

OAK RIDGE National Laboratory | LEADERSHIP COMPUTING FACILITY

Keynote

The Past, Current, and Future of HPC ODA

2026-06-26

The 7th International Workshop on "Monitoring, Observability, and Operational Data Analytics"

Woong Shin

U.S. DEPARTMENT OF ENERGY

ORNL IS MANAGED BY UT-BATTELLE LLC
FOR THE US DEPARTMENT OF ENERGY

Data ➡ Impact

HPC Operational Data

Insights, Decisions, Improvement

Operational Data Analytics

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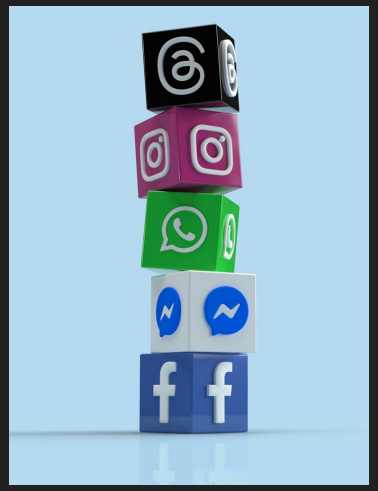
HPC Operational Data

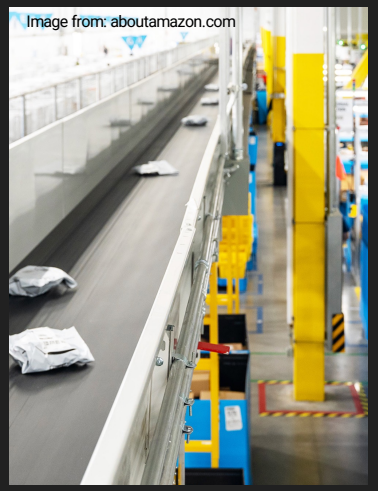
Insights, Decisions, Improvement

Operational Data Analytics









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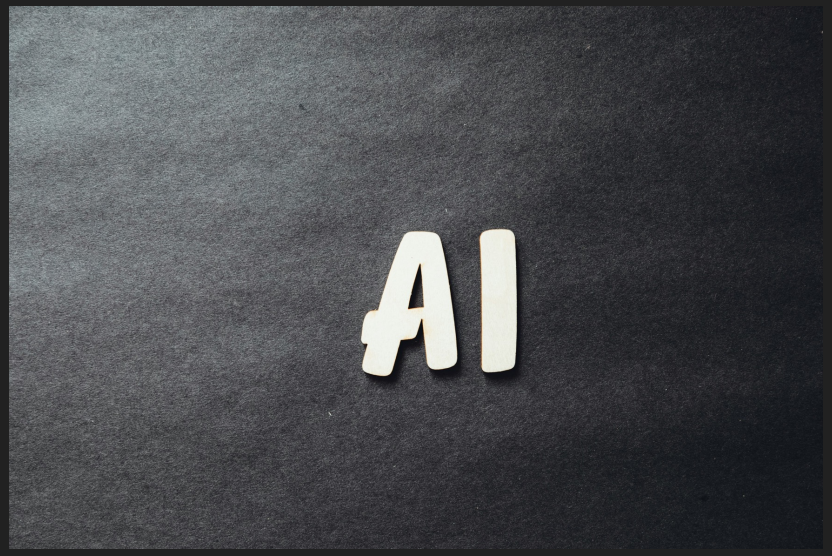

Data ➡ Impact

HPC Operational Data

Insights, Decisions, Improvement

Operational Data Analytics

Past, Present, Future

Data ➡ Impact

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The HPC Organization & Data

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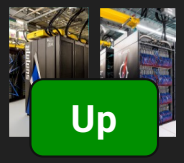

System

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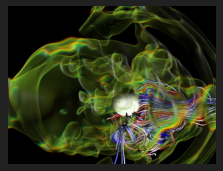
Sponsor



Open Science

???
Zetta-scale
Artificial Intelligence
Quantum
Energy Efficiency
Sustainability

Future

Open Science User Facility

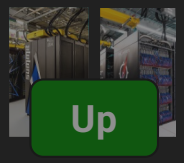
HPC Organization

Leadership

Systems	Operations	Scientific Outreach	Advanced Tech.

Areas

System Mgmt.	Facility mgmt.	Cyber security	User assistance	Program management	Application perf. eng.	R&D	Procurement



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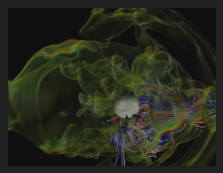

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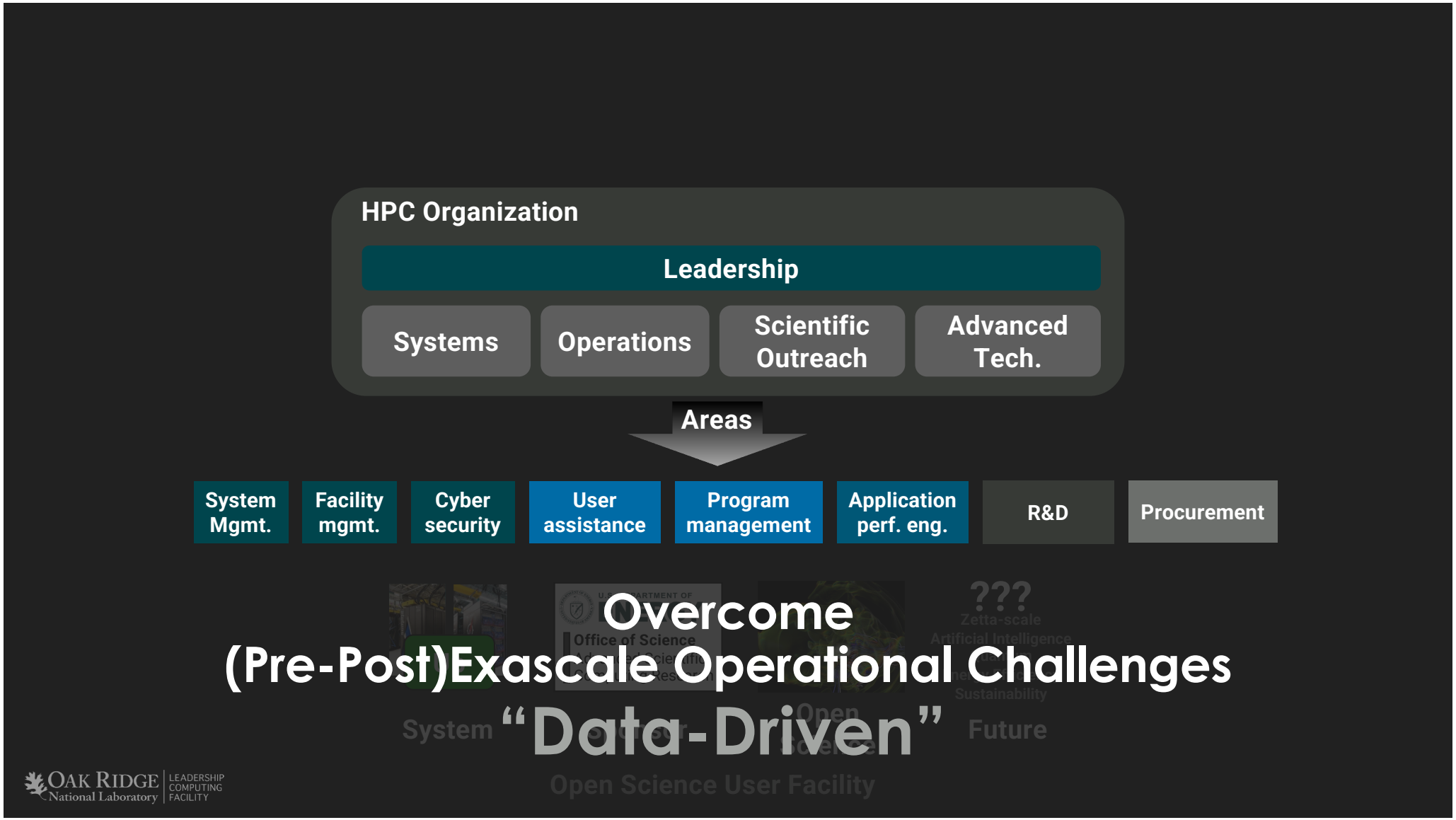
Open Science User Facility


HPC Organization
Leadership
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Application perf. eng.
R&D
Procurement
Overcome
(Pre-Post)Exascale Operational Challenges
"Data-Driven"
???
Zetta-scale
Artificial Intelligence
Sustainability
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Open Science User Facility
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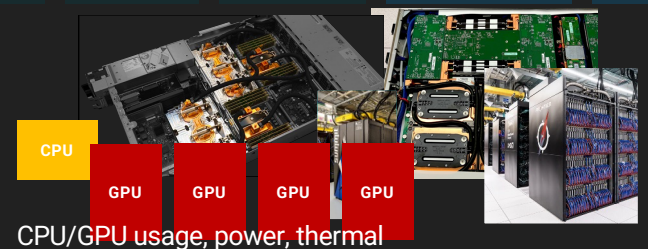
Data Sources

Areas

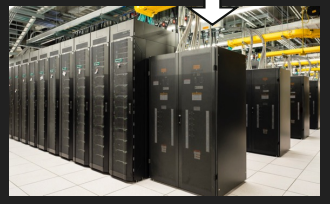
Data Sources	System Mgmt.	Facility mgmt.	Cyber security	User assistance	Program management	Application perf. eng.	R&D	Procurement
Compute System								
Perf. counters								
Resource util.								
Power and Temp.								
Storage client								
Interconnect client								
Storage system								
Interconnect								
Syslog & events								
Resource manager								
CRM								
Facility								

