Yukta: Multilayer Resource Controllers to Maximize Efficiency

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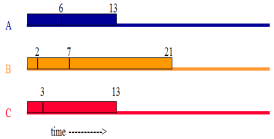
Resource Management in Computers

Configurable parameters

Frequency



Scheduling

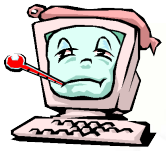
Limited resources

Energy

Storage

Many objectives

Performance

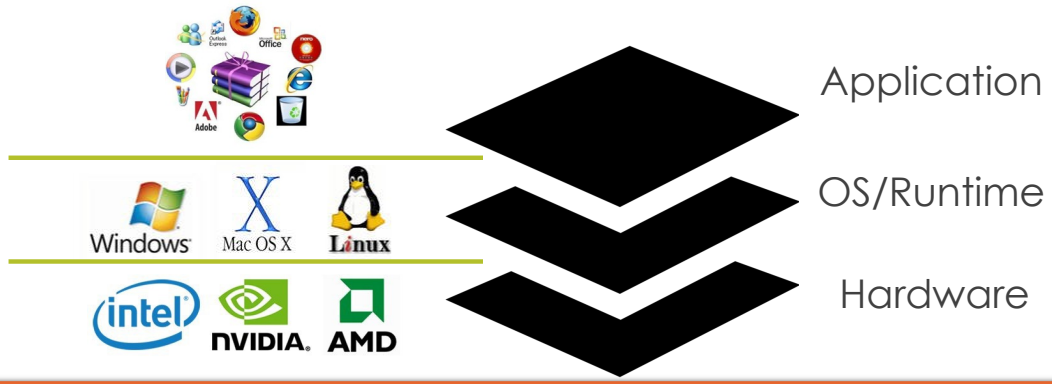


Thermals

Fairness

Resource Management System

Designing Computer Resource Management Systems



Different resources, parameters and design teams!

Modular

Coordinated

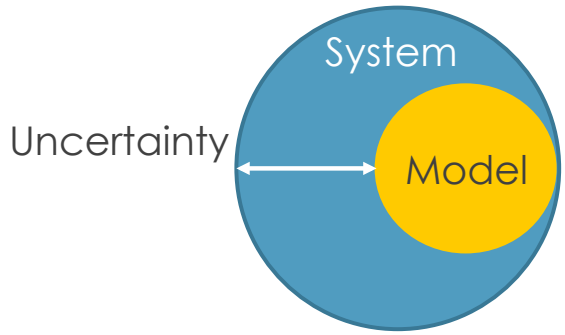
Handle uncertainty

Contributions of This Work

- Propose Robust Control Theory for computer resource management
  - Describe why robust control theory is essential for computers
- Develop Yukta, a modular approach for coordinated multilayer control
  - Present how robust control theory is applied to multilayer resource management
- Prototype Yukta on an ARM big.LITTLE octacore running Ubuntu
  - 37% better performance and 20% lower energy than state-of-the-art

Why **Robust Control Theory** is Suitable for Computers? - I

- Robust control theory: Branch of control theory for **uncertain** environments

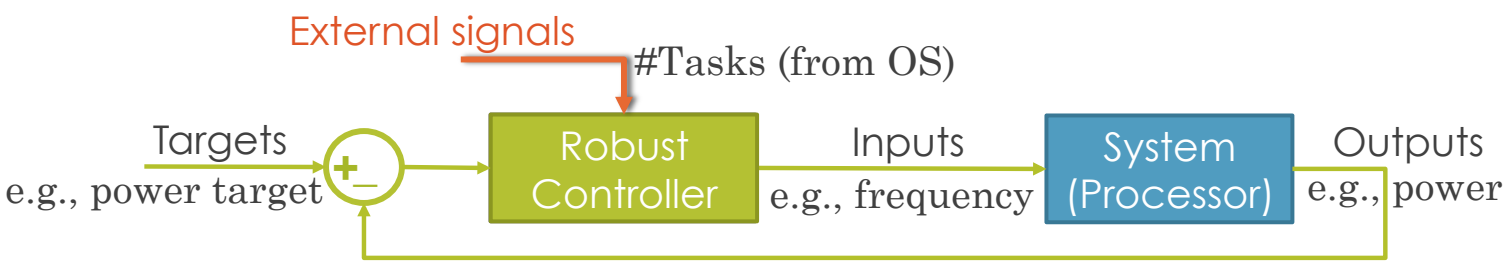


Robustness to uncertainty enables optimality under modularity

- Designers set a guardband for the amount of uncertainty to tolerate
  - 60% guardband ⇒ controller's guarantees hold even if model is off by 60%
- Computer control faces many forms of uncertainty
  - Partial system view, controller interference, program behavior, limited modeling…

