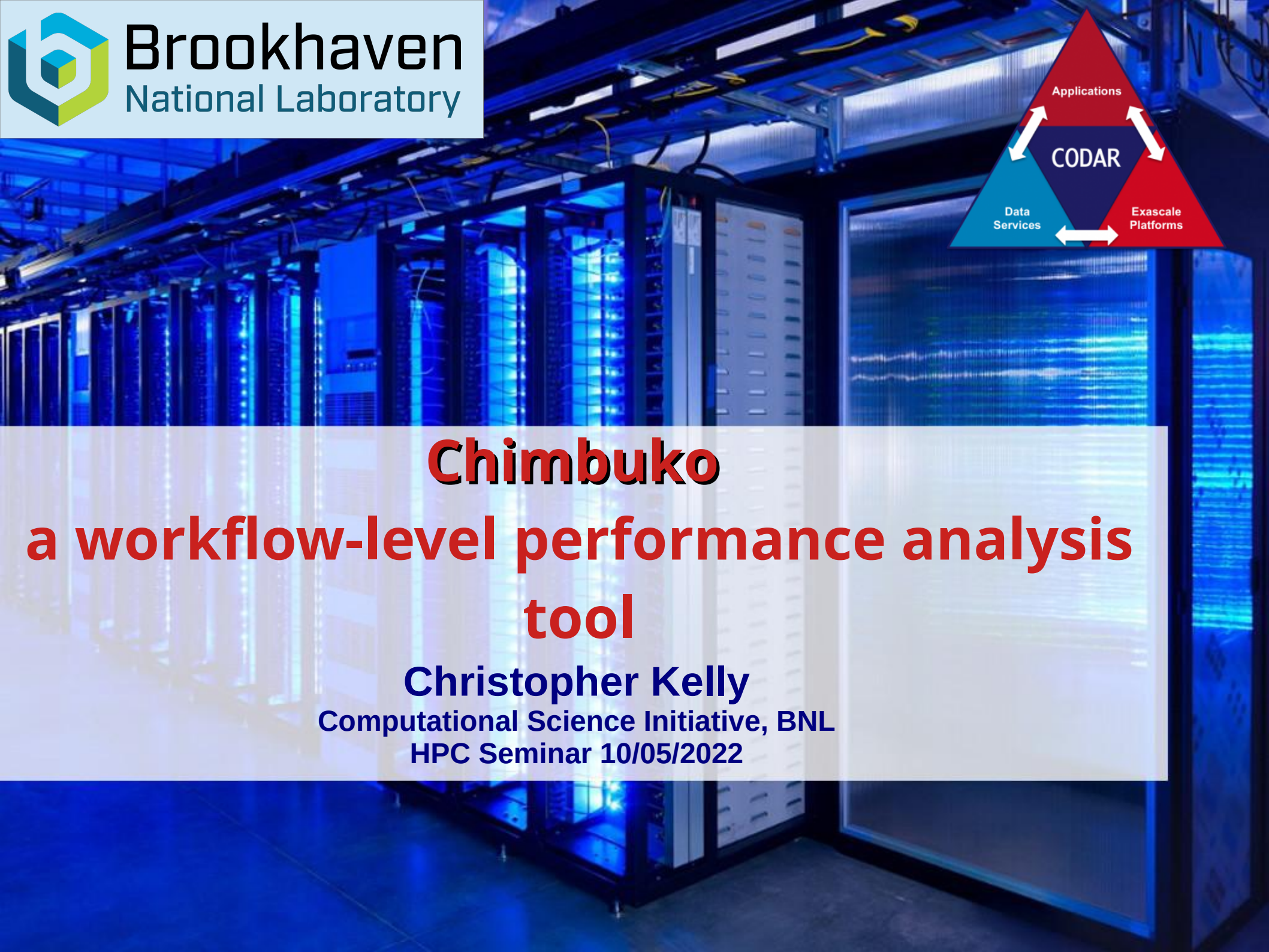
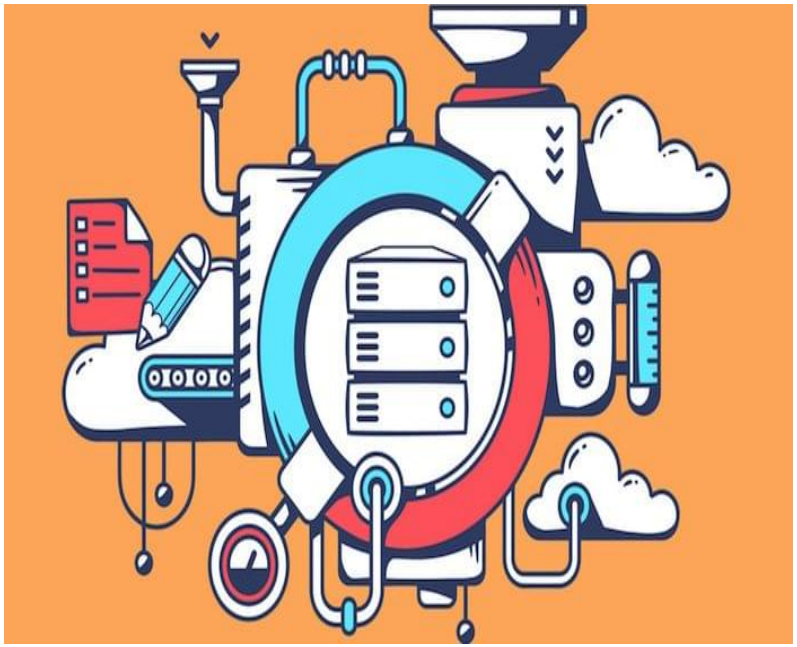


Chimbuko
a workflow-level performance analysis tool

Christopher Kelly
Computational Science Initiative, BNL
HPC Seminar 10/05/2022

The Workflow Challenge

- Many modern scientific applications form **workflows** comprising multiple interacting components.
- Components often **compete** for the same hardware resources.
- Potential for significant **performance issues** when run at-scale:
  - **Resource contention** with other workflow components or other users.
  - Temporary **bottlenecking** due to complex interactions with other components.
  - **Stochastic effects** in coupled system, e.g. interference from OS, power supply fluctuations, cosmic rays.
  - Intermittent **hardware faults**.
- Both users and system admins need to be able to identify and solve these issues.



Traditional diagnosis techniques

- Traditional tools fail:

  - **Benchmarking** and **profiling** individual components in isolation may not detect the problem.
  - **Manual timing** of critical code paths may miss the problem or if they do capture it, are unlikely to tell you *why* it happened.
  - Root cause analysis by storing **application traces** will quickly generate 100s of TB of data, and there are no practical ways to analyze it.

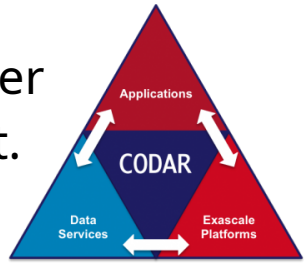
- What we need is a way to combine the **detail** of trace capture with the **ease** and small data volume of simple profiles.
- Enter **Chimbuko**.....

