



Full length article

Systematic design space exploration using a template-based ontological method

Ru Wang^a, Anand Balu Nellippallil^b, Guoxin Wang^{c,*}, Yan Yan^d, Janet K. Allen^e, Farrokh Mistree^f

^a Beijing Institute of Technology, Rm 337, No. 1 Teaching Building, No. 5 Zhongguancun South Street, Haidian District, Beijing 100081, China

^b University of Oklahoma, 202 W. Boyd St., Suite 219, Norman, OK 73019, United States

^c Beijing Institute of Technology, Rm 343, No. 1 Teaching Building, No. 5 Zhongguancun South Street, Haidian District, Beijing 100081, China

^d Beijing Institute of Technology, No. 5 Zhongguancun South Street, Haidian District, Beijing 100081, China

^e University of Oklahoma, 202 W. Boyd St., Suite 116, Norman, OK 73019, United States

^f University of Oklahoma, 865 Asp Avenue, Felgar Hall, Rm. 306, Norman, OK 73019, United States

ARTICLE INFO

Keywords:

Ontology
Decision-based design
Design space exploration
Process template
Reuse

ABSTRACT

The realization of complex engineered systems using models that are typically incomplete, inaccurate and not of equal fidelity requires the understanding and prediction of process behavior in design. This necessitates the need for extending designer's abilities in making design decisions that are robust, flexible and modifiable particularly in the early stages of design. To address this requirement, we propose in this paper, an ontology for design space exploration and a template-based ontological method that supports systematic design space exploration ensuring the determination of the right combination of design information that meets the different goals and requirements set for a process chain. Using the proposed method, a designer is able to (1) systematically adjust the design space in due time to manage the risks of errors accumulating and propagating during the design of different stages of the process chain, (2) improve the ability to communicate and understand the interactions between design information in the process chain. We achieve the said through (1) procedure for design space exploration is identified to determine the sequence of activities needed for the systematic exploration of design space under uncertainty; (2) the decision-based design information flow is archived using the design space exploration process template and represented by utilizing frame-based ontology to facilitate the management of re-usable information. We demonstrate the efficacy of this template-based ontological method for design space exploration by carrying out the design of a multi-stage hot rod rolling system in steel manufacturing process chain.

1. Frame of reference

Due to the limited information in the early stages of design, the designer has to deal with different types of uncertainty. The presence of incomplete, inaccurate and infidel models for complex engineering systems also adds to this uncertainty [1]. Design Space Exploration (DSE) refers to the activities of exploring (discovering and evaluating) design alternatives or space of potential design candidates before implementation during the system development [2]. Since the design is mainly a knowledge-driven process, it is possible to represent the inherent knowledge of many design problem through some hierarchical associative relationships, which will provide the guidance of the instantiation process for the problem-solving [3]. Several challenges have involved the management of complexity and uncertainty associated with the DSE in the model-based realization of complex engineered

systems [4]. Two major ones are: (1) the challenge of creating knowledge about the complex engineered systems and; (2) the challenge of capturing and reusing tacit knowledge, building the ability to learn from data and cases, and developing knowledge-based methods for guided assistance in decision-making.

Design productivity can be enhanced by both increasing design knowledge in the early stages of designs and maintaining design freedom throughout the design process [5]. There have been propositions that aimed to computationally support designers in the exploration of conceptual design space [6]. Such as Chong et al. [7] define a conceptual design space and its framework to organize design knowledge objects and inter-relationships, then a tailored heuristic algorithm is employed for the determination of a satisficing solution graph [6]. Instead of the traditional optimization, the paradigm of DSE is used to evaluate “what-if” scenarios and trade-off studies. Some research

* Corresponding author.

E-mail addresses: haitang.56@163.com (R. Wang), anand.balu@ou.edu (A.B. Nellippallil), wangguoxin@bit.edu.cn (G. Wang), yanyan331@bit.edu.cn (Y. Yan), janet.allen@ou.edu (J.K. Allen), farrokh.mistree@ou.edu (F. Mistree).

<https://doi.org/10.1016/j.aei.2018.03.006>

Received 9 October 2017; Received in revised form 20 March 2018; Accepted 24 March 2018
1474-0346/ © 2018 Elsevier Ltd. All rights reserved.

results put forward from the decision-based design perspective, e.g., RCEM [8], IDEM [9], which facilitate a broader design space exploration using the compromise Decision Support Problem (cDSP). Meanwhile, as traditional an optimization commercial software system, iSIGHT has grown to be a design exploration environment by integrating some methods, techniques, and modules to reflect that shift [10].

However, there is still a lack of effective means to capture, reuse, and represent tacit knowledge in the exploration process of design space in response to the second challenge above, which requires various types of design information to be assembled to form a representation of the context [11]. The contribution of this work is providing effective decision support for a designer to achieve the trade-off between identified multiple conflicting design goals, as well as manage the risk of errors. Therefore, to achieve a context environment for the exploration processes in designing complex engineered systems, a good understanding of predicting process behavior is paramount. Achieving this purpose using decision-based design perspective necessitates a systematic, flexible, and adaptive designing decision workflows involved. The decision-based design results associated with these workflows should be relatively insensitive to the uncertainties involved. The design results should also be flexible enough to accommodate any risk of errors that may accumulate along the decision workflows. To address above demands, we present in this paper an ontology for design space exploration and a template-based ontological method that supports systematic design space exploration in the model-based realization of complex engineered systems.