Why **Robust Control Theory** is Suitable for Computers? - II

- Robust controllers have input channels for communication



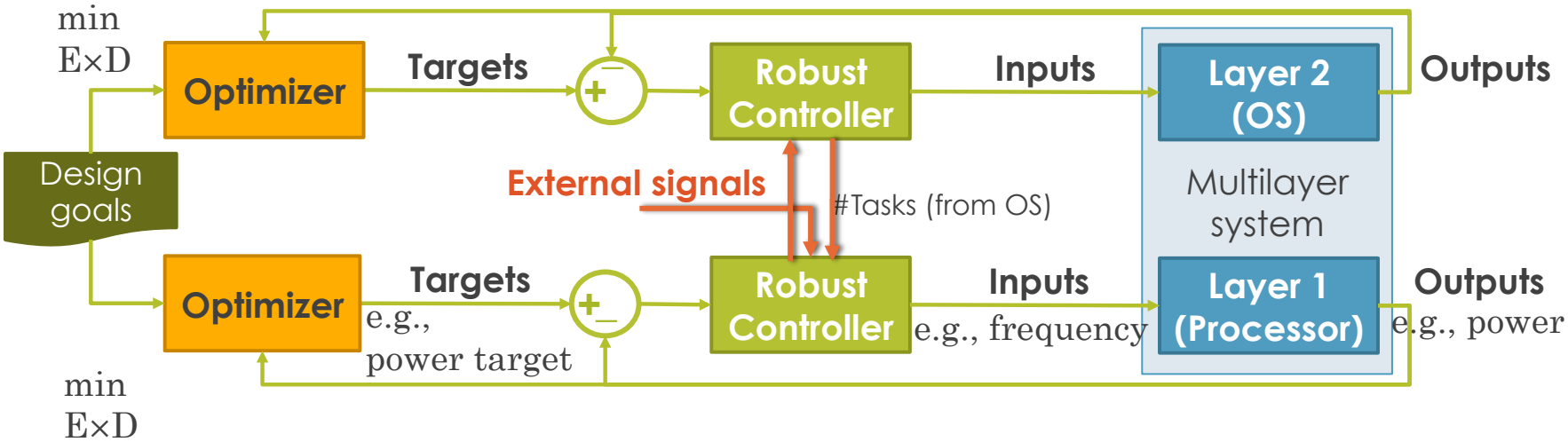
We use Externals signals for controller communication

Why **Robust Control Theory** is Suitable for Computers? - III

- Can work with discretized inputs as common in computers
  - E.g., core frequency, $f \in \{2\ GHz, 2.2\ GHz \ldots 3\ GHz\}$
- Guarantee precise bounds on meeting targets
  - E.g., core power can be kept within ± 0.05 W of the power target

Robust control theory is highly desirable for computer systems

Yukta: Multilayer Robust Controllers

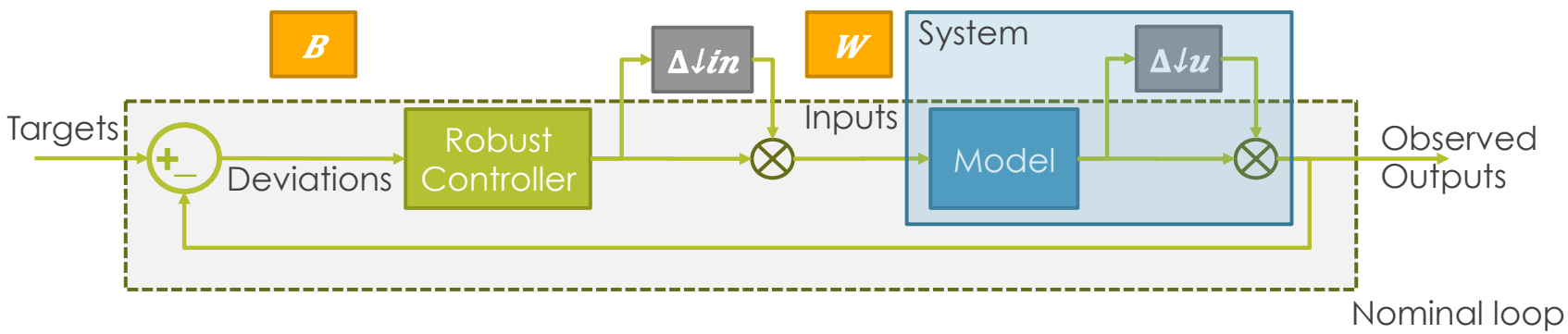


Modularly designed and **guaranteed** optimal behavior

First to propose robust control for modular multilayer management

Automated Synthesis of the **Robust Controller**

- Designer provides a model, and:
  - Output deviation bounds (B) : e.g, ±0.05W for power deviations
  - Input weights (W) : Relative overheads
  - Discrete input values ($\Delta\downarrow in$)
  - Uncertainty guardbands ($\Delta\downarrow u$) : Degree of desired robustness



