Managing Power Efficiency of HPC Applications with Variorum and GEOPM

ECP Tutorial

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Agenda

- Part I: Overview of GEOPM (15 minutes)
  - High-level design
  - User-facing, application-context markup API
  - Demonstrations (10 minutes)

- Part II: Plug-ins to extend GEOPM algorithm and platform support (30 minutes)
  - **Agent**: Run-time tuning extension
  - **PlatformIO**: Platform-specific support extension
  - Demonstrations (10 minutes)

- Part III: ECP Argo Contributions (30 minutes)
  - **ConductorAgent**: Transparent, performance-optimizing configuration selection
  - **IBM PlatformIO plugin**: Port of GEOPM to IBM Power9 + Nvidia platform

- Questions/Discussion (10 minutes)

Part I: Hands-on Tutorial on GEOPM

Background: System Software Stack for Power Management

Inherited Power Bounds

Site
- Demand Response, Renewables

Cluster
- Overprovisioning, Job scheduling

Job/Application
- Adaptive runtimes, Power balancing

Node
- Measurement and control (capping)

Software
Dashboards
RMAP, P-SLURM, PowSched
GEOPM, Conductor, Pshifter,...
Libmsr, msr-safe

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LibMSR, msr-safe

- **Critical contribution to the development of HPC power-aware system software stack.**

Power-Constrained Performance-Optimization Problem

Problem definition

Given a job-level power constraint and number of nodes, how do we optimize application performance?

GEOPM: Global Extensible Open Power Manager

- Power-aware runtime system for large-scale HPC systems

- Intel developed a production-grade, scalable, open-source job-level extensible runtime and framework
  - Extensibility through plug-ins + advanced default functionality

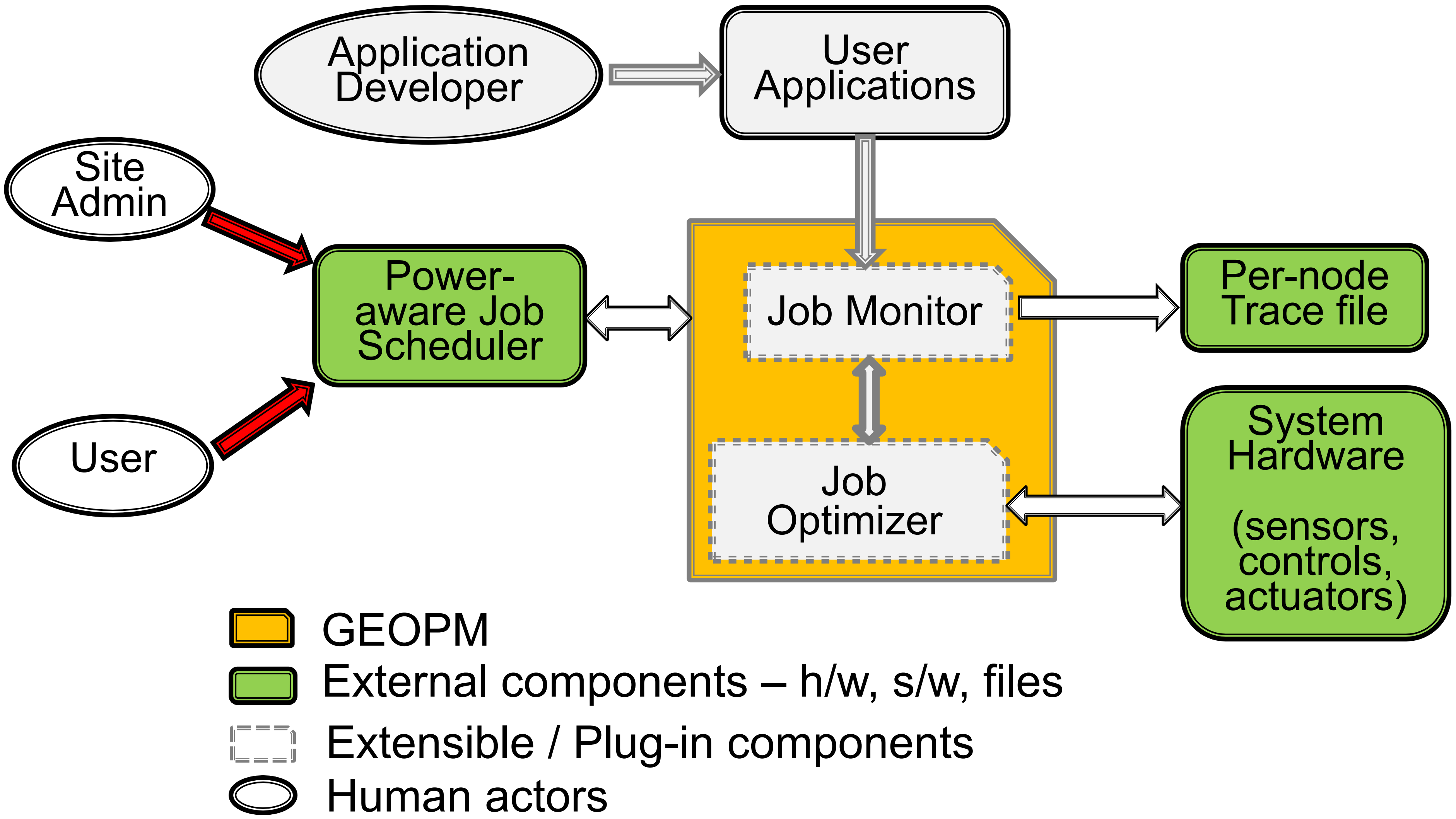
- Limitations of existing runtimes
  - Research-based codes addressed specific needs and situations
  - Ad-hoc, targeted specific architecture, memory model
  - Suffered scalability issues
  - Reliance on empirical data

- Funded through a contract with Argonne National Laboratory

GEOPM Project Goals

- **Managing power**
  - Maximizing power efficiency or performance under a power cap
- **Managing manufacturing variation**
  - Power / frequency relationship is non-uniform across different processors of same type
- **Managing workload imbalance**
  - Divert power to CPUs with more work
- **Managing system jitter**
  - Divert power to CPUs interrupted or stalled by system noise
- **Application profiling**
  - Report application performance and power metrics
- **Runtime application tuning**
  - Extensible runtime control agent with plug-in architecture
- **Integration with MPI**
  - Automatic integration with MPI runtime through PMPI interface
- **Integration with OpenMP**
  - Automatic integration with OpenMP through OMPT interface