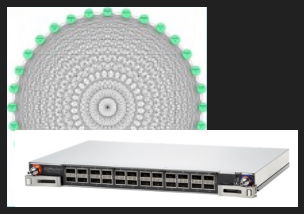


CPU/GPU usage, power, thermal

Interconnect I/O

Storage I/O



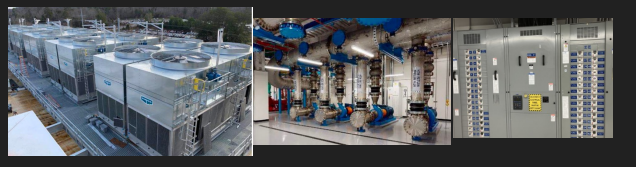




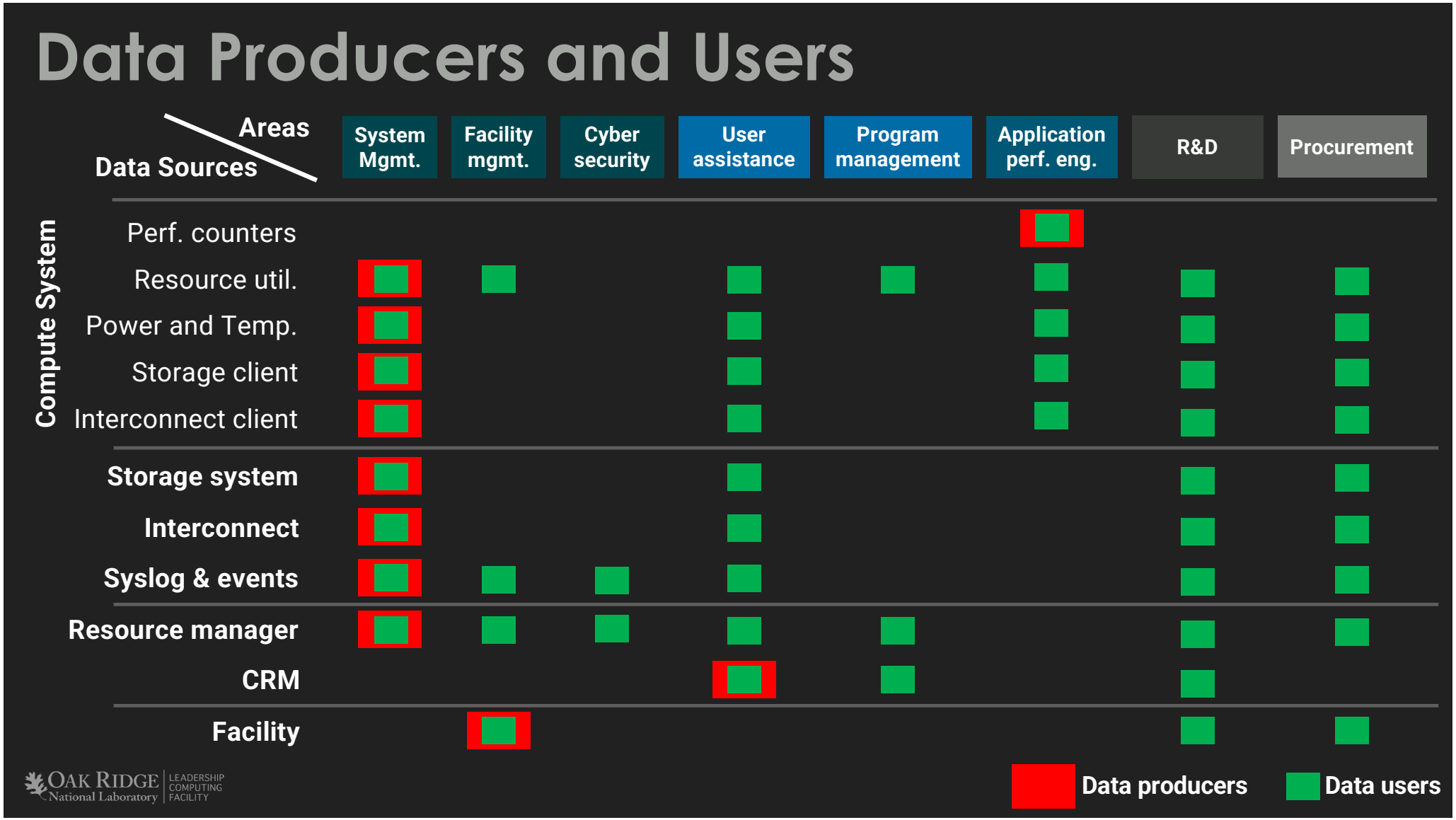
System Logs
H/W, S/W events

slurm workload manager

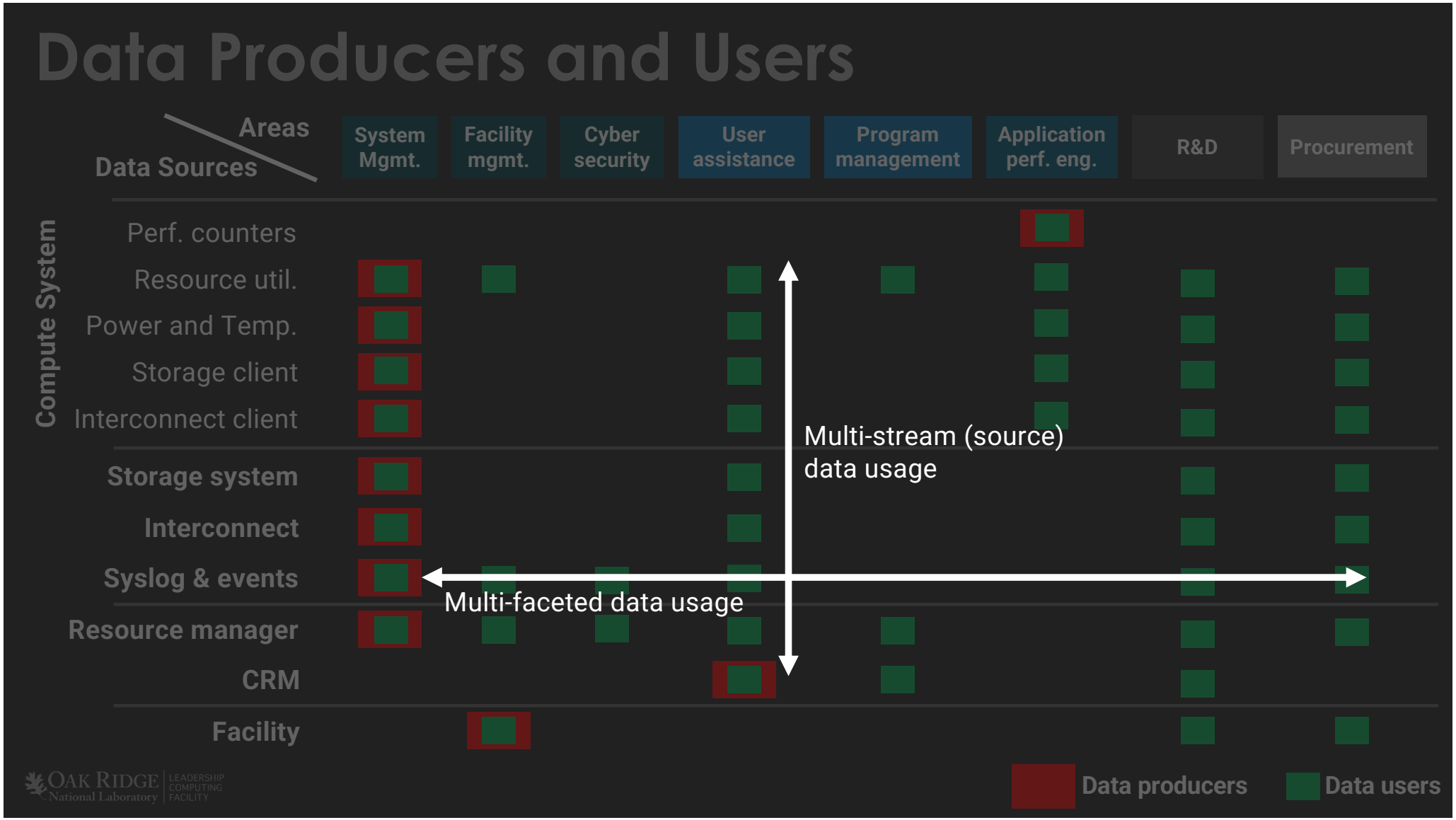
Cooling System
Electrical System



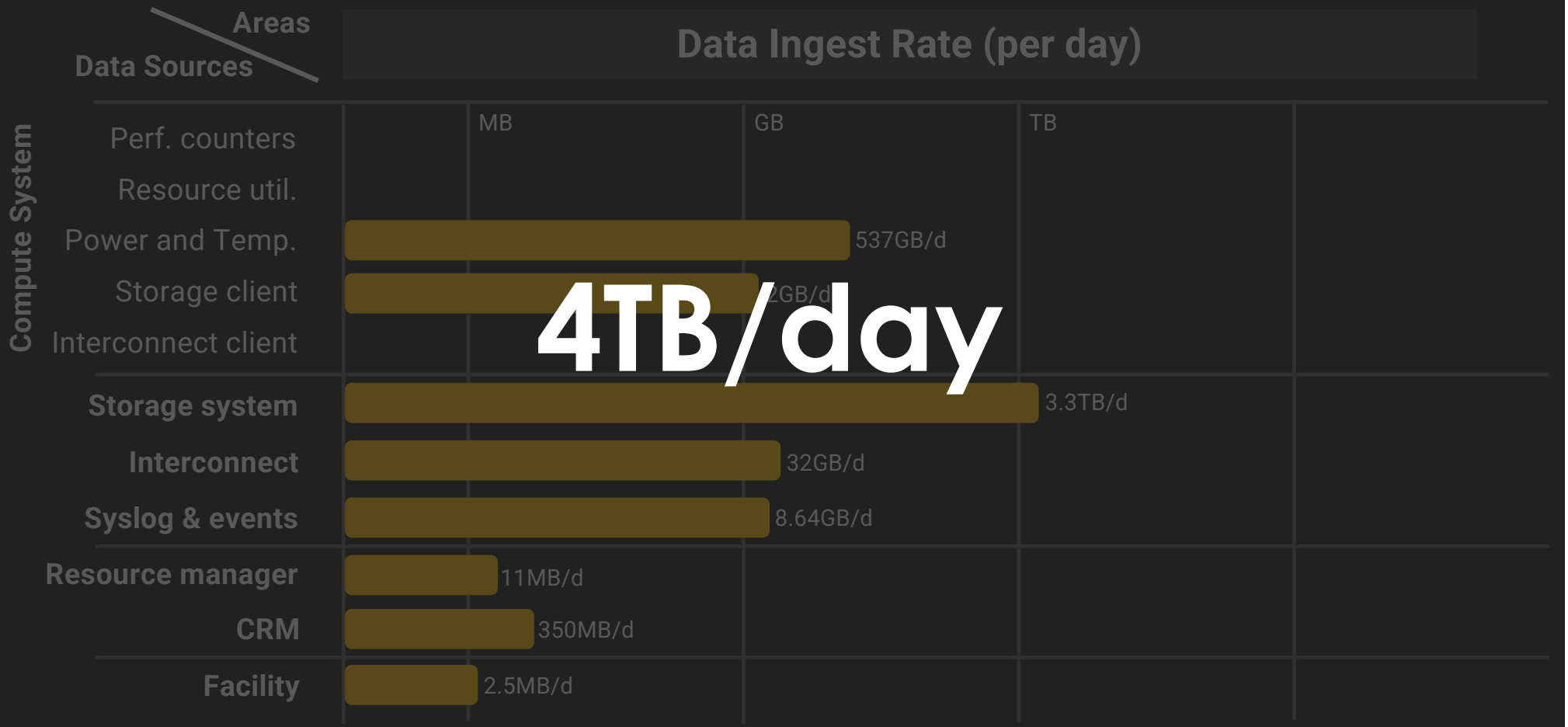
Data Producers and Users



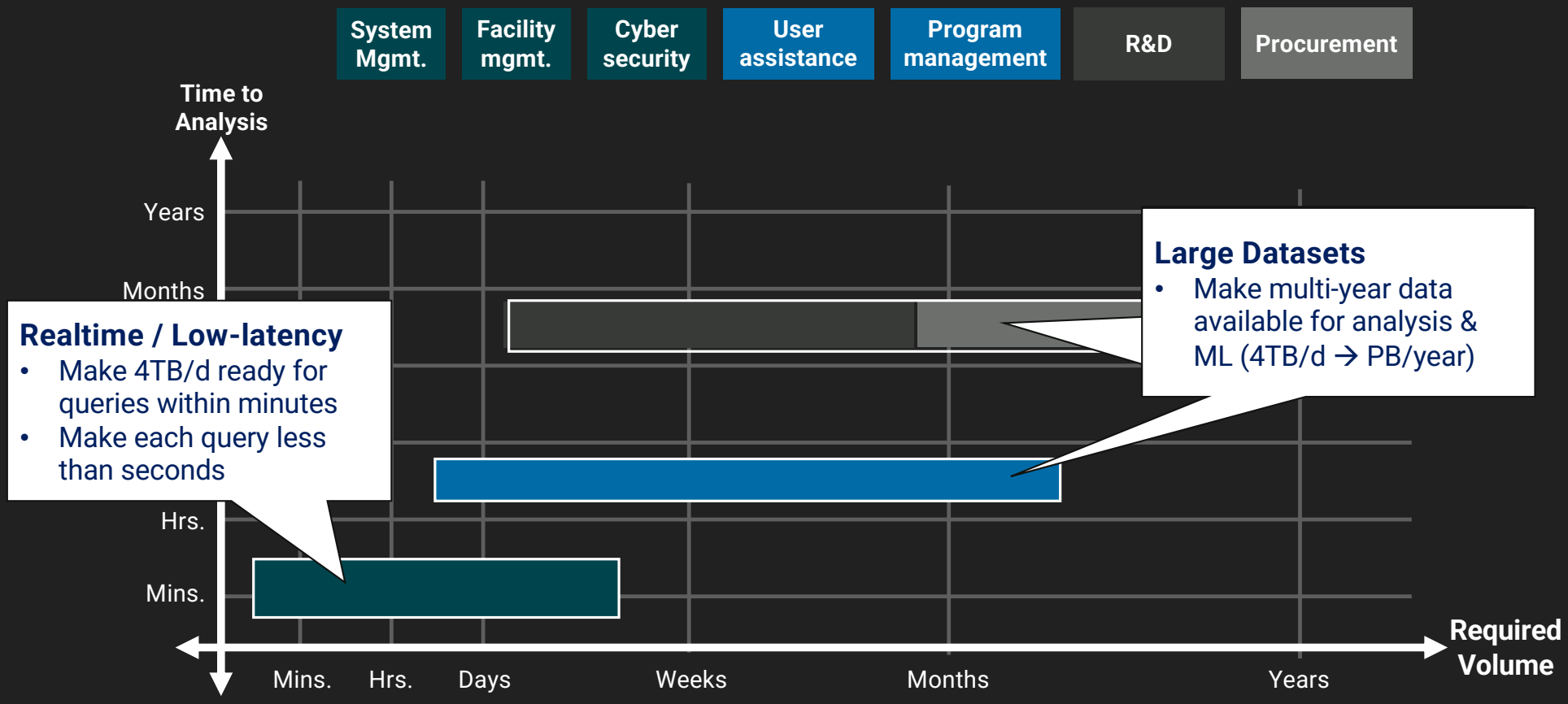
Data Producers and Users



