Process support for collaborative design

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1 Introduction

Collaborative design, i.e., design involving the participation of multiple specialists, is an inherently complex activity. It can benefit greatly from computer-based *process support* in which the emphasis is on addressing the generic needs of decision-making processes [Rag91]. Process support as defined in [Rag91] includes: supporting the planning, organization, and execution of complex and inter-related tasks that constitute decision-making including communication and conflict resolution; supporting flexible process sequences during decision-making; and maintaining details about intermediate decisions and their inter-relationships.

Process support entails *strategic knowledge*, i.e., meta-level knowledge used to decide what design action to perform next [Gau93]. A design action may involve, for example: determining design focus; refining a design decision or objective; evaluating a design alternative; selecting a design alternative; or resolving interactions among design objectives [GFG91]. A design action can have conflicting goals, complex dependencies, consequences that cannot be known completely, and resource limitations. Strategic knowledge is needed for directing the design process under such circumstances.

In this abstract we overview several efforts that address process support and strategic knowledge in collaborative design. We then identify some areas where process support is needed in biomedical engineering. We conclude with a brief discussion of one of our research directions in progress.

2 Approaches to Process Support

Process support aids the management of design activities including the organization of design tasks, and the interactions among design specialists including communication and conflict resolution. Approaches to process support include using good strategies in planning and controlling the collaborative design process, and deriving good strategies for collaboration based on past experience.

Levitt et al. [LJD91] identify the meta-knowledge used by expert designers and design managers in managing concurrent, multidisciplinary design including knowledge to: "partition the design task for efficient execution by specialists; set appropriate levels of design conservatism for key subsystem specifications; evaluate, limit and selectively communicate design changes across discipline boundaries; and control the sequence and timing of the key (highly constrained and constraining) design decisions for a given type of artifact." Such meta-knowledge forms the basis of process support.

Researchers at the Massachusetts Institute of Technology define *cooperative-design process planning* [KEW91] as a method of developing a strategy for carrying out a design process by analyzing the structure of the design problem, i.e., the dependencies between its tasks and the nature of those dependencies. The goal is to "better organize the design tasks and improve coordination among designers" [Epp90]. Tasks can range from the parameter level, e.g. *rotor width*, to the procedure level, e.g. *distribute drawings*. A strategy is modeled in terms of design tasks with information connections that allow them to be executed sequentially, iteratively, or in parallel. Numerical measures of task interdependence help determine the effectiveness of a particular strategy. The use of precedence matrices for analysis aids in: sequencing tasks, initializing iterative tasks, decoupling tasks for performance, and coupling tasks for feedback.

Agent interactions during the collaborative design process include the communication of goals and plans, and the resolution of competing objectives. Local strategies can be planned for supporting such interactions. For example, Lander et al. [LLC89] have identified sources of conflict in cooperative problem solving including resource competition, incomplete knowledge, incompatible goals, and different perspectives. They suggest the use of protocols for the resolution process and heuristics for strategy selection.

Local strategies can be acquired for agent interactions. For example, based on a case study of the cooperative design process, Klein and Lu [KL89] have formulated a computational model of conflict resolution suitable for use in a cooperative human and machine-based system. In such a system, a conflict occurs when two incompatible design commitments have been made or when a design agent has a negative evaluation of another agent's actions. Their model consists of a hierarchy of conflicts and corresponding domain-dependent and domain-independent strategies which prescribe design actions to be taken to resolve a conflict or anticipated conflict. The strategies encode conflict resolution expertise and use techniques involving, for example: abandoning a goal involved in a conflict; trying an alternate way of satisfying a goal; detailing a design to remove the conflict; and compromising by partially satisfying goals. The authors discuss the importance of representing design rationale for supporting the conflict resolution process. Such a representation captures plans and design dependencies.

More global strategies can be acquired by using retrospective analysis [WW88]. This method analyses a design process to identify major decision points and their time sequence, and the knowledge used in those decisions. One opportunity for acquiring strategy is the design review. By observing participant interactions, the design review may also suggest strategies which might be useful in the efficient and productive exchange of information among design participants.

3 An Example from Biomedical Engineering Design

Biomedical engineering design is a complex process. The need to interface to a living system provides an element of uncertainty in biomedical design which is not present in traditional engineering design fields. The nature of the uses of the products of the biomedical device industry has led to a uniquely complex set of regulatory requirements which constrain the design process throughout its course. Further, the major decisions in the design process are made and updated based on integrating uncertain information obtained from a team consisting of members from very diverse backgrounds including the designer, the manufacturer, and the potential users. In order to manage the biomedical design process, decision support systems are needed which incorporate strategic knowledge.