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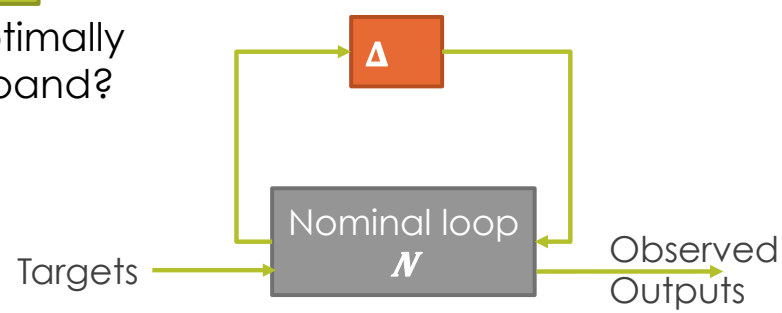
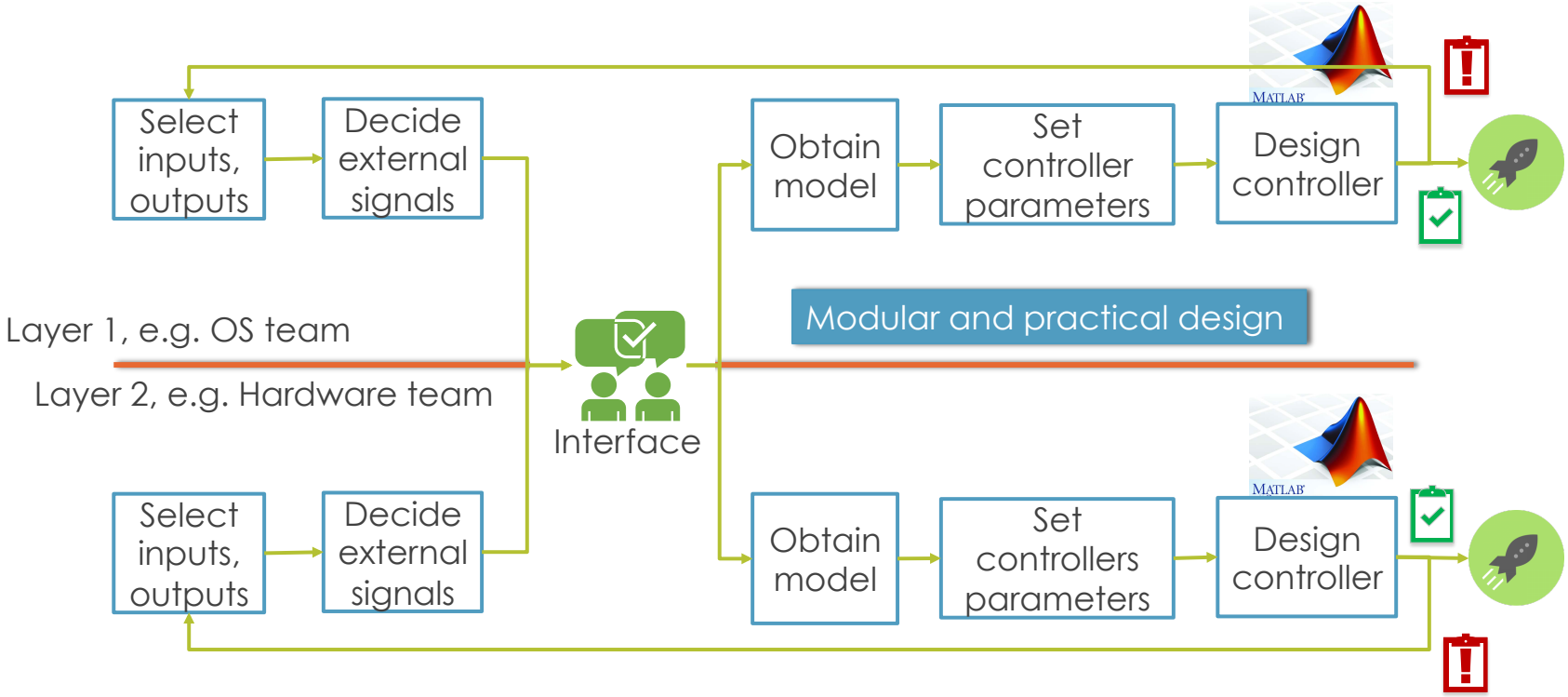
Structured Singular Value $SSV(N,\Delta)$

Can the controller guarantee the bounds optimally even under uncertainty as big as the guardband?

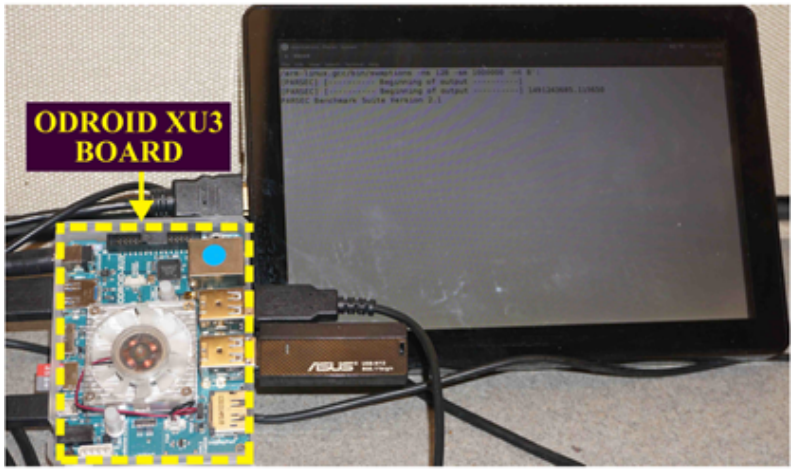
Synthesis is automated!

