Multilayer Compute Resource Management with Robust Control Theory

Raghavendra Pradyumna Pothukuchi, Sweta Yamini Pothukuchi, Petros Voulgaris, Josep Torrellas

University of Illinois at Urbana-Champaign

1 COMPUTE RESOURCE MANAGEMENT

- Compute systems have many objectives that should be met:

Performance

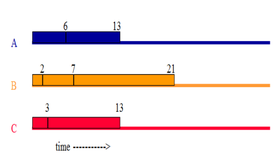
Energy/Power

Temperature

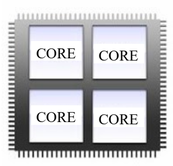
Load balancing/Fairness

- Dynamically configurable parameters enable meeting these goals:

Operating frequency



Scheduling

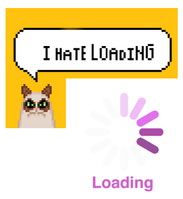


Number of compute units

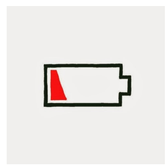
Available storage

Research problem: How to manage compute resources to meet all design objectives simultaneously and dynamically?

- Effects of inefficient resource management:



Poor performance



Wasted energy

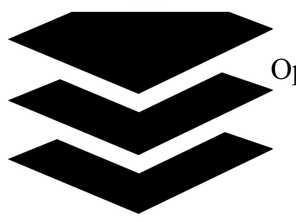
Unhappy users

Lost productivity

2 MULTILAYERED SYSTEMS POSE CHALLENGES

Applications

Each layer is designed by a different team/company



Operating System (OS) / Runtime

Hardware

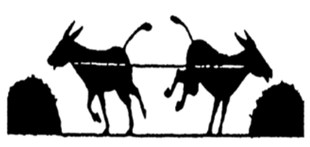
Resource management should be:

Modular in design

Coordinated in action

Robust to dynamic uncertainty

- Unrestricted use of ad hoc heuristics could be harmful:



Decision conflicts

Fragile, with unexpected failures

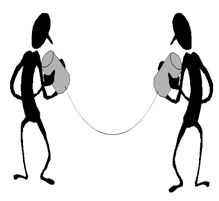
High overheads to design, tune and verify

3 A SOLUTION WITH ROBUST CONTROL THEORY

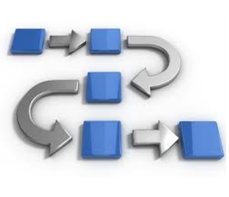
Properties of controllers from robust control theory

Decision making for systems with uncertainty

Guarantee meeting the targets precisely



Have formal channels for controller interaction



Systematic design and tuning

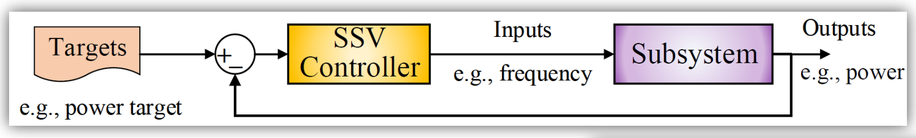
We use a robust controller called the **Structured Singular Value (SSV) controller**

First work to use robust control theory for compute resource management

Contributions

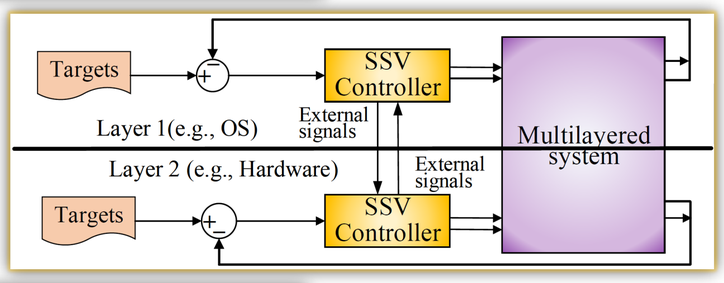
- A practical methodology to design modular multilayer SSV controllers for computers
- A multilayer control system for a heterogeneous multicore using our methodology
  - Coordinating controllers meet design goals simultaneously and dynamically
  - Controllers are robust to uncertainty and program variations