A retrospective analysis during design reviews suggested that in such a highly regulatory environment, decisions (i.e., commitments) are postponed as long as possible. This is due to the fact that regulation compliance being of first priority (with cost as second) requires extensive and time consuming evaluation of device components. In addition, clinical evaluation times are difficult to predict, thereby hampering project scheduling. Thus it is important that separate parts of the device be worked on in parallel.

From one of the author's field notes from a project developing a cancer detection device, retrospective techniques in a project review setting revealed two types of participant communication: external and internal. *Internal communication* within the project team takes the form of (usually) weekly design reviews to bring the team members up to date on ideas, progress, status, and new decisions. This verbal report is coupled with a written progress report which is used for the documentation and tracking required by regulations. Similar review meetings are held in project subgroups.

External communication occurs with the customers and vendors. This is necessary for clarification and appraisal of regulatory constraints. Such communication supports idea generation, decision making, and project tracking. The communication often takes place using concepts and language understandable by the customer.

Check points made during formal design reviews correspond to key decision points in the process where the team members get new directions and their design progress is evaluated by a manager. Formal check points made during client interaction serve to give the client a sense of ownership in the product and also ensure that the design team is progressing in the right direction. These act as control points for client feedback which is very important in large projects and helps minimize backtracking and product dissatisfaction.

Formal procedures are used for documenting the design process in a chronological fashion. The documentation process serves to develop team confidence in the project and the product. Project documentation is important both for regulatory purposes and for product modifications and redesign during the design process. It also records design decisions for later improvements and for accountability.

4 An Experimental Approach

From our brief analysis of a biomedical engineering design project in Section 3, we identify several issues which can benefit from process support: the inherent parallelism and iteration in the process; and the sharing of knowledge among group members and sub-group members to insure reliable decision making and good communication. The latter includes assistance in documentation and in developing project standards. For such process support, good strategies for structuring and carrying out the collaborative design process are fundamental. We are investigating this issue from a knowledge acquisition perspective.

We derive strategic knowledge for collaborative design through a retrospective analysis, using data collected from industrial records and interviews, of several industrial projects with different regulatory constraints. The strategic knowledge will capture the track of the major decision points and the flow of information during the design process. We will analyze whether certain strategies were successful or not, and will formulate improved strategies. We plan to use KI Shell^{TM}, a commercial knowledge integration software package, to help us model the decision-making process and analyze various strategies. KI Shell assists in process management by representing the information exchange and decision-making process as a workflow model and by providing process support during the execution of that model by end users. In addition, KI Shell's information management capabilities can provide support in the development of automated documentation assistance.

Our near-term goal is to capture good process strategies for a highly regulatory environment and to investigate how a representation of the strategic knowledge can aid in the documentation process. Our longer-term goal is the development of more sophisticated process support environments for collaborative design. Our experience with KI Shell and with real world problems from the bioengineering domain should shed light on viable technical approaches.

5 Summary

We discussed the need for process support in collaborate design and described several research efforts addressing this issue. From experience with a biomedical engineering design project we identified areas that could benefit from computer-based process support. We then outlined an experimental approach for testing various techniques on actual bioengineering product designs.

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References

[Epp90] Steven D. Eppinger et al. Organizing the tasks in complex design projects. In *ASME Design Technical Conferences - 2nd International Conference on Design Theory and Methodology*, Chicago, Ill., September 1990.

[Gau93] Dale Ellen Gaucas. Strategic knowledge in computer-based design. Technical Report 93004, Rensselaer Design Research Center, Rensselaer Polytechnic Institute, Troy, New York, February 1993.

[GFG91] R. Ganeshan, S. Finger, and J. Garrett. Representing and reasoning with design intent. In J.S. Gero, editor, *Artificial Intelligence in Design, 91.* Butterworth Heinemann, 1991.

[KEW91] V. Krishnan, S.D. Eppinger, and D.E. Whitney. Towards a cooperative design methodology: Analysis of sequential decision strategies. In *Proceedings of the ASME Design Automation Conference - DE-Vol 31, Design Theory and Methodology*, Miami, Florida, September 1991.

[KL89] Mark Klein and Stephen C-Y. Lu. Conflict resolution in cooperative design. *Artificial Intelligence in Engineering*, 4(4), 1989.

[LJD91] Raymond E. Levitt, Yan Jin, and Clive L. Dym. Knowledge-based support for management of concurrent, mulidisciplinary design. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*, 5(2), 1991.

[LLC89] S.E. Lander, V.R. Lesser, and M.E. Connell. Knowledge-based conflict resolution for cooperation among expert agents. In *Computer-Aided Cooperative Product Development, Proc. MIT-JSME Workshop*, Cambridge, Mass., November 1989.

[Rag91] Sridhar A. Raghavan. JANUS a paradigm for active decision support. *Decision Support Systems, The International Journal*, 7, 1991.

[WW88] M.B. Waldron and K.J. Waldron. Time study of the design of complex mechanical systems. *Design Studies*, April 1988.