INTERNATIONAL DESIGN CONFERENCE - DESIGN 2002
Dubrovnik, May 14 - 17, 2002.

ASPECTS TO THE COORDINATION OF COLLABORATIVE DESIGN

Michael Cumming

Keywords: design coordination, design process modelling, collaborative design

1. Introduction

This research addresses a type of process support for designers working in collaborative design situations. Such support would help designers to coordinate their work, but in a decentralized fashion. One type of design coordination is achieved when design collaborators communicate their commitments for action to one another and either perform these commitments, or revise them in some socially acceptable manner. An asynchronous design support groupware application is briefly described, that enables such a process to occur.

Collaborative design can be a complex activity. It depends on the successful interaction of many different parties, sometimes with profoundly different perspectives on the design process, and design product. Often the expertise that experts possess is very difficult to describe or formulate, such that it might be transferable to others. In collaborative design support, one goal could be to support expert designers so they can do their best work without undue constraints on their problem-solving and creative skills.

This research addresses the issue of how to provide non-prescriptive process support for designers, suitable for non-routine, collaborative design situations. In such situations, the knowledge regarding suitable design processes may not be immediately available to the design participants. Such situations tend to be unpredictable and require interactive negotiation between design stakeholders, to work out and construct appropriate processes. In other words, the focus is how to help designers figure out what to do during design, when they don't have a clear idea what to do, through perhaps no fault of their own. This is seen as a common situation, rather than an aberrant one, in collaborative design.

Lack of design knowledge can be caused by many factors, both avoidable and unavoidable. It can be the result of designers with insufficient experience, education, or access to useful techniques. It could be because a design problem presents unusual new challenges to the design team.

It could also be that a designer or a design team decides to approach a design problem in a new way, and attempts to devise innovative solutions to existing problems. In such cases a desire for innovation may not be derived simply from a given set of design requirements, but may arise from within designers, and design teams. In such cases of 'discretionary' design innovation, pursuit of innovation can become a socially constructed goal. For example, the core design requirements involved in chair design remain relatively static. This does not mean that furniture designers have abandoned attempts to produce interesting new chair prototypes. On the contrary, chair design continues to be viewed as an important venue for design exploration.

The focus is on providing support for individual designers, yet considers the normal working context for a designer to be the collaborative design team. Without employment of such teams, despite the management burdens they entail, it is inconceivable that adequate solutions to complex, multi-dimensional design problems can be found.

Design teams are seen as a type of social group composed of designers, in which the behaviour of the aggregate, that is the design team, is an emergent effect derived from the behaviours of many interacting individuals. Design teams are not seen as static entities with fixed lists of members, but as dynamic social groupings in which members can come and go freely, without necessarily jeopardizing the functioning of the team.
The main idea behind this research is that regardless of the type or content of particular design processes, designers, working in collaborative design situations must coordinate what they intend to do individually, with what their design collaborators intend to do. Such a social coordination activity involves communication and commitment.

2. Background

2.1 Models of collaborative design

Collaborative design can be viewed both from a top-down, and bottom-up perspective. The top-down approach focuses on global design issues such as how well a completed artefact fulfils its primary design requirements. The bottom-up approach focuses on interactions between low-level entities such as individual design requirements, processes, or designers. In both perspectives, what constitutes the 'top' or 'bottom' requires definition by an interested observer.