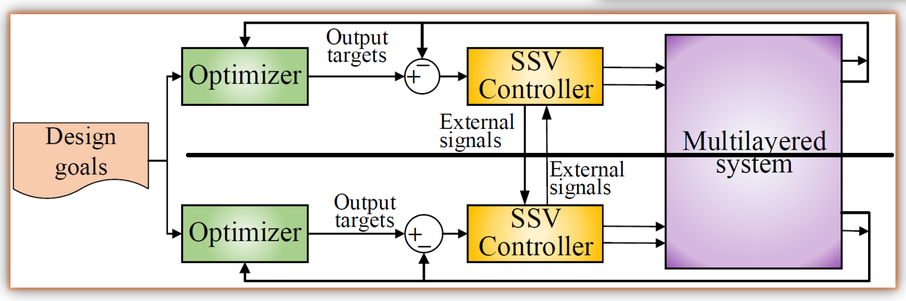
4 SSV CONTROLLERS FOR COMPUTING



SSV Controller at one layer

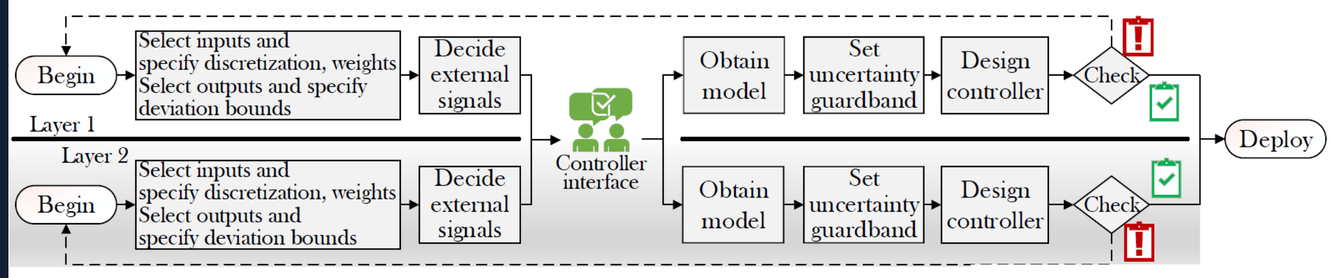
Multilayer SSV Controllers for following multilayer targets, e.g., power or performance targets





Augmented multilayer controllers to optimize combination design goals e.g., minimize Energy x Delay

5 MODULAR MULTILAYER SSV CONTROLLER DESIGN

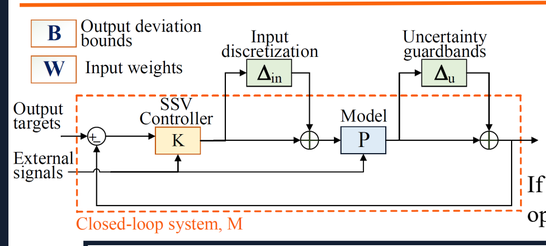


Input weights regulate aggressiveness of controller's response

Interface: Teams exchange information about
1. Signals passed between the controllers
2. Outputs monitored by controllers at multiple layers

Uncertainty guardbands are set as worst case percentage errors over the model

Behind the scenes of the automated controller design in MATLAB



$$\text{SSV} \coloneqq \frac{1}{\min\{g \mid \det(I - g \times M \times diag(\Delta, B^{-1}, W^{-1})) = 0\}}$$

Structured Singular Value

$\Delta = \text{diag}(\Delta_{in}, \Delta_u)$ — M is the closed loop

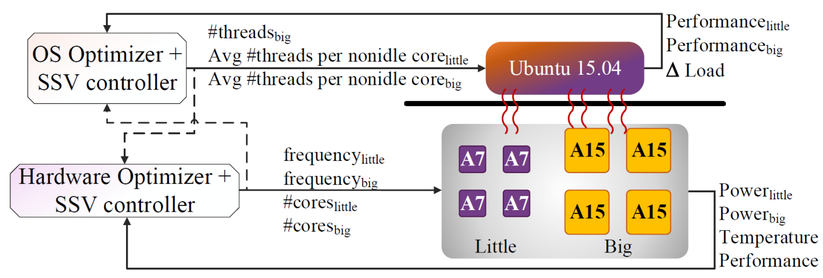
I is the identity matrix i.e. diag(1)

g is the scaling factor relative to the designer specifications that the controller can meet

