A Conceptual Framework for HPC Operational Data Analytics

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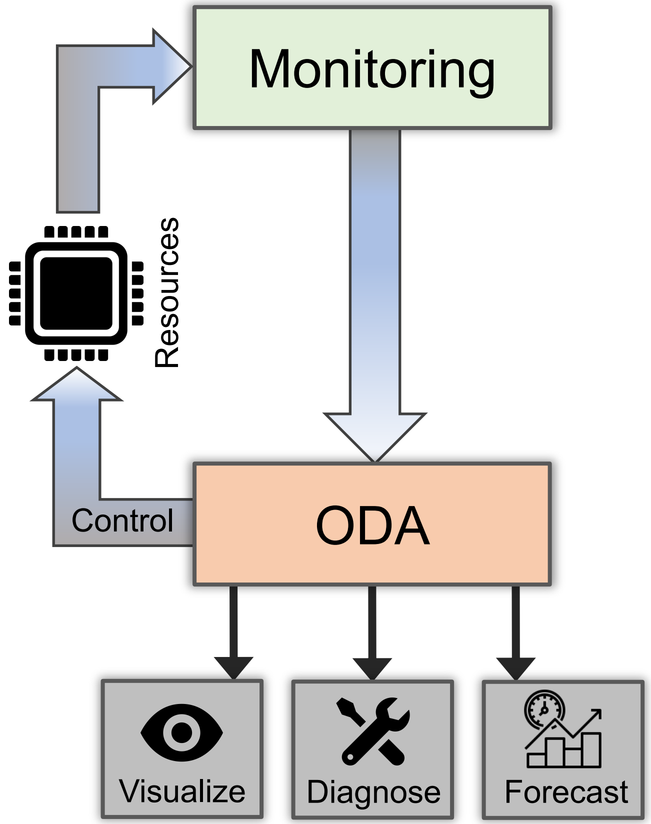
Introduction

- *Operational Data Analytics* (ODA) uses monitoring to extract actionable **knowledge** on system **behavior**.
  - Can improve energy efficiency and reliability.
  - More and more data centers use ODA.
- However, ODA is a **broad** and **diverse** field:
  - Predictive tuning of CPU frequencies is ODA.
  - Diagnosing infrastructure failures with ML is ODA.
  - Simulating scheduling policies is ODA.
  - Computing a data center’s PUE is ODA.



