Playing with power at runtime

Slightly slowed applications, major energy savings

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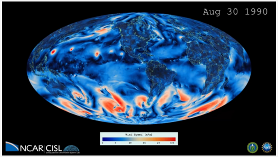
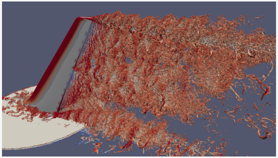
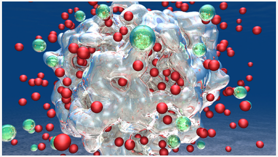
High-Performance Computing

Applications …







… running on Platforms

@ANL

Energy-aware HPC

@CBS

Performance/Energy Trade-off

Dynamic Management of HPC Systems

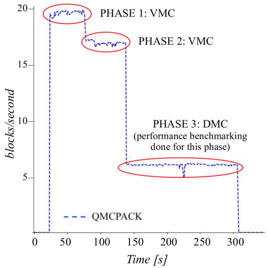
Highly variable systems ...

Offline

- HW spec.
- Aging

At runtime

- Phases
- Failures
- Temperature



(Ramesh et al. 2019)

... require dynamic management

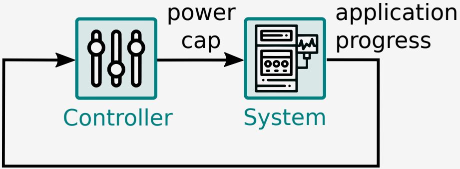
How Scheduling, Autonomic computing, Machine Learning, Feedback **Control Theory** (Hellerstein et al. 2004)

Why Stability, performance guarantees, explainability

Autonomic Computing Approach

The Autonomic Computing approach. . . (Kephart et al. 2003)

- Periodically monitor application progress
- Choose at runtime a suitable power cap for processors



. . . using Control Theory

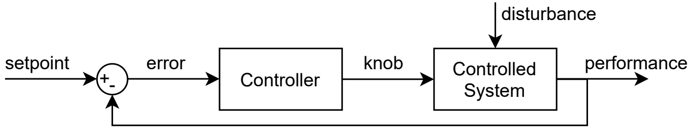
How Low-intrusive supervision

Why Stability, accuracy, transient performance, explainability (Hellerstein et al. 2004)

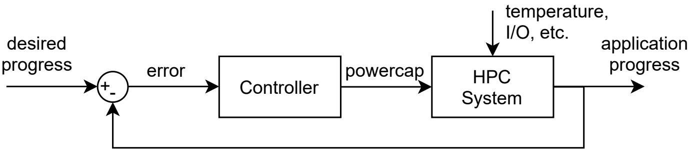
Principle of Control Theory

Feedback loops

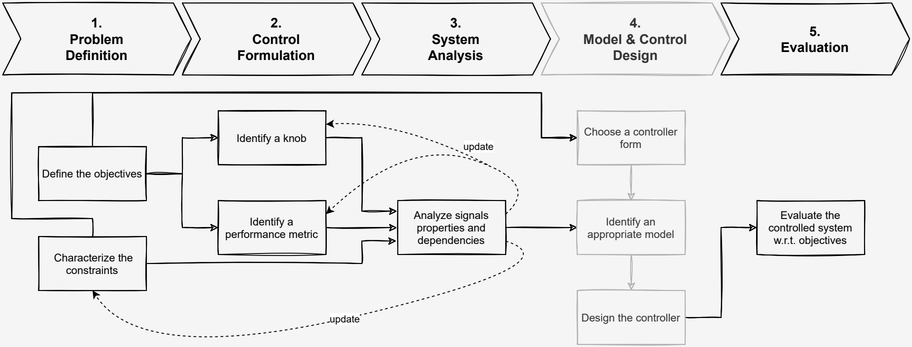
Measure **performance** and react according to the **error** w.r.t. the desired **setpoint** by leveraging system's **knob**.



Power control in HPC



Control Theory Methodology



Dynamic Power Management

Global Objectives

- Sustain execution time
- Minimize energy usage

The Runtime Perspective

- Sustain application progress
- Minimize power usage

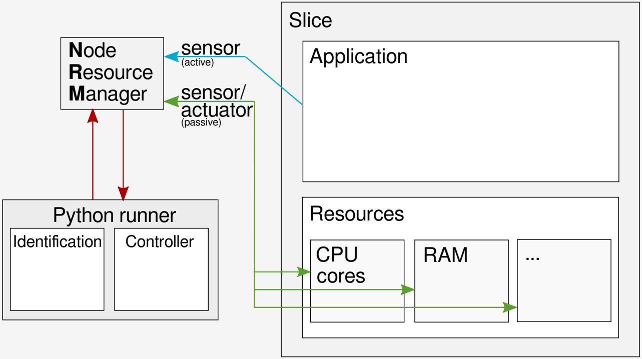
Actuator and Sensor

Power regulation DVFS (Imes et al. 2015; Imes et al. 2019);
DDCM (Bhalachandra et al. 2015);
RAPL (David et al. 2010; Rotem et al. 2012)

