Structured Singular Value Control for Modular Resource Management in Multilayer Computers

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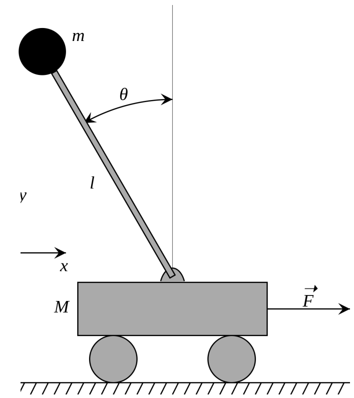
Why Computing Systems?



More computers than any of these systems in this room!

Resource Management in Computers

Configurable Parameters

Frequency, Scheduling…

Limited resources

Energy, Storage…

Many demands

Quality of Service, Fairness…

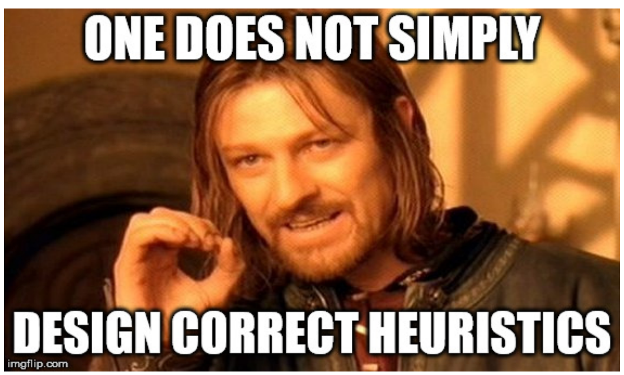
Computers have dedicated resource controllers

There is a Problem!

don’t think they
Computer architects don’t know Control theory
^ or
Machine learning

Computer Resource Management Today

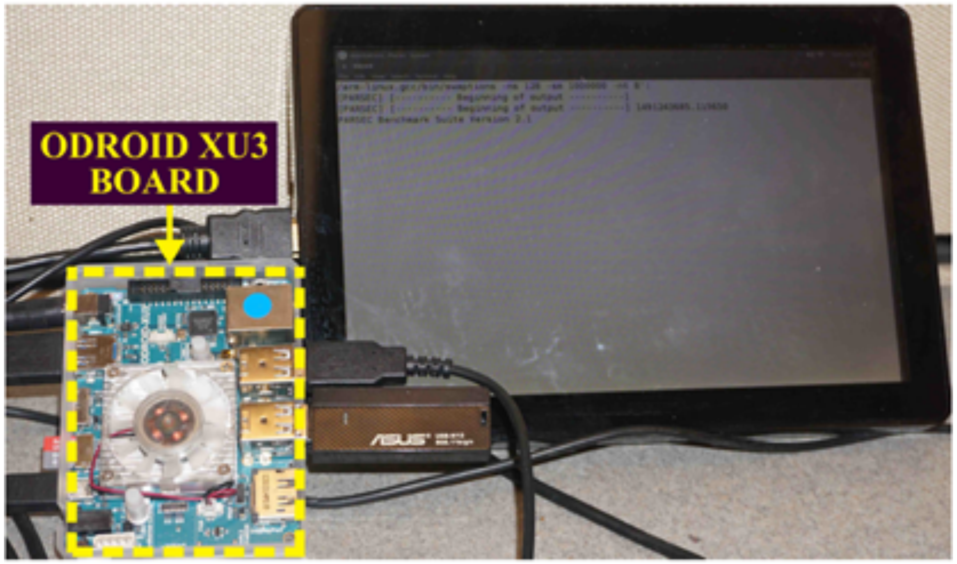
Ad hoc heuristics!