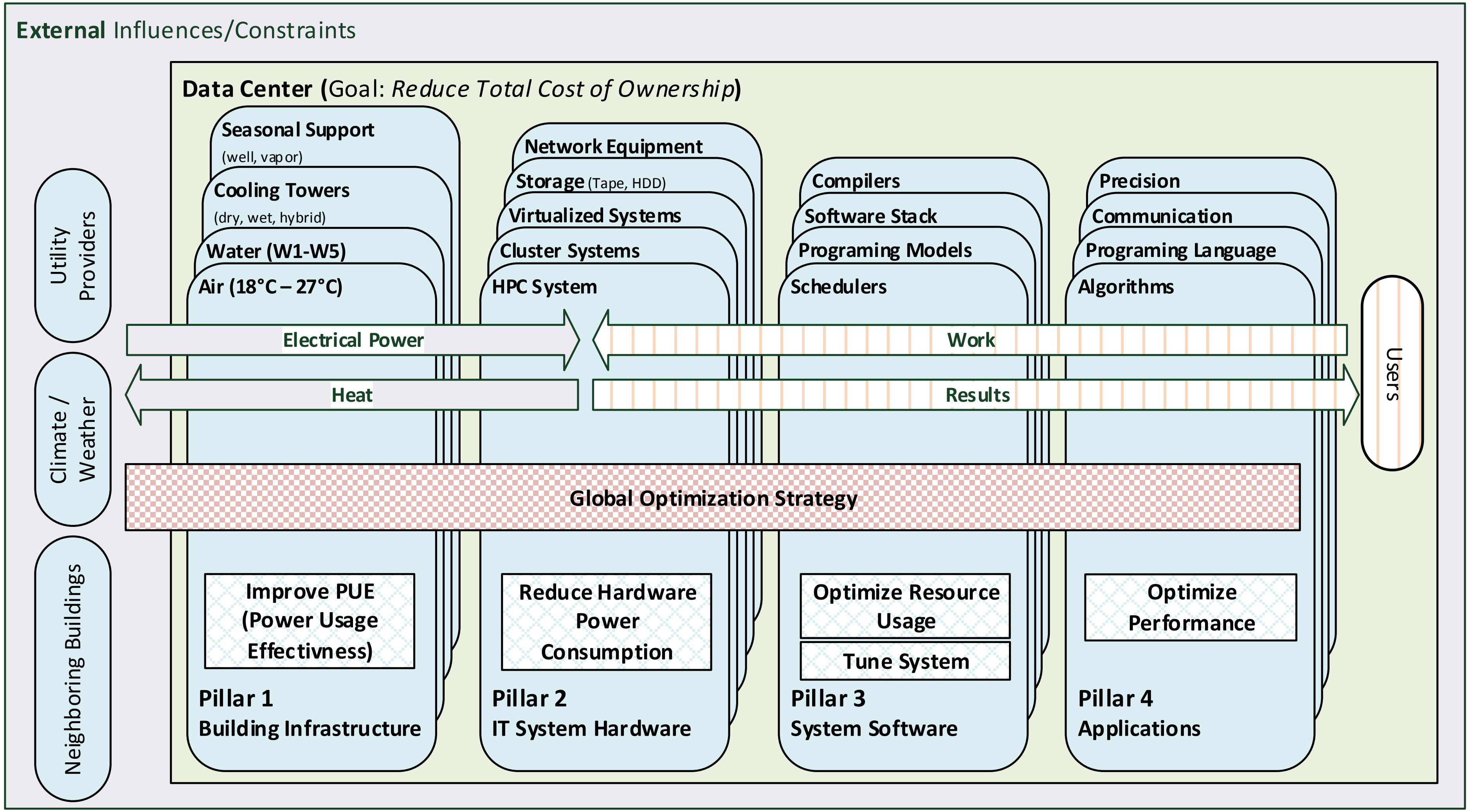
Contributions

- There is no **common language** to reason about ODA.
  - Research gaps and opportunities are difficult to identify.
  - System design and requirements are not standardized.
  - Adoption of ODA by data centers is cumbersome.
- Our **contributions** are the following:
  - A conceptual framework to help classify ODA use cases.
  - An extensive survey and categorization of ODA literature.
  - Demonstration of the framework on state-of-the-art use cases.

Designing a Framework for ODA

- Many possible **questions** about an ODA use case:
  - What is the functional **complexity** and data center scope?
  - How do we **decompose** it in simple, standard blocks?
  - Have other people already tackled a **similar** problem?
  - What are the deployment **requirements** and gains?
- We use two state-of-the-art frameworks as a **foundation**:
  - The "*4-Pillar Framework for Energy-Efficient HPC Data Centers".*
  - The "*4 Types of Data Analytics Framework*".

