ECE382N.23: Embedded System Design and Modeling

Lecture 4 – System Modeling

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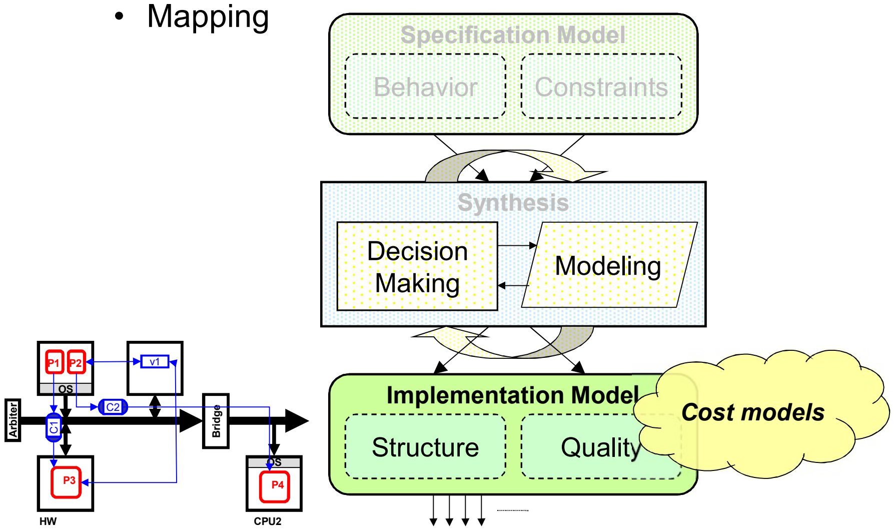
Lecture 4: Outline

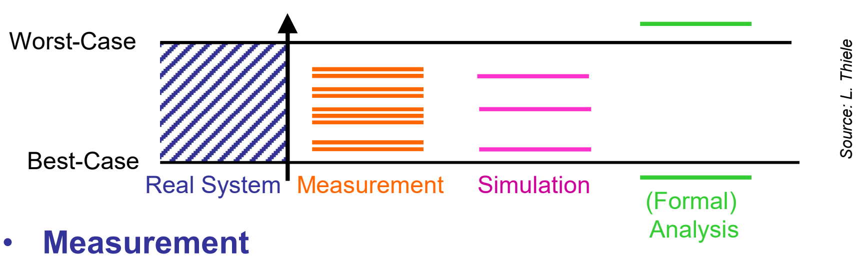
- **Evaluation and estimation**
  - Methods
- **Simulation**
  - Simulation methods
- **Analysis**
  - Component- and system-level estimation
- **Hybrid approaches**
  - Semi-analytical methods
  - Machine learning-based prediction methods

System Modeling

- **System definition**
  - Platform netlist
  - Mapping
- **System quality**
  - Performance, power, …



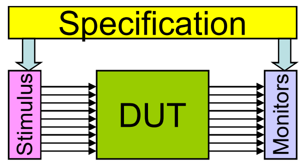
Evaluation and Estimation Methods



- **Measurement**
  - Fast (real time), exhaustive?
  - Requires physical implementation
- **Simulation**
  - Speed vs. accuracy tradeoffs
  - Quality of testbench, corner cases?
- **Analysis**
  - Worst-case/best-case assumptions
  - Tightness of upper/lower bounds? Dynamic effects?

Simulation Methods

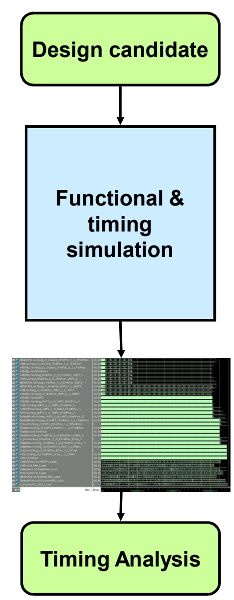
- **Create stimuli and simulate model**



- **Inputs**
  - Specification
    - Used to create interesting stimuli and monitors (golden output)
  - Model of DUT
    - Typically written in HDL or C or both
- **Output**
  - Failed test vectors (validation)
  - Quality metrics (evaluation)
- ➢ **Speed vs. accuracy**
  - ➢ Fundamental tradeoff

Co-Simulation

- **Component simulation models**
  - Functional model
  - Timing, energy, … models
- **Co-simulation**
  - System description language & model
  - Generates a trace
- **Simulation trace analysis**
  - Check functional results
  - Extract metrics from trace
  - Latency, throughput, etc.