No guarantees

No reusability

A Prototype System



Samsung Galaxy S5 processor + Ubuntu

Challenges for Formal Computer Control

- Modular control

  Robustness

  Communication

- Lack of models
- Discrete inputs

  Robustness

- Different goals

  Versatility

- Tight decision-making

  Fast and low cost

- Knowledge gap

  Tools and abstractions

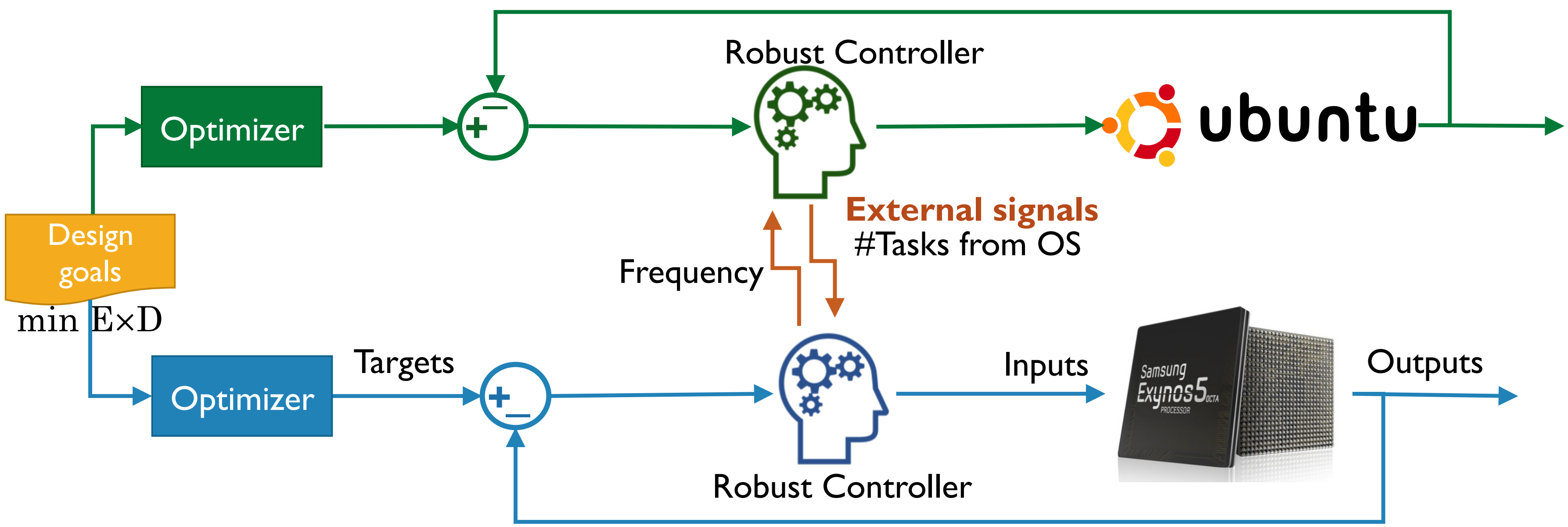
Robust control is a necessity!

1 GHz, 1.1 GHz …

Tracking goals, or
Maximize $\text{Performance}^2/\text{Power}$, s.t. constraints