2.2 A bottom-up perspective

From a bottom-up perspective, collaborative design can be modelled as a complex system. Complex systems research addresses at a fundamental level, the behaviours of interdependent entities. Complex systems typically have no central controller, and the global behaviours they exhibit, emerge as a result of local concurrent actions (Klein et al., 2001). Biological systems, such as ecosystems and organisms, are perhaps the most commonly presented examples of complex systems (Resnick, 1994). Concepts from complex system theory can also be applied to social systems, in which individuals forming social groups are seen as interdependent entities (Axelrod, 1997). Complex systems can be inorganic in nature as well.
According to Klein (2001), designers, as well as design issues, can be modelled as 'nodes' in dependency networks. In such a view, completing a collaborative design process, involves designers attempting to maximize the value of a [hypothetical] global utility function. This usually takes place in the context of extremely large design spaces. One difficulty in collaborative design is knowing what the global utility of a proposed design might be, prior to actually building a completed artefact. Even with a completed artefact, interpretations regarding the global utility of a design can vary.
Klein notes that the problem with collaborative design in general, is that the networks that most realistically model how collaborative design is done in practice, and ought to be done in practice, are also the ones that display the most complicated behaviours.
Dependency networks can have a variety of dynamics including non-linear, asymmetric, and non-convergent. Linear networks are those with single attractors. This situation is helpful in a collaborative design process, since it means, despite complex interdependencies and interactions between nodes, design solutions converge to a single point. This point corresponds to a global optimum. Klein notes that only routine design processes have been successfully modelled as linear networks.
Networks that exhibit non-linear network dynamics complicate the situation considerably, in that their utility function can have many peaks instead of single ones. These peaks represent local optima. Since local optima are often surrounded by valleys, search for global optima is made much more difficult. This applies to both software-supported design processes, as well as manual ones.
In collaborative design, this situation means that incremental improvements to a given design configuration, such as product models as they currently appear, may improve the designs, but will not necessarily lead to global optima. To discover global optima, design teams may need to consider radically different configurations of design components. This is often an expensive and risky proposition. The history of product development often shows such dramatic re-configurations, in addition to incremental improvement of existing configurations (Bijker, 1995).
The prevalence of non-linear interactions, in distributed systems, is noted by Hogg (1998). He notes

that such systems can display a wide range of behaviours including stable equilibria, continual oscillations and chaos. Chaos is considered a destructive aspect of distributed systems in that it introduces global unpredictability into the system. Hogg proposes that simple reward mechanisms, based on the assessed performance of software-based agents, can help eliminate such chaos.

Within the Distributed Artificial Intelligence (DAI) community, the strategy of distributing control, data, as well as knowledge sources, is now widely supported (Whitfield et al., 2000). Such an approach has been shown to have several advantages, including the reduction of performance bottlenecks, the increase in reliability, and the soft, rather than steep or complete degradation of performance, when systems are under stress.

Distributing control and data can also have disadvantages according to Jennings, in that 1) each agent only has a partial and imprecise perspective, 2) there is increased uncertainty about each agent's actions, 3) it is more difficult to attain global behaviour, and 4) the dynamics of such systems become extremely complex.

However, distributed control when placed in a design context is not a concept that may not have much intuitive appeal to designers. Designers are usually trained to view their primary job description as *controllers of design processes*. An argument to counter such a position is that complex collaborative design processes can indeed be centrally controlled. However, once design projects get to a certain degree of complexity, central control, while at the same time attempts to discover new design global optima, introduces so many difficulties into the collaborative process that it becomes counter-productive.

2.3 A top-down perspective

Collaborative design also has important top-down aspects that can structure both product and process. Top-down, or centralized process control can be derived from many factors, including *Social*: a strong personality or common culture that drives teams to perform in a certain way; *Technical*: a focused expertise that has a strong effect on the design direction; *Organizational*: when the hierarchy in certain organizations is reflected in the structure of a design product or process; *Financial*: when the money flows from centrally controlled sources; *Contractual*: when parties agree in a legally binding manner to submit to some central authority; *Consensual*: make parties commit themselves to a agreed course of action.

From a product perspective, certain global aspects of a design product are normally required to facilitate management of collaborative design, such as the total cost, or the quantities of materials used in a proposed product model.

The trend towards integrated product models must also be noted. Since it is usually a single unified artefact that is the intended result of a collaborative design process, it seems to make sense to attempt to make unified design product representations from the beginning stages of design. Unified product models in which all the design description information resides in one location, can be, for instance, very convenient when checking for completeness and consistency (Flemming and Woodbury, 1995).

However, centralized process control and product representation do have their limits. As Klein (1998) notes, centralized control requires that a single person or software system have some deep understanding of the entire design. This is not so difficult for small projects, but becomes impractical for large ones, with their large dependency networks. It is especially difficult for projects that require inputs from multi-disciplinary teams who often speak different 'languages'. This means that centralized control not only involves issues of excessive memory, processing and bandwidth loads, but also means that a centrally controlling party must be 'multi-lingual' as well.

In theory then, centralized control becomes impractical once design projects attain a certain size and complexity. If centralized control is impractical in certain situations, which may not be that uncommon, then forms of distributed, localized control becomes necessary.

