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Preventing design conflicts in distributed design systems composed of heterogeneous agents

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ABSTRACT

In distributed design systems, while designers are connected to each other through dimensioning couplings, they have limited control over design and performance variables. Any inconsistency among design objectives and working procedures of heterogeneous designers interacting in the design system can result in design conflicts due to these couplings. Modeling design attitudes can help to understand inconsistencies and manage conflicts in design processes. We extend the conventional bottom-up or design supervision approach through agent-based attitude modeling techniques to a more powerful level. In our model, design agents can set requirements directly on their wellbeing values that represent how their design targets are likely to be met at a given moment of the design process. Some design conflicts can in this manner be prevented at an earlier phase of the design process. Set-based design and constraint programming techniques are used to explore the overall performance of stochastic design collaborations on a product modeled with uncertainties at a given moment of the design process. Monte Carlo simulations are performed to evaluate the performance of our set-based thinking approach, providing a variety of agent attitudes. The results show that the number of design conflicts occurring during the design process and the intensity of design conflicts are both reduced through our collaborative design platform.

1. Introduction

Design processes of complex products currently involve considerable effort and expertise from different disciplines. Multiple designers from different disciplines are thus involved in performing collaborative design. The design model converges to a solution through a series of collaborative activities performed during the design process. Since the design problem has multidisciplinary boundaries, a distributed design approach can be adopted. In distributed design systems, the system is decentralized; the global problem is decomposed into sub-problems and distributed to subsystems consisting of one or several designers (Papalambros et al., 1997). Subsystems are thus heterogeneous, and have limited control over the design variables because of their limited expertise and responsibility. In a sub-problem, there are three main problem elements: design variables that can be controlled, design performances that are evaluated and constraints that must be respected. The rest of the global problem excluding a specific sub-problem does not concern the specific sub-system, but it can be only observed if it is shared and necessary. Distributed design tasks allocated to sub-problems are executed concurrently by subsystems, the global problem converging to a global solution (Zheng et al., 2011).

In the ideal case, true concurrency is expected from distributed design systems where designers can perform their design activities independently. In reality, designers are related to each other through couplings between their sub-problems. Couplings can result in conflicts among designers if some inconsistencies are presented in the design system. Inconsistencies arise from design attitudes reflected by heterogeneous subsystems during the design process. The most significant inconsistency occurs between design objectives of designers. Typically, a design problem contains multiple conflicting objectives, so designers are forced to make trade-offs. Working procedures of designers influence the performances of others, and inconsistencies present in these working procedures can negatively impact the global solution (Zhao and Jin, 2003). For instance, a designer restricting the design model more rapidly or earlier than others could influence the model more. Subsequent designers are forced to deal with a restricted model which cannot satisfy their own design objectives. If the number of conflicts and intensity of the conflicts increase; the performance of the design process decreases, because individual design objectives are not satisfied in equilibrium.

The technique chosen for modeling the design process significantly affects the collaborative solution emerging from different sub-problems. Devendorf and Lewis (2011) show that the stability

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of a distributed design system depends on how the process architecture is formed. Two main approaches can be adopted for global design process modeling. These are the top-down design approach and the bottom-up design approach (Fathianathan and Panchal, 2009). In the top-down design approach, decisions are made for parameterization of design variables in order to find detailed solutions that satisfy designer objectives. This approach is considered as a transition from an abstract level to a detailed level: in complex design problems, the effect of any parameter on the solution is usually abstract until the parameter is tested and a detailed solution is obtained. In contrast, the bottom-up design approach consists in defining detailed solutions to identify values of the design variables. Through this bottom-up design approach, designers can make decisions on their design performances. A common design issue, regardless of the design process approach used, is the presence of epistemic uncertainty due to the imprecision caused by the lack of knowledge about the final decision (Parry, 1996). The top-down design approach requires detailed decomposition of the problem where all the relations between variables are explicit. However, this may not be possible when the complexity of the design problem is very high and the problem contains too many couplings. Therefore, the effect of the decisions about design variables on design performances is highly uncertain, especially in early design phases. Engineering project failures can increase when it is not possible to predict the effect of the modifications because of the presence of intense couplings in complex design problems. Chanron and Lewis (2005) highlight the difficulty of allocating design variables to subsystems in a coupled problem where the same design variables influence the design performances of several subsystems. The allocation technique is critical, because it can influence the design quality (Kim et al., 2003) or the performance of the design process (Park et al., 2001). Fathianathan and Panchal (2009) propose the adoption of a bottom-up design approach when these limitations arise from a top-down design approach. Nevertheless, in the bottom-up design approach, it is highly uncertain to detect the best solution that satisfies all of the constraints related to design variables.

