Model Discovery for Analog/Mixed-Signal Circuits

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I. Introduction

From simple analog-to-digital and power converters to complex cellular network integrated circuits, *analog/mixed-signal* (AMS) systems are an essential component of many modern system-on-chip designs. Ever growing system complexity, performance and reliability requirements lead to an increased number of digitally assisted analog blocks [1]. This tight coupling of complex analog systems to complex digital solutions results not only in an extensive amount of verification to perform, but also necessity to combine design and validation methods for two fundamentally different system types.

The latest advances in formal design methods [2] seek to either improve existing simulation-based techniques or provide new verification methods. Our recent paper [3] introduces a novel design flow, shown in Figure 1, to address some of the problems in the design of AMS systems. The flow brings together two actively-developed tools, Workcraft and LEMA, to enhance digital components with the benefits of asynchronous logic to improve overall system robustness by employing formal verification methods. Furthermore, an important purpose of the workflow is to improve the communication bridge between analog and digital engineers via abstract modeling, expressed in the form of *labeled Petri nets* (LPNs) [4], [5].

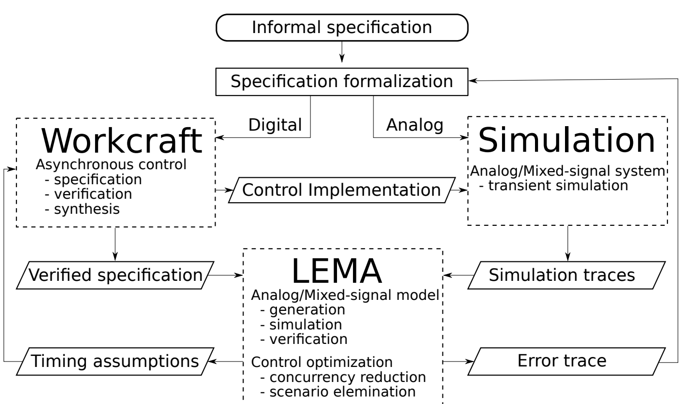

Figure 1: LEMA-Workcraft workflow.

LPNs provide a means to capture dynamics of analog systems and create models that approximate the original system in a piecewise linear manner. LEMA is capable of generating LPN models from simulation traces, simplifying the process of constructing a model for the analog environment [6]. The model generation process discovers and generalizes recurring behaviors in a set of traces and is analogous to *process mining* [7].

II. LEMA-Workcraft flow

The workflow begins with the creation of a formal specification that is then split into the digital and analog parts. The digital parts are used by the Workcraft tool to synthesize a control implementation that is coupled with the analog part for simulation. The digital specification and the simulation traces are then utilized by the LEMA tool to generate a formal model that is amenable for formal verification. The result of this verification is either an error trace or timing assumptions that can be applied to optimize the digital design.

The construction of a buck converter model in [3] revealed a number of flaws in the existing model generation module within LEMA. Due to these flaws, the automatically generated models did not reflect all necessary features of the original simulation traces and had to be manually improved, which rendered the application of the flow less appealing. To overcome the underlying issues, an improved model generation framework has been developed.

III. Model generation

Automated model generation is a relatively new research field [8] and has multiple areas of application, such as simulation models for physical systems, biochemical processes, and manufacturing. The abstract models produced by LEMA's model generator [9], [10], [11] are intended to be used in system-level simulations to verify properties such as connectivity between the digital and analog circuits [3] or for use in formal verification [4]. These models are therefore designed to abstract unnecessary details in order to make the model generation and simulation computationally feasible.

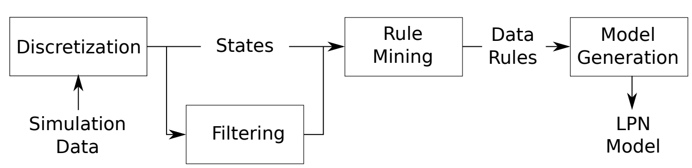

Figure 2: ModelGen flow.

A high-level flow diagram of the method is presented in Figure 2. The flow starts with the discretization of the simulation data and the grouping of data points into discrete states. If necessary, the states can be filtered to reduce the amount of noise in the system. Afterwards, the states are analyzed to create a set of *data rules*. The data rules, which describe simulation *data patterns*, are used in the new model generation module [12].

Every data rule is transformed into an LPN independently of others and resembles a state machine, which continuously checks input signals to determine, when to change the output state. The resulting model not only captures the behavior observed in the simulation trace, but it also is capable of producing new behaviors thereby generalizing the simulation trace.

IV. Discussion

Last year, we presented the initial concept for this model generation workflow. Since last year, we have made a few changes to improve the flow. This talk will highlight these recent developments:

- The project architecture has been redesigned to allow usage of metric functions at every processing stage. The appropriate algorithm for discretizing, filtering, or synthesizing an LPN is selected, based on its cost function, which provides finer control over model variability.
- Improved discretization methods for discrete-multi-valued (DMV) signals with clusterization techniques. The original methods relied on user-provided constants to detect and process DMV signals, while the new approach requires only absolute tolerance values, and provides better means for handling DMV signals.
- New filtering algorithm, which acts as an adaptive low-pass filter. The filter groups discrete states by clustering data, based on their duration, to determine states that represent the majority of signal duration. The method is supposed to be a less computationally expensive alternative to the existing pattern detection algorithm.
- Multiple improvements in rule mining and model generation modules to allow better handling of model reset conditions, state timing information and rule conflicts.
- Analysis of additional case studies from simple digital circuits to complex AMS systems such as voltage-controlled oscillator, switched capacitor integrator and tunnel diode oscillator.

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