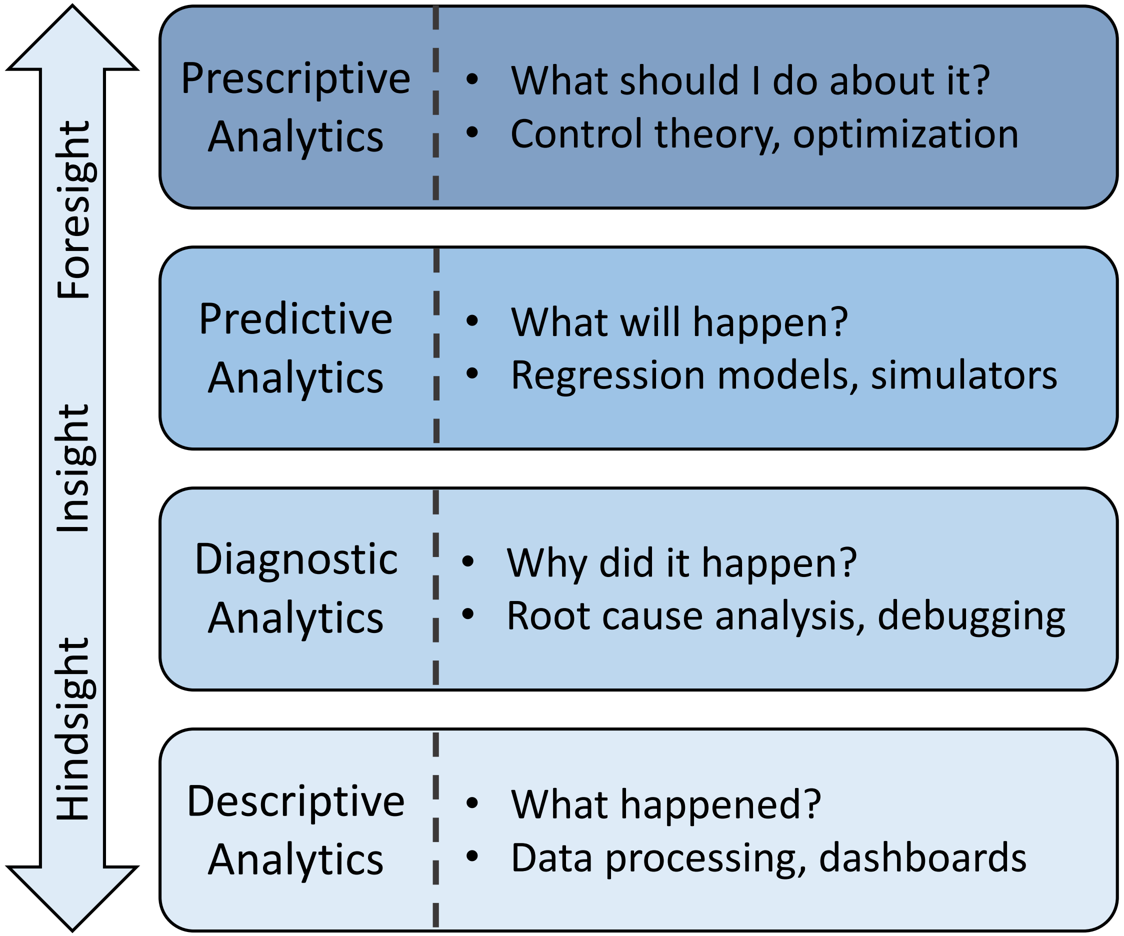
The 4-Pillar Framework



[1] T. Wilde et al. “The 4-Pillar Framework for energy efficient HPC data centers”.