Source: C. Haubelt, J. Teich

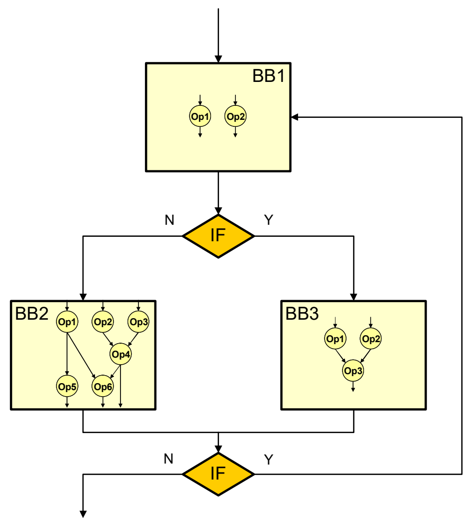
Analysis Methods

- **Static analysis**
  - Symbolic, mathematical models for avg/best/worst case
  - ➢ Worst-case execution time analysis (WCET) of single task
  - ➢ Real-time scheduling of single processor
  - ➢ Best-case roofline models of system
- **Probabilistic analysis**
  - Statistical models, distributions for "average" case
  - ➢ Queuing theory for computer systems
- **Deterministic dynamic analysis**
  - Min-plus/max-plus algebra, upper/lower bounds over time
  - ➢ Network calculus, real-time calculus
  - ➢ Modular Performance Analysis (MPA) of parallel systems

Worst-Case Analysis

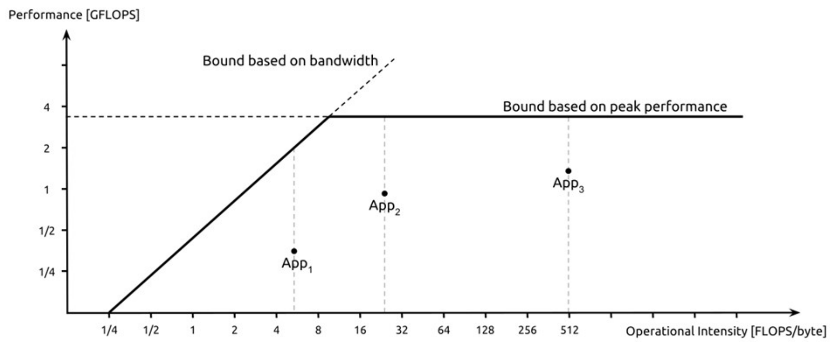
- **Example: worst-case execution time (WCET) analysis of single task**
  - Micro-architecture analysis
    - – Compute bounds for each basic execution block
    - – Symbolically simulate statements on processor model (pipeline)
    - ➢ Conservative assumptions for dynamic effects (caches, predictors)
  - Path analysis
    - – Enumerate possible paths and take maximum of block sequence
    - ➢ Possible paths often highly dynamic (loop bounds, false paths)
  - ➢ Basis for back-annotation or static system analysis
    - ➢ Combine static code analysis with dynamic system simulation
    - ➢ Static or dynamic model of inter-process cross-dependencies

Control/Data Flow Graph (CDFG)



Best-Case Analysis

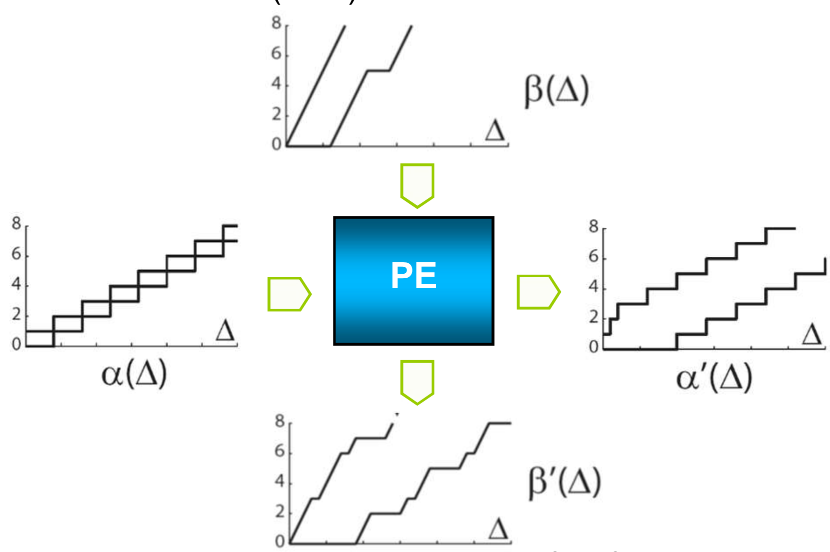
- **Example: roofline modeling**
  - Bottleneck analysis
  - Application arithmetic intensity
  - Architecture peak bandwidth and operation throughput
  - Memory- vs. compute-bound regions