Data Ingest Volume



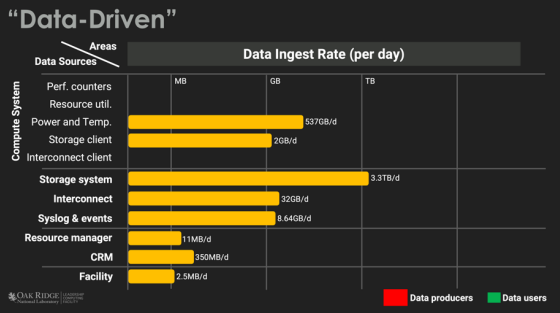
Data Velocity and Volume



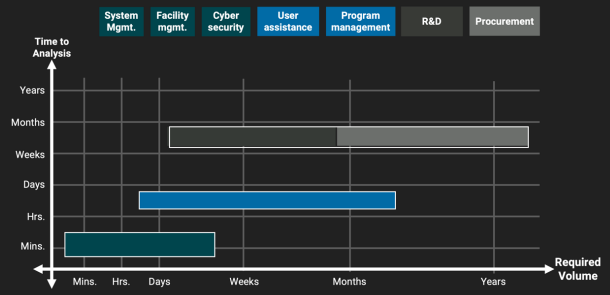
Data usage of an HPC Organization

Multi-streamed
Multi-faceted
4TB/day
High Volume
High Velocity





Data Velocity and Volume

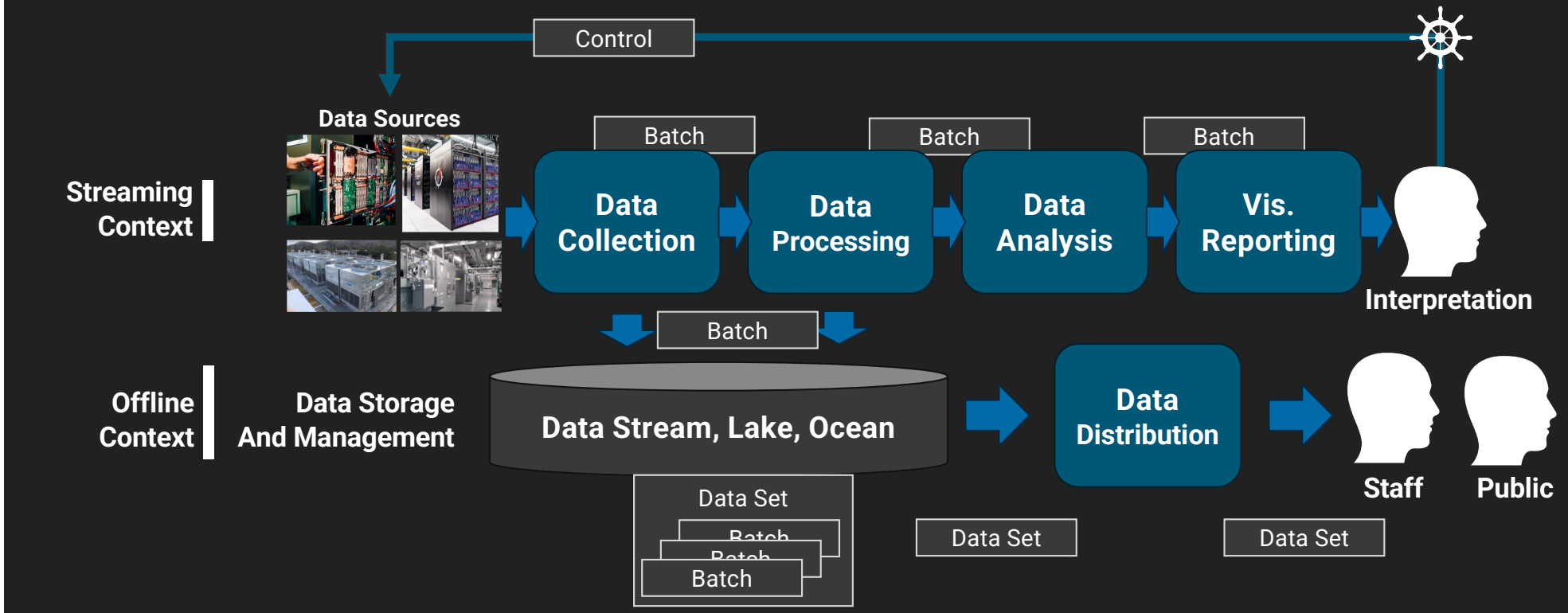


Data usage of an HPC Organization

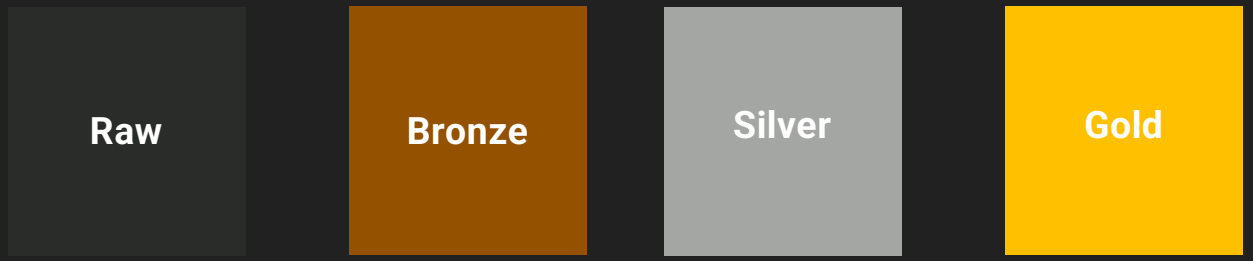
High-Variety
High-Volume
High-Velocity

How do we support this?