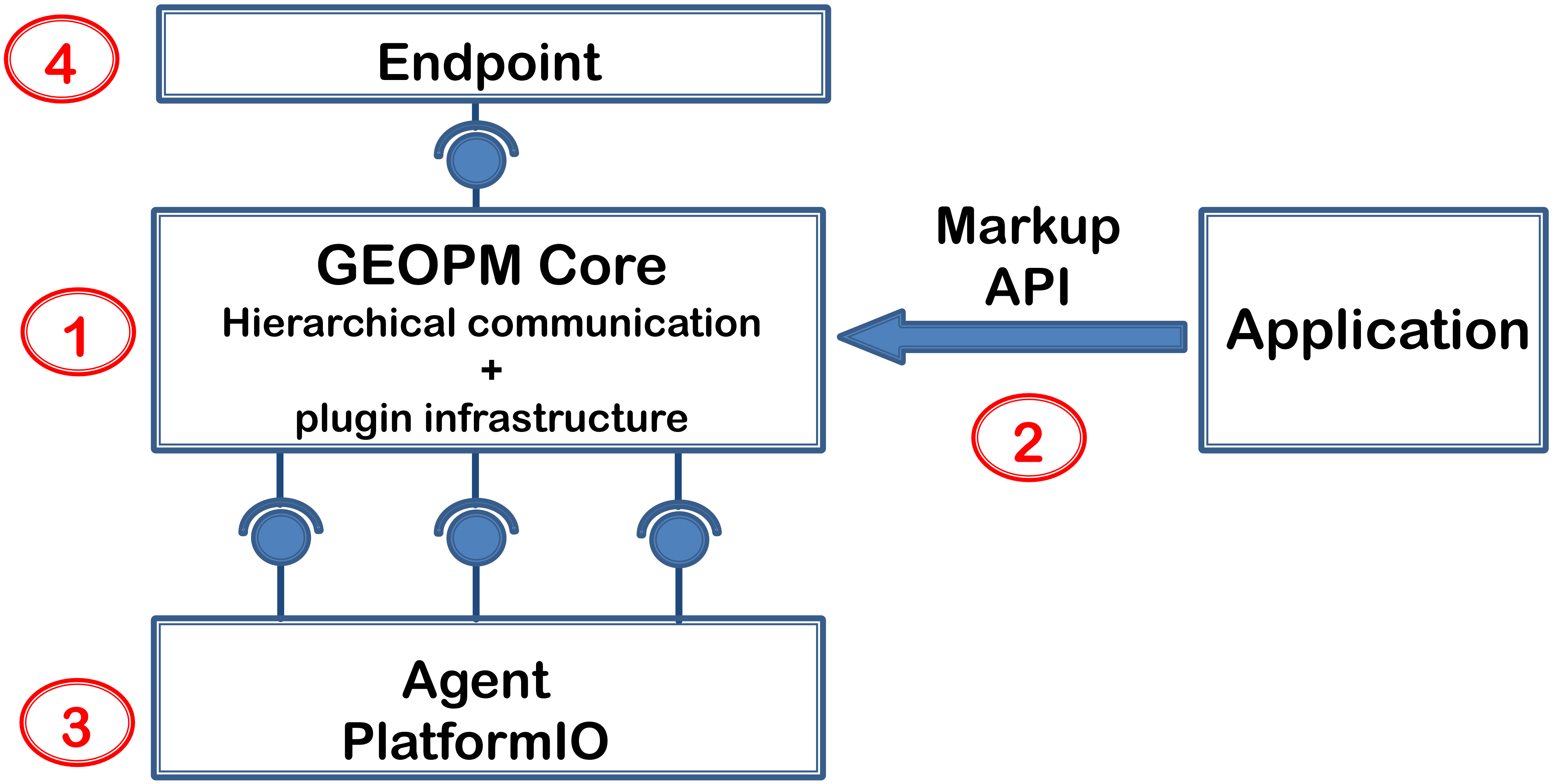
GEOPM System Model



GEOPM: Capabilities

- Enables analysis and transparent tuning of distributed-memory applications
- **Feedback-guided optimization**: Leverages lightweight application profiling
- **Learns application phase patterns**: load imbalance across nodes, distinct computational phases within a node
- **Uses tuning parameters**: processor power limit, core frequency, etc.
- **Built-in optimization algorithms**: Static Power capping, energy reduction, load balancing, limiting synchronization costs