Source: Wikipedia

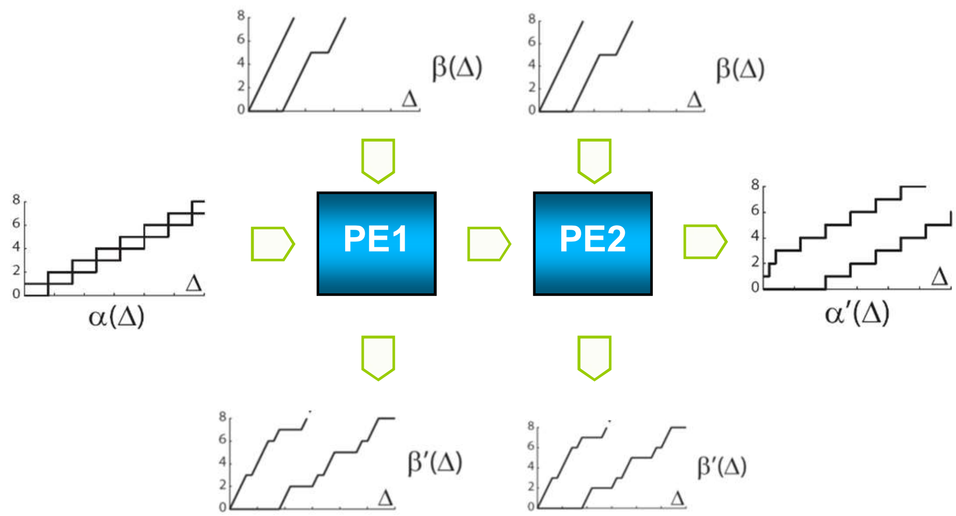
System-Level Dynamic Analysis

- **Modular Performance Analysis (MPA)**
  - Real-time calculus (RTC)



Source: C. Haubelt, J. Teich, DATE '09 Tutorial

MPSoC Analysis with MPA



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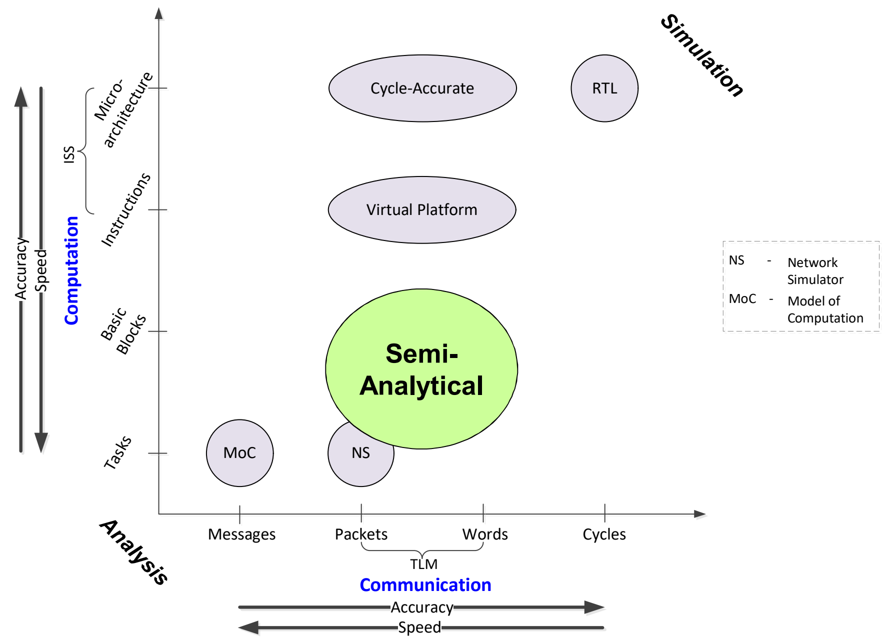
System-Level Modeling Space