Chimbuko

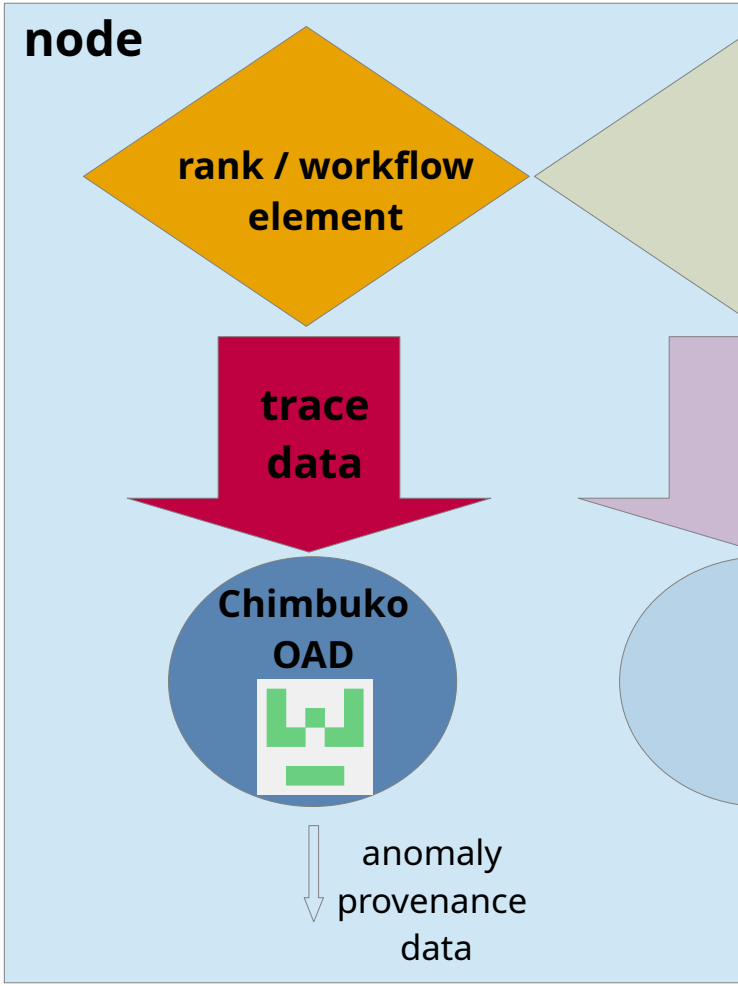
(“Provenance / origin” in Swahili)

[https://github.com/CODARcode/Chimbuko]

- Chimbuko is a tool developed under the Codesign Center for Online Data Analysis and Reduction (CODAR) project.
- Sponsored by the Exascale Computing Project (ECP).
- It succeeds in the aforementioned goals by performing **real-time *in situ* analysis** of trace data.
- The tool dynamically builds a model of the application profile of each component of the workflow.
- The model is used to isolate **anomalous behavior**, utilizing streaming anomaly detection algorithms.
- Only detailed information on the anomalies are captured and stored.
- By focusing only on anomalies we achieve **very high reduction** in data volume while retaining key information required for causal analysis.