Our Approach

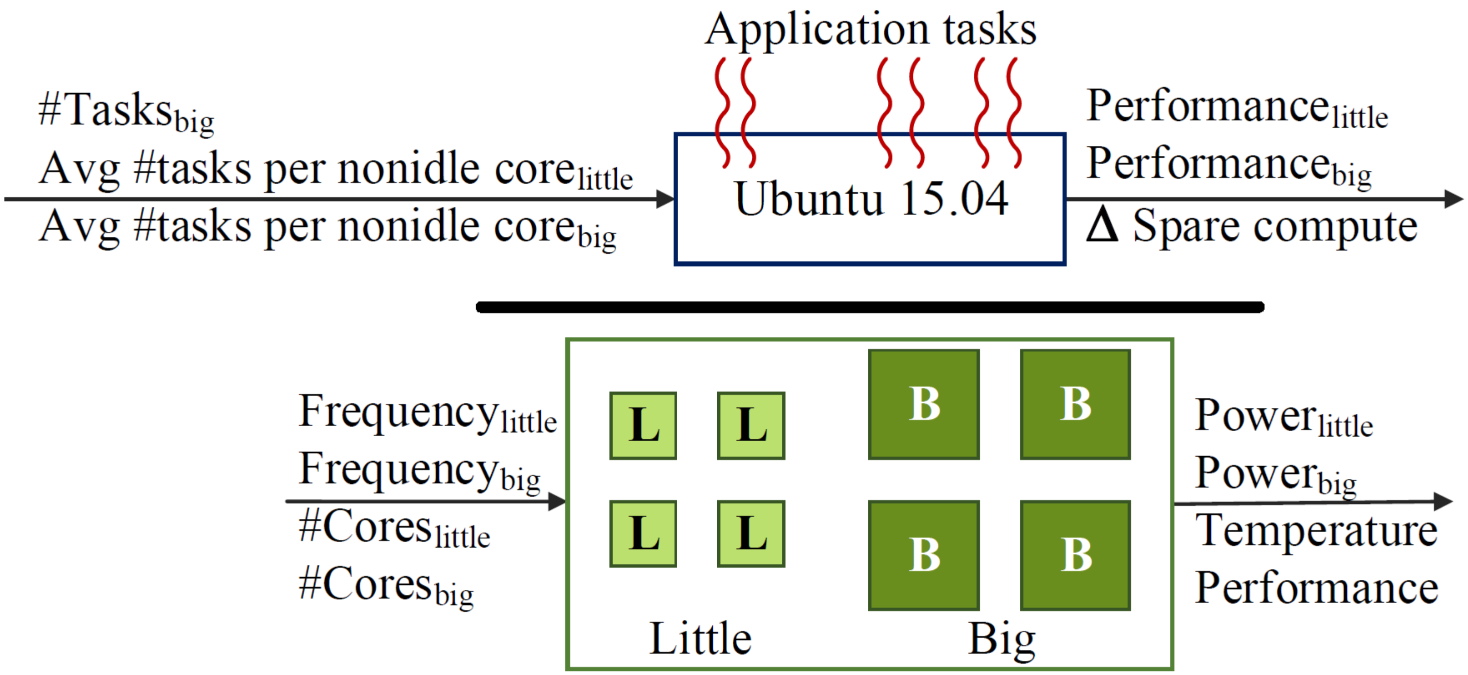
Mixed sensitivity H_{∞} design



Use black box system identification for modeling

Consider influence of other layers, nonlinearities as "uncertainty"