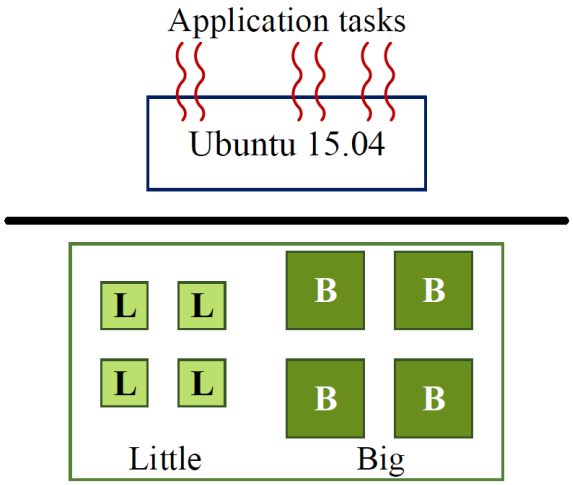


Designing Multilayer Controllers



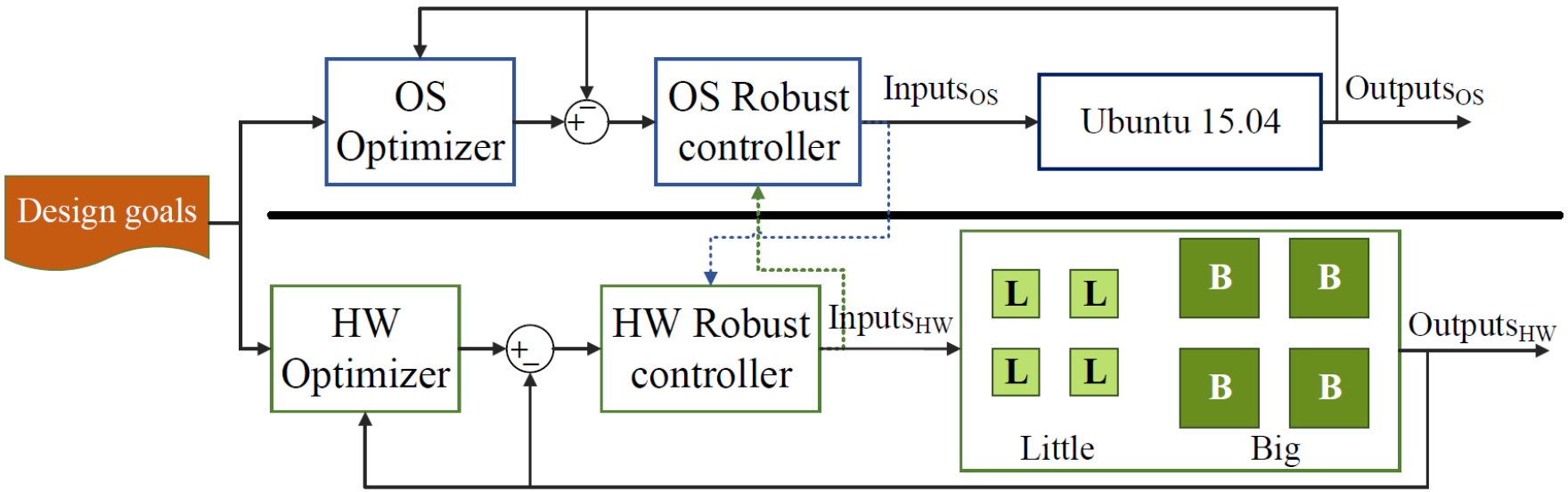
Prototype Yukta on a Challenging System



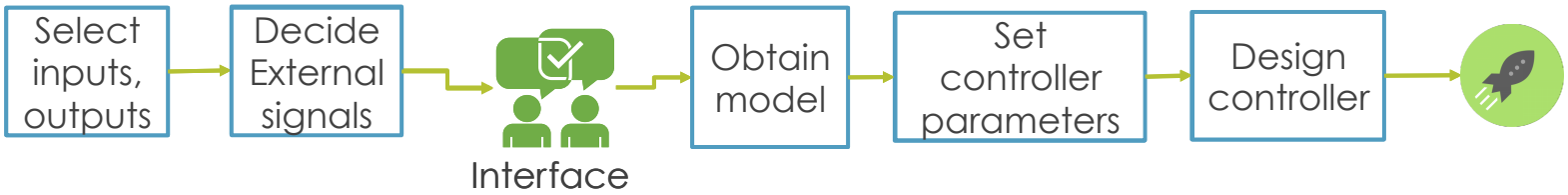


Minimize Energy×Delay under thermal and power constraints

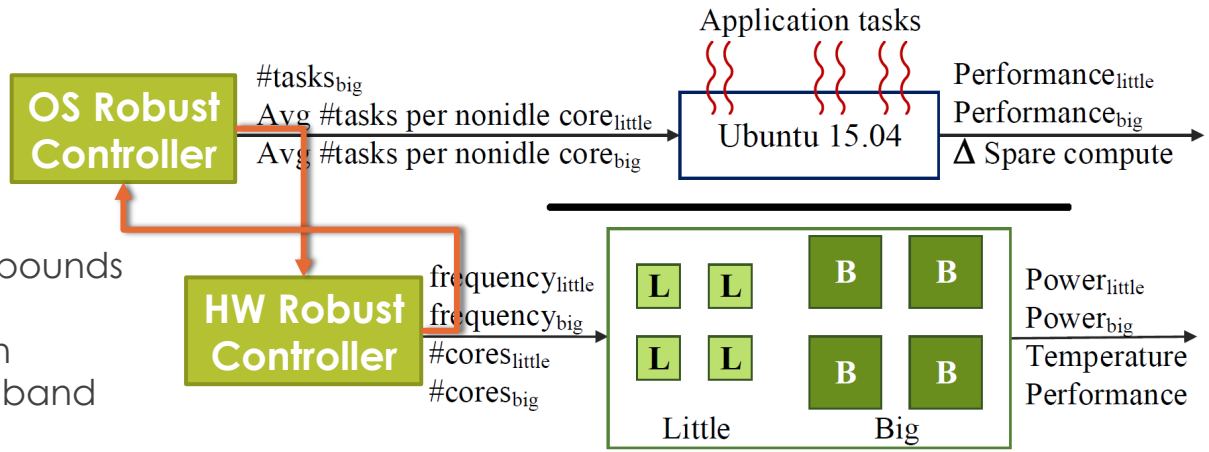
Prototyped Yukta Architecture



Designing **Robust Controllers** for the Prototype



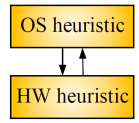
Data driven modeling (System Identification):
2 benchmarks each from SPECint, SPECfp and PARSEC



- Output deviation bounds
- Input weights
- Input discretization
- Uncertainty guardband

Evaluation

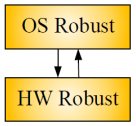
Industry based



Coordinated heuristics

[ISCA'16]

