CAREER: SOISTICe: Software Synthesis with Timing Contracts for Cyber-Physical Systems

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Timing Challenges in Software Synthesis

- Timing behavior affects functional correctness and many design metrics.
- Synthesis of CPS software faces timing-related challenges:
  - ✧ **Diversity of timing requirements** from different design metrics,
  - ✧ **Complexity of timing analysis**, and
  - ✧ **Uncertainty of timing behavior** from dynamic environment.
- Timing constraints are often set in an ad-hoc fashion.
- Lack of holistic consideration of timing through synthesis process.

SOISTICe Framework

Theme A: Co-design and Design Refinement with Timing Contracts

A1. Multi-metric Co-design with Horizontal Timing Contracts Exploration

- Explore timing constraints while trading off multiple design metrics.
- Identify critical timing factors for co-design and choose right formalism.
- Develop co-design algorithms for design space exploration.

A2. Hierarchical Design Refinement with Vertical Timing Contracts

- Assign timing "budget" for lower-level components during refinement.
- Represent timing behavior and constraints across system hierarchy.
- Efficiently estimate the timing complexity of subcomponents.

Theme B: Timing-centric Holistic Task Generation and Mapping

- Develop interactive task synthesis approaches: 1) quick assessment of feasibility and bottlenecks, 2) partial synthesis under incomplete constraints, and 3) additive synthesis under updated constraints.
- Task synthesis of heterogeneous and hierarchical functional models.

Theme C: Function-Architecture Co-simulation with Contracts

- Timing contracts modeling and monitoring during co-simulation.
- Explicit and modular representation of task synthesis options.
- Integration of simulation and analytical algorithms.

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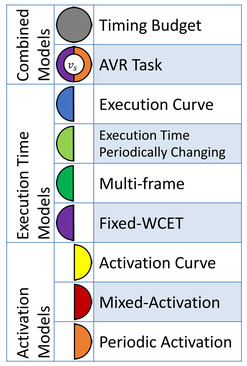
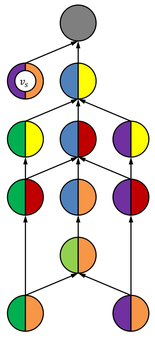
Industry Collaborators: TOYOTA InfoTechnology Center, U.S.A., Inc. · United Technologies Research Center · SRI International · National Instruments

Theme A: Analysis of Timing Models for Contract Formalism





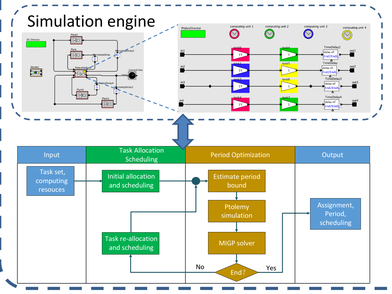
Timing Model Tree

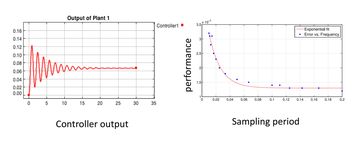
- Specific models can be converted to more general models on parent nodes.
- Facilitate integration and synthesis of heterogeneous (task) components via conversions to the unified model on their common ancestor node.
- Timing model tree can be extended to functional layer.

Cross-Layer Co-Design

- Timing contracts can be defined and explored based on timing model tree.
- Explore task activation model and time budget, together with task generation, allocation and scheduling.
- Address safety, performance, security, fault tolerance and extensibility .