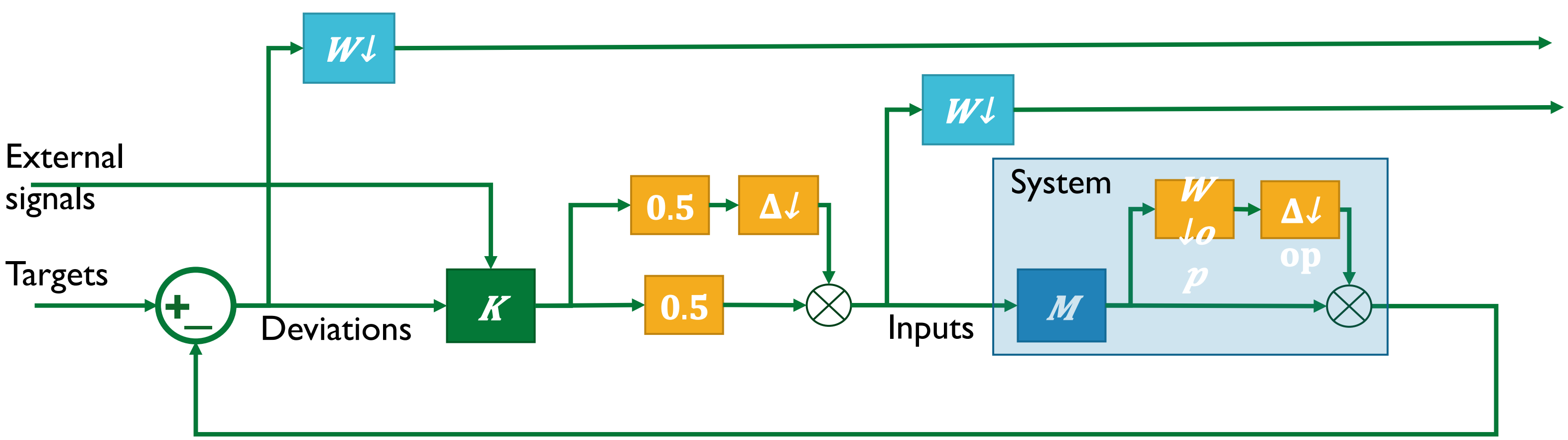
System



Minimize Energy×Delay ⇔ Maximize $\text{Performance}^2/\text{Power}$,
s.t. power and temperature are below limits

Structure Specification

- Empirical model, M
- Output multiplicative uncertainty, Δ_{op}
- Input additive uncertainty, Δ_{nl}
- Performance weights, W_p and W_u

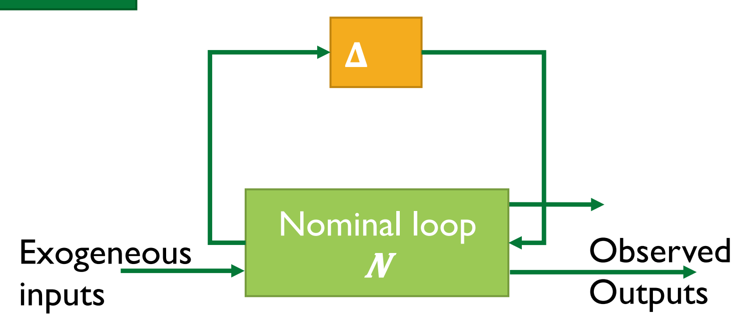


Structure Specification

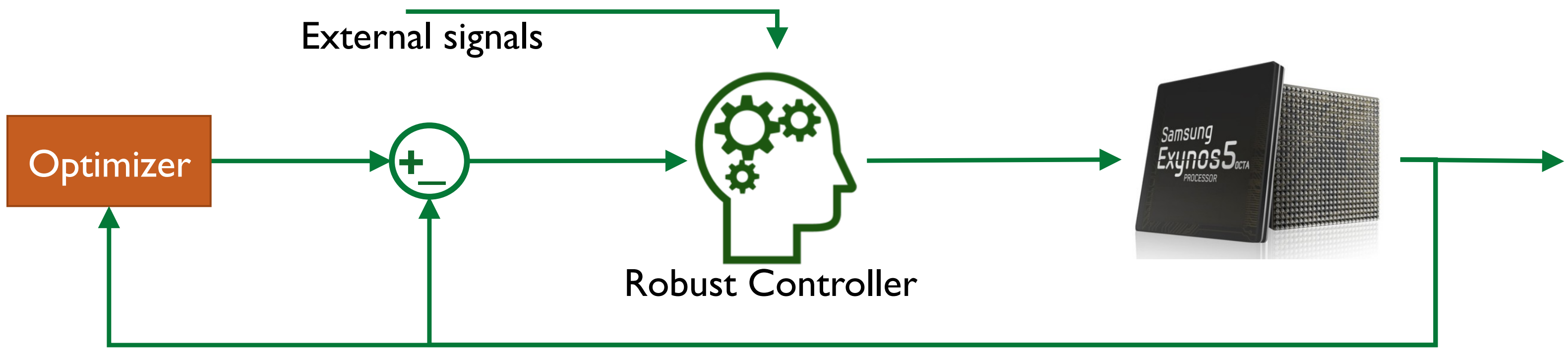
- Empirical model, M
- Output multiplicative uncertainty, Δ_{op}
- Input additive uncertainty, Δ_{nl}
- Performance weights, W_p and W_u