GEOPM Components of Interest



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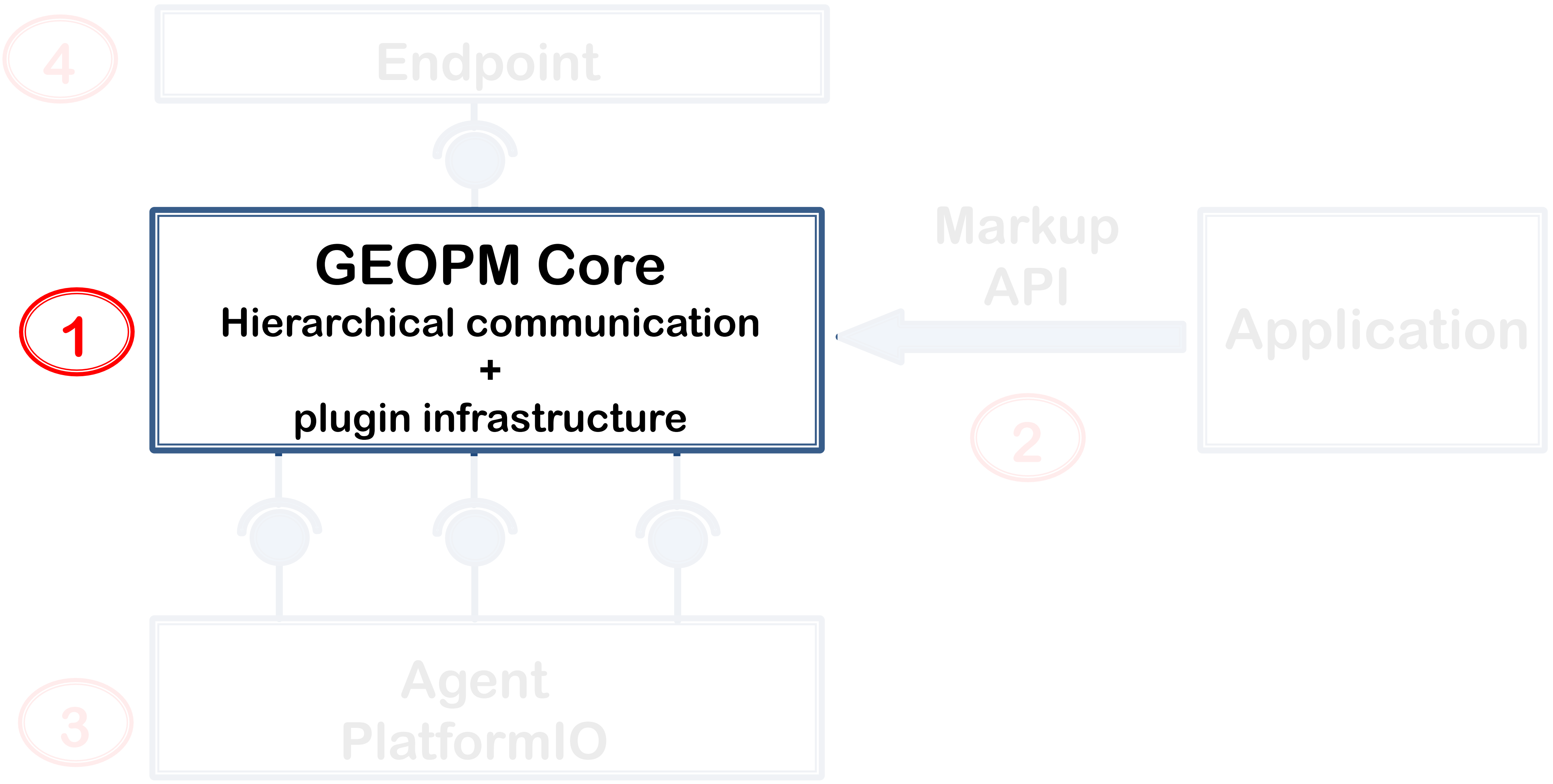
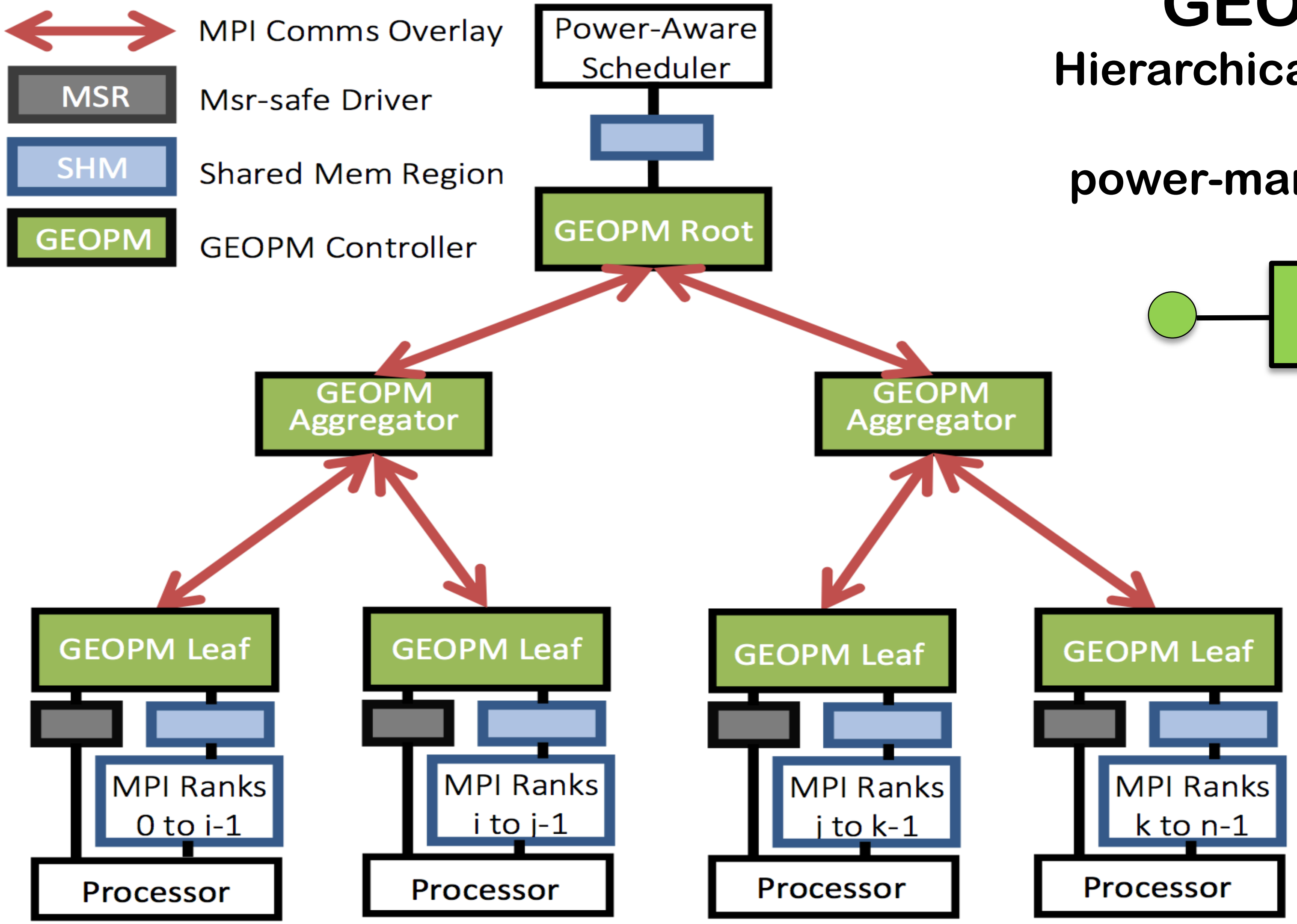