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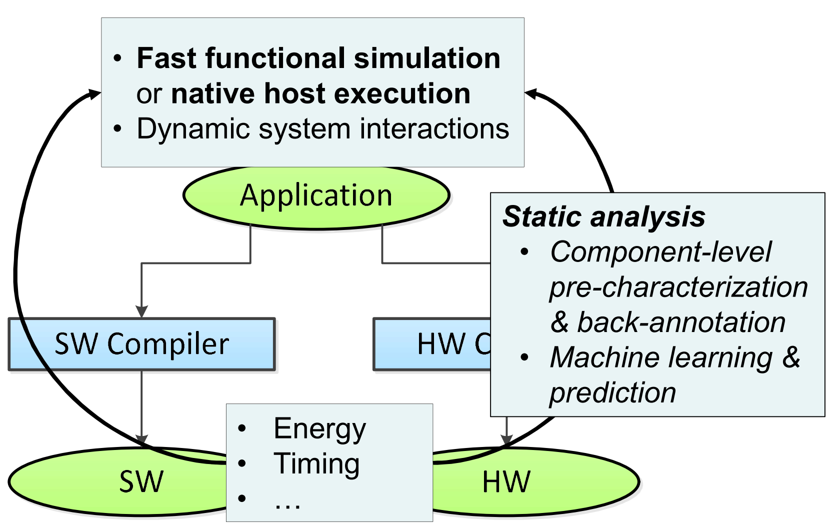
Semi-Analytical Modeling



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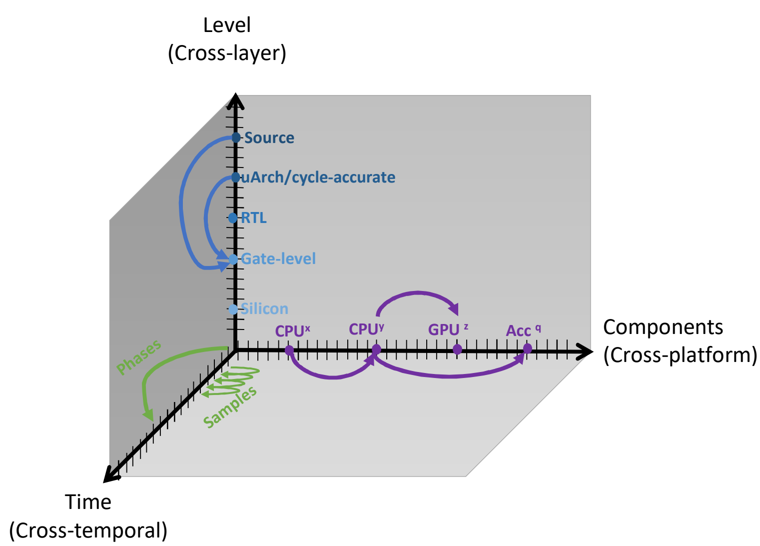
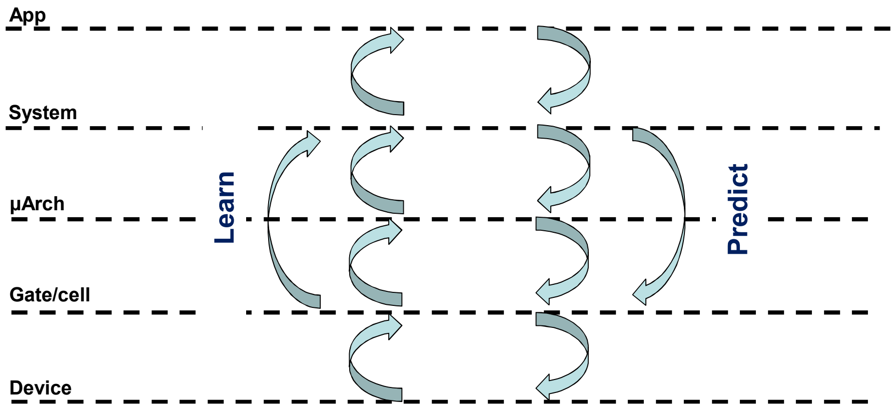
ML for System-Level Modeling

- **Learn rather than construct models**
  - Learn an abstract model from detailed observations
- **Predict rather than simulate**
  - Replace detailed simulations with predictions
- ➢ **Supervised regression formulations**
  - Interpolate/extrapolate (complex) behavior from (a few) samples
  - ➢ Linear regression: most problems are not linear
  - ➢ Non-linear regression: advanced non-linear models
  - ➢ Deep learning: often infeasible amount of training