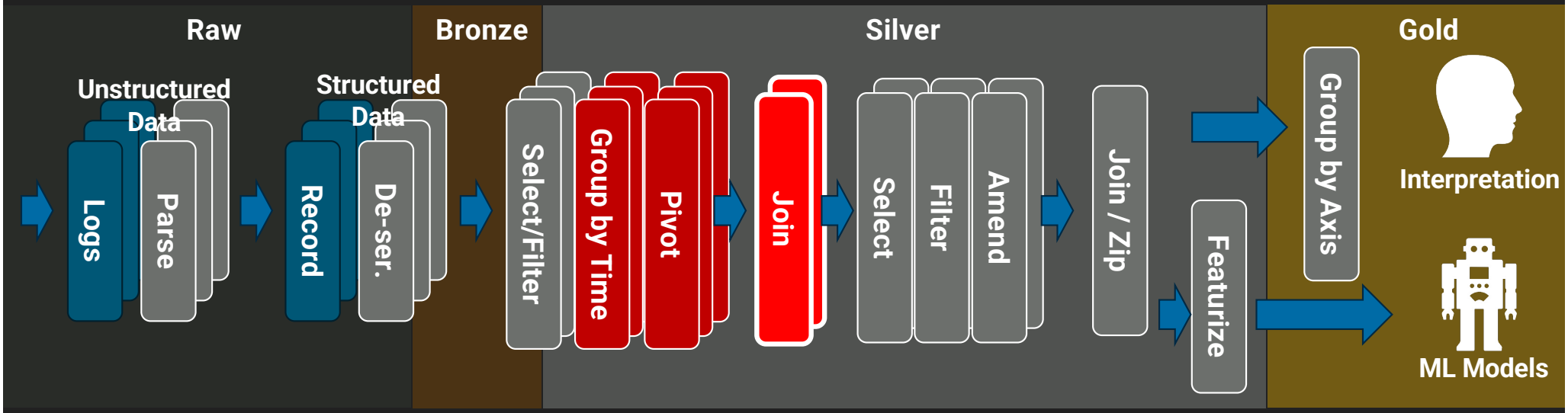
Data Lifecycle of HPC Operational Data



The Medallion Data Architecture



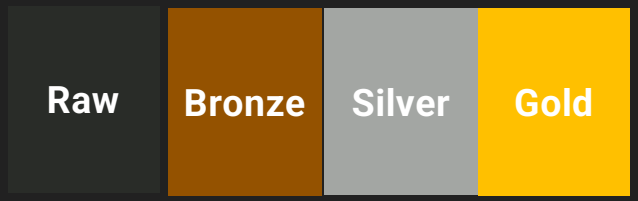
Conceptual Anatomy of a Data Pipeline

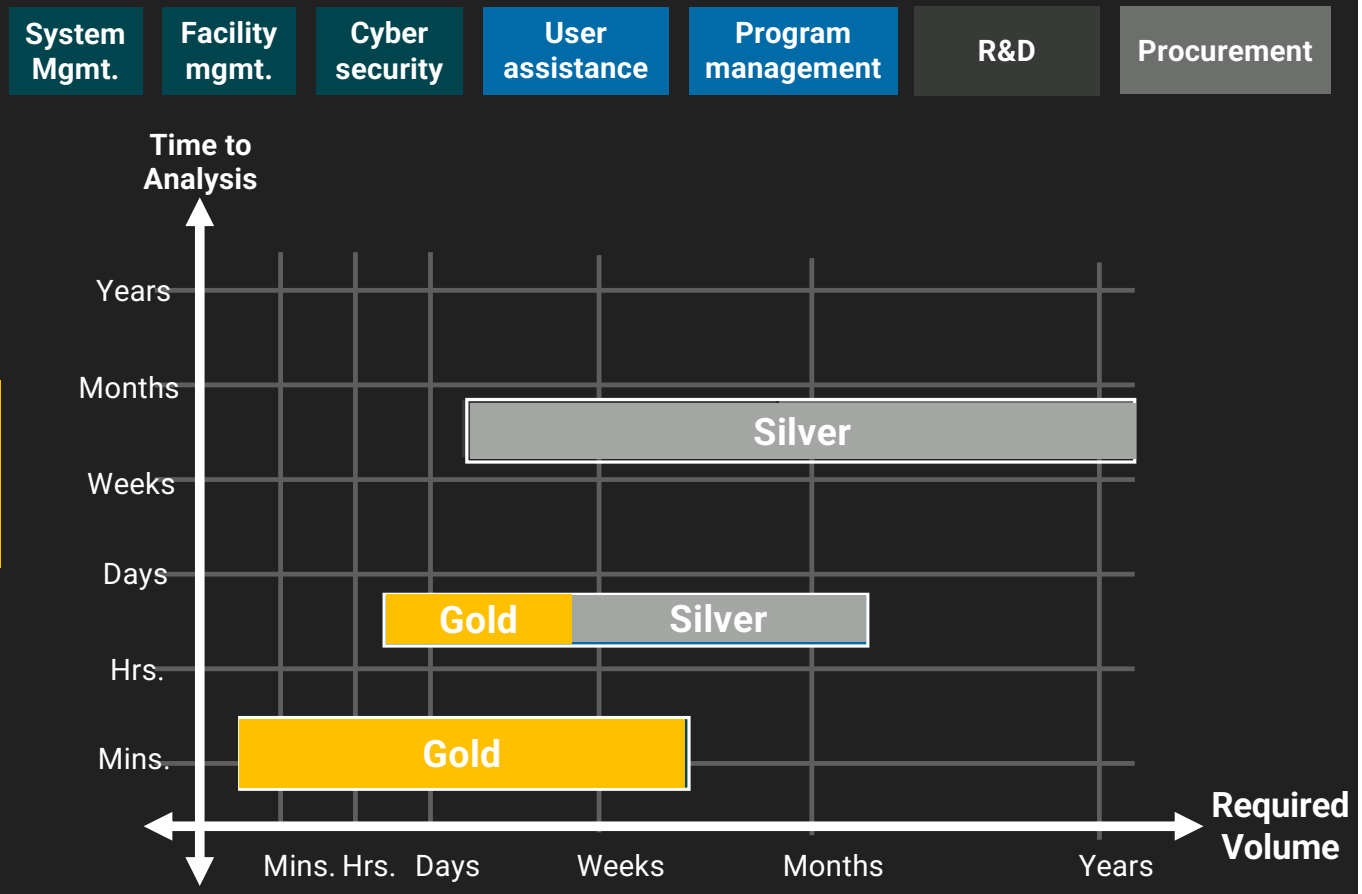


XLarge → Large → Small

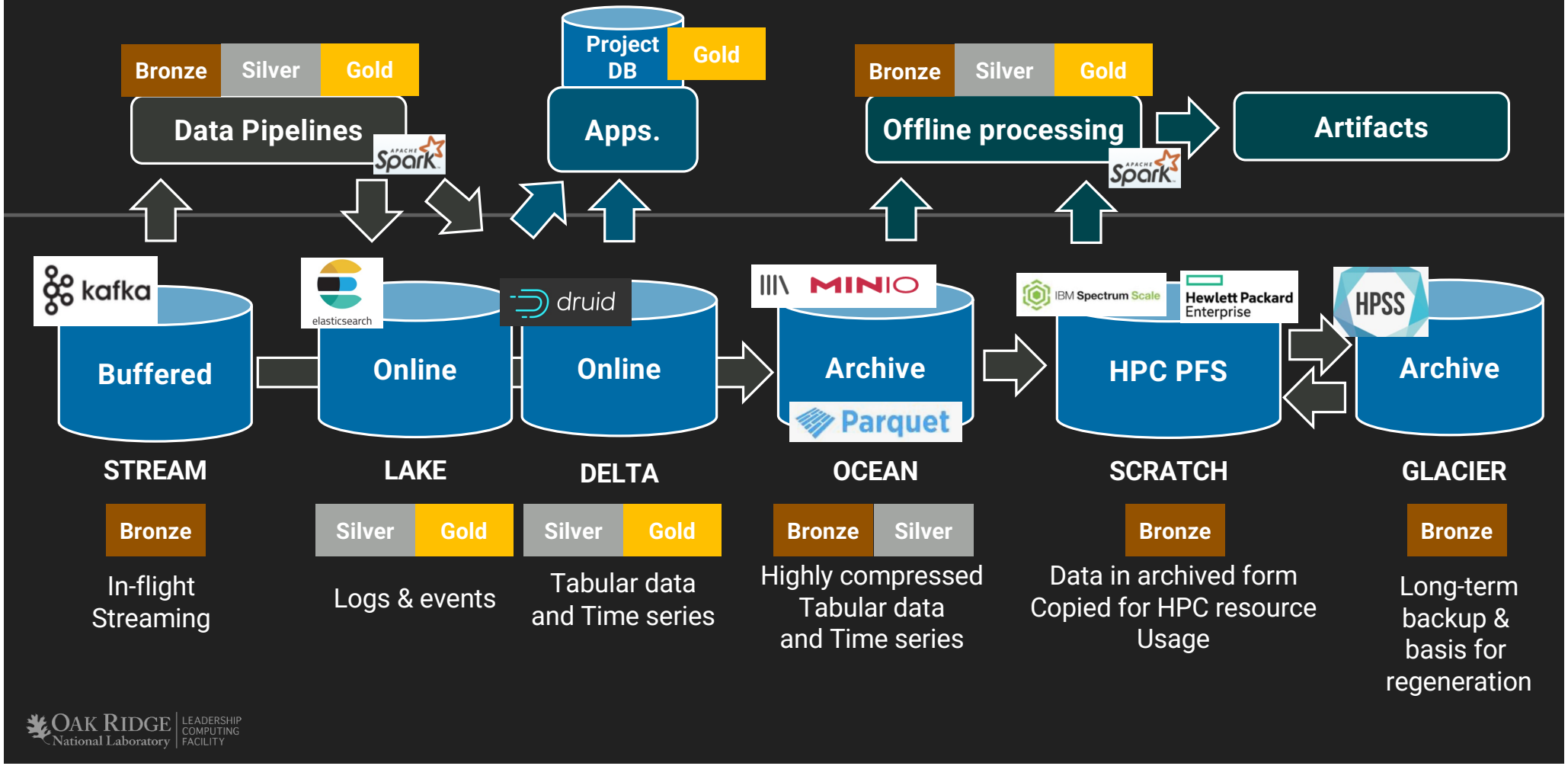
Low Quality → Medium Quality → High Quality

Impact of Data Refinement

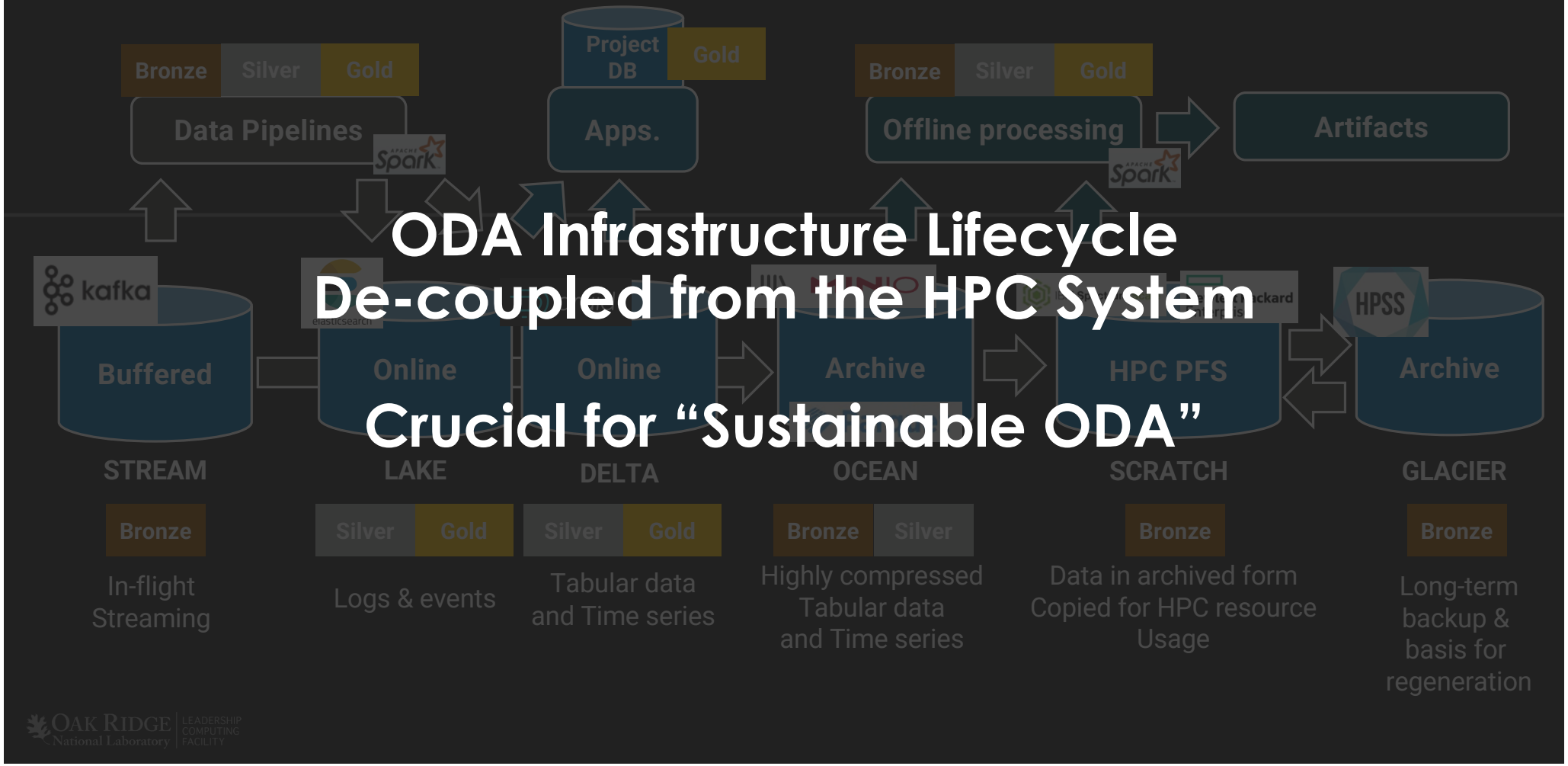




Data Engineering Infrastructure



Data Engineering Infrastructure



ODA Infrastructure Lifecycle
De-coupled from the HPC System

Crucial for "Sustainable ODA"

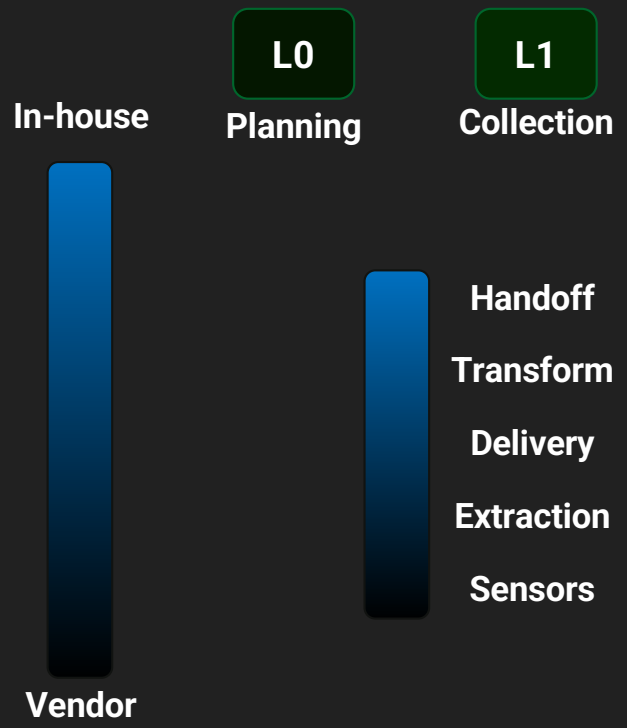
How do we avoid drowning from data?

Deliberate Data Stream Development

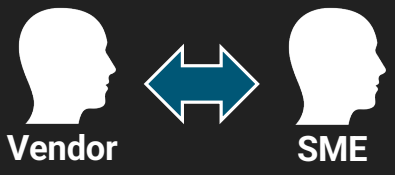


Major bottlenecks

Data Collection:
Early and Iterative Vendor Engagement



Q: When should we start engaging the vendor?



How can we maximize Day one data usage?

A: Way before the procurement

Data Collection:
Early and Iterative Vendor Engagement





L0 Planning | L1 Collection | L2 Engineering & Mgmt. | L3 Analysis & Study | L4 Refinement | L5 Usage

Data collection needs innovation

- Easy discovery of data
- Upstream data transforms tailored to downstream needs
- Low overhead accurate data extraction and delivery
- HPC tailored purpose driven H/W metrics

Analysis & Study: Data Exploration Campaign



L3

Analysis & Study

Not your normal EDA

Terabyte scale

Very messy dataset

Unknown use case

Raw | **Bronze** | **Silver** | **Gold**

Parquet — **Compressed Archive**

Apache Spark — **Stream Analytics Cluster**

Jupyter — pandas

MINIO — **Archive**

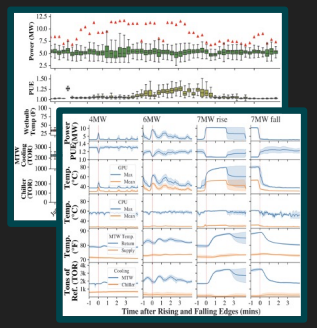
IBM Spectrum Scale | Hewlett Packard Enterprise — **HPC PFS**

HPC Resources

OCEAN **SCRATCH**

Data dictionary

Online data pipeline



End-to-end data analysis

Analysis methods

ML use cases

Usage of Data: Visualization and Reporting

L5
Usage

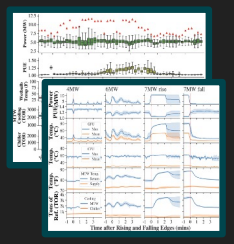


SME



Handoff
Transform
Delivery
Extraction
Sensors





Raw | Bronze | Silver | Gold

L0 Planning | L1 Collection | L2 Engineering & Mgmt. | L3 Analysis & Study | L4 Refinement | L5 Usage

Treating this as a proper software engineering project
Starts with the data pipeline development

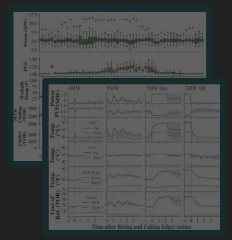
Visualization and Reporting

L5
Usage

Well canned applications integrated into existing workflows
sustainable use cases that lasts multiple generations of systems – **avoid one-offs!!**

doff
sform
very
ction
sors





Raw | Bronze | Silver | Gold

on

L2
Engineering & Mgmt.

L3
Analysis & Study

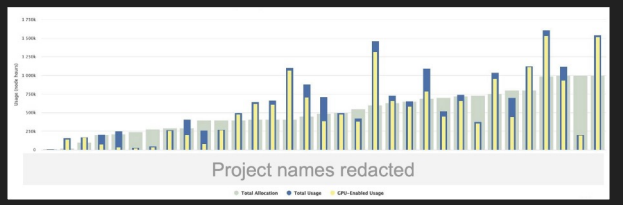
L4
Refinement

L5
Usage

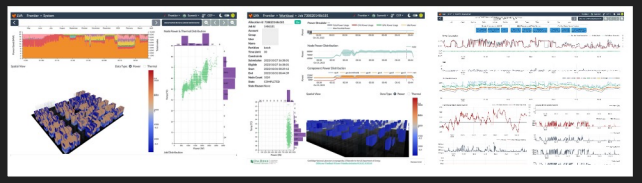
Treating this as a proper software engineering project
Starts with the data pipeline development



User Assistance
Easy access to many data streams



Resource Allocation Program Management
"Realtime" easy overview of per project usage resource usage