App. behavior Measuring progress with heartbeats (Ramesh et al. 2019)

Software Architecture

Software Stack Argo NRM resource management framework



Platform 3 clusters from Grid5000 with various nb. of sockets

Benchmark STREAM (McCalpin 1995)

Signals

Power actuator

RAPL's **power** limitation (David et al. 2010; Rotem et al. 2012)

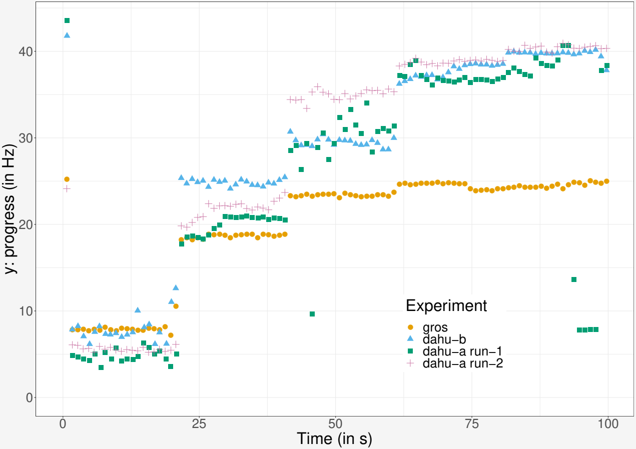
$$\text{pcap}(t_i)$$

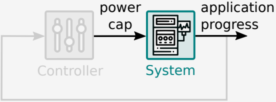
Performance sensor

Application's **progress** (Ramesh et al. 2019)

$$\text{progress}(t_i) = \underset{\forall k,\, t_k \in [t_{i-1}, t_i[}{\text{median}} \left(\frac{1}{t_k - t_{k-1}} \right)$$

Uncontrolled System Analysis (Identification)



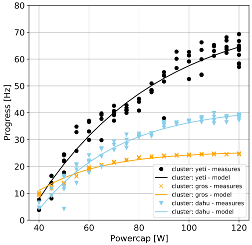


Many Sources of Variations

- Cluster
- Node
- Run
- Exogenous factors (temp., I/O)

Modeling

Static Characteristic (time averaged behavior)



$$\text{progress} = K_L \left(1 - e^{-\alpha(a \cdot \text{pcap} + b - \beta)}\right)$$

a, b: characterizing RAPL actuator

K_L, α, β: cluster- and application-specific

Dynamic perspective

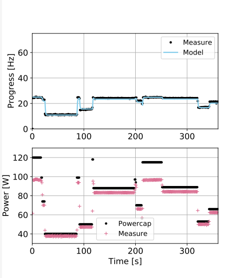
$$\text{progress}_L(t_{i+1}) = \frac{K_L(t_{i+1} - t_i)}{t_{i+1} - t_i + \tau} \cdot \text{pcap}_L(t_i) + \frac{\tau}{t_{i+1} - t_i + \tau} \cdot \text{progress}_L(t_i)$$

Shape set by control theory, parameters optimized offline

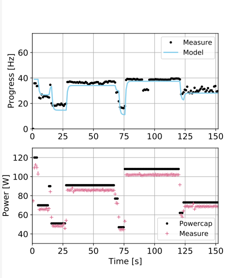
Experimental Evaluation

Measure of the Model Accuracy

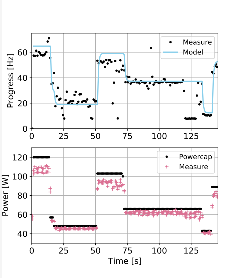
Not a prediction model but used to tune the controller



gros



dahu



yeti

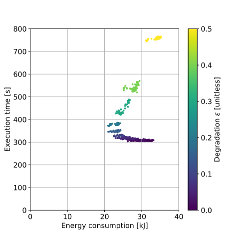
Observations

- Good accuracy.
- The model performs better on clusters with few sockets.