Modular computer control ⟶ Robust performance problem!

$$\Delta = \begin{bmatrix} \Delta_{op} & & \\ & \Delta_{nl} & \\ & & \Delta_{perf} \end{bmatrix}$$

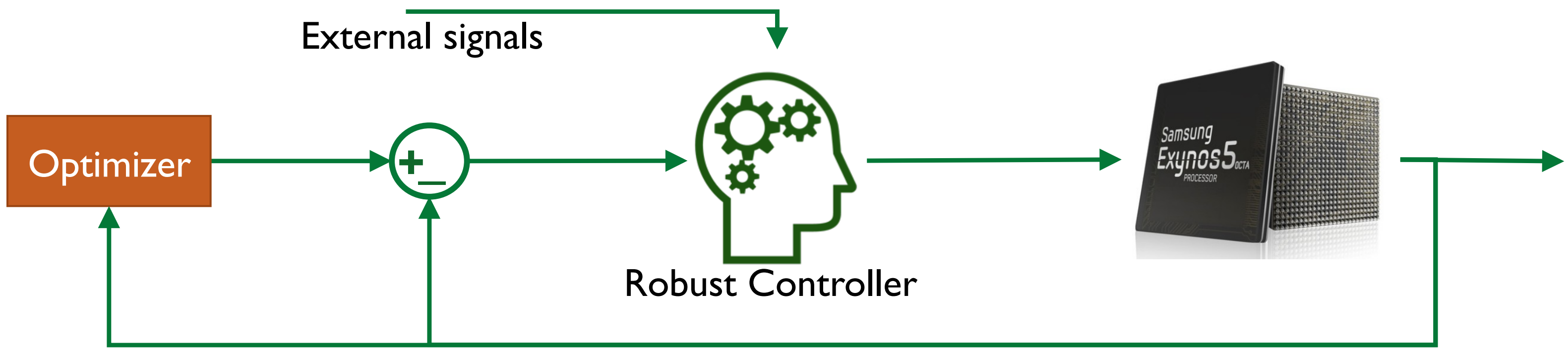


Optimizer



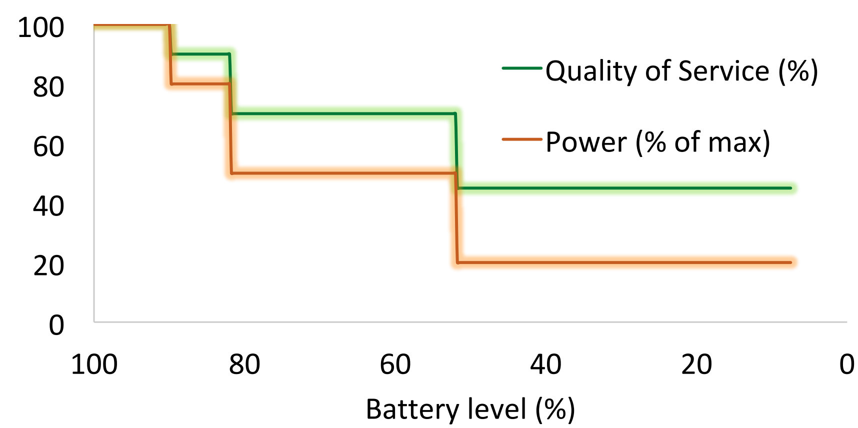
1. Meeting fixed output targets
   Video processing

