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A CYBERNETIC PERSPECTIVE ON METHODS AND PROCESS MODELS IN COLLABORATIVE DESIGNING

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1. Introduction

Cybernetic thinking provides a framework to understand the issues in creating and using methods and process models during collaborative designing. It can help understand what takes place while the creation and use is unfolding. This viewpoint allows methods and process models to be framed as aiding human decision-making, and as supporting the organisation of design activities. It casts light on how a team acts and what are they doing to solve design problems, by considering that they react to changes in the perceived solution state or goal state. Cybernetics thus provides an articulation of mechanisms for doing design. By identifying virtues that support creation and use of methods and process models during designing, cybernetics could thus help teams to design more effectively.

This article considers the creation and use of process models and methods in design from a cybernetic perspective. We suggest that a process model and method are similar in nature, in that they both give guidance for progressing the design according to the circumstances encountered. Cybernetic principles are interpreted to help understand the role of modelling and method use in design process evolution.

The article builds upon ideas introduced by Wynn, Maier and Clarkson [2010]. In that paper, cybernetic principles were used to identify factors contributing to the utility of process modelling. The present paper focuses on two further questions to place these insights in the context of team designing:

- *In what sense may a team working on a design project be viewed as a cybernetic system?*
- *How can methods and process models influence the performance of the "designing system"?*

A viewpoint on these questions is explained, and illustrated through anecdotes of design practice.

2. Designing as a cybernetic system regulated by methods and process models

The term "cybernetics" is derived from the Greek word *kybernetes* meaning helmsman or cox, from which today's terms of governor, regulator, controller also originate. Cybernetics aims to provide a meta-language to describe different kinds of systems. It is concerned with understanding how systems are, or can be controlled through self-regulation in the presence of uncertainty, disturbance and changing objectives [Ashby, 1956]. In particular, the effects of communication, control and circularity on system behaviour are considered (e.g. [Wiener, 1948]; [Ashby, 1954]).

All cybernetic systems include a "control function" that ensures the system remains as close as possible to some desired state. If there is a discrepancy between the current and desired states, the behaviour of the system is influenced according to the values or wishes of the "controller" [Glanville, 1995]. These dynamic internal interactions enable a system to guide itself towards its desired state. Cybernetics gives greater emphasis to the functional, dynamic and teleonomic view of a system than to the physical, structural and topological view. Thus, cybernetic descriptions of systems focus on the different roles that must come together and exchange information to enable regulation and co-ordination towards given objectives [Andreasen et al., 1996], rather than on parts of the system and structural relations between them. Nevertheless these perspectives are complementary, because functions must be embodied in the real world. Information flow cannot occur between real-world system elements such as people unless a "physical channel" allowing information flow connects them.

Designing can be viewed as a cybernetic system, as suggested by Figure 1. Participants in the design process can be seen as "controllers". They "sense" the state of the process from the viewpoint of their own interactions within it. They develop and use methods and process models to guide their response to the perceived state, thus becoming "actuators" that influence the process according to their goals.

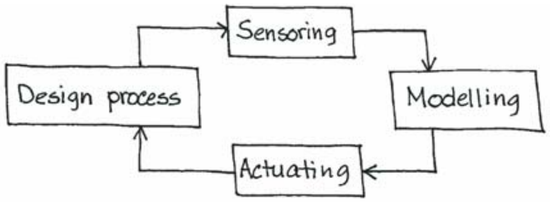

Figure 1. Control-oriented functions that design process participants perform

Using methods and process models to support design problem-solving can be described in this way irrespective of the life-cycle phase or particular problem at hand. To illustrate, Pahl and Beitz' model of the design process [Pahl and Beitz, 1996] may be chosen by a company, changed into a design procedure and instantiated for a specific project by "adding" time, activities, and resources. The model is "simulated" [Roozenburg and Eekels, 1995] by drawing consequences in that context. The insights might lead to a new plan, which would influence the unfolding process by changing the pattern of work and altering pressures on process participants. Similarly, when using a method, e.g. Quality Function Deployment (QFD), user demands in form of the voice of the customer feed into engineering characteristics for a desired product or service quality, judging whether a product is "fit for life". The team may reason about a new product's attributes and create a goal statement as a result.

Many kinds, or ways of looking at, process models exist (Table 1) and all of these can fulfil a regulatory role. For instance, regulation can be guided by formal "as-should-be" process models, mental models of the working steps required to solve a certain class of design problem, a designer's memory of past experiences, what they did and what happened, design rules that explain a next step that applies to certain design problems, and so on. Design methods like QFD provide structured, formalised and repeatable sub-sequences to help progress in certain problem situations given certain objectives. In this sense, a method may be viewed as a formalised kind of prescriptive process model.