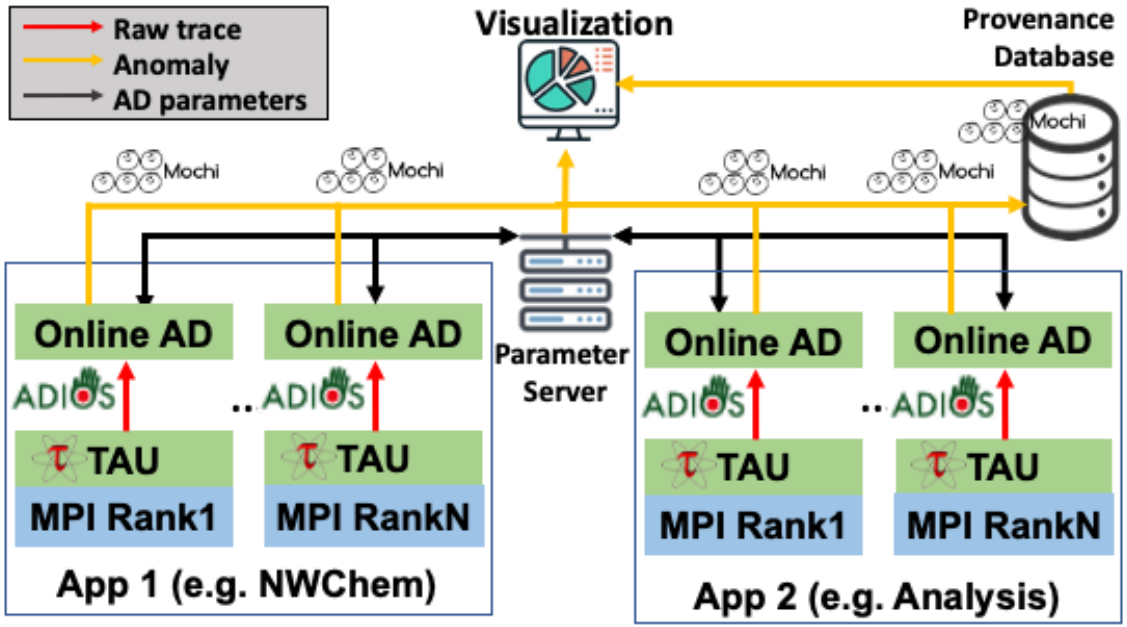


EXASCALE COMPUTING PROJECT

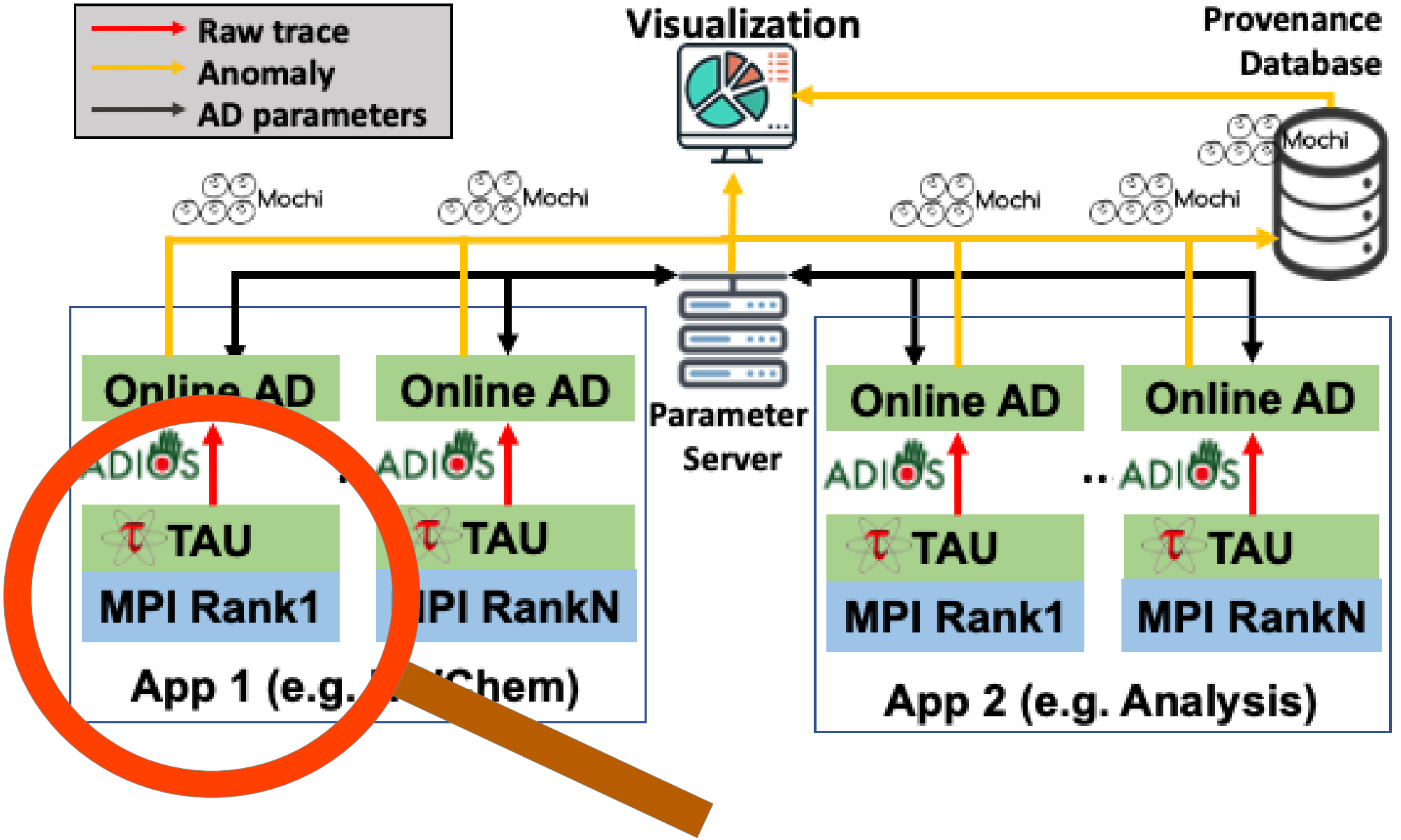


Chimbuko design overview

- **TAU Performance System:**
  - Generates real-time traces and sends to OAD.
- **Online AD**:
  - Trains anomaly detection algorithm on incoming trace data.
  - Applies algorithm to filter out anomalies
  - Gathers detailed provenance information on each anomaly.
- **Provenance database:**
  - Acts as a centralized database provenance information.
- **Parameter server:**
  - Aggregates / synchronizes parameters of AD model between OAD instances.
  - Exploit coexistence of many identical instances of workflow components.
  - Allows very rapid training that *improves with job scale.*



- Aggregates global process information / statistics and forwards to visualization.
- **Visualization**:
  - Displays real-time information on captured anomalies.
  - GUI allows manual interaction with the provenance database as the analysis is being performed.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Visualization
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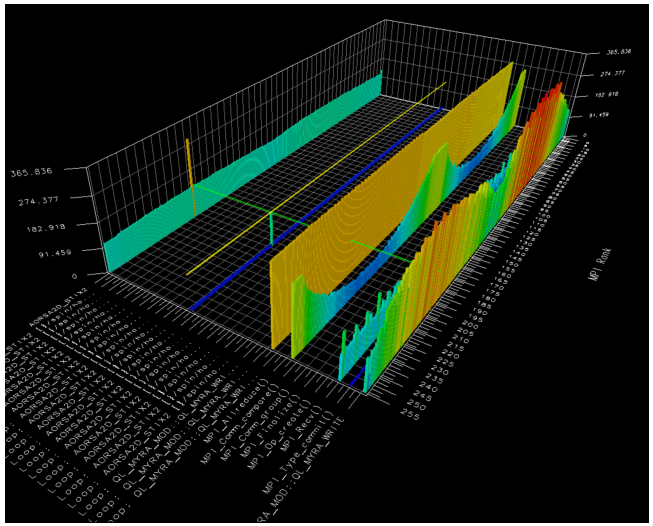
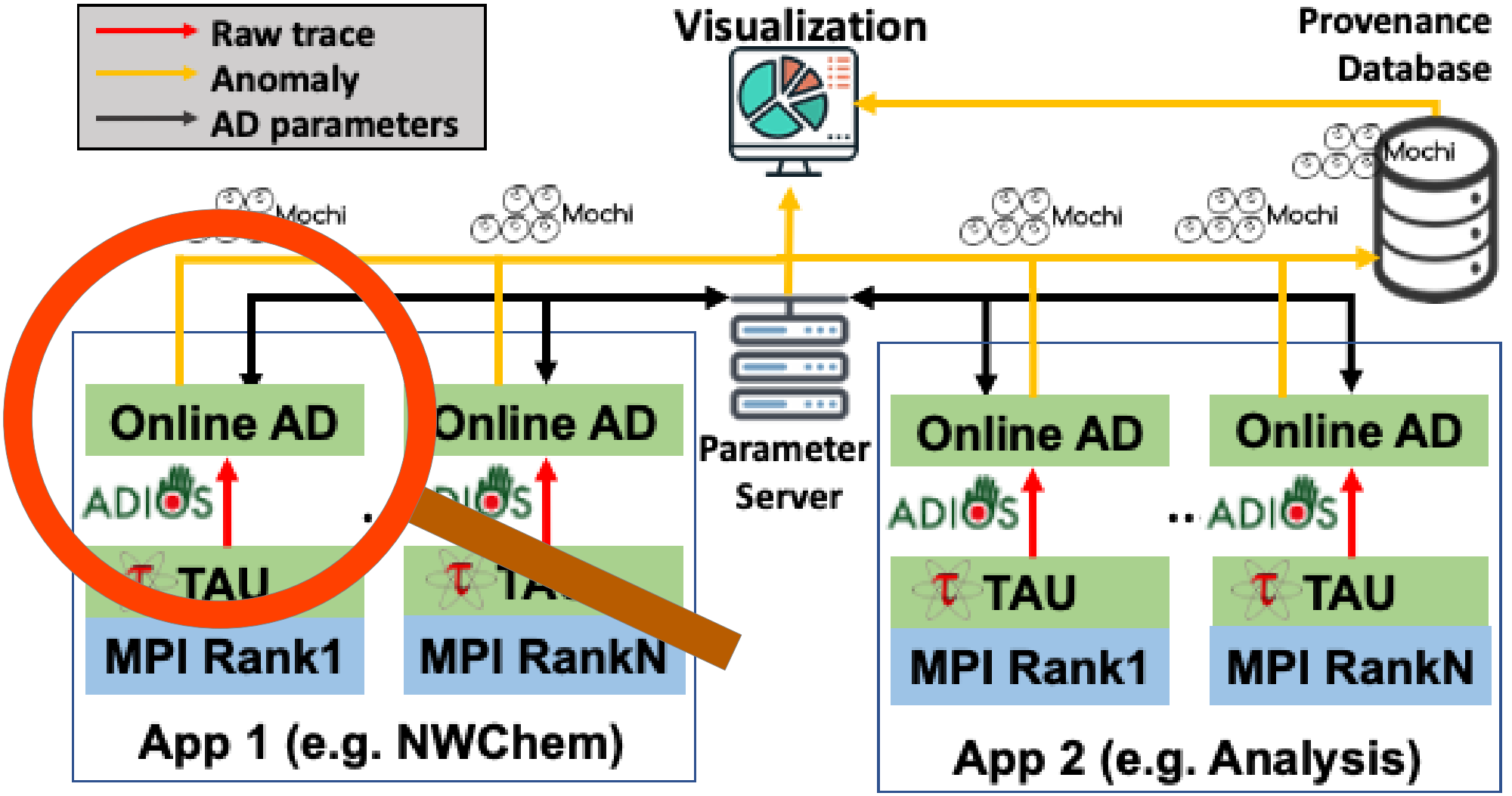
App 1 (e.g. GTC)
App 2 (e.g. Analysis)