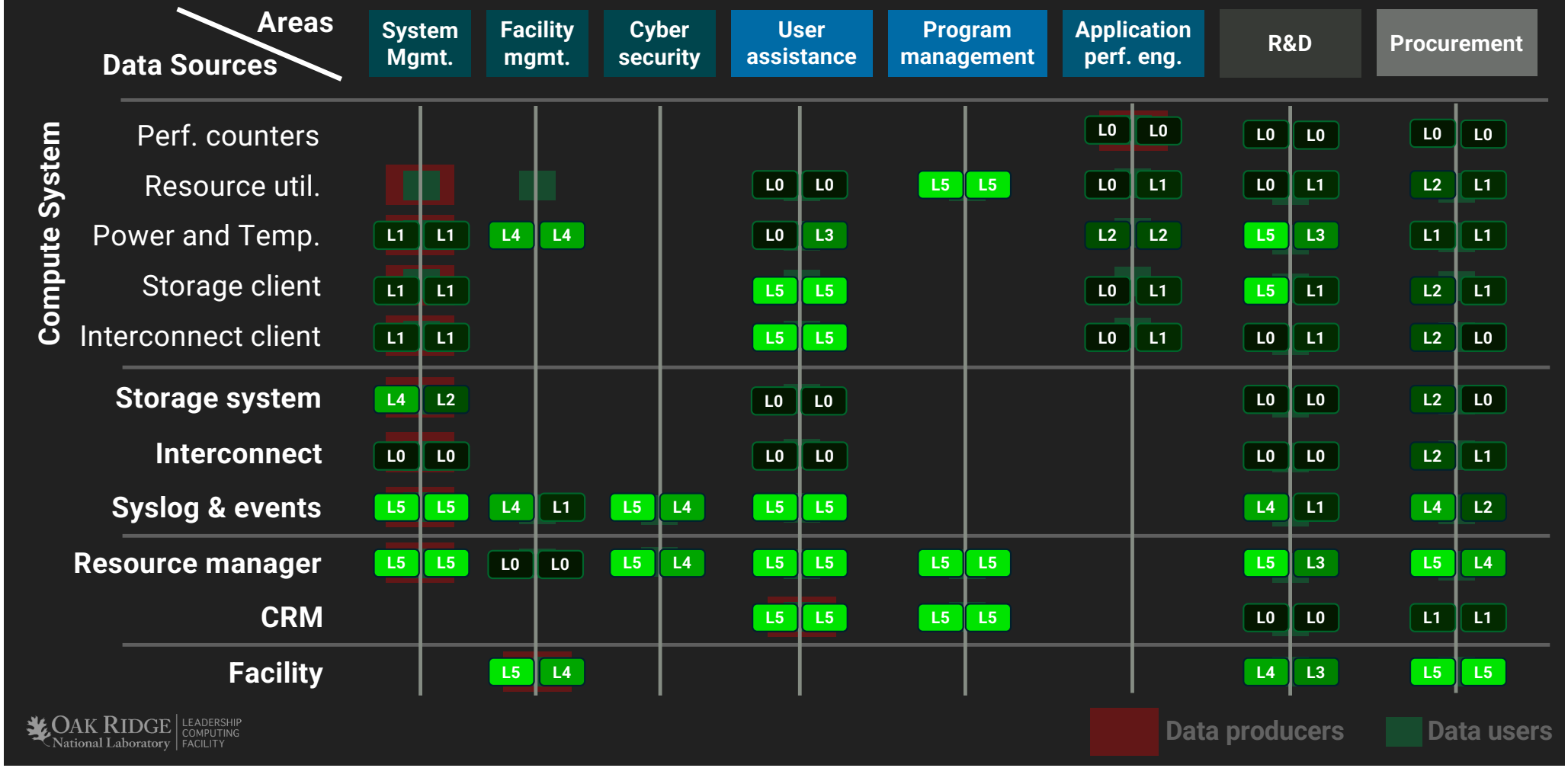


Interactive in-depth
Power & energy analytics
Interactive view into high-dimensional times series data

Progress at OLCF

summit | FRONTIER

L0 Planning · L1 Collection · L2 Engineering & Mgmt. · L3 Analysis & Study · L4 Refinement · L5 Usage



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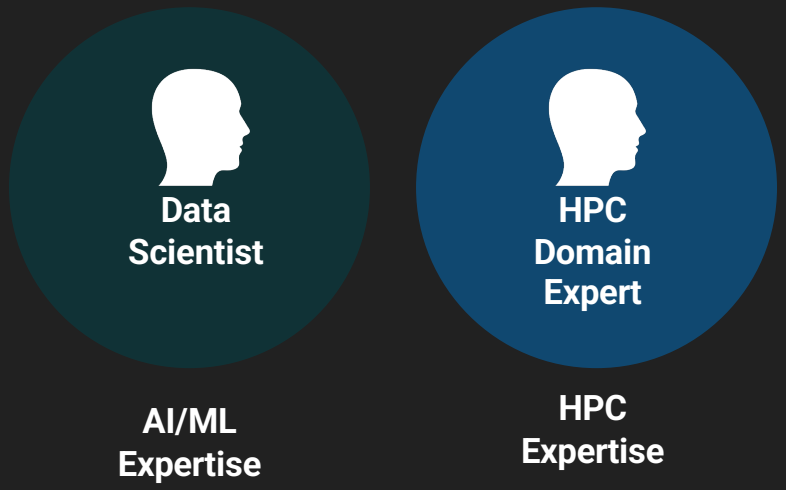
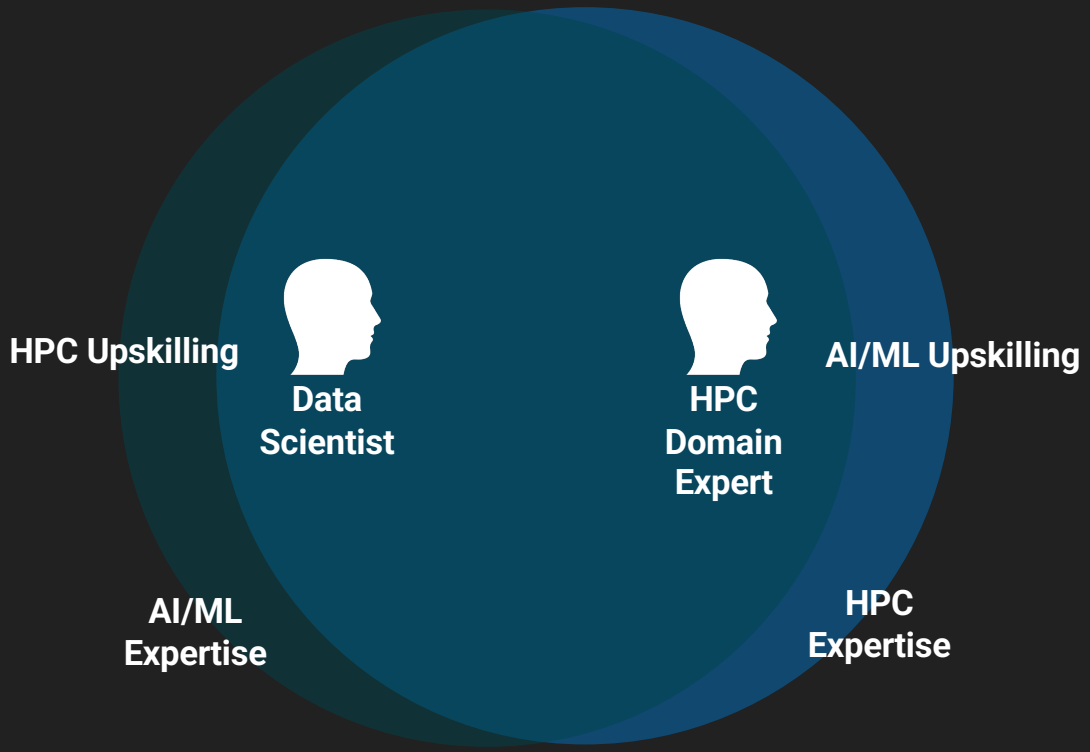
What about Machine Learning?

ODA and ML

AI/ML Talent and HPC



AI/ML Talent and HPC



The AI/ML Data Bottleneck in HPC ODA Despite Abundance

Capture Everything then Explore
But still not enough

You cannot do anything without data, so we made it cheap
to capture everything, but we're limited to what we have collected
Use cases are developed with what is available…

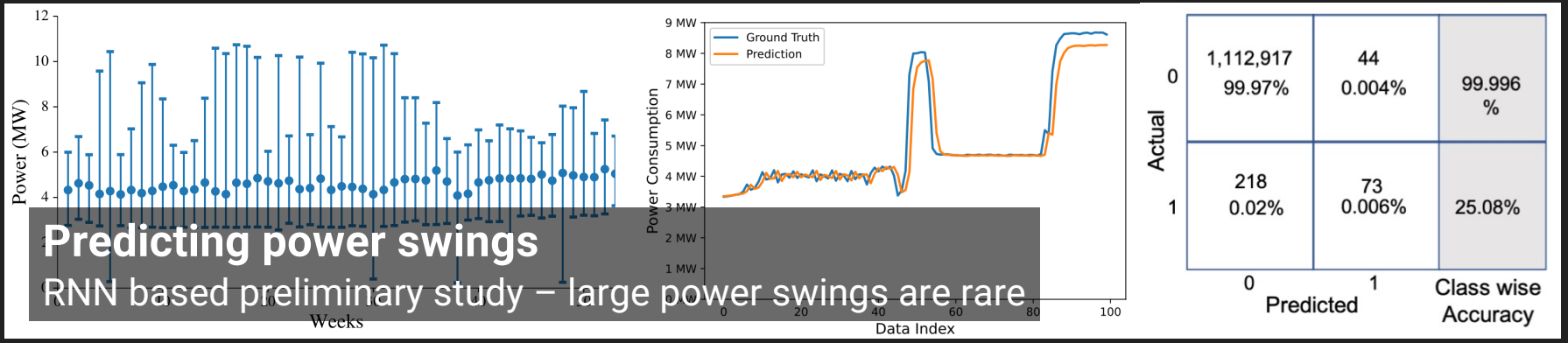


Inherent Sparsity & Skewed nature of HPC Datasets

Important features, events are rare – you've been warned!

"There be Dragons"

Sparsity in HPC ODA – Power Swing Prediction

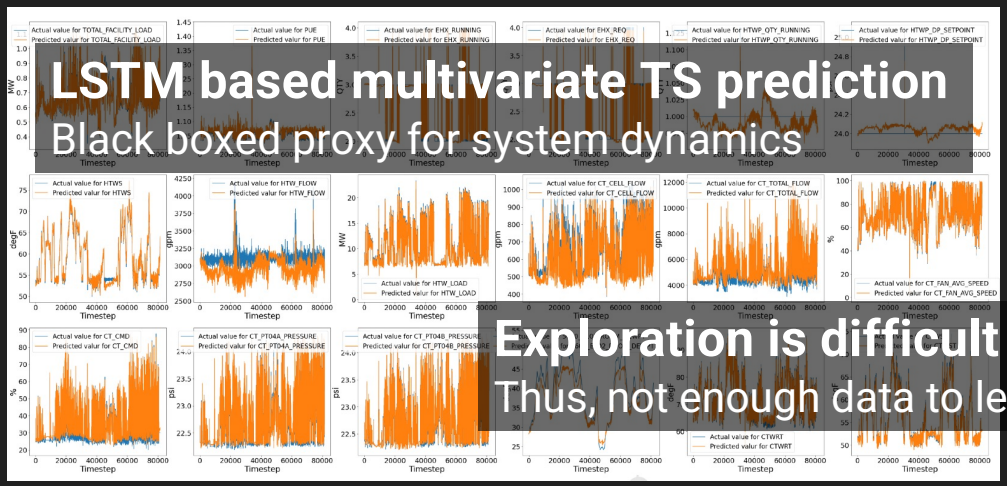


Predicting power swings

RNN based preliminary study – large power swings are rare

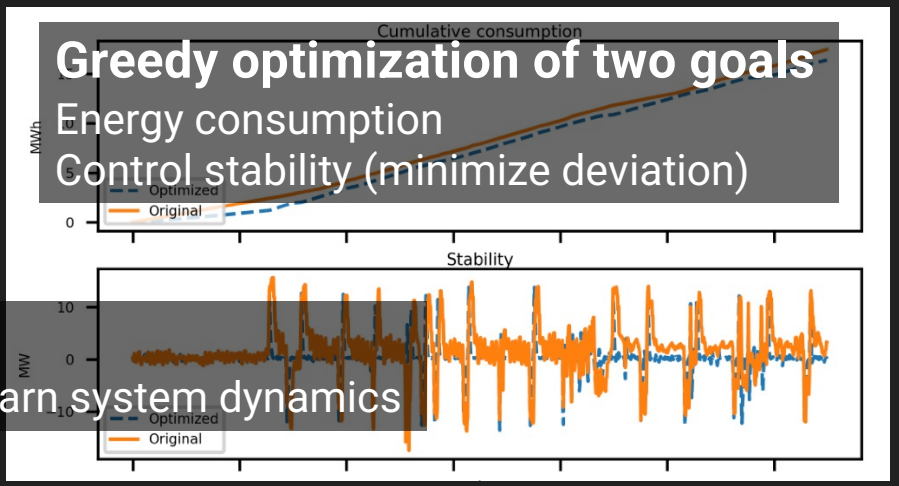
Power consumption dynamics - time series prediction

Sparsity in HPC ODA – CEP Setpoint Optimization



LSTM based multivariate TS prediction

Black boxed proxy for system dynamics



Greedy optimization of two goals

Energy consumption

Control stability (minimize deviation)

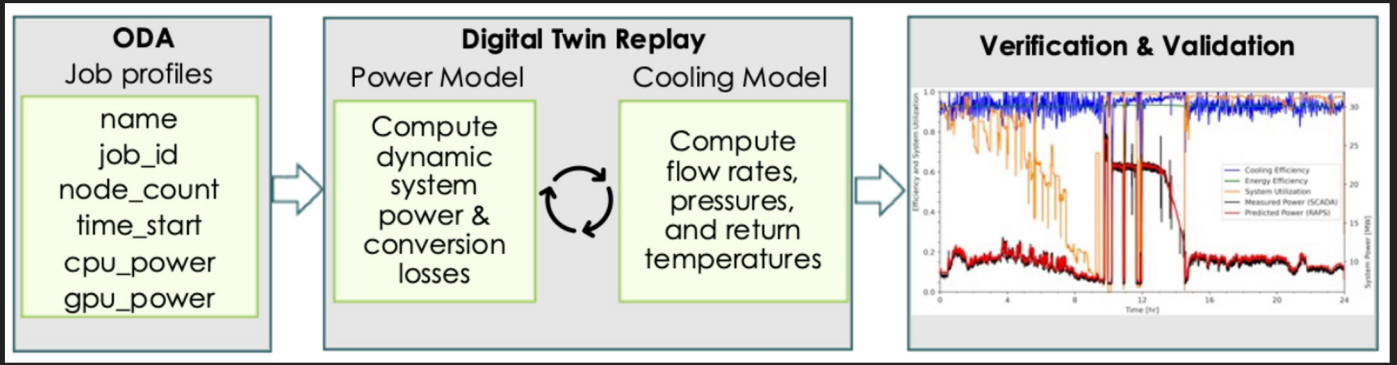
Exploration is difficult

Thus, not enough data to learn system dynamics

Frontier CEP set-point optimization

"Optimizing Cooling Controls of an Exascale HPC Central Energy Plant Using Data Driven Methods" – Helia Zandi,