Table 1. Some uses of the term "process model"

Type of model	Description	Example
Prescriptive	How it should be done	Design procedure (e.g. Stage-gate model), Project plan (e.g. Gantt chart)
Descriptive	How it is "actually" done	Description of exemplary design activity
Predictive	How it will be done	Process simulation model
Contingent	How it could be done	Design rules, principles, heuristics, mindset
Historical	How it was done	Lessons learned book

This paper thus takes a very inclusive view of the term "process model". The term "process" is used only to refer to a particular situation as it happened to unfold. Any description or conception of a process used to influence practice is viewed as a model in the cybernetic sense. A key point is that the model must not only represent a process, but also be "brought to life" by interpreting it in the context of a given situation and with respect to a goal, and the resulting insights must be used to take action. Another key point is that designing is not only a cybernetic system, but also a modelling system. A modelling system constructs and maintains models, as well as using them to regulate itself and its interactions with its environment.

The modelling processes in such a system may be characterised as incorporating all activities that form a part of developing models, including the development of the modellers' perception and imagination [Hubka and Eder, 1992: 101]. To “bring a model to life” requires that modellers interpret and incorporate aspects of the situation to be regulated into the model as they understand it. Interpreting a model to form an “actionable” mental model may be viewed as a form of modelling in itself.

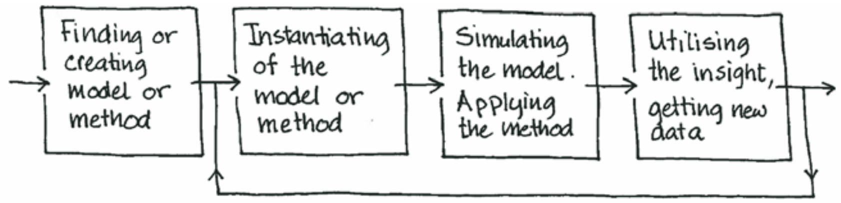

Figure 2. Similarities between model and method creation and application

To summarise, creating a process model or developing a design method can both be seen as acts of modelling, since they both involve identifying the salient features of the as-should-be and representing them in a form that can guide actions. Using a design process model involves some degree of modelling as the user reconsiders it and gains insight into its application in the context at hand. Likewise, applying a design method requires interpreting the steps according to the user’s understanding and experience, and their awareness of the design context. Thus, considering the sense in which a model or modelling process is important within a modelling system, can help understand how design process models and design methods are situated in, and enhance, the design process.

3. Using cybernetics to understand the utility of models and methods

In the DESIGN 2010 conference, cybernetic principles were used to derive eight “utility factors” that can guide design process modelling to ensure its usefulness [Wynn, Maier, Clarkson 2010]. The factors are summarised in Table 2. The following subsections explain and build on these issues, and suggest interpreting them as virtues of the design process and how it is performed.

Table 2. Eight factors influencing modelling’s utility to support designing as a cybernetic system

Factor	Influence
U1 Detection	The utility of modelling is limited by the ability of the modeler and the modelling team to detect deviations from the ideal behaviour.
U2 Knowledge	The utility of modelling is limited by the extent to which the modeler and the modelling team possess of knowledge about the system; i.e. the fidelity of the model.
U3 Actuation	The utility of modelling is limited by the ideality of the effector – the ability of the modeler and the modelling team to act out recommendations.
U4 Reflection	The utility of modelling is limited by the ability of the modeler and the modelling team to recognise when advice derived through modelling does not have the desired effect, to reflect upon the modelling to understand why, and to revise it accordingly.
U5 Alignment	The utility of modelling is limited by the ability of the modeler and the modelling team to align the objectives and success criteria for modelling with the higher-level objectives of the process or organisation, and to the objectives of other modellers.
U6 Perception	The utility of modelling is limited by the perceptual and conceptual filters of the modeler and modelling team, that determine what is available for inclusion in a model.
U7 Abstraction	The utility of modelling is limited by the ability of the modeler and the modelling team to choose which of the factors and phenomena perceived to impact upon the objectives should be considered, and what importance should be given to each.
U8 Responsiveness	The utility of modelling is limited by the delay between observation and action of the modeler and the modelling team, and by the responsiveness of reflection and learning.