2.4 Coordination science

Coordination science is a new discipline that has been developed to help explain and manage complex collaborative situations, which tend to overwhelm existing process management theory and technique. See (Whitfield et al., 2000), (Klein, 1998), and (Malone and Crowston, 1992) for excellent overviews.

Coordination of action is required, according to Klein (1998), when distributed activities, such as those found in collaborative design, are interdependent.
A good, concise definition of coordination is that provided in (Malone and Crowston, 1992) ‘the act of working together harmoniously’. Malone and Crowston also provide a list of technical definitions others have proposed for the term. A useful discussion is provided by Jennings regarding the three main reasons why the actions of multiple agents need to be coordinated (Jennings, 1996). 1) Because there are dependencies between agents’ actions, 2) because there is a need to meet global constraints, and 3) because no one individual has sufficient competence, resources, or information to solve the entire problem.
According to Klein (1998), the most fundamental aspect of support for coordination comes through communication. That is, it is inconceivable that in whatever design coordination regime, whether software-based or otherwise, that agents will be able to coordinate their work without actually communicating with one another. In hierarchical control situations, this communication may be indirect, through, for example, an agent’s manager or controller, while in distributed cases, it occurs directly between agents.
Jennings proposes that coordination is built upon four main structures: commitments, conventions, social conventions, and local reasoning capabilities. If an agent commits itself to perform a particular action, then, provided that circumstances do not change, it will endeavour to honour that pledge (Jennings, 1996). Non-performance of a commitment, made in a social setting, can entail social costs, which people sometimes go to extraordinary lengths to avoid.
However, commitments are not irrevocable, since the circumstances that inspired them in the first often change. The longer the time between making a commitment, and the time that action is required, increases the likelihood that the commitment may need revision. From a distributed systems perspective, commitment by agents to a course of action adds a degree of certainty, to future events. This is an important consideration in such systems since due to their distributed nature, they experience a great deal of uncertainty. Jennings offers a hypothesis that has the potential of providing a great deal of structure and order within the domain of collaborative design.
Centrality of Commitments and Conventions Hypothesis: 1) All coordination mechanisms can ultimately reduced to commitments and their associated (social) conventions, 2) commitments are viewed as pledges to undertake a specified course of action, and 3) conventions provide a means of monitoring commitments in changing circumstances [Jennings, 1996].

3. Design of an application

The intention behind this research is not just to create theory, but also to construct a software prototype that demonstrates ideas regarding distributed process coordination and emergence. This application is currently in implementation.

3.1 Application goals

1. *Help individual designers coordinate their work with their design peers, through the distributed communication of commitments*

Coordination and communication of commitment, is seen as a general feature of collaborative activity that can be applied to many knowledge domains.

2. *Do not increase the cognitive or social burdens on designers, when attempting to support them*

The tool should not increase the cognitive or social burdens on designers. This involves keeping the tool simple and the cognitive and time demands on users low.

3. *Do not require a group consensus before proceeding*

This tool does not first require a costly consensus or standardization effort on the part of designers or managers, before it can be used. If it is adopted by designers, in a bottom-up fashion, this will be because individual designers find it useful in their practice.

3.2 Application features

The application uses simple message-based peer-to-peer communication, in which all network components start off being the same. Individual nodes on the network serve both as clients - consumers of information, and servers - producers of information. Nodes on the network represent one designer, or other participant in a design process. Use of the application is open to anyone, but most likely will be participants working together on a design project. Whom users can send messages to is not prescribed. Users can also send messages to themselves. Design teams or other social groups, therefore, are emergent entities, from the application's perspective.

The application contains no specific process content itself, rather it supports the coordination of content that users add to it. Knowledge acquisition involves a distributed, user-constructed, 'bootstrapped' process.

Two types of messages are communicated: 1) process model content, represented as Petri nets, and 2) process model state, represented as Petri net markings. Process content, which users must add, is equivalent to a simple 'to-do' list. The to-do list is viewed as one of the simplest, yet most effective process models. Despite their simplicity, they can be very useful, especially if their content is known to be relevant, and appropriate to a current situation. Such a process representation can contain information that must be defined by an author, as well as information that could emerge, or be derived by the system.