GEOPM Infrastructure

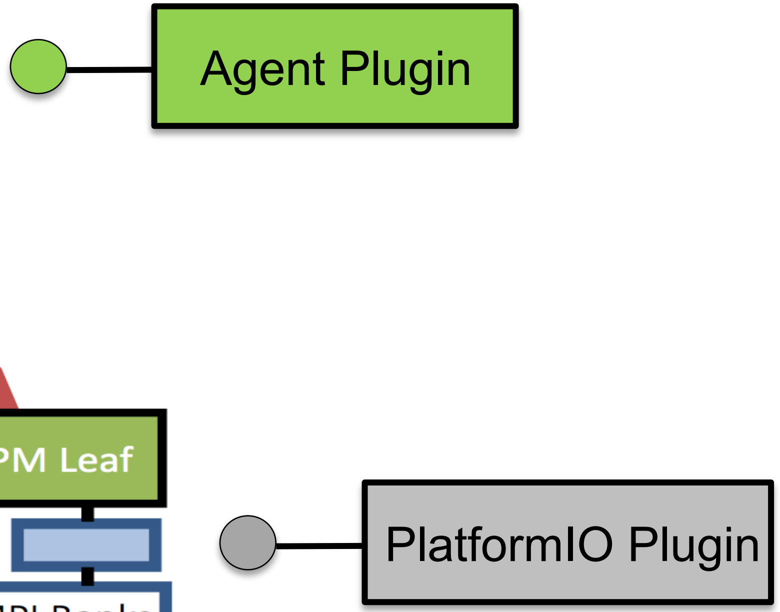


GEOPM Core

Hierarchical communication

+

power-management plugin



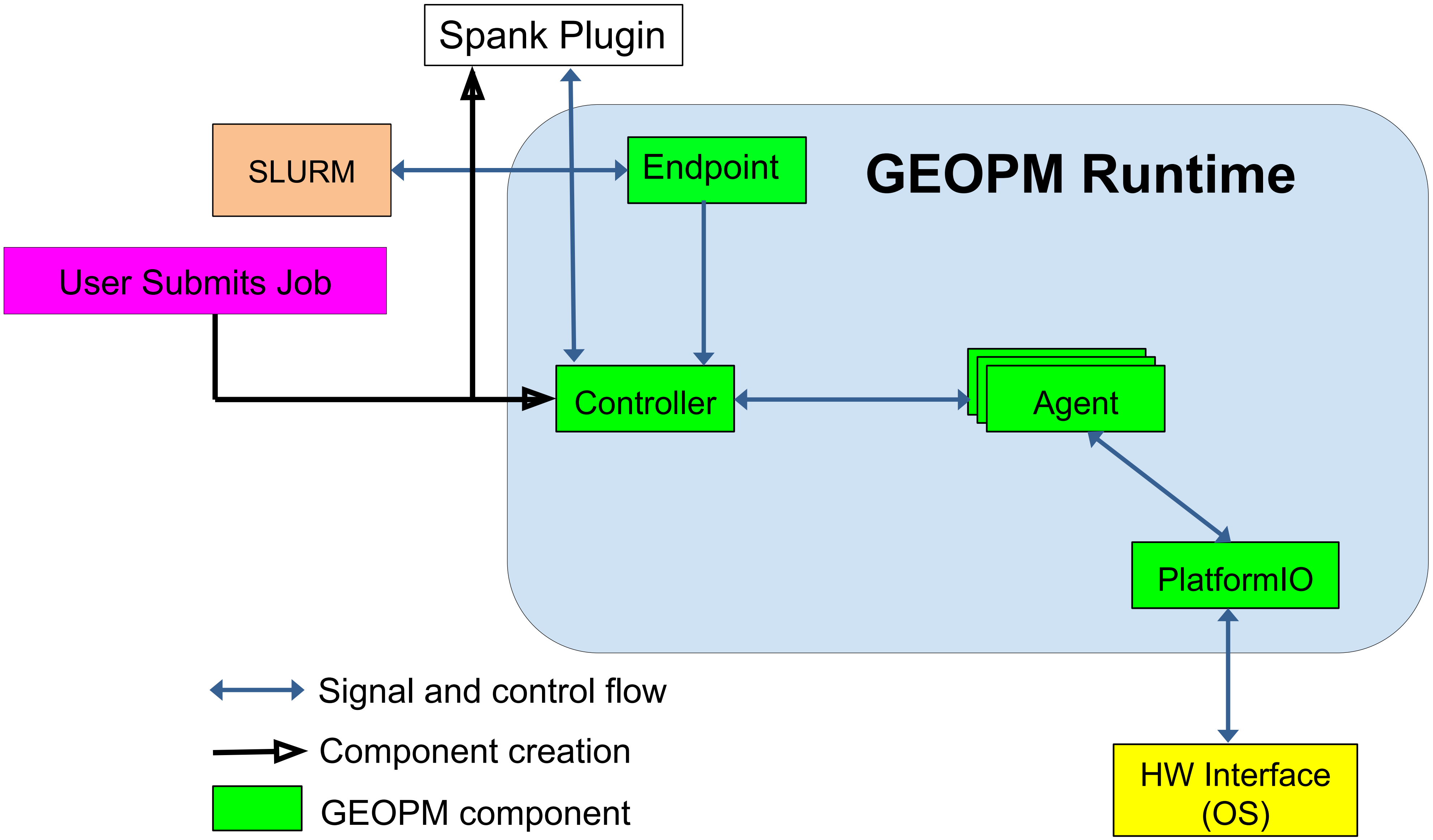
GEOPM Infrastructure

- GEOPM Source repository navigation
  - Branches, directories, releases
  - GEOPM Wiki

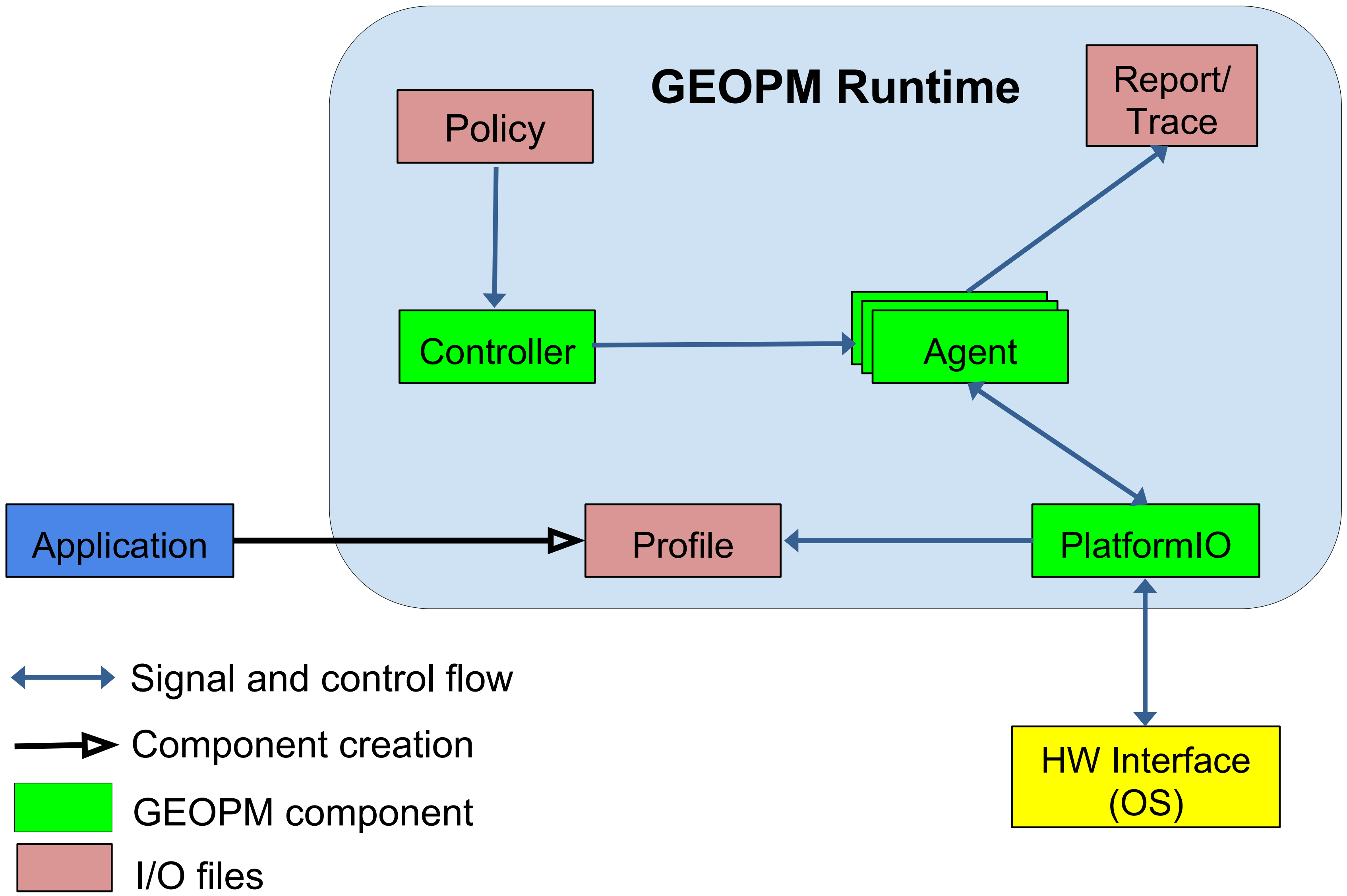
- Build process
  - Dependencies
  - Build configuration

