Integrative, Model-Based Engineering Design

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Abstract

This position statement argues that advanced, systematic modeling techniques are needed to support engineering of complex, heterogeneous systems. Models provide blueprints for the development and assessment of systems through computer simulation, pior to their deployment.

1. Model-Based Design

Modern engineering design is a highly complex process. It involves a multiplicity of objectives, constraints, materials, and configurations. Despite great strides in computational tools such as high performance workstations intended to help to cope with this rising complexity, the design process remains error prone. Given the often severe constraints imposed by cost, environmental impacts, safety regulations, etc., designers are forced to make compromises that would not be necessary in an ideal world.

Simulation modeling is increasingly recognized as a useful tool in assessing the quality of sub-optimal design choices and arriving at acceptable trade-offs. This approach is often called "simulation-based design." However, our working hypothesis is that computer simulation and other advanced computational tools are of limited effectiveness without a methodology to induce a systematic handling of the multitude of goals and constraints impinging on a design process. Therefore, our work focuses on the development of techniques in which design models can be synthesized and tested within a number of objectives, taken individually or in trade-off combinations.

Although design concepts are pervasive in state-of-the-art engineering, no single framework is accepted as fundamental. The methodologies offered by various design disciplines lack a uniform treatment of the design process at different levels of abstraction. Often there is no underlying formal basis for design representation and evaluation. Consequently, efforts to develop environments for support of design activities have little theoretical backing, and the resulting systems are usually conglomerates of different, incompatible tools whose coordination creates a substantial overhead in the design process.

In our work, we use modeling and simulation concepts to unify engineering design activities and develop a methodology for systematic construction and evaluation of design models of complex systems. The reasons for our choice of model-based techniques are motivated by the following synergies:

- Modeling is a creative act of individuals using basic problem solving techniques, building conceptual models based on knowledge, perception of reality, requirements, and objectives of the modeling project. Thus, considering models as design "blueprints" there is a direct relationship between design and its supporting modeling activities.

- By providing mechanisms for model decomposition, hierarchical specification, and aggregation of partial models, advanced modeling methodologies respond to the needs of design of large scale systems.

- By providing a spectrum of performance evaluation methods, including trade-off measurements and evaluation of multilevel, multicomponent, hierarchically specified models, our approach facilitates description of design attributes through

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quantitative and, more generally, comparative measures.

- The knowledge representation schemes offered by our framework are well structured. Formalized operations that exploit such structures are available. This facilitates a uniform treatment of design at every level of abstraction and may advance efforts to construct computer-aided environments for design support.

In several publications [1-8], we have elaborated on the fundamental concepts supporting design activities. Our concept of system entity structure (SES) is a formal representation scheme that facilitates expressing a) the decomposition hierarchy, b) the taxonomy of design components it represents, c) the constraints on coupling of objects identified in decompositions, and d) the constraints on selection of components given by the taxonomic relationships. Beyond this, procedural knowledge is available to select and synthesize the system's components identified in the chosen representation scheme, i.e., the SES. This selection and synthesis process is called pruning. Pruning results in a recommendation for alternative design object model given as sets of hierarchically arranged system's components.

Another fundamental concept, the experimental frame, is a structure that represents design objectives in the form of standard system's attributes. Such attributes express measures of input/output performance, utilization of resources, reliability assessments, etc.

Alternative design models are evaluated through computer simulation in experimental conditions (experimental frames) that reflect design performance questions. Results are compared and traded off in the presence of conflicting criteria. This results in a ranking of models and supports choices of alternatives best satisfying the set of design objectives.

Model-based engineering will become increasingly important in the development of heterogeneous systems that comprise hardware, software, and interface components. We strongly advocate the use of unified, mode-based representations that integrate the various HW and SW perspectives [1] and facilitate the design which postpones partitioning and technology assignment until the specification have been refined and verified through simulation.

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