The information that requires explicit definition by a user is *tasks* to be completed. These can be combined into 'to-do' lists. Each task has three main attributes: 1) a description of the task, 2) the party, or parties expected to complete the task - in the opinion of the person sending the message, and 3) the time frame in which the task is expected to be completed.

The process content is represented as Petri nets, communicated in a lightweight fashion using Petri net/XML technologies. Petri nets are a well known process representation with several compelling advantages: 1) A clear graphical representation, 2) the ability to handle both state and task process information equally well, 3) a syntax and semantics based on a small number of simple ideas, 4) the ability to execute models dynamically, and 5) the ability to model true concurrency correctly (Jensen, 1996). Such advantages make them particularly well suited to the modelling, for instance, of distributed algorithms.

4. Conclusion

Collaborative design projects can be modelled as complex networks of interacting agents. These networks tend not to have simple linear dependencies. This means that radically new product configurations may be required to maximize the global utility for a given set of design requirements. Attempting to maximize global utility is seen as an essential, if challenging goal for collaborative design processes. Construction of product prototypes is often necessary to establish if new configurations do in fact have preferable global utilities. This is often prohibitively expensive.

Complex design projects tend to have requirements that are difficult or impossible for centralized controllers to adequately manage. This is due to such problems as limits on memory, processing capacity, and communication bandwidth. It is also caused by the difficulty in comprehending and translating specialized domain concepts between disciplines.

If centralized control is not adequate then distributed control becomes necessary in collaborative design. Distributed control in design is not an intuitive concept since design is usually thought of as a centrally controlled activity. Centralized control in design normally comes either through hierarchical control, or through group consensus, both of which suffer from the problems mentioned above.

Coordination is necessary to manage all types of processes in which interdependencies exist. This applies to all design domains. Communication of commitment in a social setting is one important way to coordinate distributed activity. A simple way of doing, using a distributed groupware application is described.

References

Axelrod, R. "The Complexity of Cooperation: Agent-Based Models of Competition and Collaboration". Princeton, NJ: Princeton University Press, 1997.

Bijker, W. "Of bicycles, bakelites, and bulbs: toward a theory of sociotechnical change". Cambridge, MA: The MIT Press, 1995.

Flemming, U., and R. Woodbury. "Software Environment to Support Early Phases in Building Design (SEED): Overview". Journal of Architectural Engineering. Vol.1. No.4.1995 pp.147-152.

Hogg, T. "Controlling Chaos in Distributed Computational Systems". IEEE Transactions on Systems, Man, and Cybernetics. 1.1998 pp.632-637.

Jennings, N. R. "Coordination techniques for distributed artificial intelligence". In G. O'Hare & N. R. Jennings Eds. Foundations of Distributed Artificial Intelligence. pp.187-210. New York, NY: John Wiley & Sons, 1996.

Jensen, K. "Coloured Petri Nets: Basic Concepts." 2nd ed. Vol. 1. Berlin: Springer Verlag, 1996.

Klein, M. "Coordination Science: Challenges and Directions". In W. Conen & G. Neumann Eds. Coordination Technology for Collaborative Applications. pp.161-176. Berlin: Springer Verlag, 1998.

Klein, M., H. Sayama, P. Faratin, and Y. Bar-Yam. "What Complex Systems Research Can Teach Us About Collaborative Design". Proceedings of International Workshop on CSCW in Design. London, Ontario, Canada., 2001.

Malone, T., and K. Crowston. "What is Coordination Theory and How Can It Help Design Cooperative Work Systems?". In D. Marca & G. Bock Eds. Groupware: Software for Computer-Supported Cooperative Work. Los Alamitos, CA: IEEE Computer Society Press, 1992.

Resnick, M. "Turtles, Termites, and Traffic Jams: Explorations in massively parallel microworlds". Cambridge, MA: The MIT Press, 1994.

Whitfield, R. I., G. Coates, A. Duffy, and B. Hills. "Coordination Approaches and Systems - Part I: A Strategic Perspective". Research in Engineering Design. 12.2000 pp.48-60.

Michael Cumming, Architect, and Researcher
Delft University of Technology, Department of Architecture
Berlageweg, 1, 2628 CR Delft, The Netherlands
Telephone: +31.15.278.8677
Telefax: +31.15.278.4127
Email: m.cumming@bk.tudelft.nl