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Tools and Techniques for Design Space Exploration

Overview

Design Space Exploration (DSE) is an increasingly important concept in embedded system design. To mitigate the complexity of system development, designers *compose* complex systems from families of subsystems. Formalizing the design process necessitates a quantitative analysis of alternative compositions in an effort to eliminate those configurations which do not meet requirements.

The space of possible design compositions is referred to as a *Design Space*, and the traversal of the space in search of optimal or near-optimal configurations is called *Design Space Exploration*.

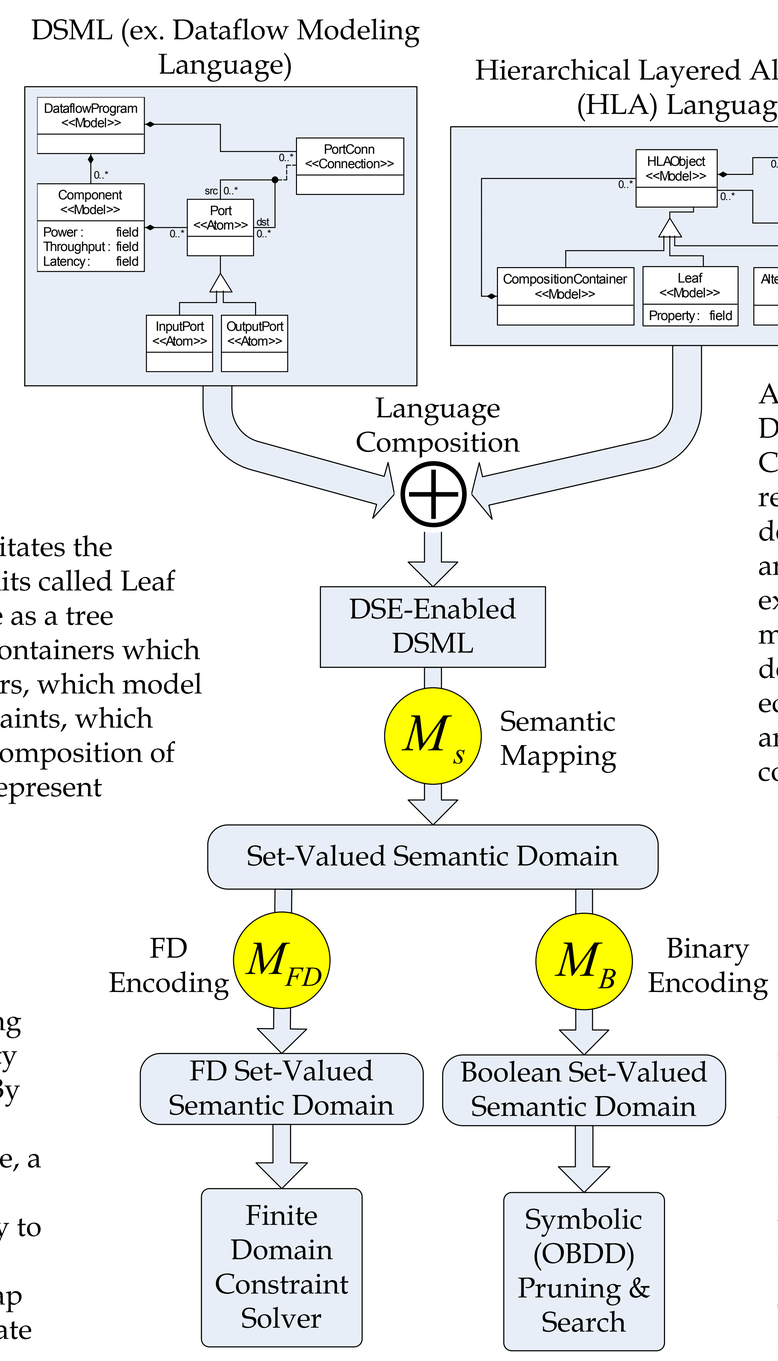
Modeling Configurations

The Hierarchical Layered Alternative modeling language facilitates the construction of a design space from individual composable units called Leaf objects. The HLA language captures the structure of the space as a tree containing two distinct types of interior nodes, CompositionContainers which model the part/whole relationshiop, and AlternativeContainers, which model selection or choice. The HLA also allows the capture of constraints, which model design requirements, translating to restrictions on the composition of the space. Constraints are expressed using OCL syntax, and represent relations between properties of HLA objects.

Composing Design Space-Enabled Languages

The Tool Architecture offers the capability of extending existing Domain-Specific Modeling Languages (DSMLs) with the ability to model design spaces, as opposed to simple point designs. By composing an existing DSML with the HLA language, an extended, DSE-Enabled language is developed. As an example, a simple dataflow language may be composed with the HLA to produce a hierarchical dataflow language that offers the ability to model component compositions and alternative component implementations. Semantic translation can then be used to map the composition into the set-valued semantic domain to facilitate exploration.

Tool Architecture



Tools for Exploration

Design Space Exploration involves a search though the Set-Valued semantic domain representation of the design space. The goal of the exploration tools is to prune from the space those design compositions which violate the specified constraints. Currently, two tools have been developed, one based on Symbolic manipulation of a binary encoding of the space using OBDDs, and another based on a Finite Domain Constraint encoding of the space.

A Finite Domain Model

An exploration tool has been developed based on a Finite Domain Constraint-encoding of the design space. Finite Domain Constraints represent relations between variables that are restricted to domains of finite cardinality. The Finite Domain design space representation offers a scalable, mathematically analyzable representation of the space, together with an expressive language for specifying constraints based on complex mathematical expressions. The equations below represent finite domain constraints generated through the FD Encoding. The equations define a set of variables that represent whether or not an object has been pruned from the space, and are used in conjunction with other FD constraints to prune the space.

$$Sel(n) \in \{0,1\}, \forall n \in Nodes$$

$$Sel(Node_i) = \begin{cases} \prod_{c \in children(Node_i)} Sel(c), & dec(Node_i) == AND \\ \sum_{c \in children(Node_i)} Sel(c), & dec(Node_i) == OR \end{cases}$$

Conclusion

As composition becomes increasingly important in managing and mitigating the complexity of embedded system designs, design space exploration represents an enabling technology for capturing, analyzing and optimizing across the space of design compositions.

The tool architecture presented here offers the capability of developing DSMLs which can be used to model sets of design configurations, together with tools to traverse and optimize across the configuration space.