System-Level Predictive Modeling



Cross-Layer Prediction



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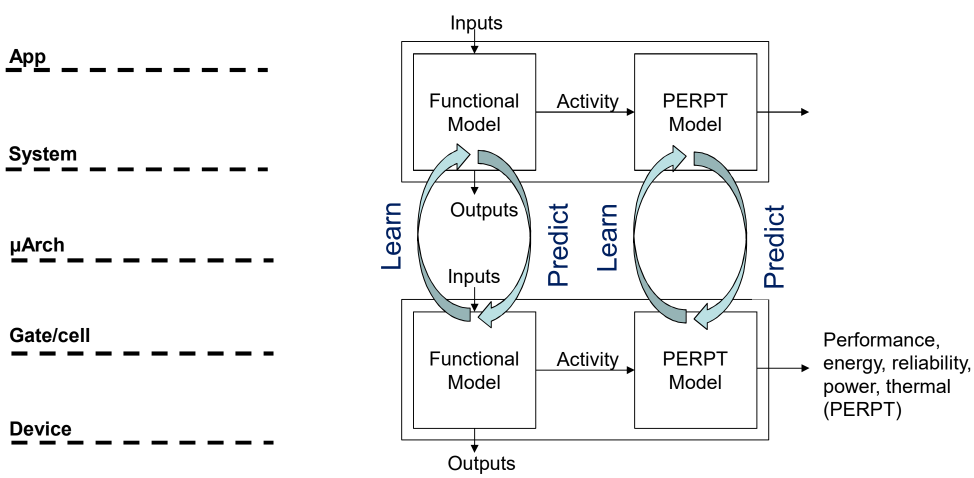

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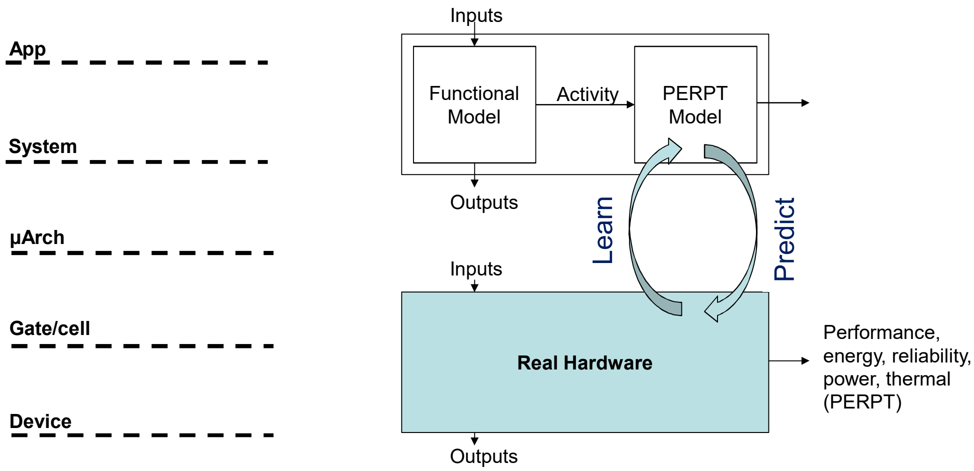
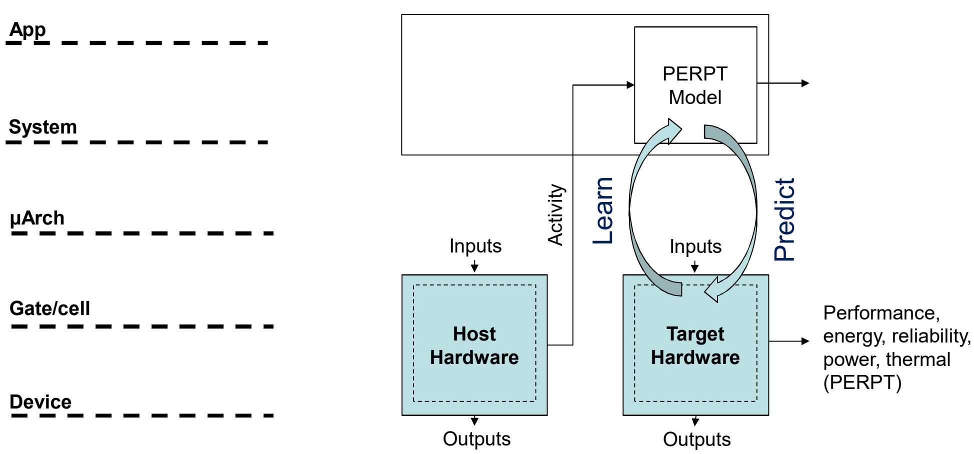


Cross-Platform Prediction



Lecture 4: Summary

- **Simulation**
  - Detailed system simulation
  - Trace-based simulation
- **Static analysis**
  - Worst/best/average case bounds
  - Execution time analysis of single task
  - Real-time calculus for concurrent systems
- **Hybrid approaches**
  - Semi-analytical modeling
  - Machine learning-based prediction