- GEOPM core infrastructure source
  - Overview of important classes
  - Plug-in source
  - Tutorials and examples
  - Test coverage

GEOPM: Component Communication



GEOPM: Input/Output Files



GEOPM Configuration, Build and Launch

Building an Application with GEOPM

Step 1 : Set the environment

$> module load **geopm**

$> module load **<intel compiler>**

$> module load **<MPI compiled with intel-c>**

Step 2: Link the Application to GEOPM library

```
$> mpicc  APP_SRC.c -L$GEOPM_LIB -lgeopm \
        -o APP_EXEC \
        COMPILER_FLAGS
```

Example

```
$> mpicc helloworld.c -L$GEOPM_LIB -lgeopm -o a.out
```

Running an Application with GEOPM

Step 3: Generate a policy file

$> geopmagent **--agent**=AGENT_NAME **--policy**=INPUT_PARAMS > POLICY_FILE.json

Example:

$> geopmagent --agent=monitor --policy=None > monitor_policy.json

Step 4: Launch application with GEOPM launcher wrapper

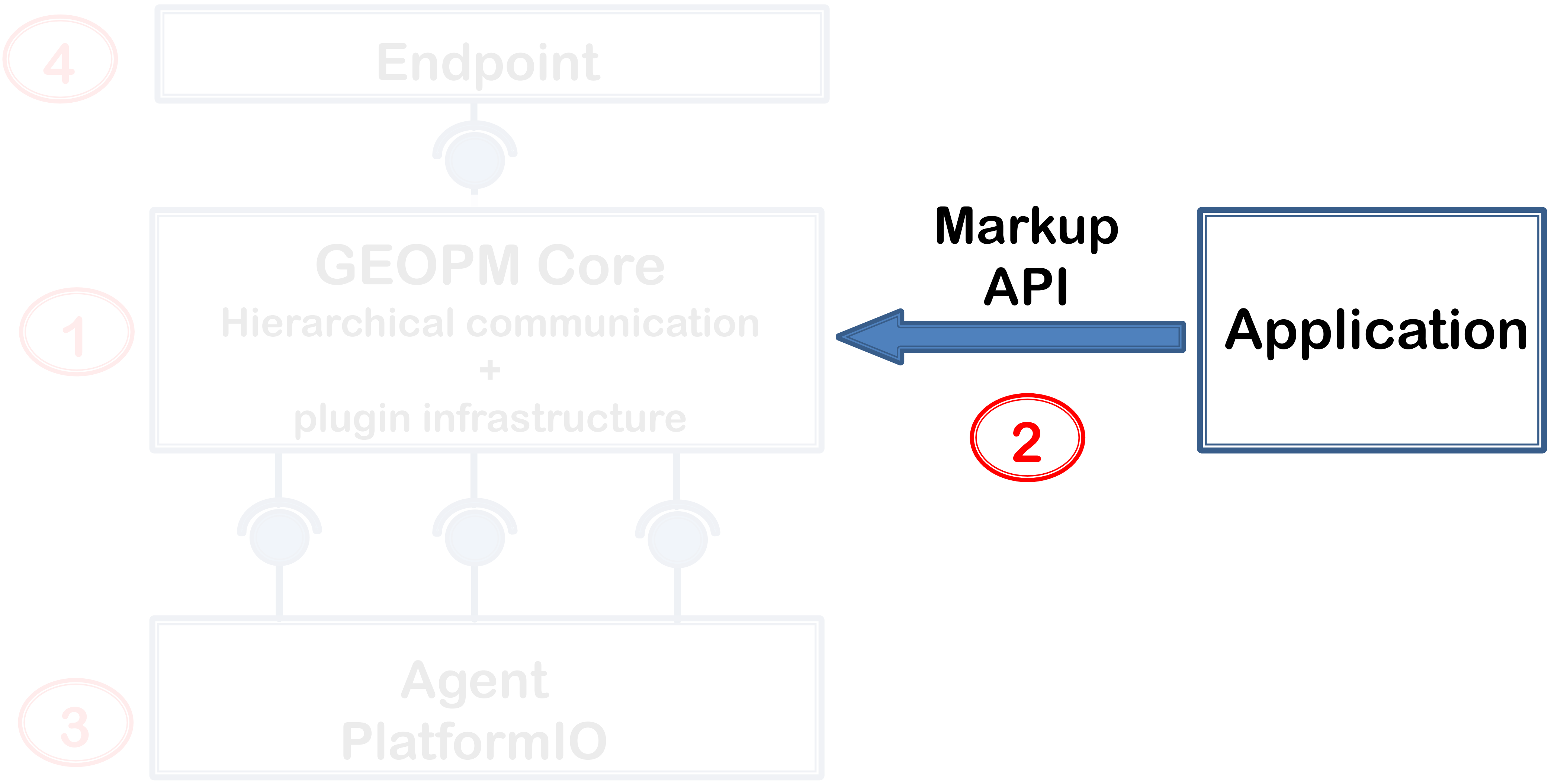
```
$> geopmlaunch srun -n < > -N < >\
    --geopm-ctl=process \
    --geopm-agent=AGENT_NAME \
    --geopm-policy=POLICY_FILE.json \
    --geopm-report=REPORT_FILE.txt \
    --geopm-trace=TRACE_FILE.csv \
    --   APP_EXEC   APP_OPTIONS
```

Example:

```
$> geopmlaunch srun -n 4 -N 1 \
    --geopm-ctl=process \
    --geopm-agent=monitor \
    --geopm-policy=monitor_policy.json \
    --geopm-report=report.txt \
    --geopm-trace=trace.csv  \
    --    a.out
```

Demo: Running Application with GEOPM

GEOPM Components of Interest



GEOPM: Components and Interfaces

Collecting Application Context

- Application region markup API
  - Computation/communication regions of interest
- Epoch
  - End of iteration
- OpenMP event callbacks

Power Assignment Policies

- Governed policy
  - Node-level assignment
- Balanced policy
  - Cluster-level assignment

Extension Interfaces

- New Agent plugin: ConductorAgent
- New PlatformIO plugin: IBM port of GEOPM

GEOPM Markup API: Purpose

- C interfaces provided in GEOPM that the application links against
  - Resemble typical profiler interfaces
- Annotation functions for programmers to provide information about application critical path and phases to GEOPM
  - Points where bulk synchronizations occur
  - Phase changes occur in an MPI rank (i.e. phase entry and exit)
  - Hints on whether phases will be compute-,memory-, or communication-intensive
  - How much progress each MPI rank has made in the phase (critical path)

Application Markup API

MPI/Sequential Region

- Marking up regions of interest
  - geopm_prof_region(name, hint, ID)
  - geopm_prof_enter(ID)
  - geopm_prof_exit(ID)
- Marking region progress
  - geopm_prof_progress(ID, %progress)
- Marking a timestep
  - geopm_prof_epoch()

OpenMP Region

- Marking up regions of interest
  - geopm_tprof_init(num_work_unit)
  - geopm_tprof_init_loop(num_thread,
    thread ID,
    num_iter,
    chunk_size)
- Marking region progress
  - geopm_tprof_post()

