Yukta: Multilayer Resource Controllers to Maximize Efficiency

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International Symposium on Computer Architecture (ISCA) 2018
Resource Management in Computers

Configurable parameters

Limited resources
- Energy
- Storage

Many objectives
- Frequency
- Scheduling
- 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
- 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, \( f \in \{2 \text{ GHz}, 2.2 \text{ GHz}, ..., 3 \text{ GHz}\} \)
- Guarantee precise bounds on meeting targets
  - E.g., core power can be kept within \( \pm 0.05 \text{ W} \) 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, $\pm 0.05W$ for power deviations
  - Input weights ($W$) : Relative overheads
  - Discrete input values ($\Delta_{\text{in}}$)
  - Uncertainty guardbands ($\Delta_{\text{u}}$) : Degree of desired robustness
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 ($\Delta_{in}$)
  - Uncertainty guardbands ($\Delta_u$) : Degree of desired robustness

**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

Select inputs, outputs
Decide external signals

Layer 1, e.g. OS team

Layer 2, e.g. Hardware team

Select inputs, outputs
Decide external signals

Obtain model
Set controller parameters
Design controller

Modular and practical design

Interface
Prototype Yukta on a Challenging System

Minimize Energy×Delay under thermal and power constraints
Prototyped Yukta Architecture
Designing Robust Controllers for the Prototype

Select inputs, outputs → Decide External signals → Obtain model → Set controller parameters → Design controller → Interface

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

OS heuristic

HW heuristic

Coordinated heuristics

Monolithic non-robust

Yukta: Multilayer robust

[ISCA’16]

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