Digital Twins – White-box Approaches



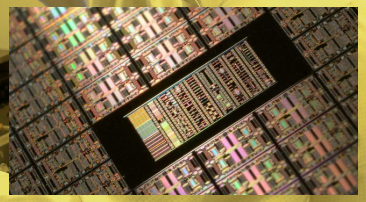
Digital Twins
White-box models validated on top of real telemetry data
What if analysis & optimization – efficient exploration

Overcomes sparsity of ODA data – but with a cost…

The Future of ODA

Post-exascale Challenges

Power efficiency growth rate
Diminished rate of growth in power efficiency (flops / watt)



AI/ML demands on the die space
Conflicting compute requirements (FP64 vs. Tensor cores)

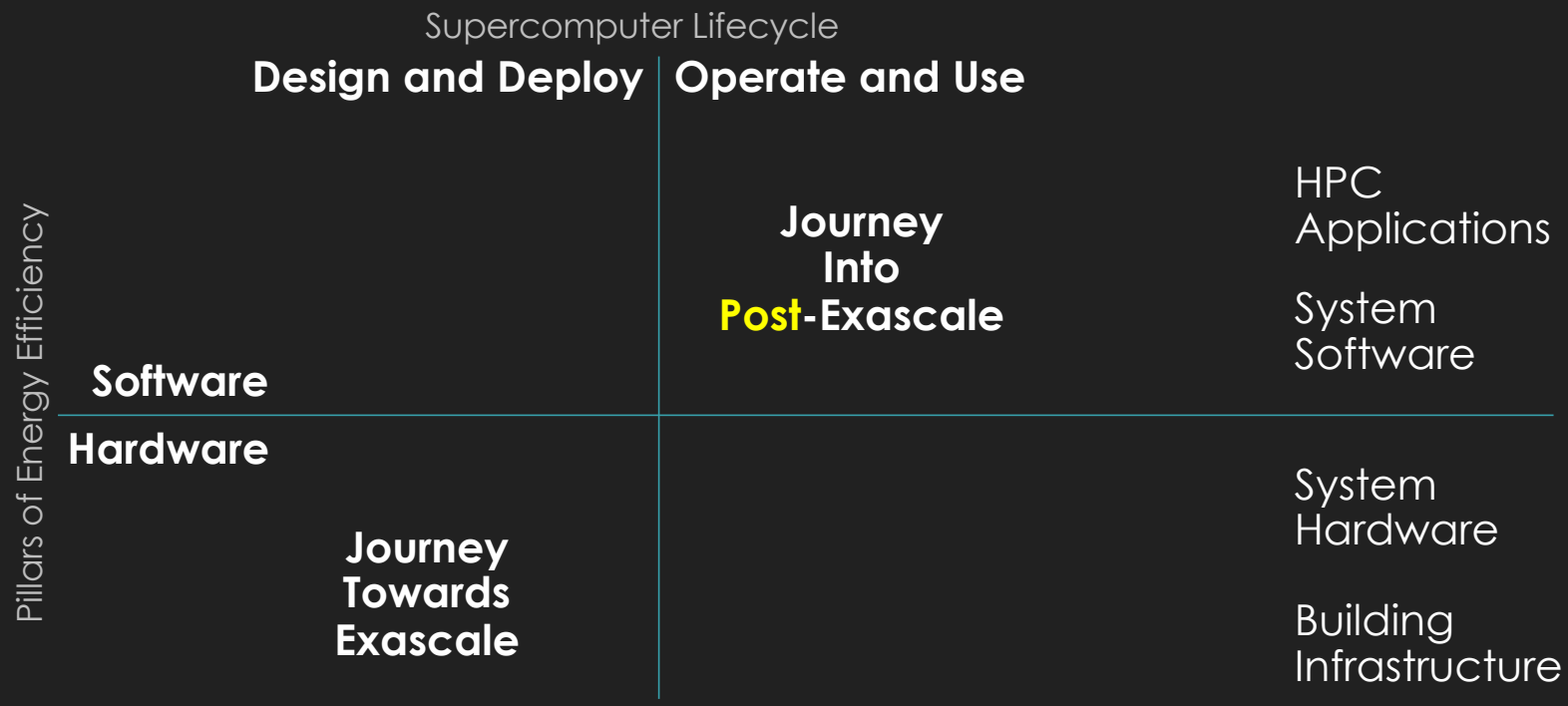


Limited local power budget
Constrained power infrastructure for an individual HPC site

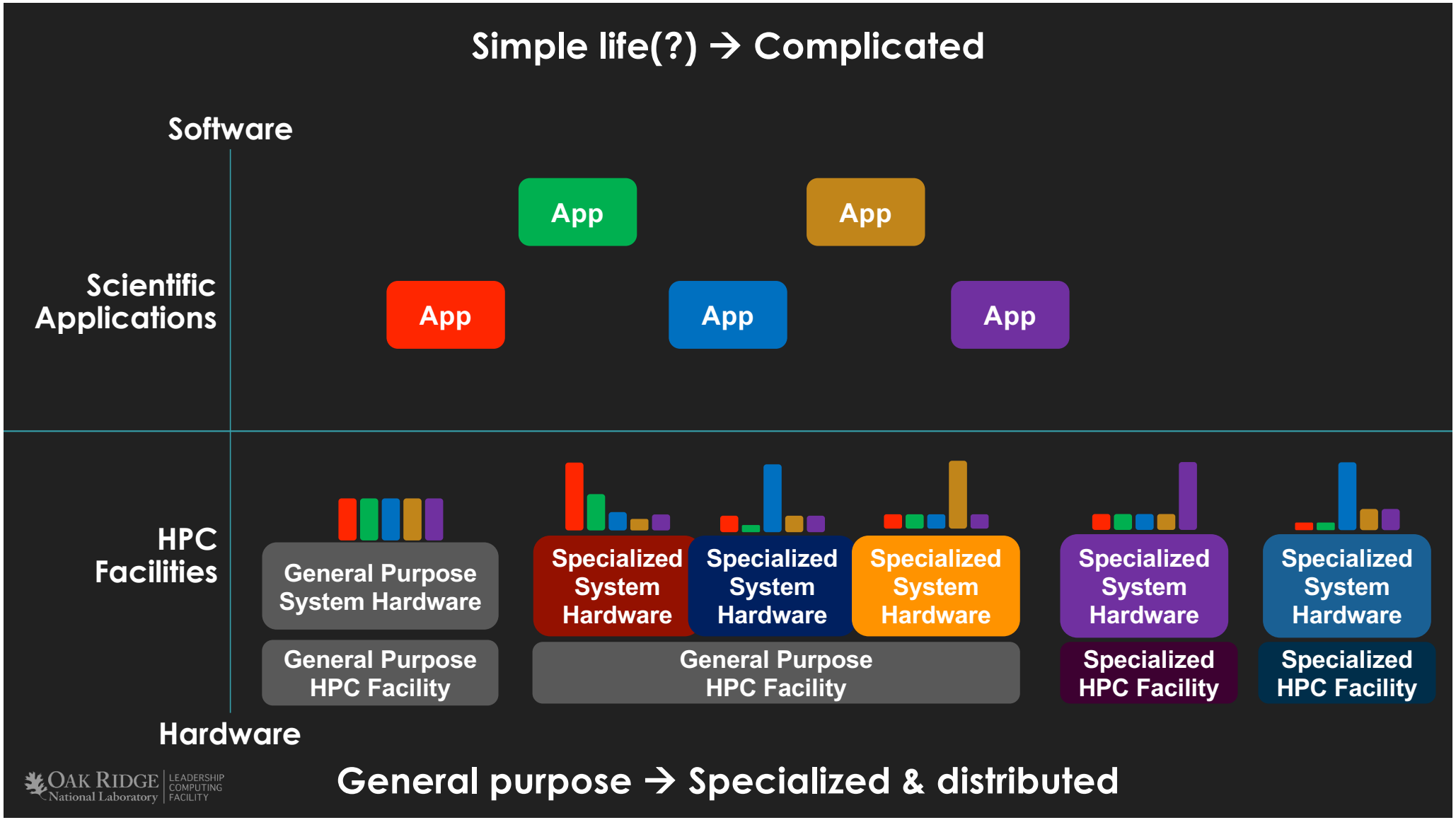


Carbon emission reduction goals
Renewable energy
Supply chain

Post-exascale: More Emphasis on Operation-time Efficiency



Wilde et. al, "The 4-pillar framework for energy efficient HPC data centers", 2014



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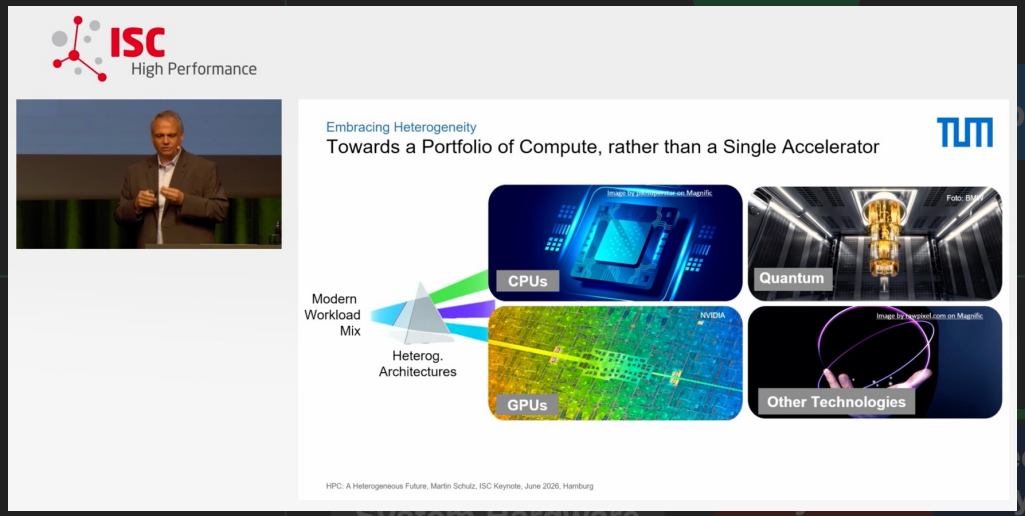
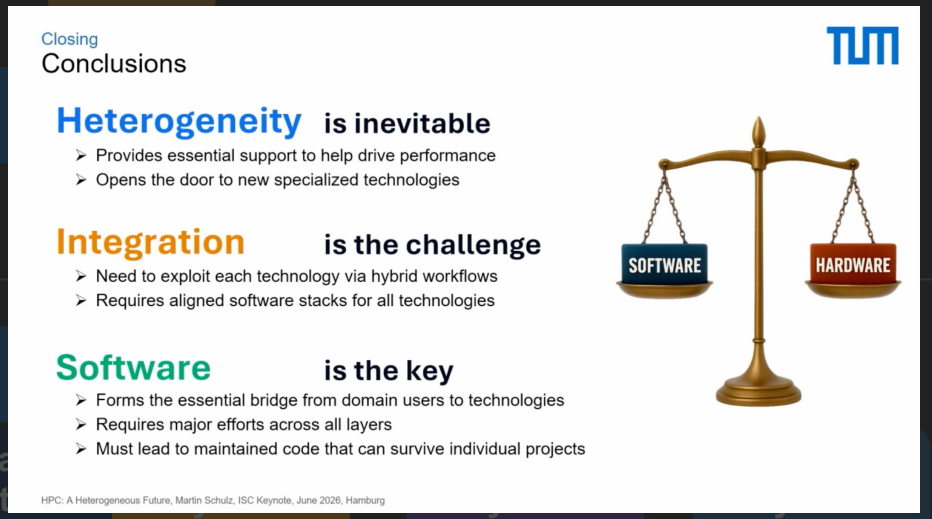
Simple life(?) → Complicated