TAU tracing

https://github.com/UO-OACISS/tau2
https://github.com/ornladios/ADIOS2

- Application performance traces are provided by TAU.
- **GPU kernel traces** supported for all major platforms via vendor APIs
- **CPU traces** require instrumentation of source code for compiled languages:
  - TAU PDT tool for Fortran, C, old C++
  - TAU LLVM plugin for modern C++ (backup Python tool)
  - TAU LLVM backend for auto-instrumenting source allows C++ instrumentation with other compilers (experimental)
  - Compiler instrumentation for most languages and compilers is available but often instruments *everything* ; larger overheads
- **Python support** available but also instruments everything
- (Use selective instrumentation to reduce overheads)
- Additional data:
  - **PAPI counters** (TAU compilation option)
  - **Node state** (memory/cpu utilization,etc) from */proc/pid* (monitoring plugin).
- TAU trace data output **in batches** (typically 1/s) using *ADIOS2* library; either via memory (SST) or disk (BPFile/BP4/BP5).

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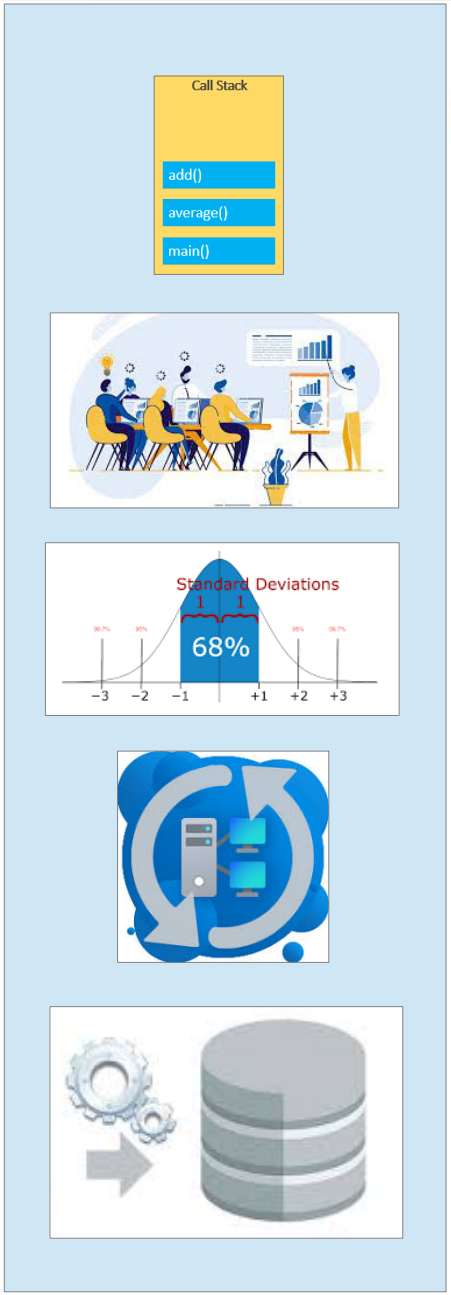
App 1 (e.g. NWChem)
App 2 (e.g. Analysis)

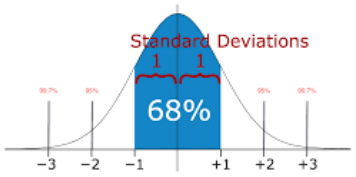
Online Anomaly Detection

- 1 instance of OAD per application rank / workflow component instance.
- **Roles**:
  - **Parse trace data** into call stack, assigning counters and MPI events to function executions.
  - **Train** local AD model and synchronize with parameter server to obtain global model.
  - Apply global model to function execution times to **identify anomalies.**
  - **Gather provenance data** and send to provDB.
  - **Compute batch statistics** and send to parameter server.
- **Requirements:**
  - Support O(100k+) trace events per second.
  - Complete all activities on batch *within batch receive period.*
  - Low overheads to avoid interfering with application.
- **Features:**
  - Highly configurable with numerous options for customizing the analysis.
  - Flexible launch: can be launched with or without MPI.

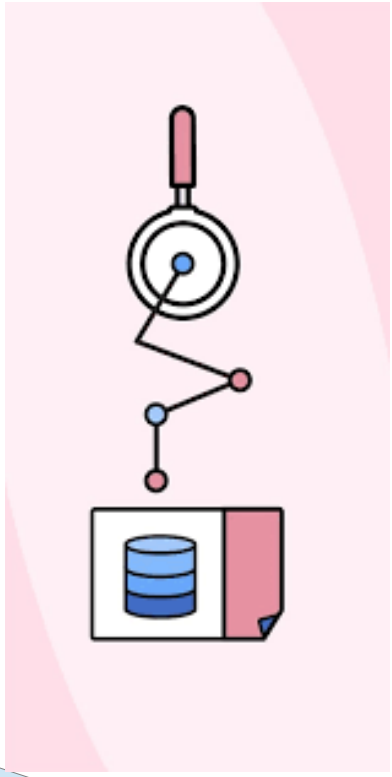


Anomaly Detection Algorithms

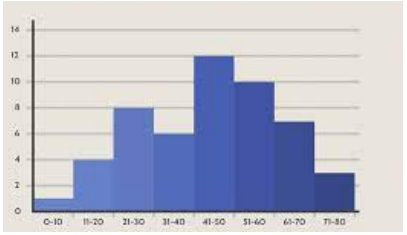
- Due to **extreme data volume** we cannot utilize many common anomaly detection algorithms which act on the entire dataset.
- Instead we require **streaming** (batched) algorithms.
- Algorithms must be **unsupervised** with **minimal hyperparameters.**
- Currently provide 3 algorithms based on the **function execution time.**



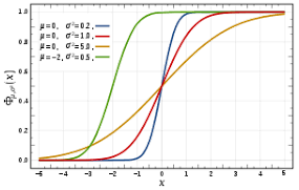
- **SSTD (Sample STandard Deviation):**
  - Compute moments (mean, variance) for each function execution.
  - Synchronization combines across ranks to obtain global moments.
  - Anomalies are assigned based on number of std. deviations from mean.