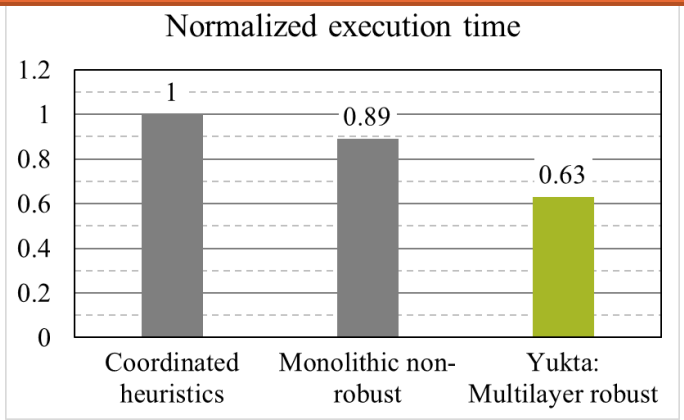
Monolithic non-robust

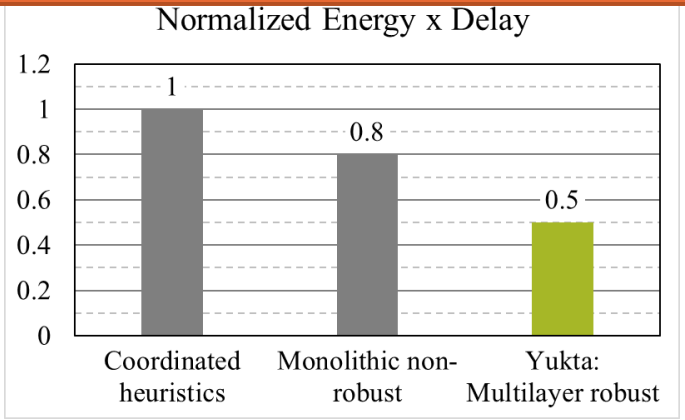


Yukta: Multilayer robust

Average across 8 PARSEC and 6 SPEC (multiprogrammed) workloads

Yukta makes the system 37% faster with 20% lower energy ⇒ 50% better ED





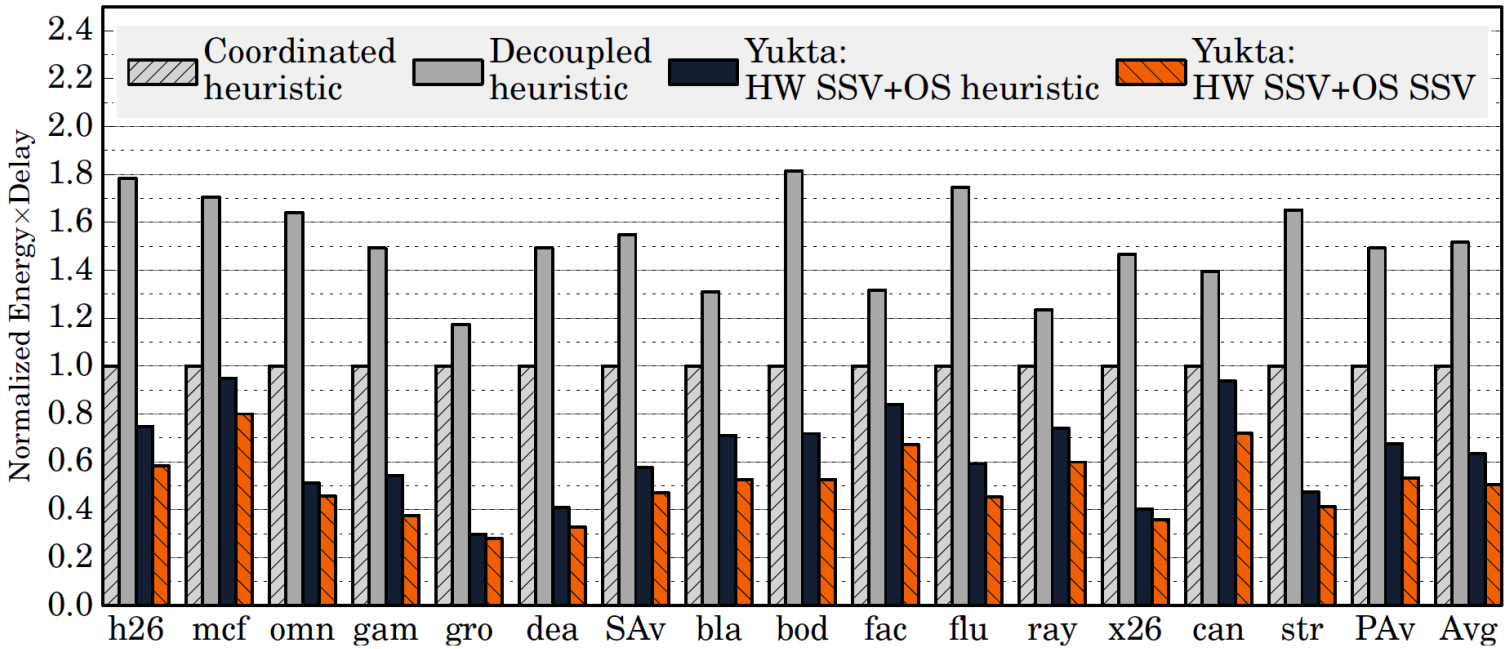
Summary

- Dynamic resource management must meet many goals simultaneously
- Resource controllers should be modular and coordinated
- We propose using **Robust Control Theory** for computer management
  - Optimized for uncertainty
- We develop **Yukta** for formal multilayer resource management
- **Prototype** demonstrates significant advancement
  - 50% reduced Energy×Delay on average
- Yukta is essential for resource efficient computing