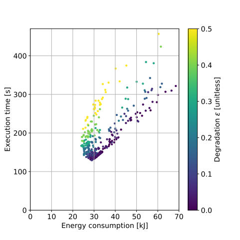
Experimental Evaluation

Post-mortem analysis

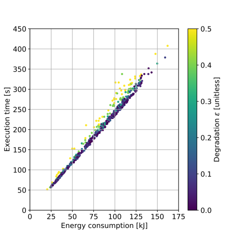
12 degradation levels, min. 30 repetitions each



gros



dahu



yeti

Pareto Front

gros, dahu Family of trade-off from 0% to 15% degradation level
gros with $\epsilon = 0.1$: -22% energy, +7% execution time

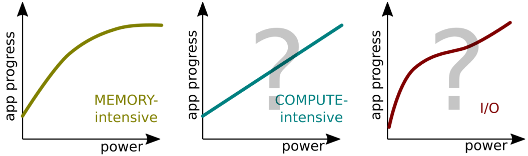
yeti no front, no negative impact of the controller

Perspectives

Applications' phases

Adaptation steps

1. Phases characterization

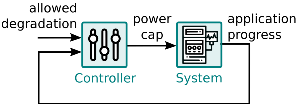


2. Online phase detection (?)
3. Dedicated control: robust, adaptive or hybrid

Conclusion

Objective Reducing energy consumption while sustaining performance

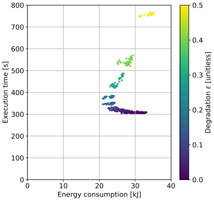
Approach Dynamic power regulation using Control Theory



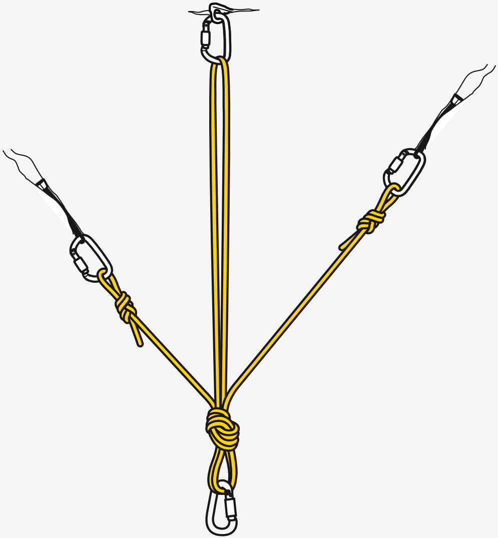
Contributions

- Control theory × HPC systems
- Experimental validation on several clusters

https://doi.org/10.6084/m9.figshare.14754468



Open **post-doc/engineer** positions @CTRL-A!



Backup slides

Related Works

On power regulation in HPC

Different objective or static schema

(Eastep et al. 2017) application-oblivious monitoring

On using control theory for power regulation

Applications: web servers (Abdelzaher et al. 2008), cloud (Zhou et al. 2016), real-time systems (Imes et al. 2015)

Metrics: RAPL (Imes et al. 2019; Lo et al. 2014)
Progress metric (Santriaji et al. 2016)

Model and Controller Parameters

Description	Notation	Unit	gros	dahu	yeti
RAPL slope	a	[1]	0.83	0.94	0.89
RAPL offset	b	[W]	7.07	0.17	2.91
	α	[1/W]	0.047	0.032	0.023
power offset	β	[W]	28.5	34.8	33.7
linear gain	K_L	[Hz]	25.6	42.4	78.5
time constant	τ	[s]	1/3	1/3	1/3
	τ_{obj}	[s]	10	10	10
lower power limit	$pcap_{min}$	[W]	40	40	40
higher power limit	$pcap_{max}$	[W]	120	120	120

PI Controller Parameters Computation

K_P and K_I are based both on the model parameters K_L and τ and on a tunable parameter τ_{obj} (Åström et al. 1995):

$$K_P = \tau / (K_L \cdot \tau_{\text{obj}})$$

$$K_I = 1 / (K_L \cdot \tau_{\text{obj}})$$

with τ_{obj} defining the desired dynamical behavior of the controlled system.

The controller is chosen to be nonaggressive:

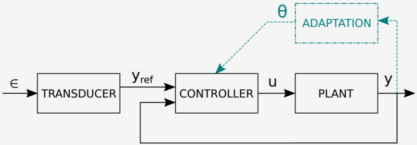
$$\tau_{\text{obj}} = 10\,\text{s} > 10\tau$$

Model Reference Adaptive Control

Model $y(k+1) = b_0 u(k) + a_0 y(k)$

Parameter vector $\theta = [s_0]$

Regression vector $\phi(k) = [y(k)]$



Control Law (Akhtar et al. 2005)

$$u(k) = -\frac{1}{b_0}\left[\phi^T(k)\hat{\theta}(k) - b_m y_{\text{ref}}\right]$$

$$\hat{\theta}(k) = \hat{\theta}(k-1) + \frac{1}{\phi^T(k-1)\phi(k-1)}\Big[a_m y(k-1) - b_0 u(k-1) - \phi^T(k-1)\hat{\theta}(k-1)\Big]\phi(k-1)$$

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