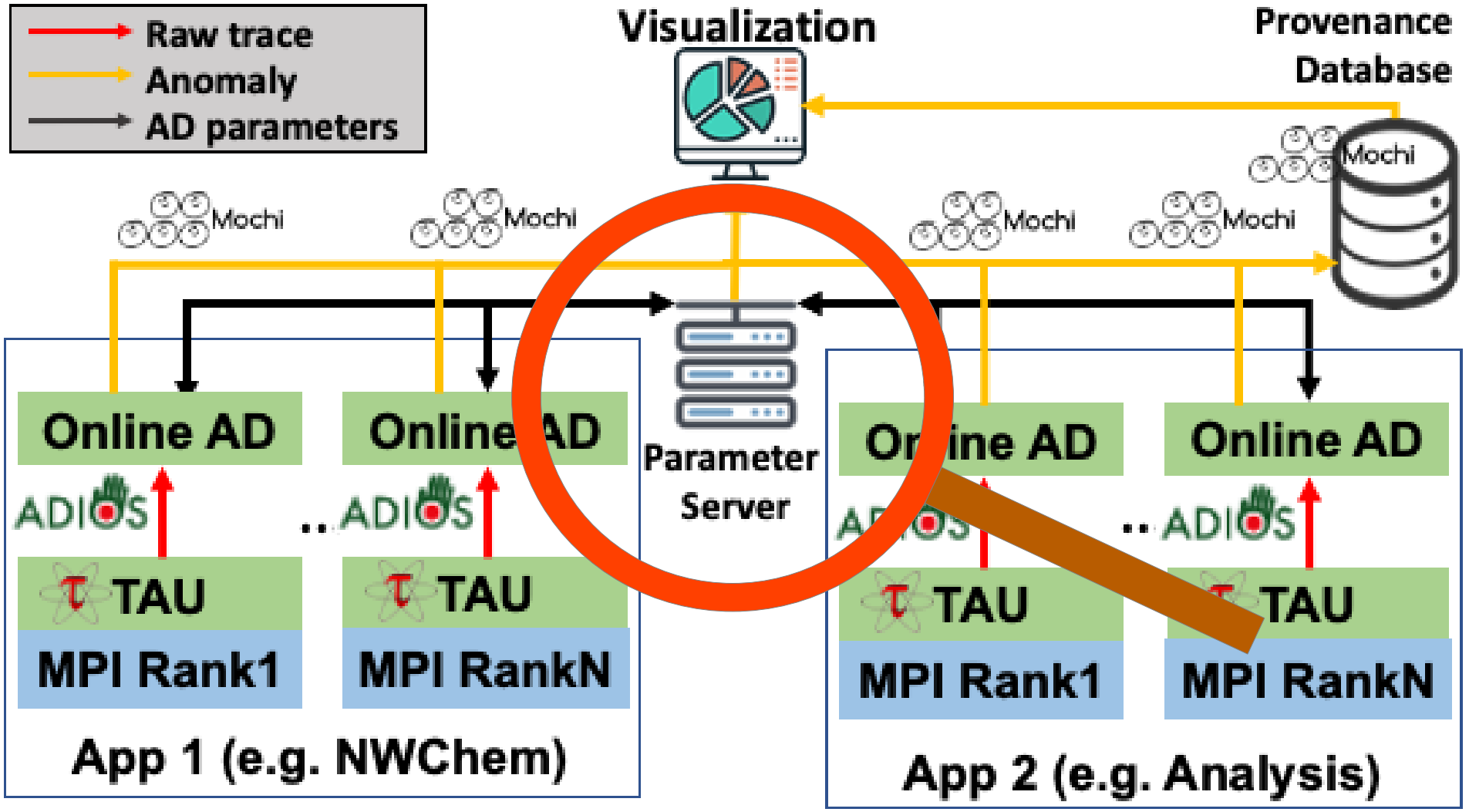
- **HBOS (Histogram Based Outlier Selection):** (Goldstein, Dengel 2012)
  - Generate a local histogram for each function.
  - Synchronization merges histogram across ranks.
  - Scores are assigned based on bin probability of each event
  - Dynamic threshold seeks to isolate only extreme outliers.



HBOS best choice for multimodal distributions



- **COPOD (Copula Based Outlier Detection):** (Li 2009)
  - Use histograms in same way as HBOS but utilizes copula (generalization of CDF) to assign event scores.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AD parameters
Visualization
Provenance Database
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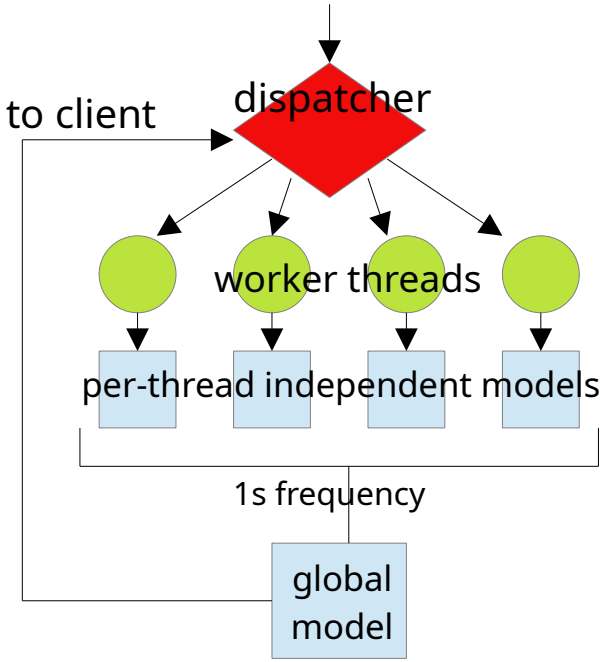
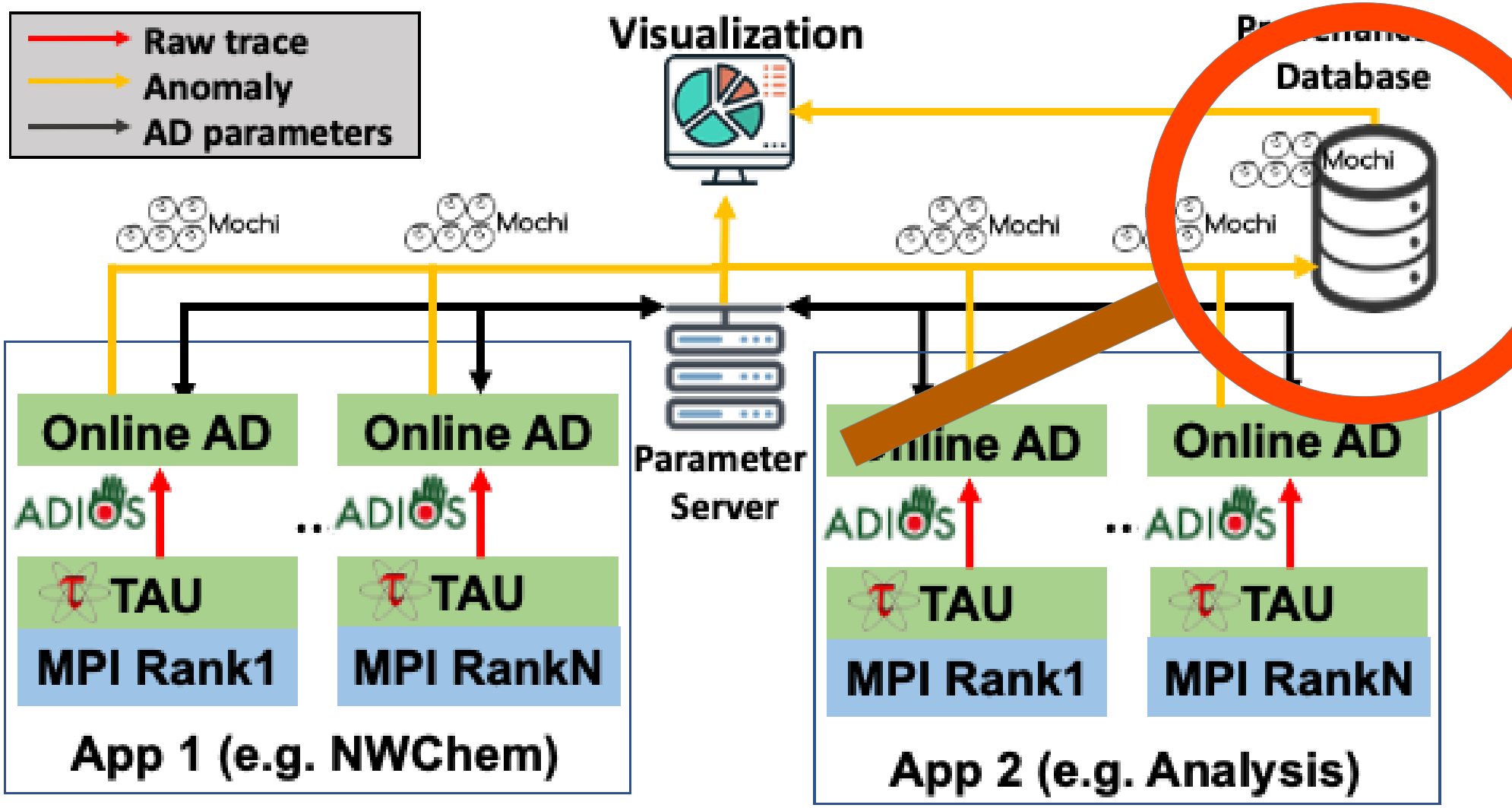
Parameter server