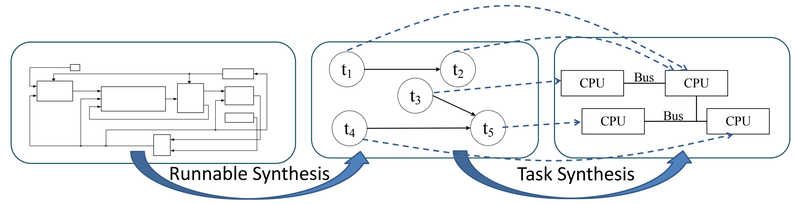
Theme C: Control Performance and Schedulability Co-design with Simulations in Ptolemy

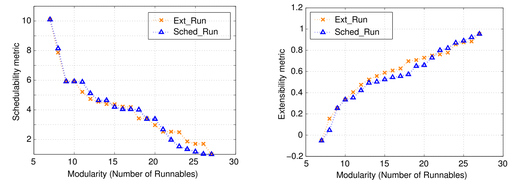




- Integrate simulation with analytical optimization.
- Explore task allocation & scheduling with heuristics.
- Explore task sampling periods with MIGP, while using simulations to estimate control performance.
- Iterate between task allocation/scheduling and period optimization.

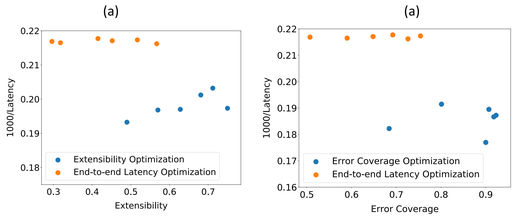
Theme B: Task Generation and Mapping with Consideration of Extensibility, Fault Tolerance and Communication Cost

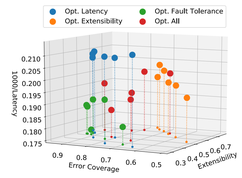




Industrial case study:

- 58 subsystem block, 5 inputs, and 10 outputs.
- Two heuristics based on optimizing extensibility (Ext_Run) and optimizing schedulability (Sched_Run).
- Ext_Run provides slightly better runnable-level extensibility and similar schedulability, when compared with Sched_Run.





Trade-off among system extensibility, fault tolerance and communication cost

- Define system-level metrics on extensibility, fault tolerance (error coverage) and communication cost (total path latency).
- Simulated annealing based optimization with parameterizable objective function.
- Clear trade-off between extensibility and communication cost, and between fault tolerance and communication cost.

- Bowen Zheng, et al., "Timing and Security Analysis Framework for VANET-based Intelligent Transportation Systems", *ICCAD*, 2017.
- Hongjia Li, et al., "Deep Reinforcement Learning: Framework, Applications, and Embedded Implementations", *ICCAD*, 2017.
- Bowen Zheng, et al., "Delay-Aware Design, Analysis and Verification of Intelligent Intersection Management", *SMARTCOMP*, 2017.
- Yongxing Bao, et al., "Quantitative Performance Evaluation of Uncertainty-Aware Hybrid AADL Designs Using Statistical Model Checking", *TCAD*, 2017.
- Qi Zhu, et al., "Extensibility-Driven Automotive In-Vehicle Architecture Design", *DAC*, 2017.
- Hengyi Liang, et al., "Addressing Extensibility and Fault Tolerance in CAN-based Automotive Systems", *NOCS*, *2017.*
- Tianshu Wei, et al., "Deep Reinforcement Learning for HVAC Control in Smart Buildings", *DAC*, 2017.
- Mingsong Chen, et al., "Sustainability- Oriented Evaluation and Optimization for MPSoC Task Allocation and Scheduling Under Thermal and Energy Variations", *TSUSC*, 2017.

Scientific Impacts

- Explore timing constraints quantitatively throughout the software synthesis process to produce correct, efficient, and predictable CPS software implementation.
- Develop new methodologies for timing contracts definition and exploration, novel algorithms for timing-centric task generation and mapping, and a simulator with explicit timing contracts evaluation.
- Use automotive and transportation systems as primary case studies and provide new tools for automotive software development.

Broader Impacts and Education

- Enable fundamental advances in design automation methods and tools for cyber-physical systems.
- Establish close industry collaborations and facilitate potential technology transfer.
- Leverage research findings to build an interdisciplinary education program for K-12, undergraduate, and graduate students: 1) outreaching to K-12 schools with Lego Mindstorm, 2) extending undergrad embedded systems course and advising senior design projects, 3) developing new graduate course on CPS, and 4) writing a textbook in collaboration with industry.