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!

One does not simply design correct heuristics.

Scheduling Frequency
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
- 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 Performance, Power, s.t. constraints
Our Approach

Mixed sensitivity $H_{\infty}$ design

Use black box system identification for modeling
Consider influence of other layers, nonlinearities as “uncertainty”
Minimize Energy × Delay ⇔ Maximize Performance \( \frac{f_2}{Power} \),

s.t. power and temperature are below limits.
Structure Specification

- Empirical model, $M$
- Output multiplicative uncertainty, $\Delta_{\text{top}}$
- Input additive uncertainty, $\Delta_{\text{nl}}$
- Performance weights, $W_{\downarrow p}$ and $W_{\downarrow u}$
Structure Specification

- Empirical model, $M$
- Output multiplicative uncertainty, $\Delta_{\text{op}}$
- Input additive uncertainty, $\Delta_{\text{nl}}$
- Performance weights, $W_{\text{p}}$ and $W_{\text{u}}$

$\Delta = [\Delta_{\text{op}} \& \& \Delta_{\text{nl}} \& \& \Delta_{\text{perf}}]$

Modular computer control $\rightarrow$ Robust performance problem!
Optimizer

1. Meeting fixed output targets
   Video processing

External signals

Robust Controller

Optimizer

60 FPS
1. Meeting fixed output targets
   Video processing

2. Meeting changing output targets
   Battery optimization
1. Meeting fixed output targets
   Video processing

2. Meeting changing output targets
   Battery optimization

3. Optimization
   \[ \text{min Energy} \times \text{Delay} \Leftrightarrow \text{max Performance} \]
   \[ e^{T_2} \div \text{Power} \]
First work to use Robust control theory for multilayer computers

37% faster with 20% lower energy ⇒ 50% better ED
Case Study with *blackscholes*
## Low Overheads

<table>
<thead>
<tr>
<th>Parameter</th>
<th>HW SSV</th>
<th>OS SSV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimension</td>
<td>20</td>
<td>16</td>
</tr>
<tr>
<td>Required storage</td>
<td>2.6 KB</td>
<td>2.1 KB</td>
</tr>
<tr>
<td>Number of operations</td>
<td>~700</td>
<td>~600</td>
</tr>
<tr>
<td>Computation time</td>
<td>~28μs</td>
<td>~25μs</td>
</tr>
<tr>
<td>Power consumption</td>
<td>~20-25mW</td>
<td>~20-25mW</td>
</tr>
</tbody>
</table>
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