https://zeromq.org/

https://uscilab.github.io/cereal/

- **Roles:**
  - Maintains and synchronizes the AD model with the clients.
  - Aggregates **profile information**, and **statistics** on anomalies, counters, etc.
    - These are forwarded to the provDB at the end of the run.
    - Also optionally forwarded in realtime to the visualization.
- **Requirements:**
  - Must accept connections from remote clients across many possible network types.
  - Must be **scalable** to support 1000s of clients.
  - Synchronization is **blocking;** require **minimal latency (<<1s).**
- **Design:**
  - Custom RPC server implementation using **ZeroMQ** with **Cereal** serialization. Supports many client workers.
  - Workers update independent instances of AD model **maximizing parallelization**.
  - These instances are combined by a separate external thread once per second to ensure the global model is current.

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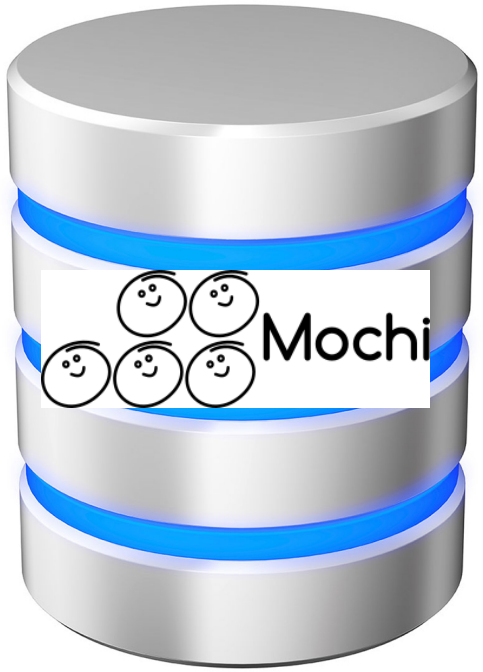
Provenance database

https://mercury-hpc.github.io/
https://github.com/pmodels/argobots
https://github.com/mochi-hpc/mochi-sonata

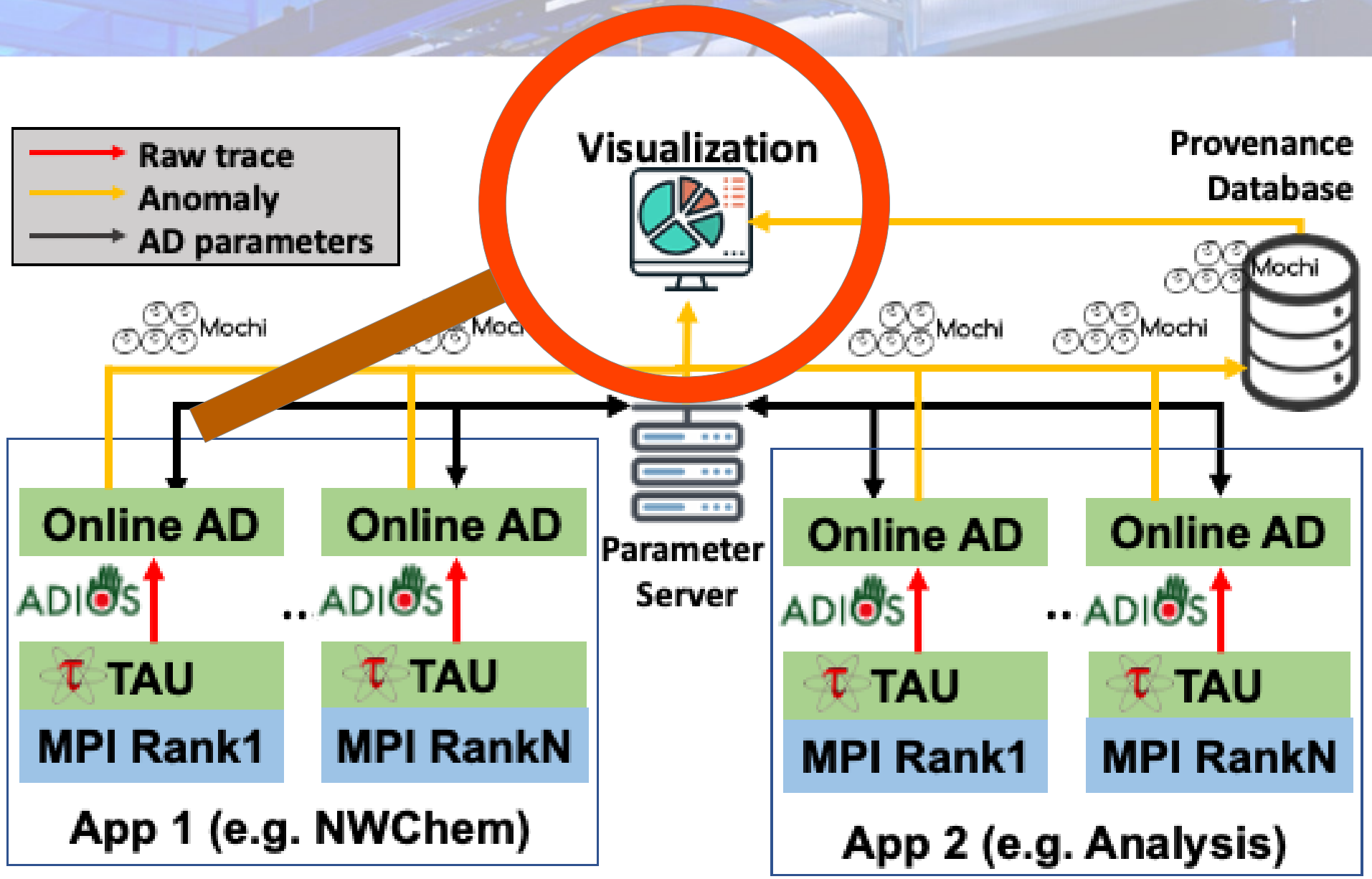
- **Role:**
  - Store and allow querying of anomaly provenance data from clients.
  - Store and allow querying of global information (profiles, final AD model, statistics) from parameter server.
  - All records are stored as JSON documents.
- **Requirements:**
  - Accept connections from remote clients across many possible network types.
  - **Scalable** to support 1000s of clients.
  - Convenient API for search and filtering by user and visualization.
  - Support asynchronous sends from clients for latency independence.
- **Design:**
  - Co-designed with the ECP Mochi team.
  - **Mochi** stack implements a generalized RPC server/client built on top of **Mercury** (RPC) and **Argobots** (threading).
  - Mochi and Chimbuko teams codesigned a flexible JSON remote database solution, **Sonata**
  - Achieve arbitrary **scalability** through database sharding for thread scalability and multiple servers if necessary.
  - Offline query tools programmed through convenient Python and C++ APIs.



