivational information systems in focus had five overt purposes:

- Catalogue annual research outputs of individual academic staff, research groups, and faculty groups
- Compare annual research outputs for motivational purposes
- Distribute access to seed funding for research to persuade staff to increase research outputs and align the direction of their research activity with that chosen by university management
- Provide metrics to Australian Federal government departments for use in identifying how much funding will be given to the university the following year
- To provide reference measures of research output for other academic motivational, decision-making and resource allocation processes (e.g. promotion, distribution

funding to Faculties, hiring and firing programs, etc)

The motivational pressures from the information systems were to encourage staff to correspond with management wishes for increased outputs and to align their research with preferred research directions are applied by tying research outcomes data to access to research funding, and linking outcomes from the motivational information system to other university decision-making systems of interest to staff such as performance management, .promotion, priority in academic leave allocation, and personnel reshaping decisions (i.e. whether a staff member is likely to be made redundant).

The designed effects of motivational information systems are of course tightly linked to:

- What is counted
- How counted elements are relatively weighted
- How, and how much, access to resources and penalties are linked to what is counted and weighted (i.e. the scale and type of carrot and stick)
- Who controls the above decisions and how this is done

Using causal loop modeling of the influences and distribution of benefits shows the designer several feedback loops by which a particular group within the organization is able to influence the behaviour of the system to redirect funding and resources to themselves by influencing what is counted, the weighting attributed to what is counted, how that influences the distribution of benefits and how that can be used to increase power for a particular group whilst blocking entry to that group by others. . These effects are shown graphically in the causal loop diagram of Figure 4 below.