Demo: Using the GEOPM Markup API

Part II: Plug-ins to extend GEOPM algorithm and platform support

GEOPM: Policy plugins

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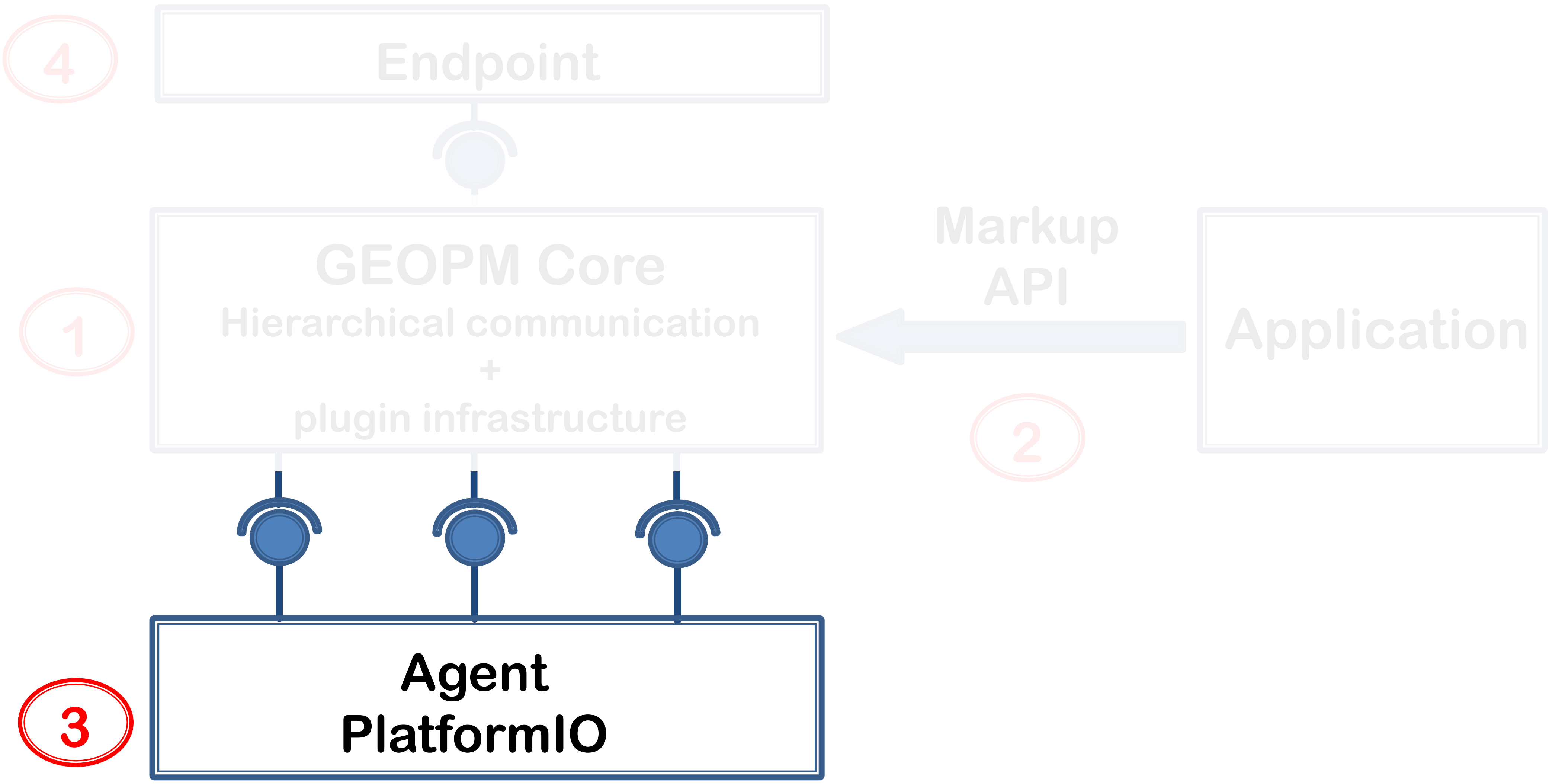
Demo: Using the Default GEOPM Policies

GEOPM Components of Interest



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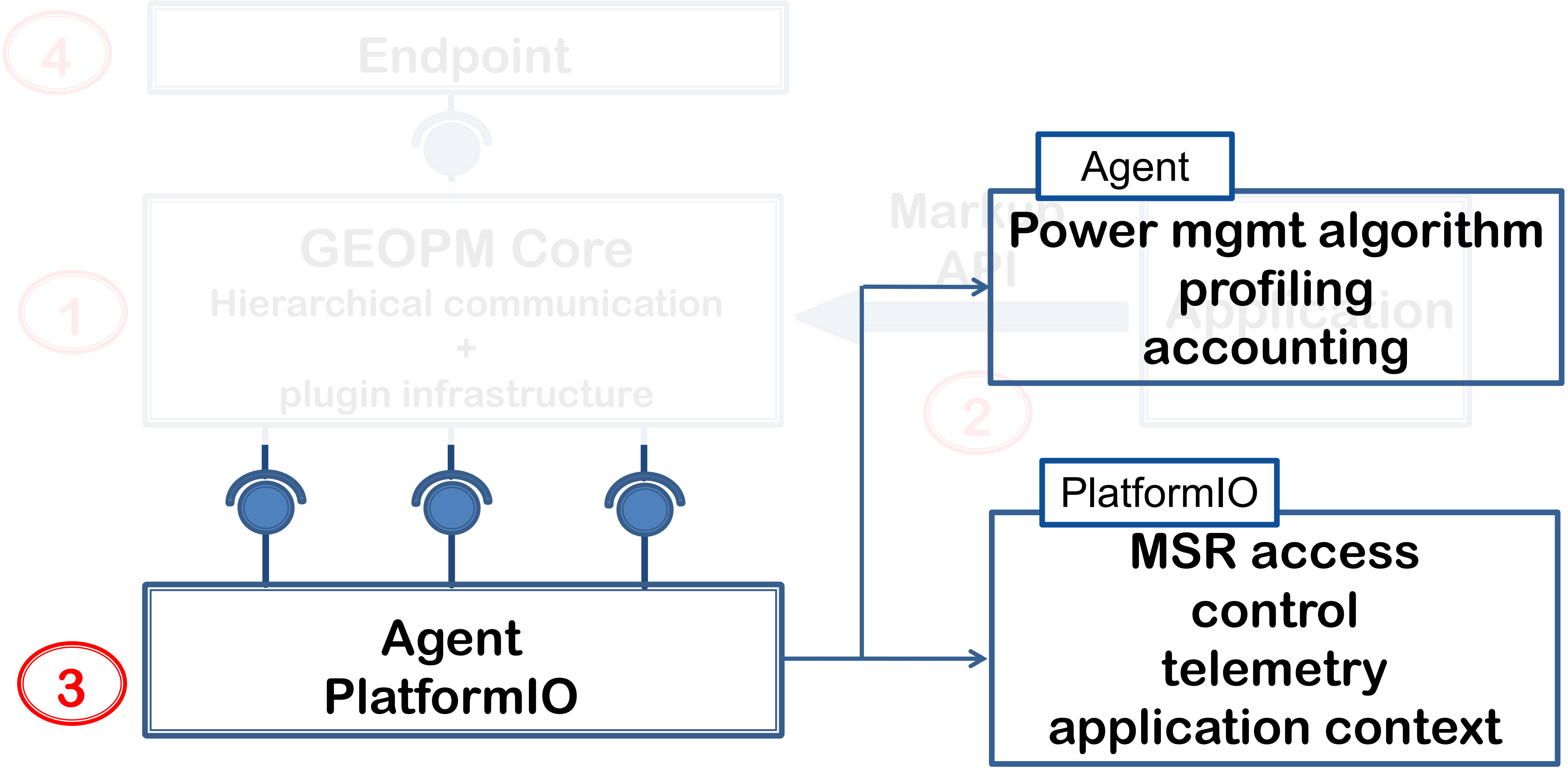