Software

App

App





System Hardware

Hardware

Hardware

Hardware

Hardware

General Purpose HPC Facility

General Purpose HPC Facility

Specialized HPC Facility

Specialized HPC Facility

Hardware

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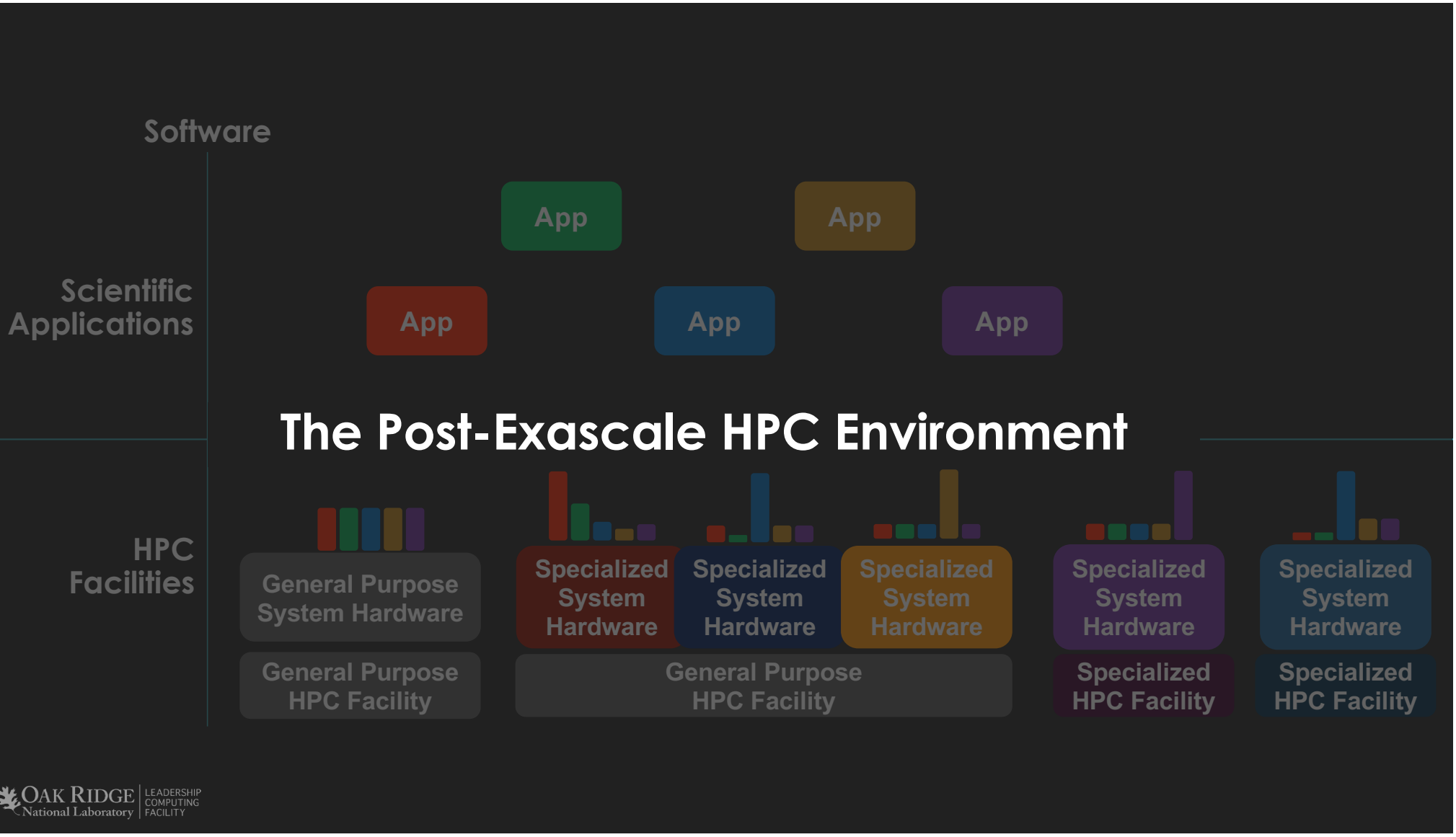
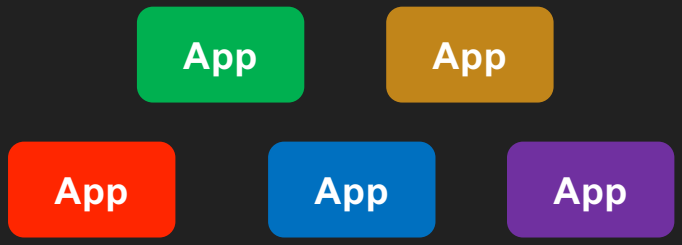
General purpose → Specialized & distributed

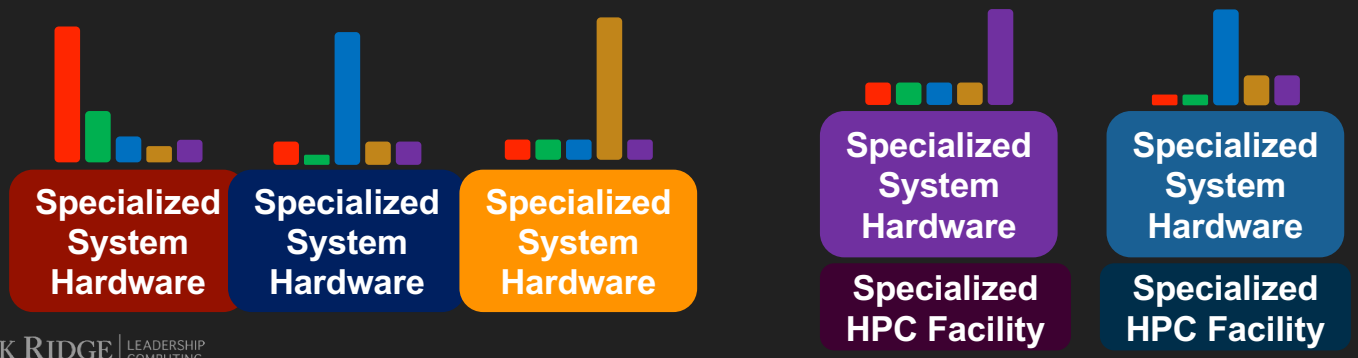
The Post-Exascale HPC Environment



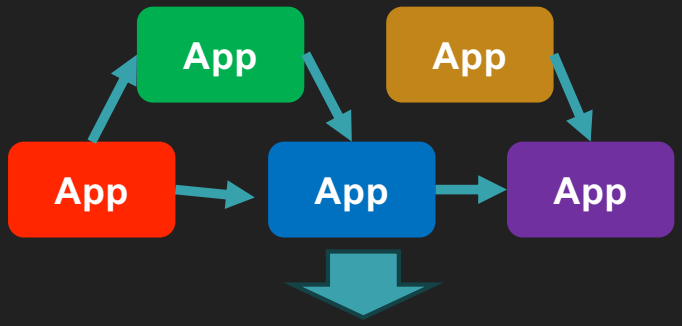
Specialization & Complexity



Geographically Distributed HPC Capabilities "Extreme Complexity"



Specialization & Complexity

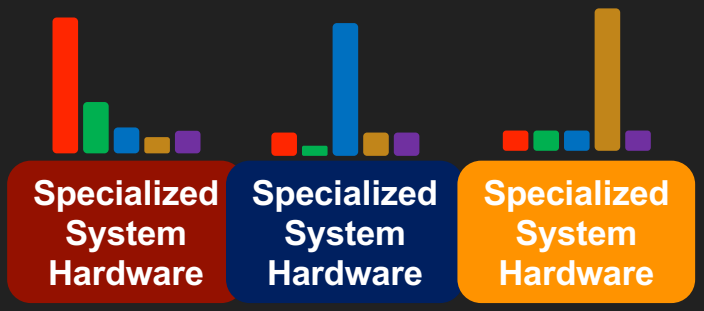


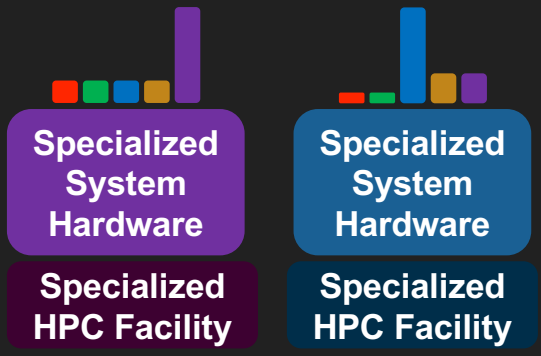
Distributed Workflow Middleware

System Software

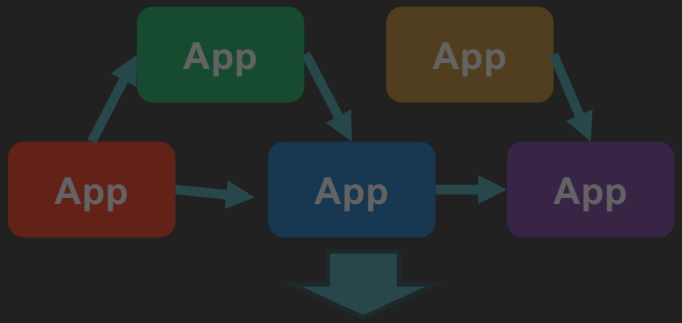
System Software

System Software





Specialization & Complexity



Workflow Optimization
Performance & energy awareness, compute and data movement and placement

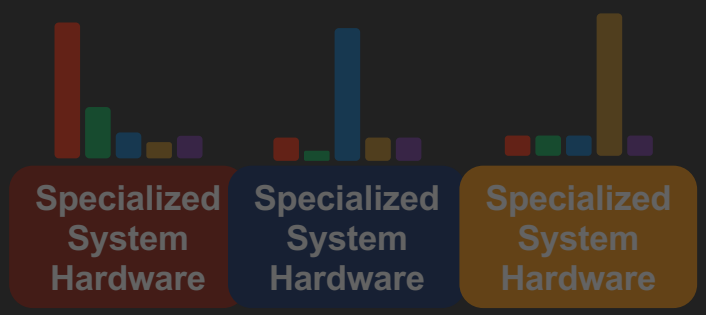
Innovations Required
Digital Twins
Multi-objective optimizers
Multi-tenancy
Runtime resource usage profiling