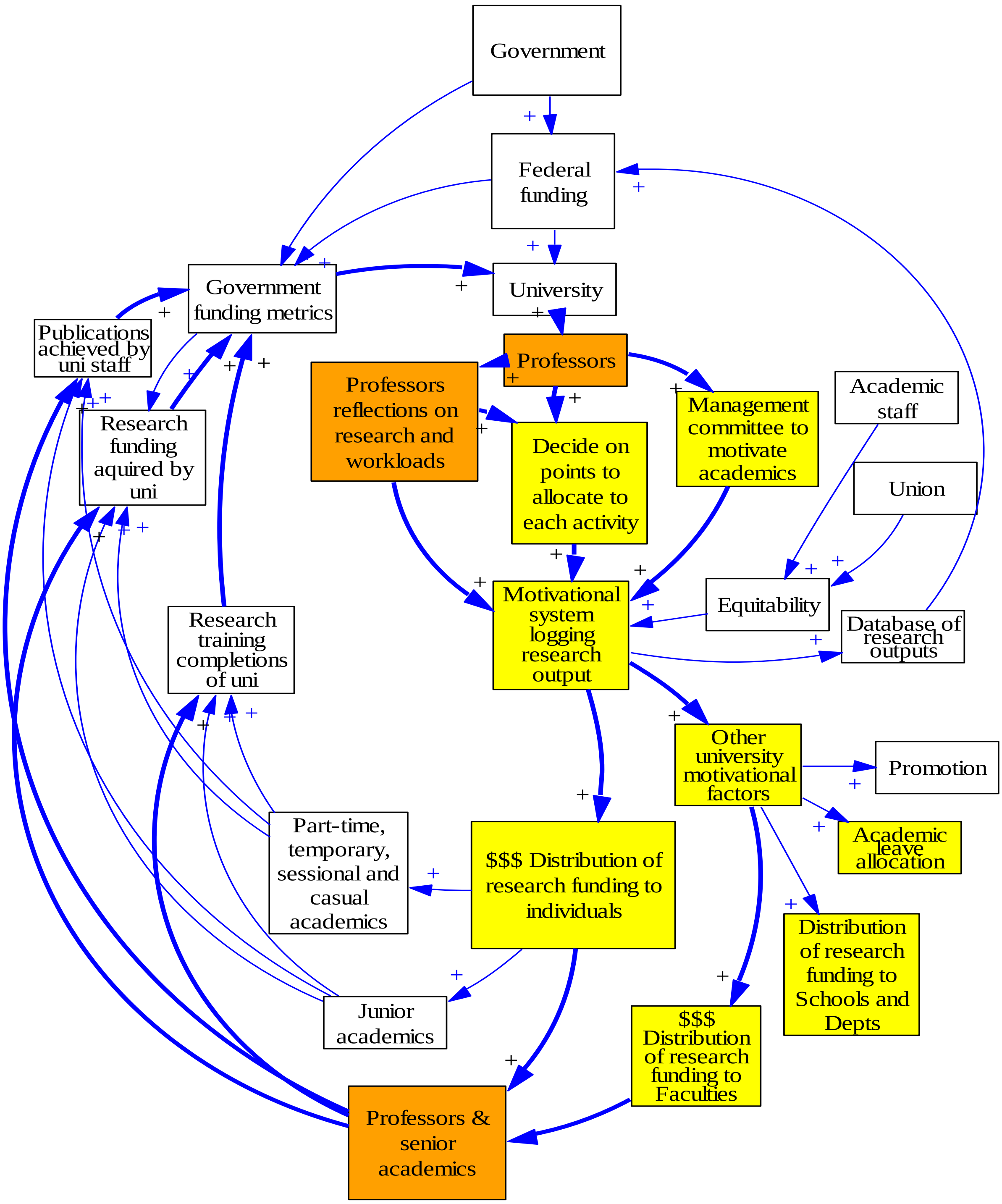


Figure 4: Causal loop model of motivational information system

Incidentally, this analysis also led to the development of a sixth extension to Ashby's Law of Requisite Variety that can be used as a design guideline:

In complex socio-technical systems in which the distribution of variety of individuals' tasks and authority are hierarchically layered

AND

individual and subgroup variety is assessed via information systems used for motivation

THEN

the motivational information system will tend to distribute value preferentially to individuals and groups higher in the hierarchy; act as a barrier to movement of individuals up the hierarchy; and increase the amount of control variety higher in the hierarchy.

(Love & Cooper, 2008)

The approach described in this section demonstrates the benefits of causal loop modeling for gaining insights into complex socio technical situations involving motivation and the design and use of information systems. . It reveals more generic understandings of the behaviour of motivational information systems in hierarchical organisational contexts. The sixth extension to Ashby's Law of Requisite Variety provides a design heuristic for the design of motivational information systems in organisaitonal contexts.

Summary and Conclusion

The article has described describes five 'new' design approaches developed by the authors that target design and design research at the intersect of systems and design.

- a simple six level taxonomy of complexity in systems as they relate to design activity
- , the 2 feedback loop hypothesis differentiating 'traditional' design from 'complex' design situations
- variety-based analysis and associated variety-based design heuristics]
- multi-layered systems dynamics graphs of design theory and phenomena
- The concept of Motivational Information Systems design and the use of causal loop

These new design approaches were described in terms of practical design scenarios to illustrate their role in new directions in design practice, research and theory.

References

Barros, M. d. O., Werner, C. M. L., & Travassos, G. H. (2002). Enhancing Meta-models with Scenarios: Plug-&-Simulate Extensions for Model Developers. In *The 20th International Conference of The System Dynamics Society July 28 - August 1, 2002 - Grand Hotel Villa Igiea, Palermo, Italy*. Palermo: The System Dynamics Society.

Belyazid, S. (2002). *Studying a Multi-dimensional Problem using System Dynamics The Case* *of Sustainability in the Semi-aridArgane Forest in Morocco*. Paper presented at the The 20th International Conference of The System Dynamics Society July 28 - August 1, 2002 - Grand Hotel Villa Igiea, Palermo, Italy, Palermo.

Damasio, A. (1994). Descartes' Error: Emotion, Reason and the Human Brain. New York: Grosset.

Damasio, A. (1999). *The Feeling of What Happens*. London: Random House.

Deming, W. E. (1986). *Out of the crisis*. Cambridge, Mass: Massachusetts Institute of Technology and Cambridge University Press.

Fernandez-Armesto, F. (2004). *So You Think You're Human?: A Brief History of Humankind*. Oxford: Oxford University Press.

Forrester, J. W. (1971). Counterintuitive Behavior of Social Systems. *Technology Review, 73*(3), 52-68.

