

Efficient Design Space Exploration and Optimization for Electrical Architectures

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ABSTRACT

The ability to provide a tool integrated environment for quick exploration and optimization of system architecture design alternatives is of paramount importance to the automotive industry. An integrated analysis environment can help reduce development and production costs as well as production time to the market. Given a large number of design alternatives, engineers cannot evaluate them manually due to time constraints. Thus a flexible and scalable tool that helps engineers to automatically explore the design space and optimally select a design meeting the design objectives and constraints is a key for succeeding in this area. This paper discusses lessons learned through hands-on experiences with an existing commercial tool and provides in-depth insights of the development process and complexities.

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INTRODUCTION

As automotive in-vehicle feature complexities increase, so do the architectures implementing them. Designing, evaluating, and selecting different architectures is a difficult task that cannot be done manually due to the complexity and time constraints. To facilitate this task, system-level design tools are needed. In this paper, we propose a model integration and optimization platform using an off-the-shelf optimization and workflow system-level design tool (e.g. ModelCenter by Phoenix Integration [4] and modeFRONTIER by ESTECO [5]). This type of tool has been used in the aerospace and defense industry. For example, using ModelCenter, NASA put into place a framework for supersonic aircraft design to better understand the design space, explore optimal designs, and quickly advance conceptual design concepts [3]. In the system-level design tool, users can create workflows by wrapping design models and apply optimization methods and third-party tools to perform trade studies or optimize designs. Interfaces are provided to third-party tool/model integration as well as for custom tools, such as Excel, MATLAB, Rhapsody.

In this paper, we investigate both the logical and electrical/physical dimensions for the optimization of electrical architectures. In the logical-dimension, we study the functional partitioning and allocation to ECUs and propose a workflow to achieve best worst-case response time for communications among ECUs. In the physical-dimension, we study how to select the wire sizes and how to route wires for electrical architectures so as to minimizing the wiring cost. Physical constraints including total resistant constraints and bundle size constraints are considered.

To help evaluate the application of new technologies (e.g. wireless communication for wire reduction), we also add a wireless communication module in the electrical architecture model. To understand the tradeoff between wireless communication and wired communication, we define a decision variable of wireless on/off to indicate one connection is wireless or wired. The logical and physical aspects of electrical architecture design result in a highly coupled design problem that cannot be solved independently. There are significant tradeoffs among them. For example, the functional partitioning and allocation to ECUs may impact the network topology and hence impact the wire sizing and wire routing in the physical-dimension optimization. We provide a holistic optimization solution with multi-objective optimization. When comparing different configuration options of electrical architectures, a multi-objective decision making process is a must. Further, we use tradeoff analysis and trade space visualization tools to understand the design space and graphically identify designs that satisfy design requirements.

In the following sections, we first discuss the modeling of a multi-objective optimization problem for electrical architecture design. Then we discuss the model integration and optimization platform that we created to evaluate and demonstrate the design space exploration and tradeoff analysis capabilities. With a real use case, we show the trade space visualization. Finally we provide the summary and conclusion of this paper.

ELECTRICAL ARCHITECTURE MODELING

When developing the electrical architecture of automotive electrical systems, challenges arise. Electrical systems are becoming increasingly critical for the implementation of complex driver-facing

features. The maximum size and complexity of electrical systems and their architecture are exponentially increasing. Further, software is having an ever-increasing influence on system architectures in terms of design decisions, tradeoffs, and etc. While developing such complex electrical systems with a large number of components, it is necessary to involve multiple technical teams. A proper electrical architecture-engineering platform is needed to manage the design complexity and improve the communication and collaboration among technical teams. It is also worth noting that some problems with electrical architectures cannot be found until system integration. For example, increasing reliability may decrease system performance, and increasing security may decrease system usability. Hence, system integration and large design space exploration are needed for such an electrical architecture-engineering platform. In this paper, we present our solution of an integrated optimization platform that can optimize the electrical architecture design by exploring a large design space in an effective and efficient manner.