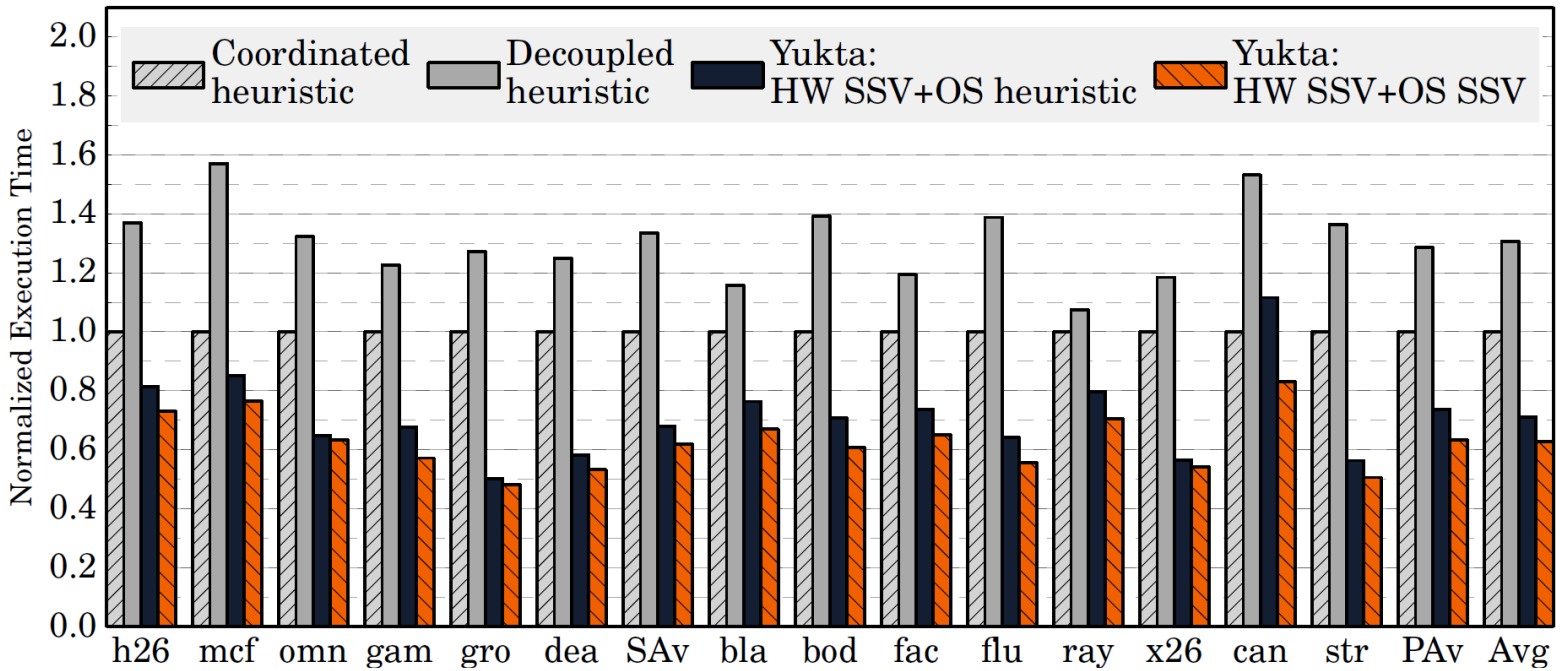
Concluding Remarks

- More details in the paper
  - Mathematical background of the Robust Controller
  - Yukta design details
  - Prototype design choices
  - Comparison with other designs and heterogeneous workloads
  - Sensitivity analysis
- Future work
  - Heterogeneous components in a layer
  - Hierarchical organization of controllers