The 4 Types of Data Analytics

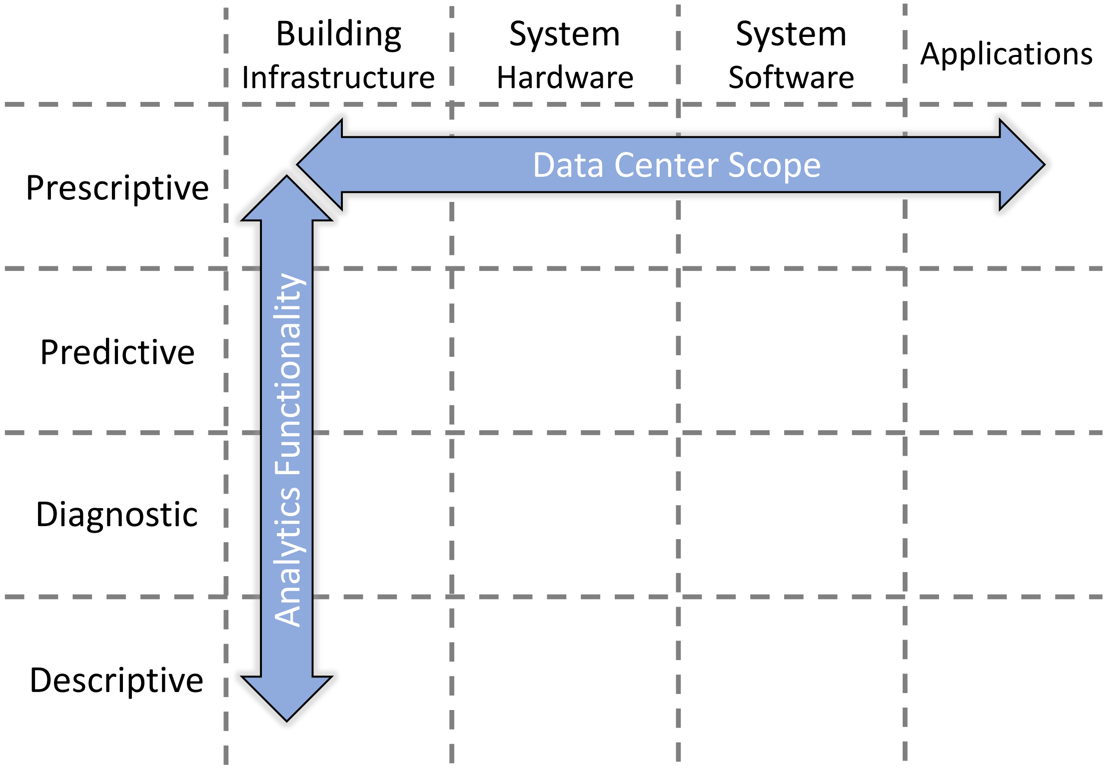
- Model used by large consultancy firms to categorize **data analytics**.
- Consists of 4 *types*, which differ in the **functionality** they offer.
- Some types focus on **historical** events (*hindsight*), others on anticipating **future** ones (*foresight*).
- The types are not necessarily **ranked** by complexity.



[2] K. Lepenioti et al. "Prescriptive analytics: Literature review and research challenges".

The 4x4 Conceptual ODA Framework

- We **combine** the 4-Pillar and the 4-Type models in a single framework.
- It consists of a 4x4 **matrix**:
  - The *pillars* in the horizontal axis describe the scope of ODA.
  - The *types* in the vertical axis describe ODA functionality.
- Any complex ODA system can be **decomposed** to fit the cells of the framework.



Applying the ODA Framework

- We now **demonstrate** the framework's effectiveness.
- We conducted a **survey** of ODA research literature:
  - 70+ works analyzed and categorized.
  - ODA examples extracted for each category.
  - Provides an overall picture of the ODA field.
- We **applied** the framework to three state-of-the-art use cases:
  - Focus on complex ODA systems.
  - Discussion of the framework's limitations.

Classifying ODA Research Literature

	Building Infrastructure	System Hardware	System Software	Applications
Prescriptive	• Switching between types of cooling • Tuning cooling knobs • Responding to anomalies	• Cooling optimization at the system level • CPU frequency tuning • Tuning hardware knobs	• Intelligent task placement • Plan-based scheduling • Power and KPI-aware scheduling	• Auto-tuning of HPC applications • Code improvement and recommendations
Predictive	• Predict data center KPIs • Predict cooling demand • Models for cooling performance	• Forecast sensors • Component failure prediction • Predict instruction mix	• Simulating HPC systems and schedulers • Predicting HPC workloads	• Predicting job durations • Predicting resource usage • Predicting performance profiles of code regions
Diagnostic	• Fingerprinting data center-level crises • Infrastructure anomaly detection • Stress testing	• Node anomaly detection • Root cause analysis at the system level • Diagnose network contention issues	• Detect data locality issues • Detect software anomalies • Diagnose OS noise	• Application fingerprinting • Identify application performance patterns • Diagnose code-level issues
Descriptive	• PUE calculation • Facility data processing • Facility-level dashboards	• ITUE calculation • System performance indicators • System-level dashboards	• Slowdown calculation • Scheduler-level dashboards	• Job performance models • Job data processing • Job-level dashboards