Optimizer

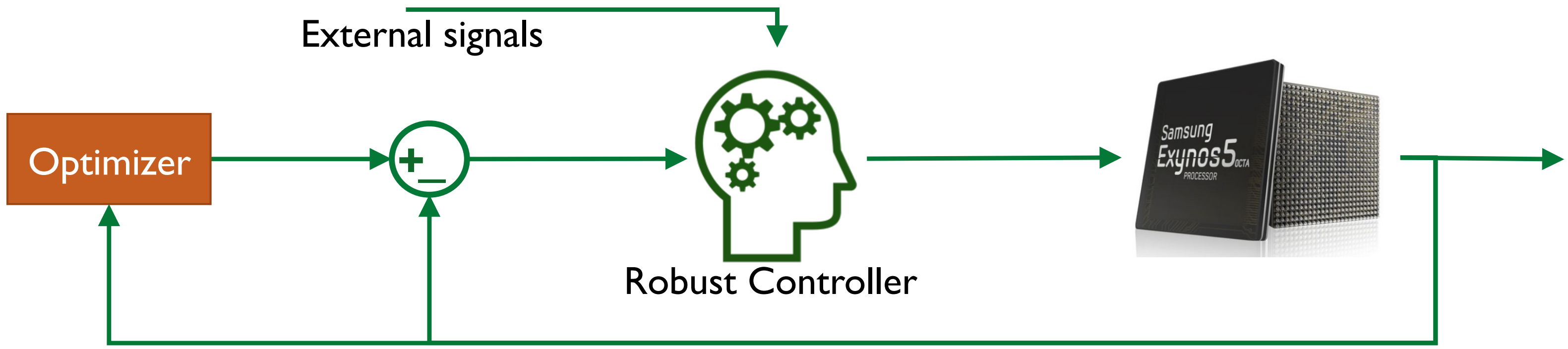


1. Meeting fixed output targets
   Video processing

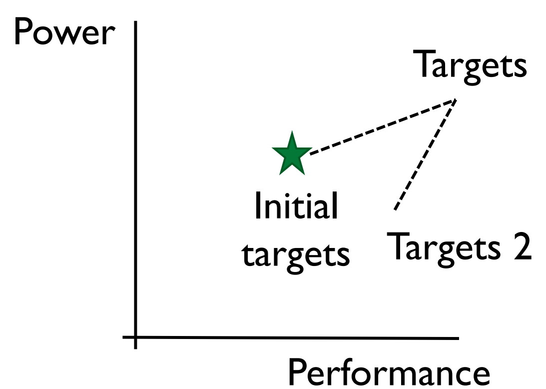
2. Meeting changing output targets
   Battery optimization



Optimizer

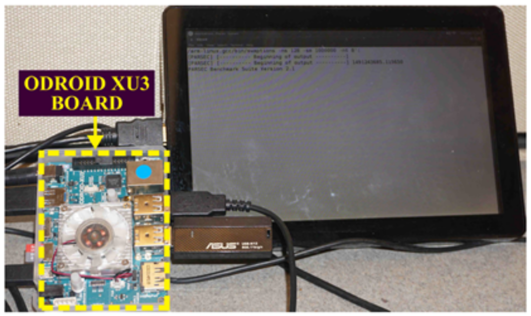


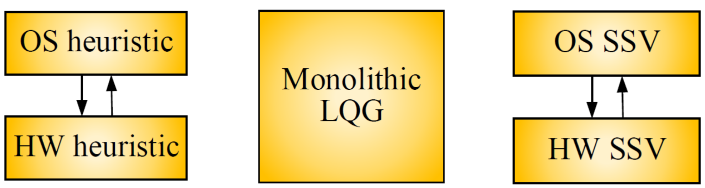
1. Meeting fixed output targets
   Video processing
2. Meeting changing output targets
   Battery optimization
3. Optimization
   min Energy×Delay ⇔ max $\text{Performance}^2/\text{Power}$