If SSV ≤ 1, the controller can keep output deviations within **B** and change inputs optimally according to **W**, even with design uncertainties/imprecisions as large as **Δ**

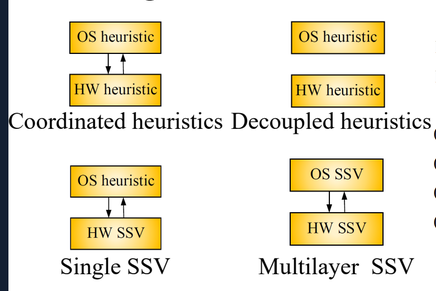
MATLAB runs an iterative optimization to generate a controller with SSV < 1 for the given specification
If the optimization fails, specification is relaxed and the optimization re-run

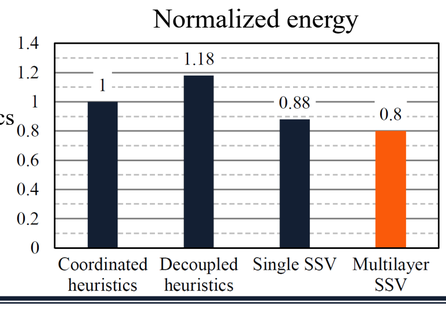
6 REAL SYSTEM EVALUATION

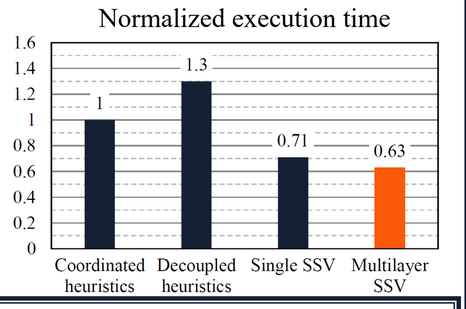


Multilayer SSV Control architecture for Samsung Exynos 5422 (ARM big.LITTLE Octacore)
Goal: Minimize energy and execution time, keeping power of each cluster and temperature below limits

Average results over 8 PARSEC (multithreaded) and 6 SPEC (multiprogrammed) benchmarks

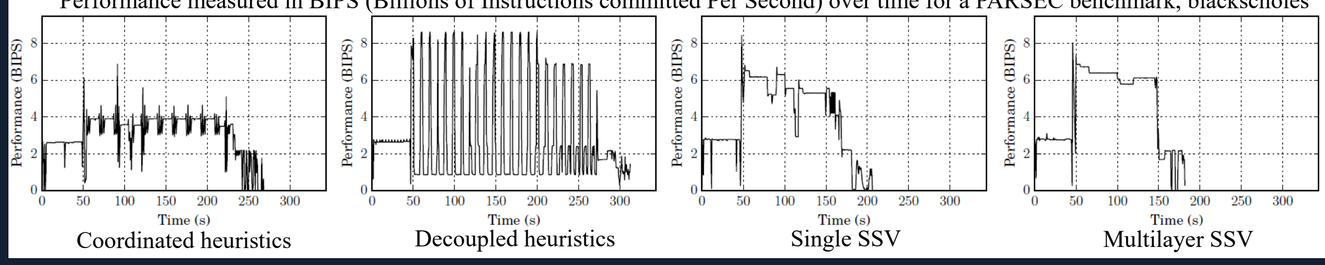






Multilevel SSV has 37% faster execution, 20% lower energy over state-of-the-art heuristics

Performance measured in BIPS (Billions of Instructions committed Per Second) over time for a PARSEC benchmark, blackscholes



7 CONCLUSIONS

- Multilayer computers require modular and coordinated resource management
- We propose a multilayer control design methodology using robust control theory
  - Novel systematic approach for modular design and coordinated decisions
- Multilayer controllers designed with our approach are effective on real systems
  - On average, applications run 37% faster and consume 20% lower energy over state-of-the-art designs using coordinated heuristics

This work was supported in part by NSF under grants CCF-1012759 and CCF-1536795

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