According to Malak et al. (2009), the issue of imprecision in design requires representing the uncertainty with imprecise intervals/sets and delaying uncertain decisions to later process stages when the information about the related decision becomes available. In this paper, we use this set-based design (SBD) concept in order to deal with the issue of designing under uncertainty. The objective of this paper is to develop a process approach that prevents design conflicts of heterogeneous subsystems in distributed SBD, and simulate this approach in design automation. In Section 2, we discuss the works related to design conflicts, and introduce our proposed solution. In Section 3, we discuss the ability of SBD and constraint satisfaction problem (CSP) techniques to manage imprecision in design. In Section 4, the attitudes of design agents in multi-agent systems and egoistic and altruistic agent characters emerging from dynamic attitudes are considered. Our agent-based SBD model is introduced in Section 5 and the CSP simulation process of this model is presented in Section 6. Monte Carlo simulations of our approach are performed on a design problem which involves variable agent characters composed of variable design attitudes that define how design agents react during the design process. The sequence of the agent reactions is stochastic. Problem definitions and simulation results are presented in Section 7. A large scale case study of our methodology is presented in Section 8.

2. Related works and proposed solution

Some significant attempts have been made to coordinate and resolve existing conflicts in distributed systems. Zheng et al. (2011) propose to resolve conflicts by integrating resultant models of conflicting Boolean decisions in individual sub-problems of distributed computer-aided design. Kwon and Lee (2002) define a multi-agent based model that integrates a coordination mechanism. This can manage conflicting agents in a decentralized enterprise in order to resolve interdepartmental conflicts. Koulinitch and Sheremetov (1998) define a constraint-based dynamic design system model that includes facilitator agents which are responsible for coordination and conflict resolution during the design process. When a conflict occurs amongst design agents, facilitator agents send messages to relax some constraints until a consistent solution is obtained. Huang et al. (2006) develop a fuzzy interactive multi-objective optimization model for engineering design. The collaborative relationships among the objectives are improved with adjusting the threshold of satisfaction degree and weighting coefficients of objectives. The least conflicting solution is therefore selected among the generated set of Pareto optimal results. The selected solution gives the maximum satisfaction degree and the minimum divergence of the individual satisfactions of local objectives. Yvars (2009) proposes a collaborative design system where decisions of distributed designer agents are represented with constraints added to the model dynamically. Constraints restricting the design model restrict the degree of freedom of agents also, so that they cannot add anymore constraints to the design model. This results in conflicts that are represented as unfeasible models. Design conflicts are resolved by detecting a compromise solution that maximizes the number of accepted constraints by removing some constraints from the model. While these approaches focus on resolving conflicts that have already occurred, they overlook the idea of preventing and avoiding potential conflicts that have not yet occurred in the process. They interrogate the issue at a late phase of the problem, since the avoidance of a conflicting problem is usually more efficient and less time-consuming than the resolution of a conflicting problem. The approaches outlined above also fail to take into account attitude models of heterogeneous agents. Modeling design attitudes can help understand the design inconsistencies resulting in design conflicts, and as a result certain collaboration strategies can be defined with attitude models.

In this paper, we propose to extend the bottom-up design approach with agent-based attitude modeling techniques in order to prevent design conflicts at an earlier phase of the design process. For extending the bottom-up design approach, a wellbeing indicator is presented that shows how the preference objectives of various designers are satisfied. Fig. 1 shows the comparison of our extended bottom-up design approach with the traditional bottom-up approach and the top-down approach. In the top-down design approach, alternatives are generated first by making decisions on the design variables, and emerging solutions are subsequently evaluated considering design performances. In the bottom-up approach, solutions are generated by making decisions on design performance values

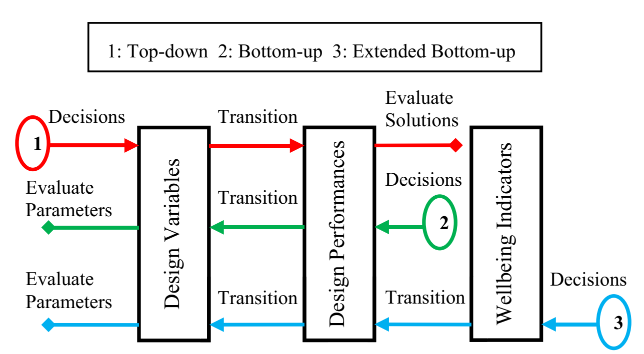

Fig. 1. Comparison of process approaches.