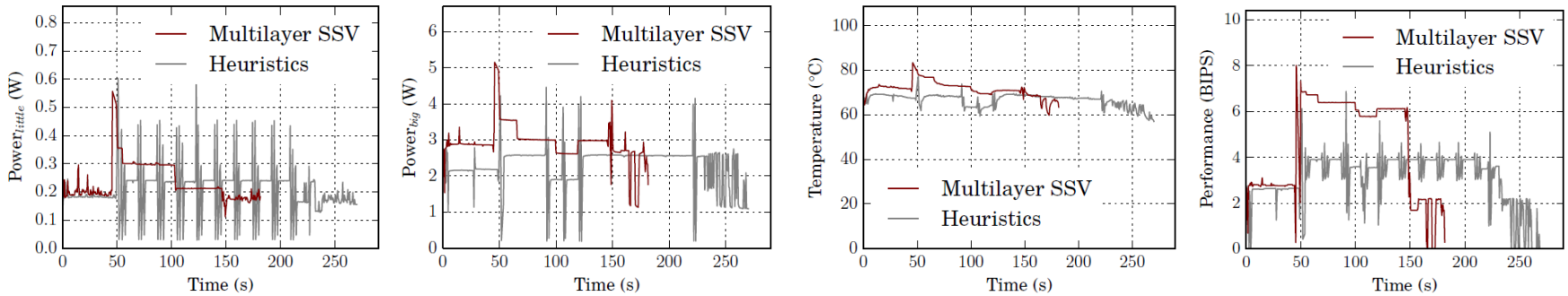
Yukta: Energy×Delay minimization



Yukta: Energy×Delay minimization

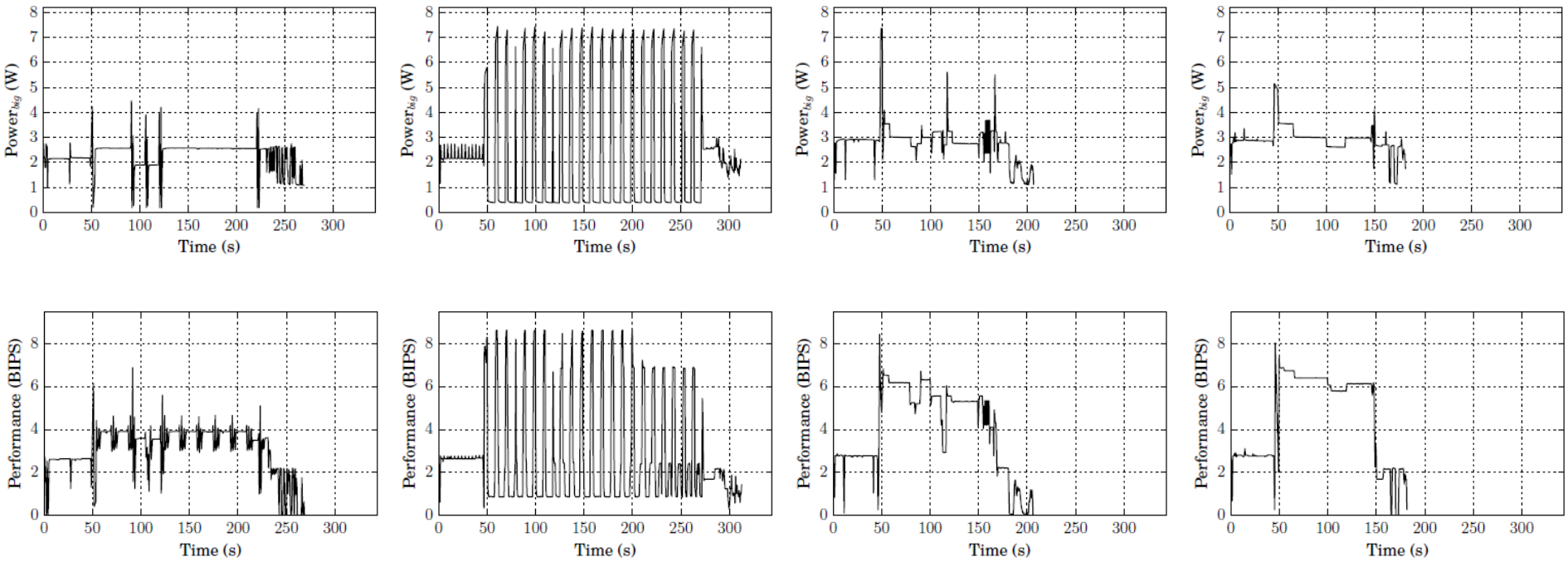


Case Study with *blackscholes*



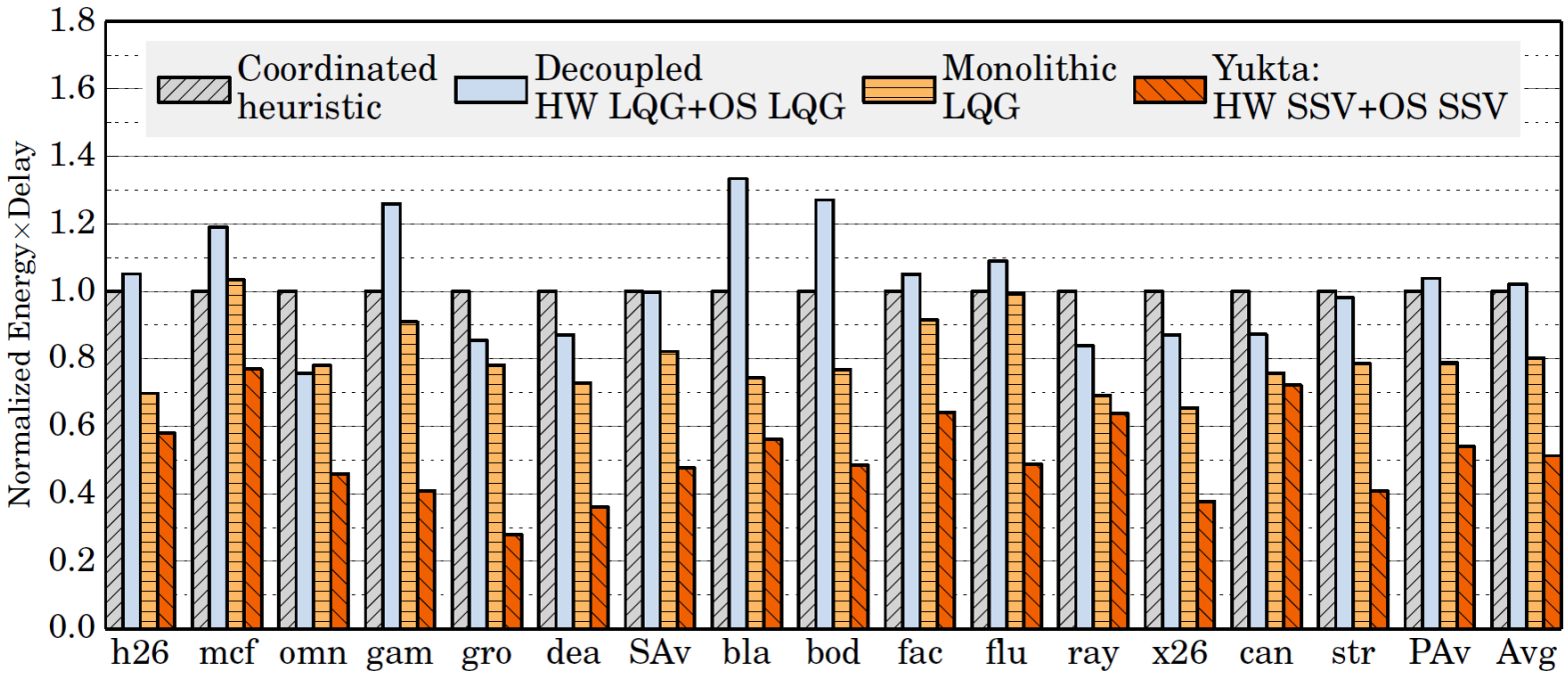
(a) Power of little cluster (b) Power of big cluster (c) Temperature (d) Application performance