GEOPM Plugin Interface

- Two types of plugins: PlatformIO and Agent plugins
- Example Agent plugins
  - MonitorAgent
  - BalancerAgent
  - GoverningAgent
  - EnergyEfficientAgent
- Example PlatformIO plugins
  - MSRIOGroup
  - KNLIOGroup
- Tutorial plugins: ExampleAgent and ExampleIOGroup
  - Key methods and code blocks
  - Policy description interface

Demo: GEOPM Agent Example

Part III: ECP Argo Contributions

ECP Argo: Selecting Power-Optimizing Configuration

- **Approach:** Hardware Overprovisioning with job-level power guarantees
  – More compute resources than you can power up at once
- **Objective**: Optimize job performance under a power constraint
- **Solution**: GEOPM – power-constrained performance optimization
- **ECP Argo Contributions**:
  – Augment GEOPM’s algorithm with performance-optimizing application configurations: # threads, Frequency, etc.
  – Port GEOPM to IBM POWER9 (support for LLNL Sierra)

ECP Argo Contributions: Components and Interfaces

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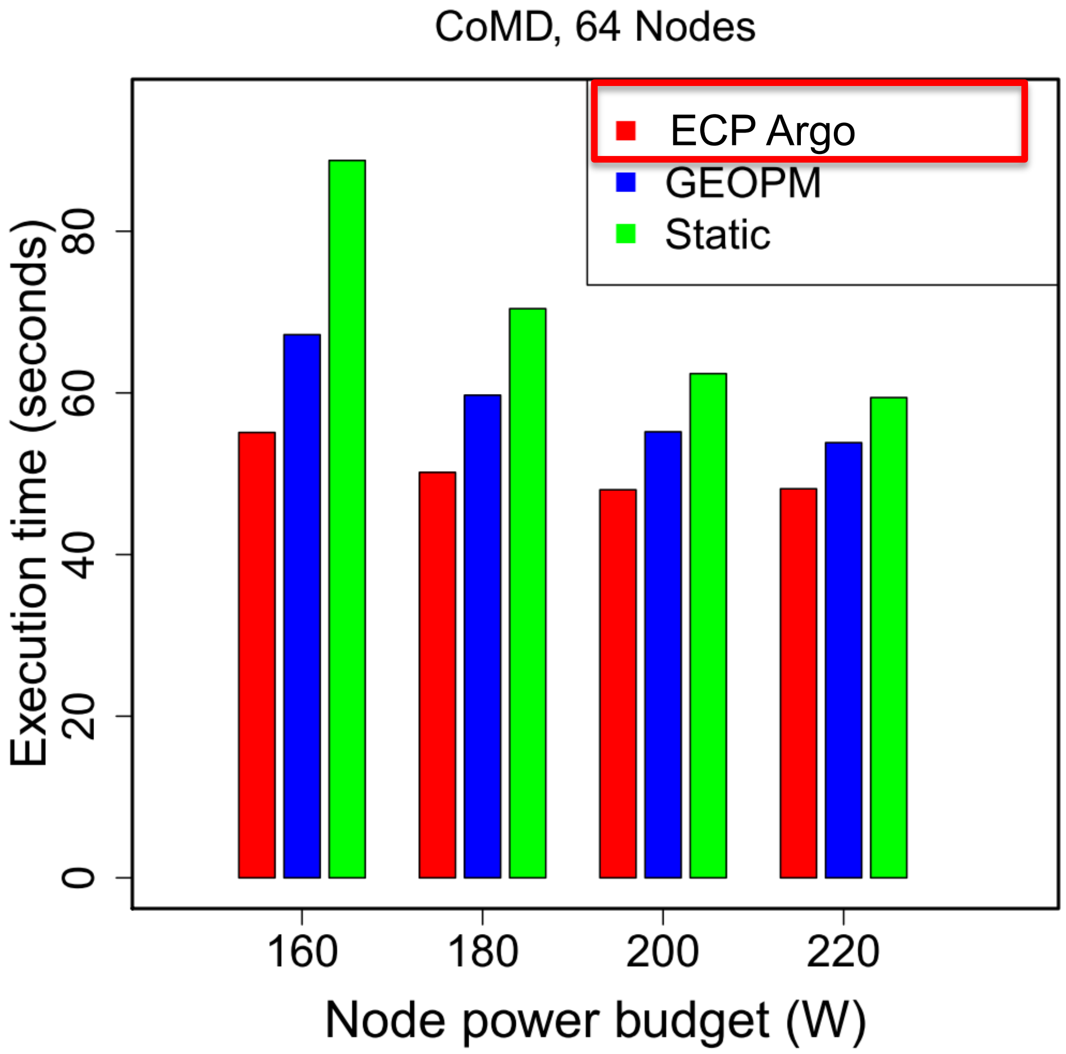
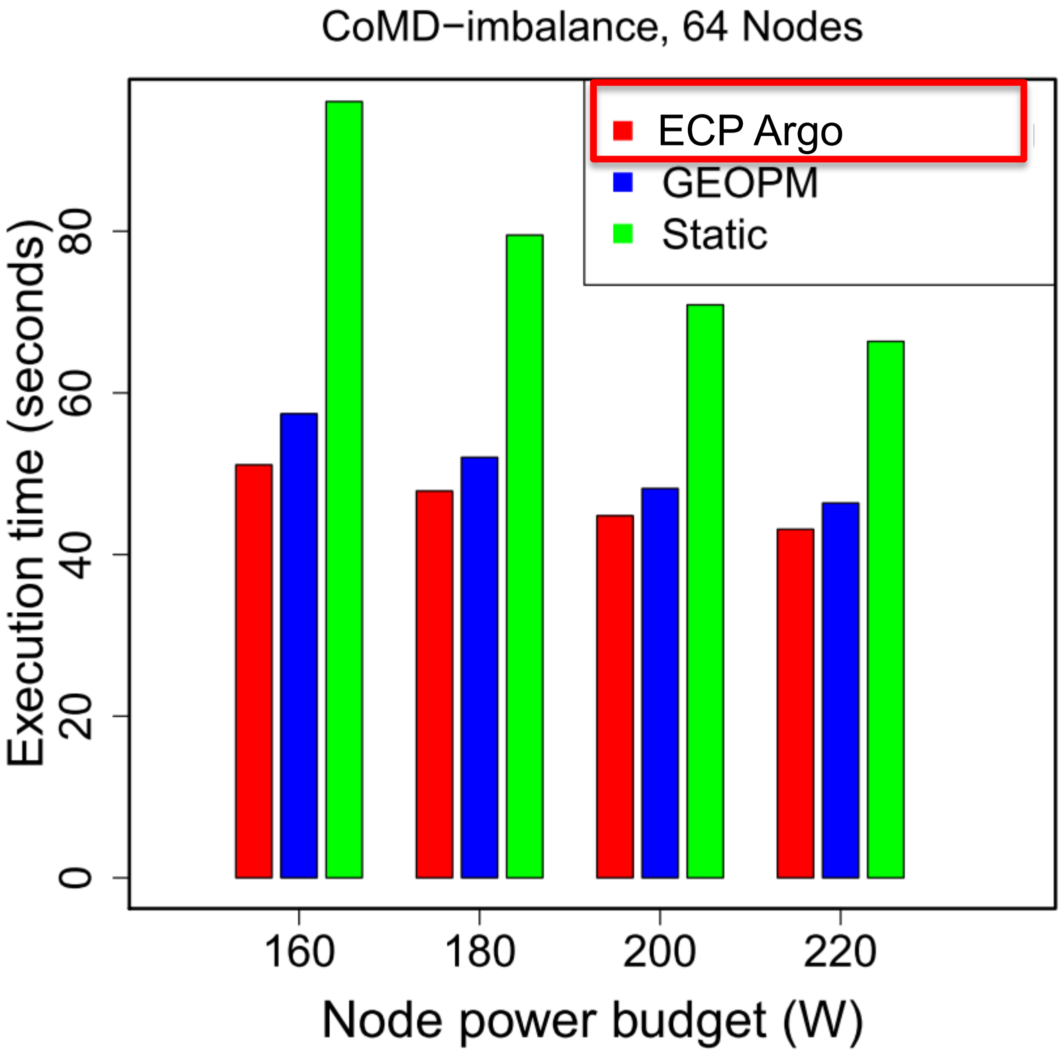
ECP Argo: How Much Do We Gain With Configuration Tuning?

