

Energy-Aware Computing Systems

Energiebewusste Rechensysteme

XI. Infrastructure

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EASY



Agenda

Preface and Terminology

Linking (with) the Physical World

Dependencies and Impact
Considerations and Metrics

Infrastructure

Temperature-Aware Workload Placement
Building Operating System Services (BOSS)
Runtime System for Heterogeneous HPC Clusters

Call for Participation

Uncharted Lecture next Wednesday

Summary

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3-18

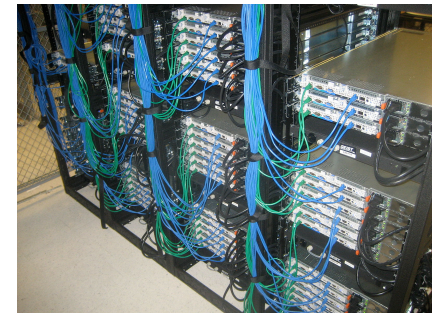
Infrastructure

- **motivation**
 - indirect resource demand → costs
 - „many a little makes a mickle”
- **operational goals**
 - identify necessary operating conditions
 - ...but invest reasonable efforts, only



Dependencies and Impact

- dependency on external factors
 - device (e.g., power supplies)
 - moving parts (e.g., fans)
 - kinetic energy (e.g., heat)
 - physical properties (ambient air)
 - not all environmental conditions can be controlled
- impact on external systems
 - control resource demand
 - temporal delay
 - workload (re)positioning
 - control types
 - implicit: activation of additional resources
 - explicit: system control



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Considerations and Metrics

- common infrastructure considerations
 - power demand of computing systems → secondary energy (i.e., heat)
 - heating, ventilation, and air conditioning (HVAC) **required**
 - ↔ especially heat distribution
- common metric: power usage effectiveness (PUE)
 - $PUE := \text{total energy demand} / \text{energy demand of computing systems}$
 - total energy demand includes infrastructure, HVAC etc.
 - perfect system: $PUE \leq 1.0$
 - ↔ electricity generation
- PUE refinements
 - mixed use of renewable and non-renewable energy
 - reuse of secondary energy
 - various additions and alternatives
 - Green Energy Coefficient (GEC)
 - Energy Reuse Factor (ERF)
 - Carbon Usage Effectiveness (CUE)



Temperature-Aware Workload Placement

- Motivation
 - reduce cooling costs in data centers
 - workload placement → hot spots and cold spots in data centers
 - cf. thermal-aware task scheduling [2], Lecture 7
- Temperature-Aware Workload Placement [5]
 - temperature-aware workload placement algorithms
 - reduce cooling costs over the worst-case placement by almost 50 %
- ▶ J. Moore et al.
**Making Scheduling "Cool":
Temperature-Aware Workload Placement in Data Centers**
Proceedings of the USENIX Annual Technical Conference (ATC '05), 2005.



Building Operating System Services (BOSS)

- Motivation
 - energy demand of buildings: 73 % (2011) in the US (data centers: 3 %)
 - reduce costs of commercial buildings using operating systems for buildings
 - cf. occupancy-driven energy management [1], Lecture 6
- Building Operating System Services (BOSS) [3]
 - distributed operating system plus services
 - query language and control infrastructure
- ▶ S. Dawson-Haggerty et al.
BOSS: Building Operating System Services
Proceedings of the 10th USENIX Conference on Networked Systems Design and Implementation (NSDI '13), 2013.



Runtime System for Heterogeneous HPC Clusters

- Motivation
 - variable power pricing becomes increasingly common
 - exploit dynamic pricing to reduce operating costs of HPC systems
- Runtime System for Heterogeneous HPC Clusters (Albatross) [4]
 - implement different operation modes for varying electricity pricing
 - use heterogeneous compute components to execute workloads
- ▶ T. Hönig et al.
**How to Make Profit:
Exploiting Fluctuating Electricity Prices with
Albatross, A Runtime System for Heterogeneous
HPC Clusters**
Proceedings of the 8th International Workshop on Runtime and Operating Systems for Supercomputers (ROSS 2018), 2018.



Subject Matter

- considerations on **infrastructure** are necessary during design and operation of energy-aware systems
- **metrics** help to analyse the efficiency → use different metrics depending on **actual systems** and **infrastructure**
- **exploit external factors for own advantage** at system level

- Evaluation: please **participate** until end of this week
- Uncharted Lecture by Ralph Schlenk (Nokia) on **energy-efficient optical networks**
 - Wednesday, 30. January 2019, 14:30 s.t.
 - room 02.037 („e-Studio”), RRZE (second floor)



Reference List I

- [1] AGARWAL, Y. ; BALAJI, B. ; GUPTA, R. ; LYLES, J. ; WEI, M. ; WENG, T. :
Occupancy-driven Energy Management for Smart Building Automation.
In: *Proceedings of the 2nd Workshop on Embedded Sensing Systems for Energy-Efficiency in Building (BuildSys '10)*, 2010, S. 1–6
- [2] CHOI, J. ; CHER, C.-Y. ; FRANKE, H. ; HAMANN, H. ; WEGER, A. ; BOSE, P. :
Thermal-aware Task Scheduling at the System Software Level.
In: *Proceedings of the 2007 International Symposium on Low Power Electronics and Design (ISLPED'07)*, 2007, S. 213–218
- [3] DAWSON-HAGGERTY, S. ; KRIOUKOV, A. ; TANEJA, J. ; KARANDIKAR, S. ; FIERRO, G. ; KITAEV, N. ; CULLER, D. :
BOSS: Building Operating System Services.
In: *Proceedings of the 10th USENIX Conference on Networked Systems Design and Implementation (NSDI '13)*, 2013, S. 443–458
- [4] HÖNIG, T. ; EIBEL, C. ; WAGENHÄUSER, A. ; WAGNER, M. ;
SCHRÖDER-PREIKSCHAT, W. :
How to make profit: Exploiting fluctuating electricity prices with Albatross, a runtime system for heterogeneous HPC clusters.
In: *Proceedings of the 8th International Workshop on Runtime and Operating Systems for Supercomputers (ROSS'18) ACM*, 2018, S. 1–8



Reference List II

- [5] MOORE, J. ; CHASE, J. ; RANGANATHAN, P. ; SHARMA, R. :
Making Scheduling "Cool": Temperature-aware Workload Placement in Data Centers.
In: *Proceedings of the USENIX Annual Technical Conference (ATC '05)*, 2005, S. 61–75