The remainder of this paper is organized as follows. In Section 2, we describe the foundation for this work – the Decision Support Problem (DSP) and its applicability in providing insight to designers for managing complexity and uncertainty. We also address the utility of ontology-based knowledge modeling in facilitating efficiency and effectiveness in the applications of DSPs. In Section 3, we propose a template-based method for computationally modeling the processes of DSE in response to the defined requirements, which includes a systematic procedure, design space adjustment, and a template scheme. In Section 4, we develop an ontology that represents the underlying knowledge related to the DSE process template, as well as the instantiation approach in keeping with the model of DSE process template. The efficacy of this method is illustrated by using an example associated with the design of a multi-stage hot rod rolling system in Section 5, and we end with the closing remarks in Section 6.

2. Foundations

2.1. Decision support problem construct

Due to the complexity and uncertainty associated with complex systems with emergent behavior, the model-based realization of complex engineering systems is characterized by models that are typically incomplete, inaccurate and not of equal fidelity especially in the early stages of design [4]. From the perspective of decision-based design, the primary role of designers is to make robust design decisions given the uncertainties associated with the system and models. Mistree et al. [12] present the compromise Decision Support Problem (cDSP) as a decision construct to aid designers in carrying out trade-offs among multiple conflicting goals. Using the cDSP model *satisficing* solutions for the desired system performance are sought rather than optimum solutions that are valid only in the narrow range of conditions. The generic mathematical formulation of the cDSP construct is shown in Fig. 1. A PEI-X (Phase-Event-Information - X) diagram is proposed to represent the decision workflows, which is defined as various sequences of computational tasks related decision-making.

Robustness refers to mitigating the consequences of variability to variations in engineering design, which means the ability to tolerate perturbations from some noise source. Many researchers have focused

on the methods and applications for robust design in engineering design, Taguchi being the first to provide initial insight into the robust design and its principles which are widely advocated by both industry and academia. Despite this, there are some limitations to the Taguchi approach, the details of which are available in [1]. The design decisions in the earlier stages of design have a profound impact on the performance and quality of the final product. Chen et al. [8] formulate a robust design problem as a decision model using the cDSP construct. Building on this work, they present the Robust Concept Exploration Method (RCEM) and its applications [5]. These works are foundational in addressing the incorporation of robustness in the early stages of design. Based on these foundational work, several integrated computational methods are proposed to explore the design space by utilizing the cDSP construct [13–15]. Such as Nellippallil et al. [16] present a goal-oriented, inverse decision-based design method to achieve the vertical and horizontal integration of models for a multi-stage hot rod rolling system. In this work, they employ well-established empirical models, response surface models generated from simulation experiments as well as the cDSP construct supported by the Concept Exploration Framework (CEF). We will be addressing this work in the following sections.

2.2. Ontology-based knowledge modeling

The formalization and representation of knowledge have received strong attention in the last decades, especially in the context of knowledge-intensive system engineering [17,18], product lifecycle management [19], knowledge management [20,21], and artificial intelligence-based solutions [22,23]. As an idea of a design solution, “design concept” means a designer’s knowledge of process behaviors in design [24]. Thus design is also regarded as a structured reflection process [25], whereby a designer stepwise handles a problem via the developing and evaluating of a design concept. As a specification of a conceptualization, ontology provides a common vocabulary for the representation of domain-specific knowledge [26]. The two key elements of an ontology are concepts and relations, which facilitate the capturing and reusing in-context design knowledge with an integrated representation model [20,24].

Ontology has a great potential impact on the designing of engineering system [27]. The applications of ontology in design engineering have three major categories [28]: (1) concept interoperability [17–19]; (2) annotation of design information, sharing, and retrieval [20–22]; (3) product design configuration [23], which benefit from the following characteristics:

- Flexibility - knowledge is defined in terms of an ontology instead of “hardcoding” within the platform.
- Intelligent behavior - knowledge can be derived from the factual knowledge explicitly represented in the ontologies.
- Semantic interoperability - semantics of the (possibly several) languages used by the platform’s external parties can be defined by a set of interrelated ontologies.
- Expressiveness - context information is represented using a formal representation language, which enables to check the consistency of the models automatically.

In the past work, ontologies for representing the knowledge in cDSP template [29], a selection DSP (sDSP) template [30], and a hierarchy DSP template [31] are presented to facilitate efficiency and effectiveness in design, respectively. A PEI-X ontology for meta-design process hierarchies [32] is proposed, which can capture, represent and document the knowledge for supporting the re-usability of information in the decision workflows. Here, we focus on the integration of vertical information in the decision workflows.

Download English Version:

<https://daneshyari.com/en/article/6679590>

Download Persian Version:

<https://daneshyari.com/article/6679590>

[Daneshyari.com](https://daneshyari.com)