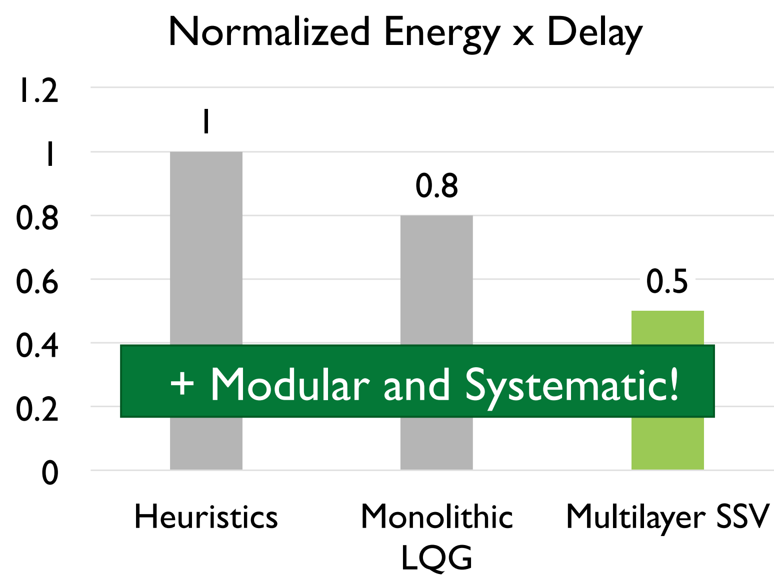


Impact

First work to use Robust control theory for multilayer computers



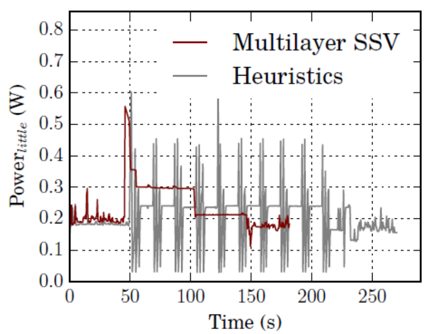




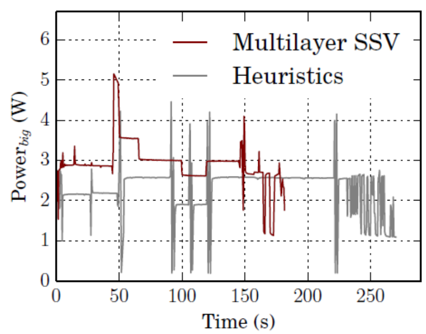
Average across 14 standard applications

37% faster with 20% lower energy ⇒ 50% better ED

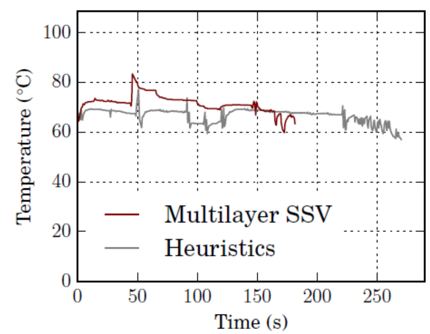
Case Study with *blackscholes*



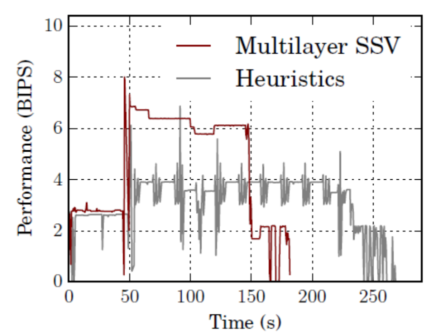
(a) Power of little cluster



(b) Power of big cluster



(c) Temperature



(d) Application performance

Low Overheads

Parameter	HW SSV	OS SSV
Dimension	20	16
Required storage	2.6 KB	2.1 KB
Number of operations	$\approx$700	$\approx$600
Computation time	$\approx 28\mu s$	$\approx 25\mu s$
Power consumption	$\approx$20-25mW	$\approx$20-25mW

Conclusions

- Computers need to be extremely efficient
- Unique challenges in formal control for computers
  - E.g., modularity, abstractions
- Our approach uses Robust control theory
  - Prototyped results demonstrate effectiveness
- Tremendous opportunity for this community!

- In the paper:
  - Challenging scenarios with program mixes
  - Optimizer details