Analytics across Multiple Types

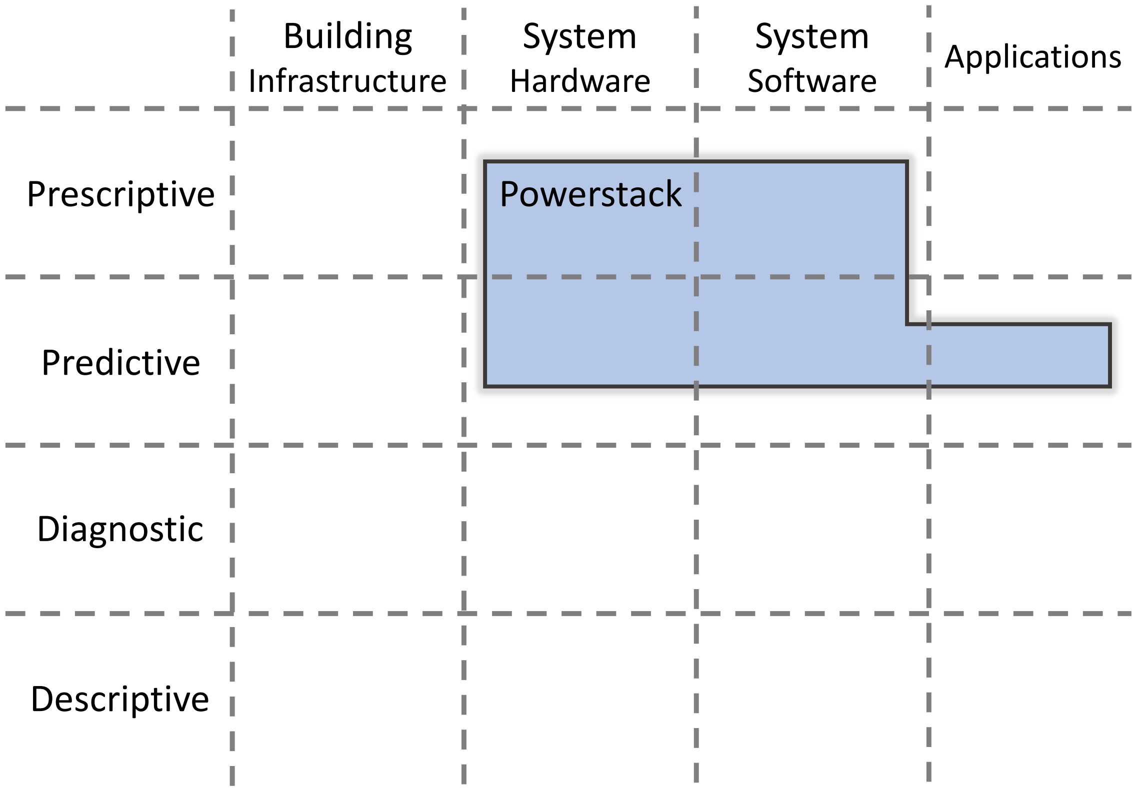
- Infrastructure anomaly detection (*diagnostic*) and cooling set-point tuning (*prescriptive*) at **ENI** [3].
- **Better** *prescriptive* decisions can be made with the help of *predictive* and *diagnostic* components.
- Higher technical **complexity**.
- Requires **fusion** of heterogeneous disciplines.

	Building Infrastructure	System Hardware	System Software	Applications
Prescriptive	ENI			
Predictive				
Diagnostic	ENI			
Descriptive				

[3] L. Bortot et al. "Data centers are a software development challenge".