Provenance information

(cf. https://chimbuko-performance-analysis.readthedocs.io/en/ckelly_develop/io_schema/schema.html)

- The goal is to allow a user to identify
  - **How important** the anomaly was:
    - Anomaly metrics associated with likelihood and importance
    - The algorithm parameters at the time of identification
  - **Where** the anomaly occurred:
    - Rank, device/thread, date/time
    - Call-stack of function execution
    - Window snapshot of executions before/after
    - For GPU events, which CPU-side execution launched the kernel
  - **What** happened during the anomalous execution:
    - Execution inclusive/exclusive runtime.
    - MPI events occurring during execution.
    - Counters from PAPI or other sources if supported by TAU.
    - Node state including CPU usage, memory usage, cache misses (*/proc/pid)*
    - A selection of non-anomalous events are also collected for comparison.
- Hopefully together this enables the user to identify **why**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Anomaly
AD parameters
Visualization
Provenance Database
Mochi
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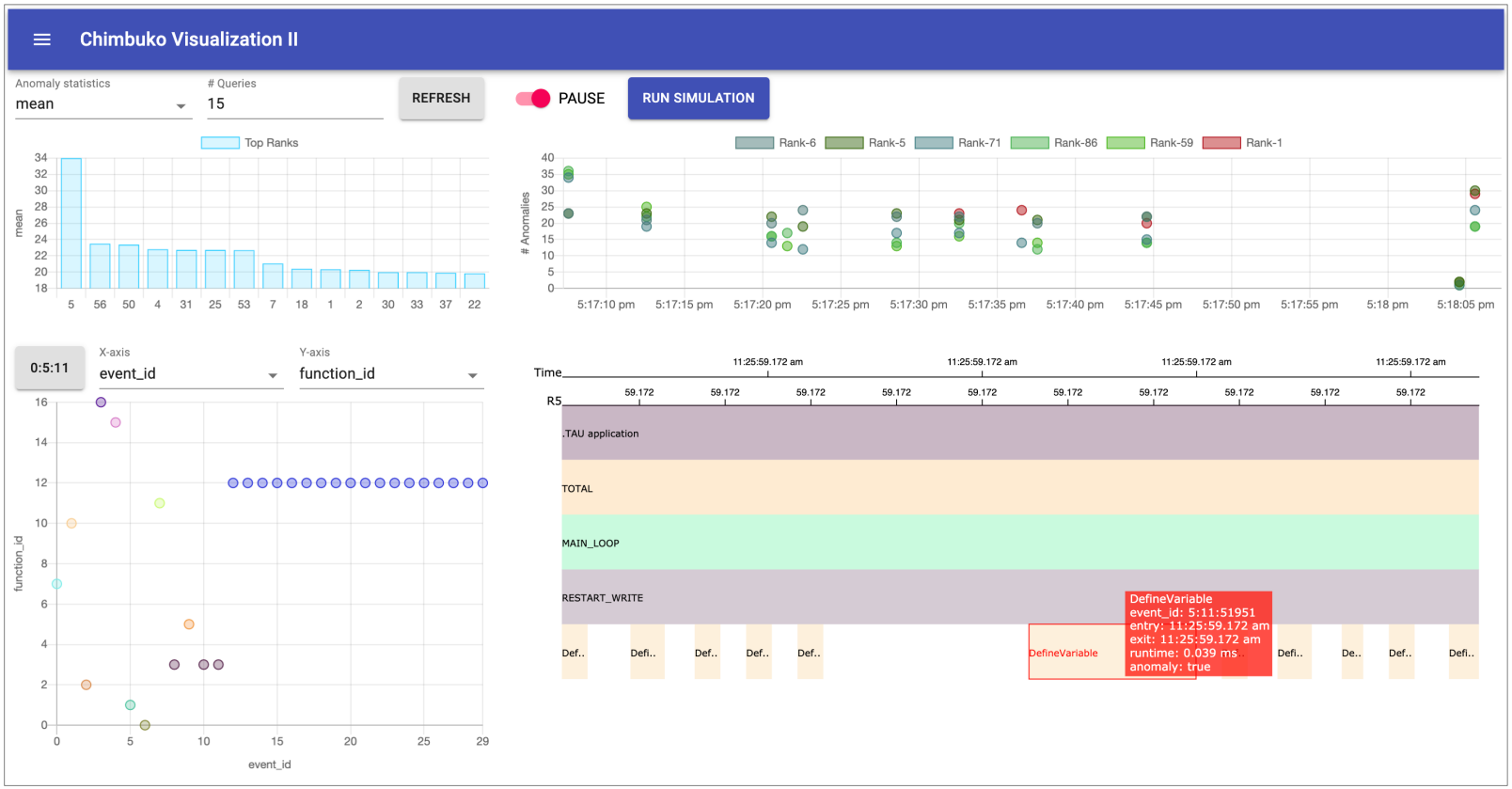
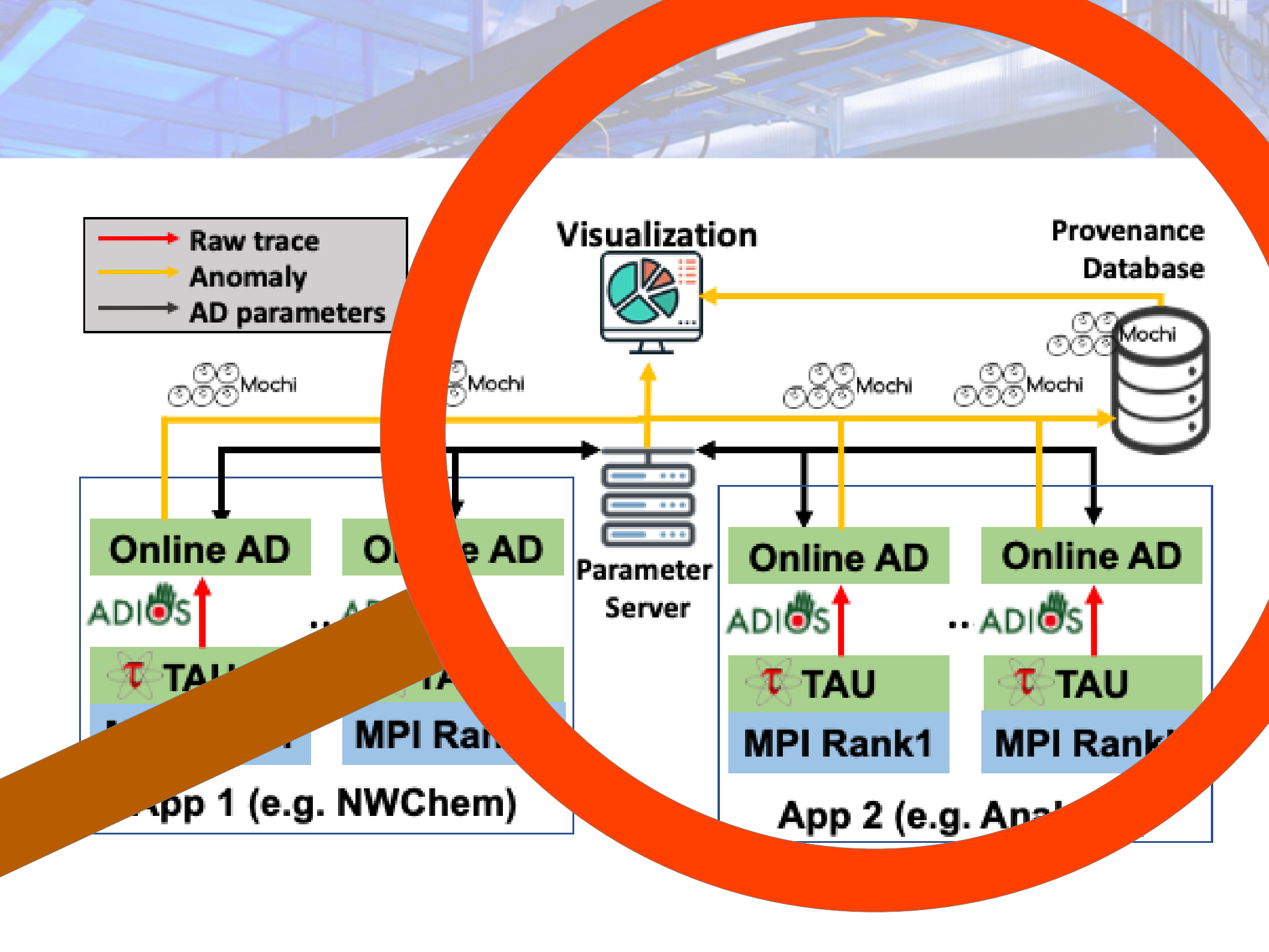
Chimbuko visualization