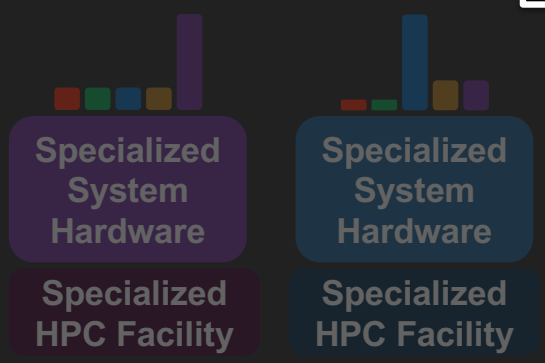
Distributed Workflow Middleware

System Software

System Software

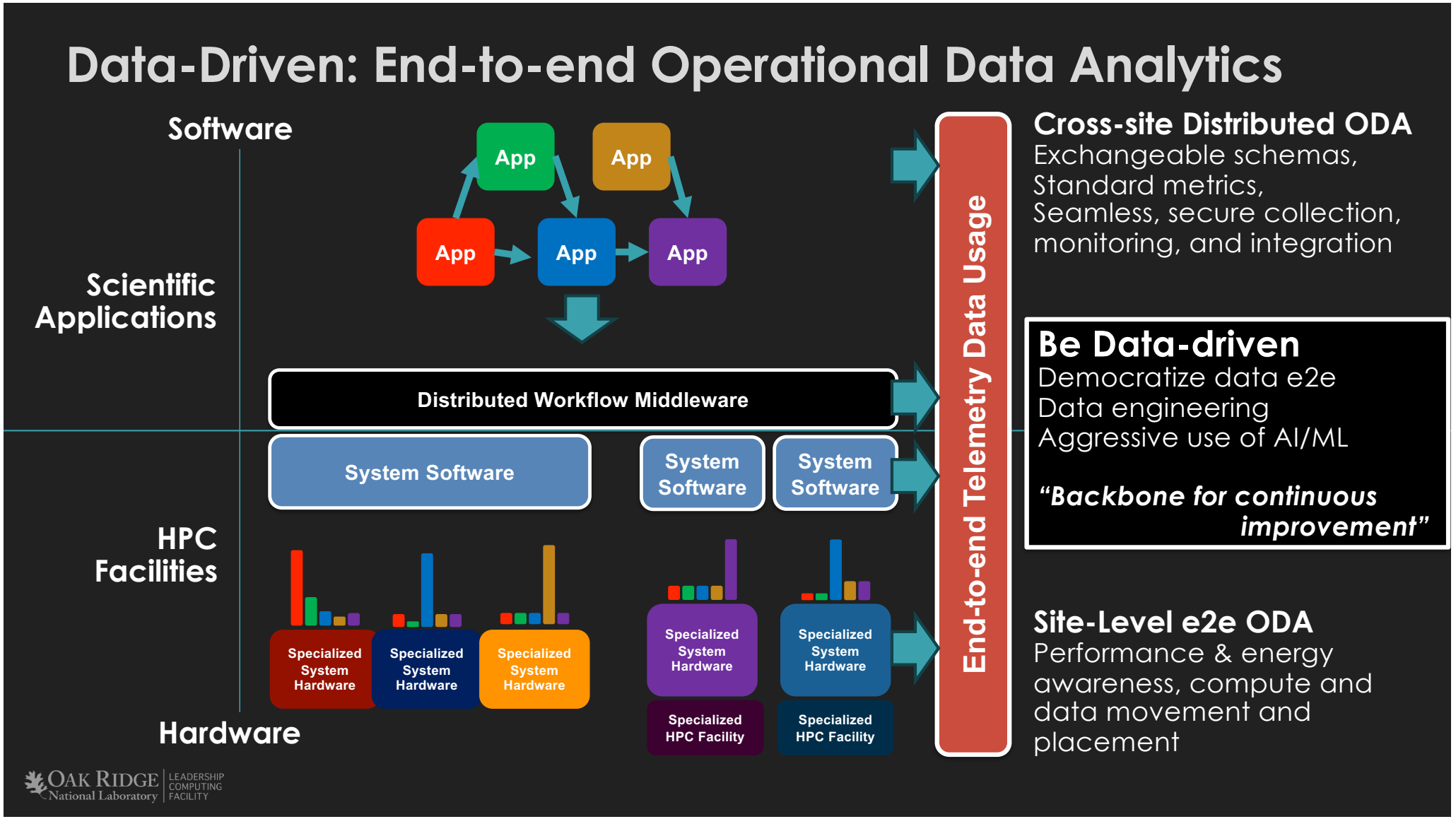
System Software





System Optimization
Energy awareness
Resource usage-based placement optimization

Data-Driven: End-to-end Operational Data Analytics



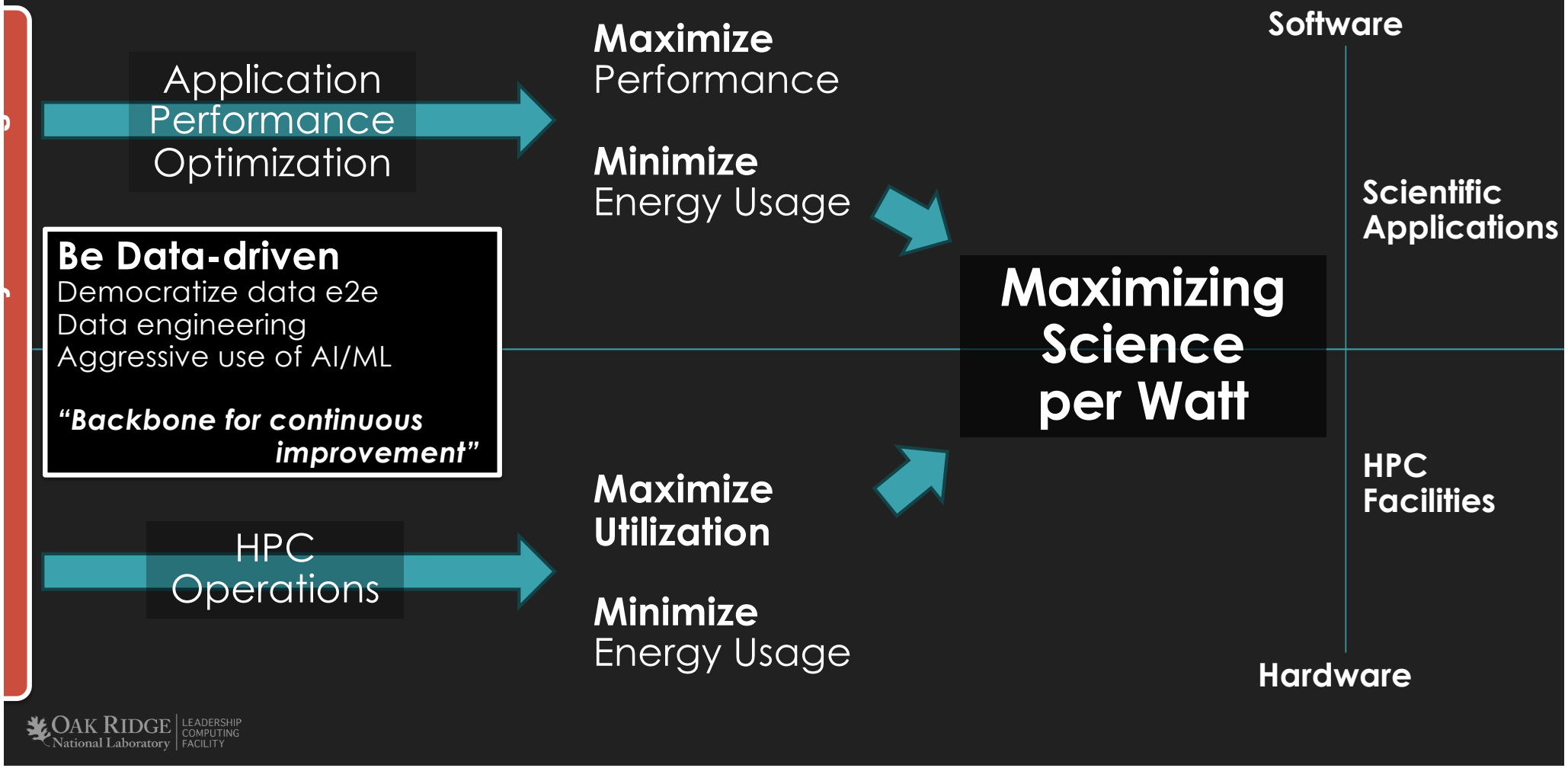
Cross-site Distributed ODA
Exchangeable schemas,
Standard metrics,
Seamless, secure collection, monitoring, and integration

Be Data-driven
Democratize data e2e
Data engineering
Aggressive use of AI/ML

"Backbone for continuous improvement"

Site-Level e2e ODA
Performance & energy awareness, compute and data movement and placement

Data-Driven: End-to-end Operational Data Analytics



So… The Future of ODA

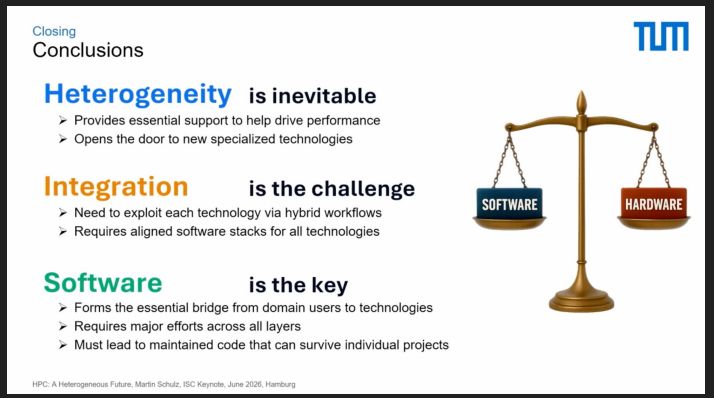
Are we Ready?

So… The Future of ODA

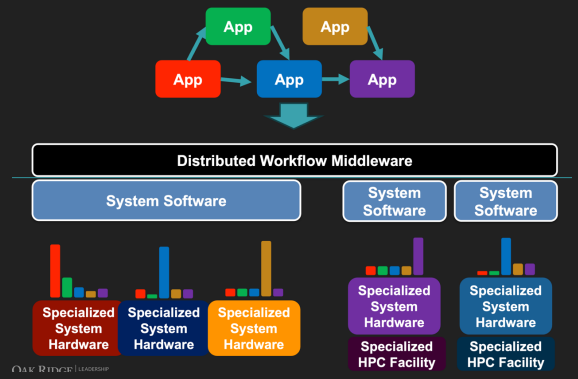
Are we Ready?

L0	L1	L2	L3	L4	L5
Planning	Collection	Engineering & Mgmt.	Analysis & Study	Refinement	Usage





Heterogeneous



Geographically Distributed

Extreme Complexity Ahead

So… The Future of ODA

Are we Ready?

L0	L1	L2	L3	L4	L5
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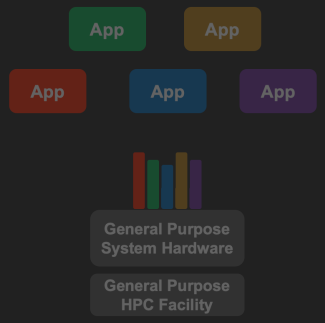
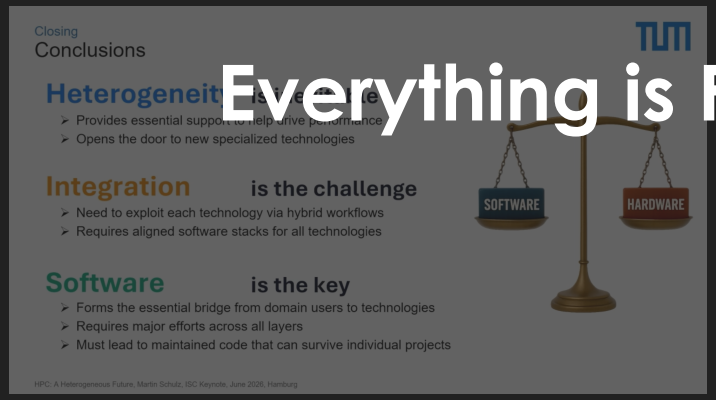
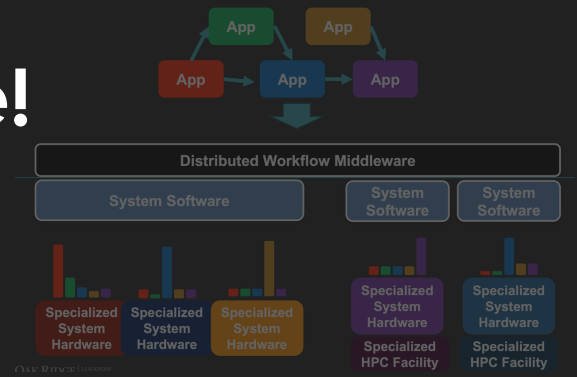




Heterogeneous

Everything is Fine!



Geographically Distributed

Extreme Complexity Ahead

What could possibly go wrong?

Everything is Fine!

Community, Venues, Standards

- Industry
- HPC Sites
- Academia
- Users

Talent & Expertise



Technology Innovation

- High fidelity
- Low-overhead
- Low-latency
- Heterogeneous
- High-bandwidth & throughput
- Realtime
- Realtime

HPC, Quantum, Neuromorphic, AI

Funding and Resources

- Compute
- Storage
- Human Resources
- Project
- Operations



Conclusion

Summary (Past & Current)

ODA for a HPC organization

Two generations of supercomputers – end-to-end
Made progress in data engineering, data is useful
for more people and parties than you think

Know thy data usage end-to-end

Multi-stream, Multi-faceted Data Usage
Volume, Velocity, Variety
Cost effective center-wide multi-tiered infrastructure

SME Driven Deliberate data stream development

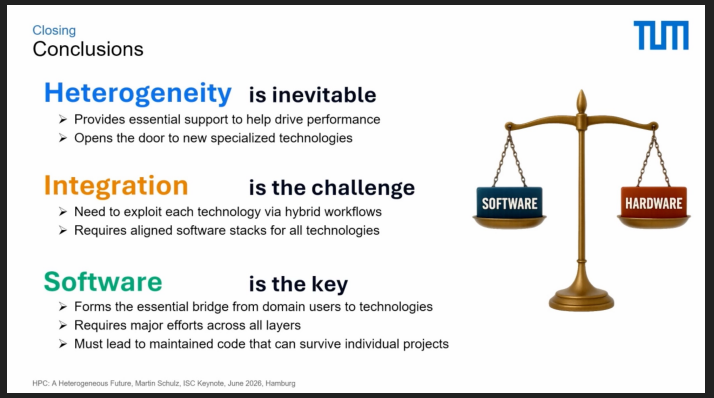
We took a "***capture everything then think route***"
Breaking through data usage bottlenecks
Otherwise… you drown…

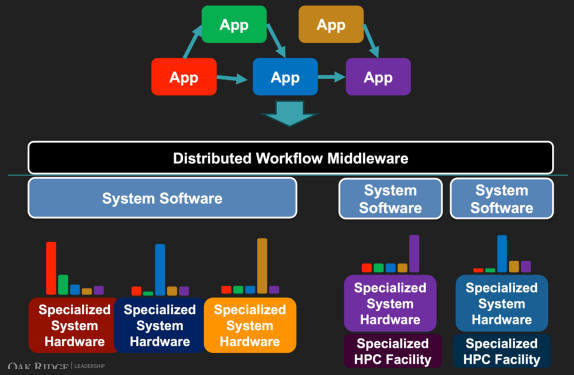
Community Challenge!
Maximizing Day One Data Usage

Future of ODA: Call for Action



Heterogeneous





Geographically Distributed

Future of ODA: Call for Action

Community, Venues, Standards

- Industry
- HPC Sites
- Academia
- Users

Talent & Expertise



Not

Everything is Fine

Technology Innovation

- High fidelity
- Low-overhead
- Low-latency
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- Realtime

HPC, Quantum, Neuromorphic, AI

Funding and Resources

- Compute
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- Human Resources
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- Operations


Thank You!
FRONTIER
DEPARTMENT OF ENERGY
Hewlett Packard Enterprise
AMD
OAK RIDGE National Laboratory | LEADERSHIP COMPUTING FACILITY