3.1. Principles of requisite knowledge and requisite variety

Cybernetic principles pertaining to the effectiveness of a regulated system are the *principle of requisite knowledge* [Heylighen, 1992] and *the principle of requisite variety* [Asbhy, 1954]. The former states that effective regulation requires an accurate model of the effects of one's actions. In other words, on each observation-action loop an action is selected from the range of possibilities based on predictions of the action's outcome. Selecting an action that is exactly optimal would require that the cybernetic-model used to make these predictions has a level of complexity requisite to that of the system under regulation. Whereas requisite knowledge refers to the fidelity of the model, in this context requisite variety refers to the ability not only to select, but also to carry out an appropriate action, placing constraints on actuators as well as models. In a complex system such as the design process requisite knowledge and variety are not usually possible, since models are, by nature and intent, far simpler than the processes they represent. Thus, one might think of regulation as influence, rather than control. Consideration of these principles highlights three factors influencing modelling utility (U): Detection (U1), Knowledge (U2), and Actuation (U3). In overview, an effective modelling system must detect deviation from a desired state, must possess suitable models to decide what action to take to address the deviation, and must be able to implement those actions. Models and methods could then be seen to influence the factors/behavioural elements of cybernetic systems such as team designing. These factors are summarised in Table 2.

3.2. Principles of single-loop and double-loop learning

As modelling systems seek to adapt to an ever-changing environment they can be said to learn. Learning uses feedback about system performance to improve the model that governs response to stimuli. Argyris and Schön [1978] distinguish between single-loop and double-loop learning. Single-loop learning corresponds to changes to strategies and action in such a way that leaves the "values of a theory of action" unchanged. In terms of process operation and improvement, because a model is only a limited abstraction of a system, it requires updating when advice derived through that model, or through knowledge gained in the modelling process, does not cause the process to respond in the anticipated way. This updating of the model could be viewed as refinements in understanding of the results of a given action, and thereby to the way actions are selected in response to observations. In double-loop learning, a connection is made at a higher level between 1) the observed effect of actions; 2) the models that were used to guide action; and 3) the values and norms by which models are developed and selected. Consideration of these principles leads to the following factors influencing modelling utility: Reflection (U4) and Alignment (U5). In overview, an effective modelling system should reflect on the consequences of its actions, and should align the objectives of its modelling-parts to minimise conflicting actions. A related principle, Perception (U6), stipulates that decisions can only be made based on observations, yet observations are subject to interpretation and are thus inevitably distorted by the (mental) model used to interpret them.

3.3. Principles of parsimony

"A model is a map, not the territory". While being a limitation of models which can affect their utility, as mentioned in Section 3.1, this is also an important and unavoidable aspect of modelling – taking away or abstracting the complexity of a real system to highlight certain factors which are most pertinent to decision-making according to the system's objectives. In the context of mathematical or simulation modelling, for instance, it is necessary to determine a small set of assumptions and variables in order to render analysis tractable. Finding an appropriate way to do this is often not obvious when a modeller is faced by complex, ambiguous situations such as human-centric processes. Consideration of this principles leads to the factor Abstraction (U7) shown in Table 2.

3.4. Principles of homeostasis

The ability of a system to preserve stability of response under changing conditions is often referred to as homeostasis. Stability in the face of disturbance and changing objectives is not only important to system performance, but also to other factors which influence the utility of modelling. In particular, enhanced stability may assist learning by making it easier to identify whether modelling interventions actually result in improved performance. This is especially important when the system and its environment are continuously changing and when many models are in operation concurrently. Consideration of this principles leads to the factor Responsiveness (U8) as summarised in Table 2.

4. Application of cybernetic principles to designing: A process episode

The cybernetic perspective outlined above can be used to analyse the collaborative process of constructing and using methods and process models to operate or improve a design process. This section presents a hypothetical account illustrating how a cybernetic lens might be adopted to describe a real situation and what insights could be gained. The account is based on challenges and situations that can occur during design of a complex system, such as a car or an aircraft.

The overall objective of the design process is to achieve the common high-level goal of creating the design, within constraints of high quality, low cost, low product development time, and so forth. The situation is depicted in Figure 3. This shows how the design team, designers/modellers, and models are embedded together in the cybernetic system that is collaborative design or designing. An ecology of process models and methods exists in this system, and they are available for use to regulate the processes that occur as the design emerges. As particular problems are encountered (expectedly or unexpectedly), processes are initiated to solve them, and different models and methods may be used to regulate those processes towards their goal – and hopefully thus the whole system towards its overall goal. The process participants and models themselves act as carriers of the cybernetic properties discussed earlier; for instance, an individual's position in the organisation will influence their actuation possibilities, and thus limit the utility of any modelling system in which they participate.