In this paper, to illustrate the idea of our integrated optimization platform, we discuss an example of multi-objective optimization problem. We discuss the modeling of multi-objective optimization problem in this section. Figure 1(a) shows an architecture, and Figure 1(b) and Figure 1(c) show its physical dimension view and logical dimension view, respectively. A part can be an ECU, a sensor, an actuator or a splice in an architecture. In this architecture in Figure 1(a), there are five parts and their connections are shown accordingly in the figure. In the physical dimension, we need to decide how to implement the wiring, which includes the decision of parameters like wire routing and wire sizing and etc. For more detailed modeling in the physical dimension, please refer to [1] and [2]. In the logical dimension, we need to decide how to allocate software components (SWCs) to parts, and how to allocate network signal to buses accordingly. To further facilitate the study of new technologies, we consider about wireless communication in this example: a segment/multiple segments of wires can be replaced by wireless radios so as to use wireless communications instead of wired communications.

There are important tradeoffs among the logical-dimensional and physical-dimensional decision-makings, hence we consider the study of these two dimensions in a single example. For example, software component allocations can impact the signal communications among parts, and hence impacting the physical topology of the connections. Sometime, a better worse-case response time (logical dimension) on the buses may result in a higher wiring cost (physical dimension).

In the multi-objective optimization problem, the objectives are to minimize the total wiring cost, minimize the worst-case response time as well as maximizing the reliability of wireless communications. The constraints include upper bounds on bundle sizes, upper bound on the total wiring resistance, upper bound on the packet loss rate. The decision variables are wire size, wireless on/off, and software component allocation.

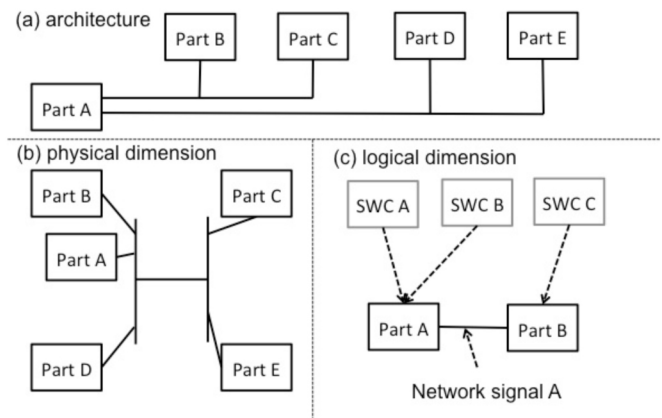


Figure 1. An architecture, as well as its physical dimension and logical dimension representations.

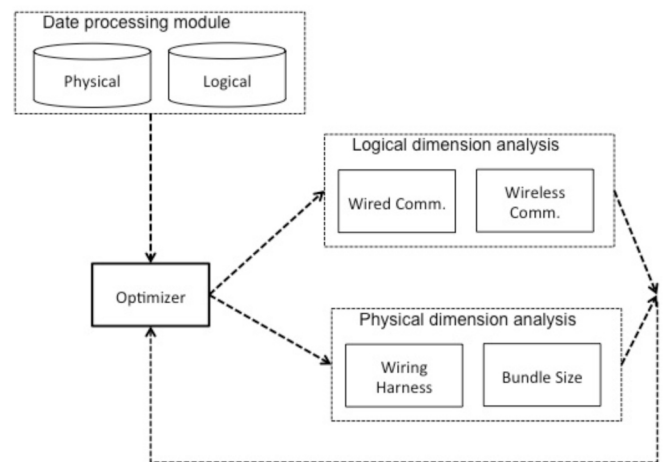


Figure 2. Proposed model integration and optimization Platform with a commercial tool.

MODEL INTEGRATION AND OPTIMIZATION DESIGN

In the early phases of E/E architecture definition and selection, decisions about different functional partitioning and architecture topologies are determined, among others, by software component allocation, wire routing and sizing. During our collaboration with engineering architecture experts, we develop use cases and integrate these use cases in a commercial tool to enable a broader than the manually supported trade-off study for electrical architecture optimizations. In this section, we discuss about the model integration and optimization design in the tool based on the joint logical-dimension and physical-dimension study, using the modeling concepts discussed in the previous section.

Figure 2 illustrates the proposed model integration and optimization platform with our selected commercial tool. As shown in the figure, the data processing module imports physical-dimensional data and logical-dimensional data from existing databases and prepares the required data for the optimization module. The goal of the data processing module is to build a process where data can be read automatically from existing database to be fed into the physical and