

Energy-Aware Computing Systems

Energiebewusste Rechensysteme

X. Infrastructure

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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

Uncharted Lecture next Thursday

Summary



Infrastructure

■ motivation

- indirect resource demand → costs
- „many a little makes a mickle”

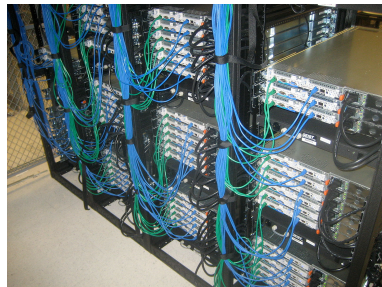
■ operational goals

- 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



- 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)



- 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.



■ 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.



- 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.*



- paper discussion

- ▶ X. Fan et al.

Power provisioning for a warehouse-sized computer

Proceedings of the 34th International Symposium on Computer architecture (ISCA'07), 2007.



- considerations on **infrastructure** are necessary during design and operation of energy-aware systems
- **metrics** help to analyze the efficiency → use different metrics depending on **actual systems** and **infrastructure**
- **exploit external factors** for **own advantage** at system level
- Uncharted Lecture by Ralph Schlenk (Nokia)
 - Topic: Energy-Efficient Optical Networks
 - Date: Thursday, July 30, 2020 at 10:00 am
 - Presentation: Microsoft Teams, check your inbox for the invitation link



Reference List I

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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.
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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