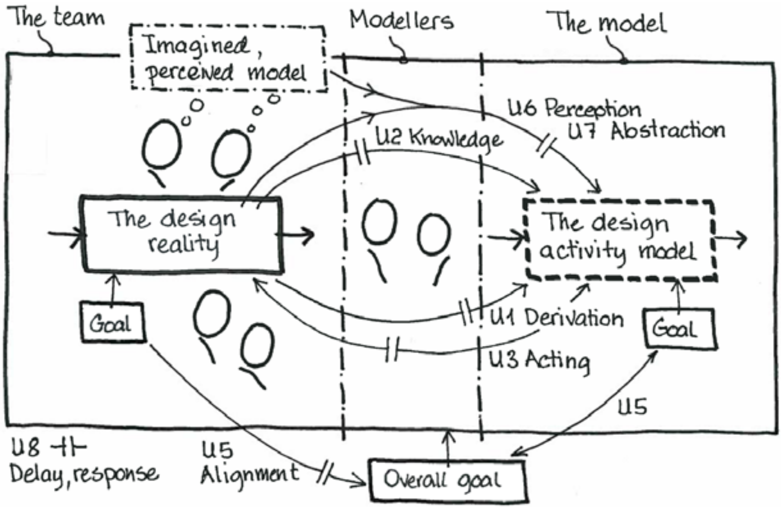

Figure 3. Cybernetic principles in the context of collaborative designing

One situation that requires regulation is that design process participants must work according to an often-implicit network of relationships between goals and sub-goals, and proposed ways of meeting them. For instance, one goal might be to "identify the design constraints". This might be followed by "identify a system breakdown", and eventually by "design a subsystem with certain performance characteristics within certain design constraints". Other goals relate to the design process itself, i.e., "complete the aforementioned task within a certain timeframe". Yet others might relate to the company environment, such as "make effective use of a product platform". In one sense, regulation could be viewed as a process of reaching agreement on these goals, monitoring progress, and taking corrective actions when monitoring reveals it is necessary. Corrective actions might include changing the goals or the plan for addressing them. In either case this would likely involve conversations and negotiations among the process participants.

To clarify the role of process models and methods in this regulatory activity, it can be helpful to imagine them providing a "theory of action" that the process participant uses to guide their actions in response to certain stimuli [Argyris and Schön, 1978]. For example, a designer may interact with the design itself and, through an analysis activity realising it does not meet their performance objectives, take an action to alter it. This situation might be interpreted cybernetically as “sensing” information about the shortcoming via the analysis activity, interpreting this newly-gained information through a model taking the form of mental rules of thumb. These allow an appropriate design action to be chosen to “regulate” the emerging design with respect to the particular objective. The rules of thumb themselves are liable to change, as they probably only hold within a given context. Over time, the rules, or interpretation thereof, will gradually evolve as the designer learns how to make them more effective through repeated application to a range of problems. Approaches that prove successful will be detailed and passed verbally to colleagues or perhaps codified to form the basis of a design method. Regardless of success, the whole approach might need to change if it is no longer suitable to an altered context. For instance, a new material or design tool might mean that established ways of doing things are no longer valid. Reducing weight may become less important than increasing life-cycle cost.

To give another example, a designer within this process may realise that their current problem is too complex to be solved within the time they had promised. In which case, they could initiate a conversation with their colleagues. Together, they might consult a model of the process (such as a Gantt chart) to determine what action should be taken, such that the design might still be completed in time. In this case actions might include adding more resource, or re-negotiating the unachievable goal.

5. Discussion

5.1. Issues surrounding the responsive and emergent nature of design processes

Herbert Simon writes that the sciences of the artificial – in contrast to sciences of the natural – are *“concerned not with the necessary but with the contingent – not with how things are but with how they might be – in short, with design.”* [Simon, 1996: xii]. His thesis is that “*certain phenomena are “artificial” in a very specific sense: they are as they are only because of a system′s being moulded, by goals or purposes, to the environment in which it lives. If natural phenomena have an air of “necessity” about them in their subservience to natural law, artificial phenomena have an air of “contingency” in their malleability by environment.*” [Simon, 1996: xi]. This highlights two relevant issues in the context of modelling:

Firstly, a model is a representation and abstraction of ‘reality’. A model is executed in order to gain knowledge about actions that are possibly required today in order to guarantee or even generate a satisfactory future [Simon, 1996: 143]. Yet, if design itself is concerned with how things might be and only the future will show how they ‘turn out’, then a model is used to simulate how things that might be might be. By working with constraints and trying to adapt to the environment, modelling could then perhaps be seen as working towards creating the future by adaptation.