Forrester, J. W. (1998). *Designing the Future*. Seville: Universidad de Sevilla.

Gilovich, T. (1993). How We Know What Isn't So: The Fallibility of Human Reason in Everyday Life. New York: The Free Press.

Jung, J., Schneider, C., & Valacich, J. (2010). Enhancing the Motivational Affordance of Information Systems: The Effects of Real-Time Performance Feedback and Goal Setting in Group Collaboration Environments. *Management Science, 56*(4), 724-742.

Klein, E. (1996). *Conversations with the Sphinx: Paradoxes in Physics* (D. Le Vay, Trans.). London: Souvenir Press.

Knight, J. (1999a). How stressful days steal your memories. *New Scientist*(26 June 1999), 6.

Knight, J. (1999b). Sex on the brain. *New Scientist*(26 June 1999), 17.

Labossiere, M. C. (1995). Fallacies. *Journal*. Retrieved from http://www.nizkor.org/features/fallacies/

Love, T. (2000). Philosophy of Design: a Meta-theoretical Structure for Design Theory. *Design Studies, 21*(3), 293-313.

Love, T. (2001). Concepts and Affects in Computational and Cognitive Models of Designing. In J. S. Gero & M. L. Maher (Eds.), *Computational and Cognitive Models of Creative Design* (pp. 3-23). Sydney: University of Sydney.

Love, T. (2002). Constructing a coherent cross-disciplinary body of theory about designing and designs: some philosophical issues. *Design Studies, 23*(3), 345-361.

Love, T. (2009a). Complicated and Complex Crime Prevention and the 2 Feedback Loop Law. In T. Cooper, P. Cozens, K. Dorst, P. Henry & T. Love (Eds.), *Proceedings of iDOC'09 'What's Up Doc' International Design Out Crime Conference*. Perth: Design Out Crime Research Centre.

Love, T. (2009b). *Counter-intuitive Design Thinking: Implications for Design Education, Research and Practice*. Paper presented at the Cumulus38 South Conference Hemispheric shifts across teaching, learning and research.

Love, T. (2010). *Can you feel it? Yes we can! Human Limitations in Design Theory (invited keynote)*. Paper presented at the CEPHAD 2010. from http://www.dkds.dk/media/forskning/cephad/konference/planary%20sessions/PS%20Love%20v3%20CEPHAD2010%20DKDS.pdf

Love, T., & Cooper, T. (2008). Motivational Information Systems: Case study of a University Research Productivity Index and 6th Extension to Ashby's Law In T. Love, C. Cooper & W. Hutchinson (Eds.), *ANZSYS'08: 14th International Conference* (pp. CDROM). Perth, WA: Edith Cowan University.

Mandel, T. (2000). History and Systems. *Journal*. Retrieved from http://www.newciv.org/ISSS_Primer/seminare.html

Meadows, D. (1999). *Leverage Points. Places to Intervene in a System*. Hartland, VT: The Sustainability Institute.

Newell, A. (1990). *Unified Theories of Cognition*. Cambridge, Mass.: Harvard University Press.

Schacter, D. L. (1999). The Seven Sins of Memory: Insights From Psychology and Cognitive Neuroscience. *American Psychologist, 54*(3), 182-203.

Shah, I. (1968). *The Way of the Sufi* (2nd ed.). England: Penguin Books Ltd.

Sloman, A. (1998). Damasio, Descartes, Alarms and Meta-management. In Proceedings Symposium on Cognitive Agents: Modeling Human Cognition, IEEE International Conference on Systems, Man, and Cybernetics. San Diego: Cybernetics.

Stroessner, S., & Heuer, L. B. (1996). Cognitive Bias in Procedural Justice: Formation and Implications of Illusory Correlations in Perceived Intergroup Fairness. *Journal of Personality & Social Psychology, 71*(4), 717-728.

Warren, N. T. (1976). Self-esteem and sources of cognitive bias in the evaluation of past performance. *Journal of Consulting & Clinical Psychology, 44*(6), 966-975.

Wolstenholme, E. F. (1990). *System Enquiry: A System Dynamics Approach*. Chichester: John Wiley & Sons.