Implementing Multi-pillar ODA

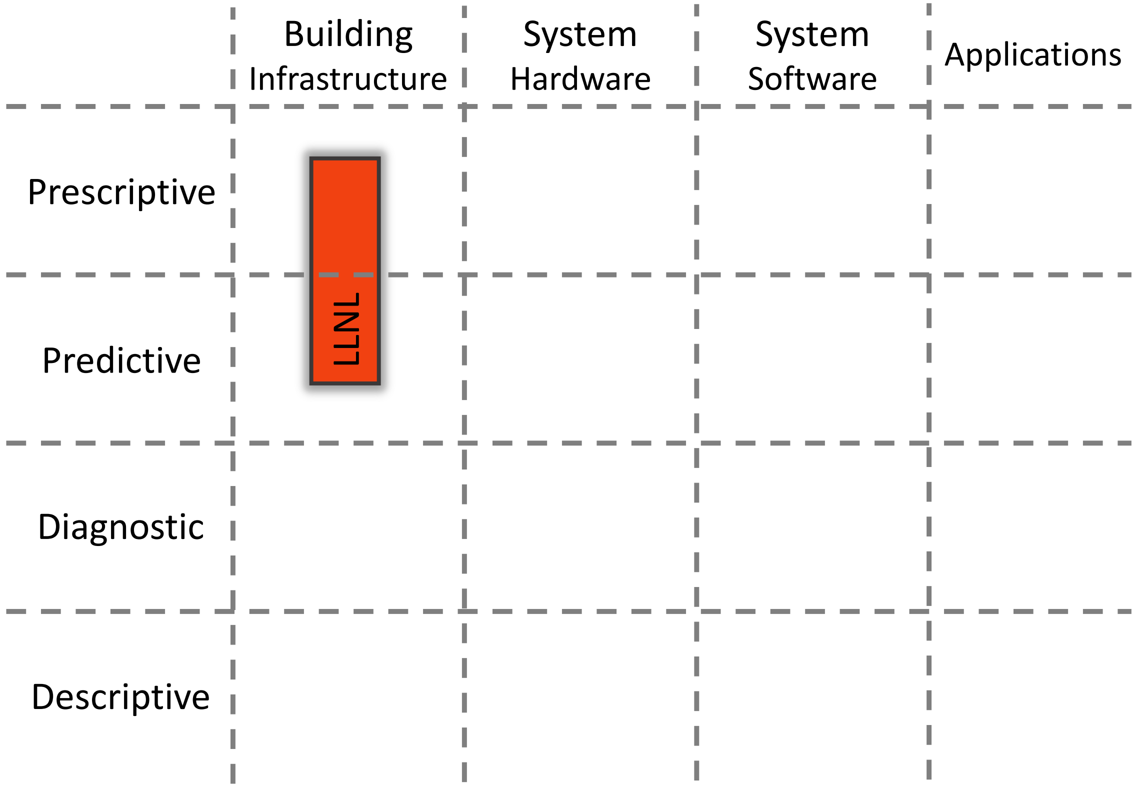
- The **Powerstack** framework for power management (*prescriptive*) using data science (*predictive*) [4].
- Most ODA systems are **closed** and cover a single pillar (or *silo*).
- Multi-pillar designs must be **holistic** and integrate many levels of scope.
- Major operational **opportunities**.



[4] X. Wu et al. "Toward an end-to- end auto-tuning framework in HPC powerstack".

ODA beyond Building Infrastructure

- Forecasting (*predictive*) and notifying (*prescriptive*) excessive power swings at **LLNL** [5].
- The electrical grid as an **extension** of the data center's infrastructure.
- Monitoring and control capabilities are **limited**.
- Practical implementation can be **challenging**.



[5] G. Abdulla et al. "Forecasting extreme site power fluctuations using fast fourier transformation".

Conclusions

- Use of *Operational Data Analytics* (ODA) is becoming more and more **common** in HPC data centers.
- We propose a conceptual **framework** to classify ODA use cases according to their scope (*pillars*) and functionality (*types*).
- We aim to establish a common language to **simplify** discussion, analysis and adoption of ODA by the community at large.
- Thank you for your attention!

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