Secondly, a design process is not concerned with simply processing information relative to a fixed goal, or a goal that varies along fixed dimensions. Rather, design is about doing something new, or at least on some level in a new way. The design process creates structures of understanding that in turn refine or even redefine the design objectives themselves. The design process thus redirects itself in unforeseeable ways even whilst regulating itself. It is not only goal-directed, but also goal-directing and even goal-defining. Each step in the design process, as it unfolds, *creates* possible options for progression while closing off others. Because of this, both single- and double-loop learning must take place in ‘real time’ alongside the process operation. The constant change created contributes to difficulty in handling many of the issues implied by Table 2.

Recall that to be useful in guiding a process, a system of models and methods must exhibit variety requisite to that of the process. This principle suggests that, because of the dynamic and emerging nature of designing, a method or process model should not be too detailed and prescriptive, because it could then only provide guidance for very specific situations. It is important, perhaps even necessary, that models be open for many interpretations and that a collage of perspectives and alternatives exists, in the individual and collectively. Many models, and possible interpretations thereof, allow selection of guidance based on apparent best fit of each model to the ambiguous information available at each point in time [Pask, 1975]. Pask explains how new methods may be dynamically synthesised to encompass the existing ones, if the situation provides insufficient information to choose between them. The population of methods and models and interpretations they afford are continuously refined, developed, and discarded as knowledge is created and accumulated regarding the design context, and as particular models prove to be useful, or not, within that context. The variety of interpretation allows the emerging complexity to be managed. It may be suggested that experience with new objectives, constraints, options, and their effects, leads design process participants to develop more sophisticated models and methods as they try to encompass the overall complexity that has been encountered. For instance, a novice designer might be hypothesised to possess simple ‘if in this situation, do this’-type rules that they learned from a textbook, which are gradually enhanced and form the basis of structured experiences relating to more-generally-applicable issues, interactions and effects.

5.2. Methods and process models to support designing as a cybernetic system

The ideas presented above can provide a viewpoint on the questions: *In what way shall we understand team work?* And, *How can teams be supported to design effectively?*

Methods and process models help to direct what a team is doing by articulating possible behaviours and possible interactions with its environment. Cybernetic thinking helps to explain why well-planned co-ordination is not sufficient to solve design problems effectively; it is also necessary to react to context changes, which are inevitable due to the knowledge-creating nature of designing. The (mental) models used to guide reactions to change have a key role in determining a design team’s performance. In turn, these mental models are based on the population of methods and process models that the team can draw upon. The eight dimensions in Table 2 indicate attractive behavioural characteristics of cybernetic systems which we suggest should be sought by teams. These characteristics can be enhanced by ensuring that methods and process models used by those teams have suitable properties, as indicated in the table.

5.3. Suggestions towards concrete interpretation

Like many aspects of systems thinking, the ideas outlined in this paper can provide a useful, although rather abstract viewpoint on the design process. However, it is important not only to theorise and describe, but also to interpret the generic insights to provide useful guidance for practice. Table 2 summarises our initial thoughts in this regard, although further work is needed.

Because of its functional perspective, the cybernetic view of designing and these resulting insights can be mapped onto observed issues from many perspectives and many levels of abstraction. A suggested starting point for more concrete analysis is the role of the individual process participant in process regulation. The participant can be clearly demarcated- unlike other process subsystems such as groups, objectives, and activities. Each participant can influence and observe their working environment through direct action, or through communication. They can use these channels to regulate that environment according to their own goals, which hopefully are aligned to those of their co-workers. The goals themselves are formulated dynamically by the individual according to what comes through the information channel, i.e., through communication with co-workers.

6. Conclusions

The use of methods and process modelling is ubiquitious in engineering design, computer supported collaborative work, business process management, and many other domains. Modelling is an integral aspect of the design process and many methodologies have been developed to advise on how to perform such activities and ensure, for example, correspondence between the model and actual work practices. This article has outlined some thoughts regarding implications of a cybernetic lens on modelling in design. It shows how cybernetics could provide a theoretical base for analysing a team´s modelling activity in design. As Dong (2004) suggests, central to such a view is the consideration of a range of possible behaviours that a participant in a system may produce. It could help make designers and managers more aware of their role in creating models, and in understanding how those models can go on to influence others and the outcome of the design process. Finally, the factors in Table 2 could assist researchers and practitioners working on development of methods and processes. This might not change current ideas of what constitutes good modelling practice, but it could help understand and communicate why this might be good modelling practice.

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