https://github.com/CODARcode/ChimbukoVisualizationII



- **Roles:**
  - Obtain and display real-time statistics information to monitor the application status.
  - Allow user to focus in increasing detail on specific ranks / anomalies, querying the provDB where appropriate.
- **Design:**
  - Browser-based interactive frontend built using JavaScript/React with Python backend (+Redis/Celery).
  - Dynamic access to provenance database via Sonata API.
  - Connect to backend server running on job head node via ssh tunnel.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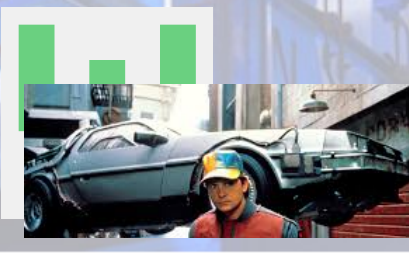
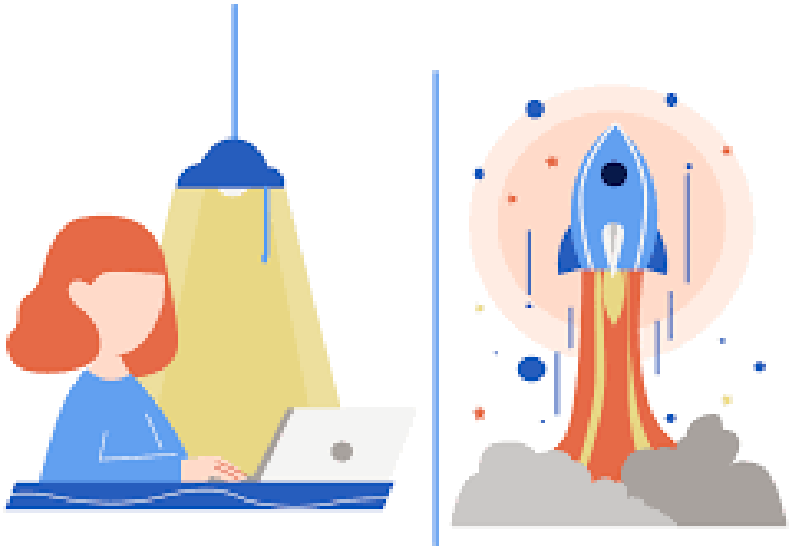
Chimbuko current features

- Analyze arbitrary workflows at-scale with **robust components** tested to scales of 100s of ranks on HPC installations (e.g. Summit).
- Supports workflow components written in **most major languages** (C/C++, Python, Fortran) and vendor-specific GPU paradigms (Cuda, HIP, DPC++) and common APIs (MPI, OpenMP).
- Launch of service components controlled by unified interface with a single configuration script.
- Online AD component can be launched via MPI or by hand in a wrapper script. Can also be integrated into workflow tools (e.g. Radical Cybertools).
- Supports **multiple AD algorithms** and offers **flexible control** for filtering out uninteresting data (e.g. filter-out functions, choose minimum anomaly time) and for tuning hyperparameters.
- **Detailed anomaly provenance** stored in a queryable database accessible with command line tools and full Python API for user analysis scripts.
- Online monitoring tool allows **real-time insights** into workflow performance.
- **Offline analysis tools** (currently rudimentary) offer at-a-glance analysis of profile and anomalies for single runs and between multiple runs.

Chimbuko planned features

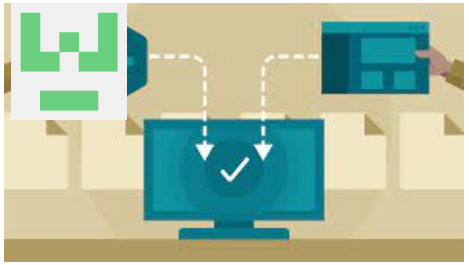


- Aim to expand on the capabilities of Chimbuko into the future:
  - **Incorporate counter information into anomaly detection** rather than just execution time.
  - Expand on **offline analysis tools** with command line and GUI-based tools for exploring the database and performing causal analysis.
  - Explore **closer integration with TAU** to simplify launch procedure.
  - Explore options to remove the parameter server as a bottleneck to **arbitrary scalability**.
- And more!



Obtaining and running Chimbuko

- Recommended way to install Chimbuko is through the **Spack** package manager.



- Spack repo available in source:

```
git clone https://github.com/CODARcode/PerformanceAnalysis.git
git clone https://github.com/mochi-hpc/mochi-spack-packages.git
spack repo add PerformanceAnalysis/spack/repo/chimbuko mochi-spack-packages
spack install chimbuko
```

- Provide **Spack environment configurations** for several HPC installations (Summit, Crusher, Spock, HPC1) to utilize system libraries, MPI and GPU APIs.
- **Docker images** for experimentation are available:

```
docker pull chimbuko/run_examples:latest
```

- **Detailed documentation** available including instructions on basic running as well as running on some major HPC installations:
  - https://chimbuko-performance-analysis.readthedocs.io/en/ckelly_develop/index.html
- **Numerous examples** of run and configure scripts can be found in the PerformanceAnalysis source code:
  - PerformanceAnalysis/benchmark_suite/

If you are interested in trying out Chimbuko, feel free to contact me!
<ckelly@bnl.gov>

https://chimbuko-performance-analysis.readthedocs.io/en/ckelly_develop/index.html

https://github.com/CODARcode/Chimbuko (`ckelly_develop` branch for bleeding edge)