Yukta: *blackscholes*

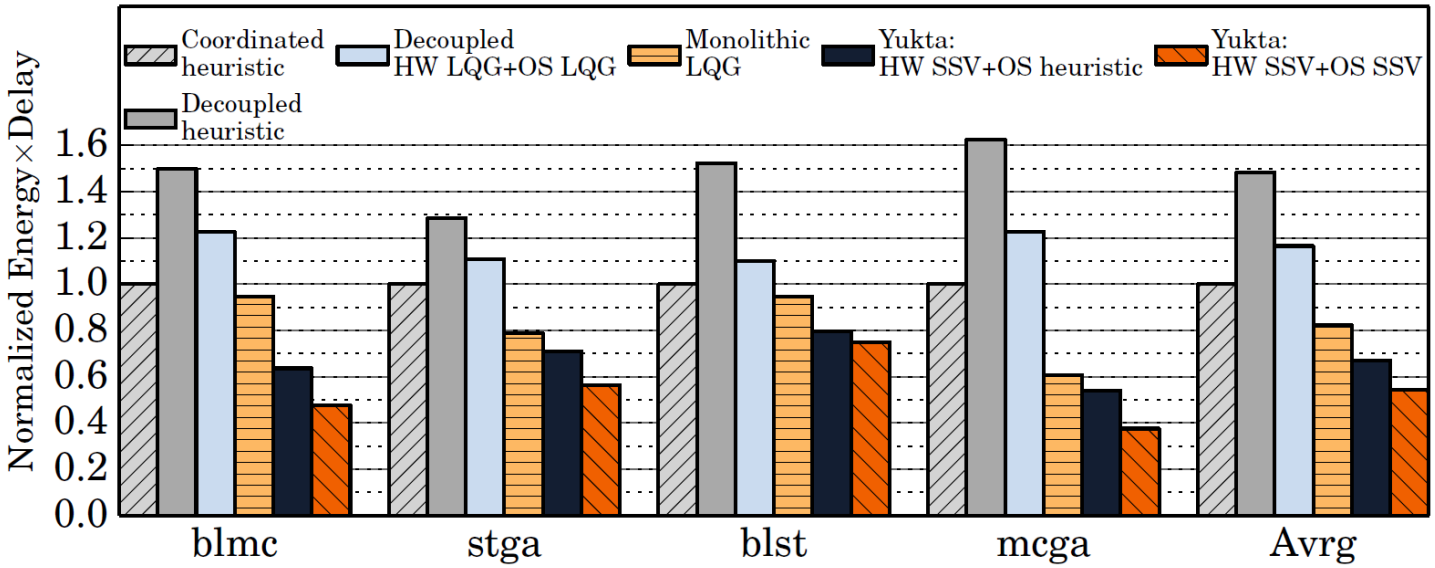


(a) *Coordinated heuristic* (b) *Decoupled heuristic* (c) *Yukta: HW SSV+OS heuristic* (d) *Yukta: HW SSV+OS SSV*

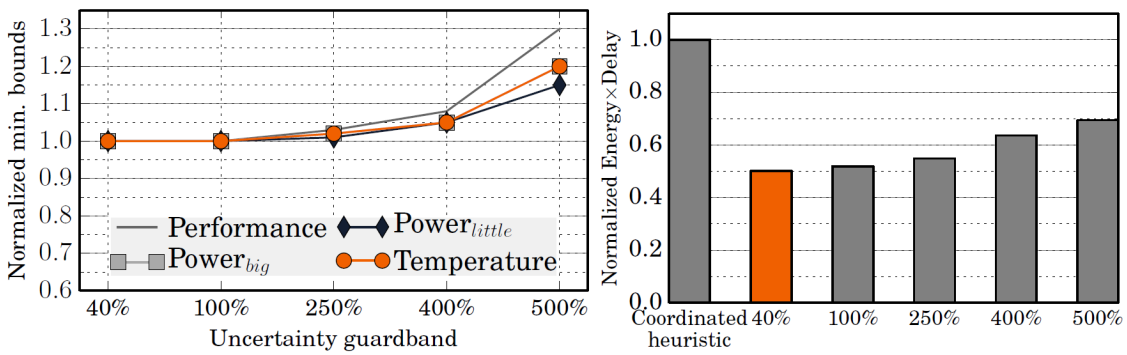
Yukta: Comparison with LQG control



Yukta: Heterogeneous Workloads

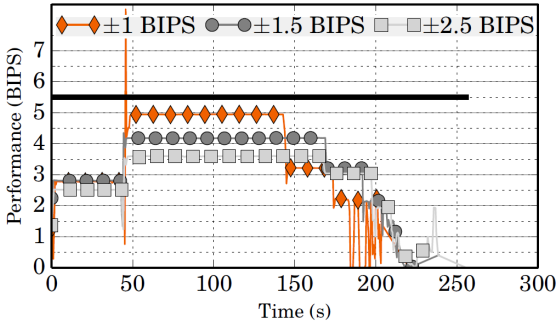


Yukta: Sensitivity to Uncertainty Guardbands

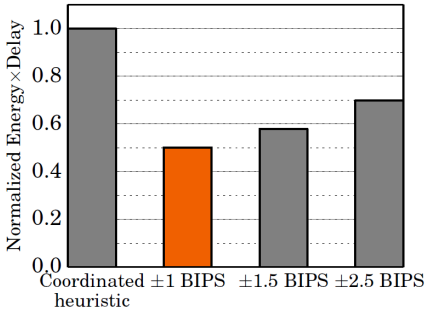


(a) Normalized output bounds. (b) E×D.

Yukta: Sensitivity to Output Bounds



(a) Tracking 5.5BIPS of performance.



(b) Minimizing E×D.

Yukta: Sensitivity to Input Weights