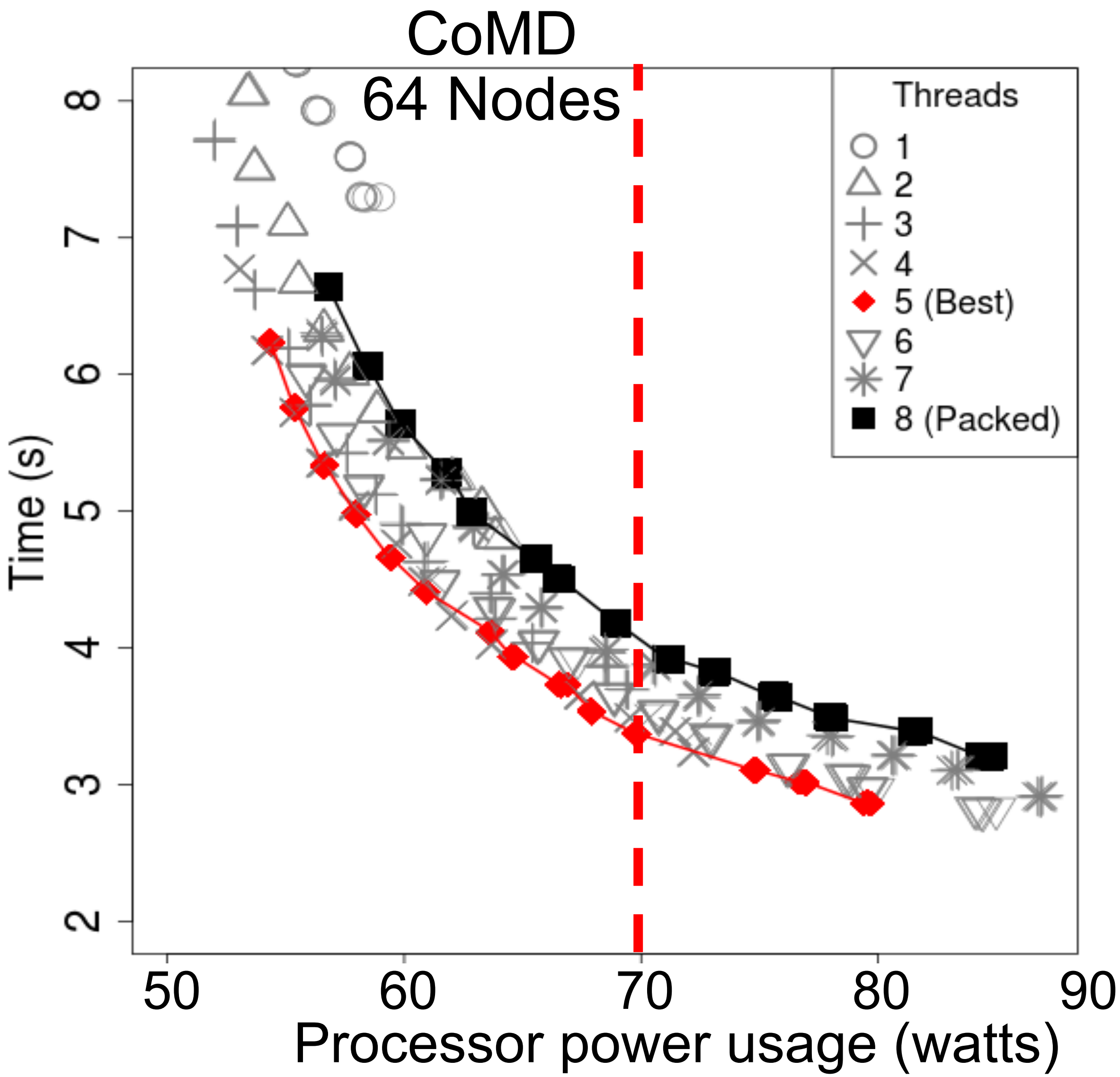




Naïve Scheme: Static Power Allocation

- Equally distribute and enforce power constraint over all nodes of a job
  - Uses Intel's Running Average Power Limit (RAPL) interface
- Statically select a *configuration* under the power constraint
  - Configuration: {Number of cores, Frequency/power limit}
  - Commonly used: *Packed* configuration
    - Maximum cores possible on the processor
    - Frequency or power limit as the control knob

Limitations of Static Power Allocation



1. Trivial node-level configurations may be inefficient

   Input: {# cores, frequency/power limit}

   Output: {Execution time, power usage}

- Up to 30% slower than the optimal configuration
- Needs prohibitively large number of runs of the application

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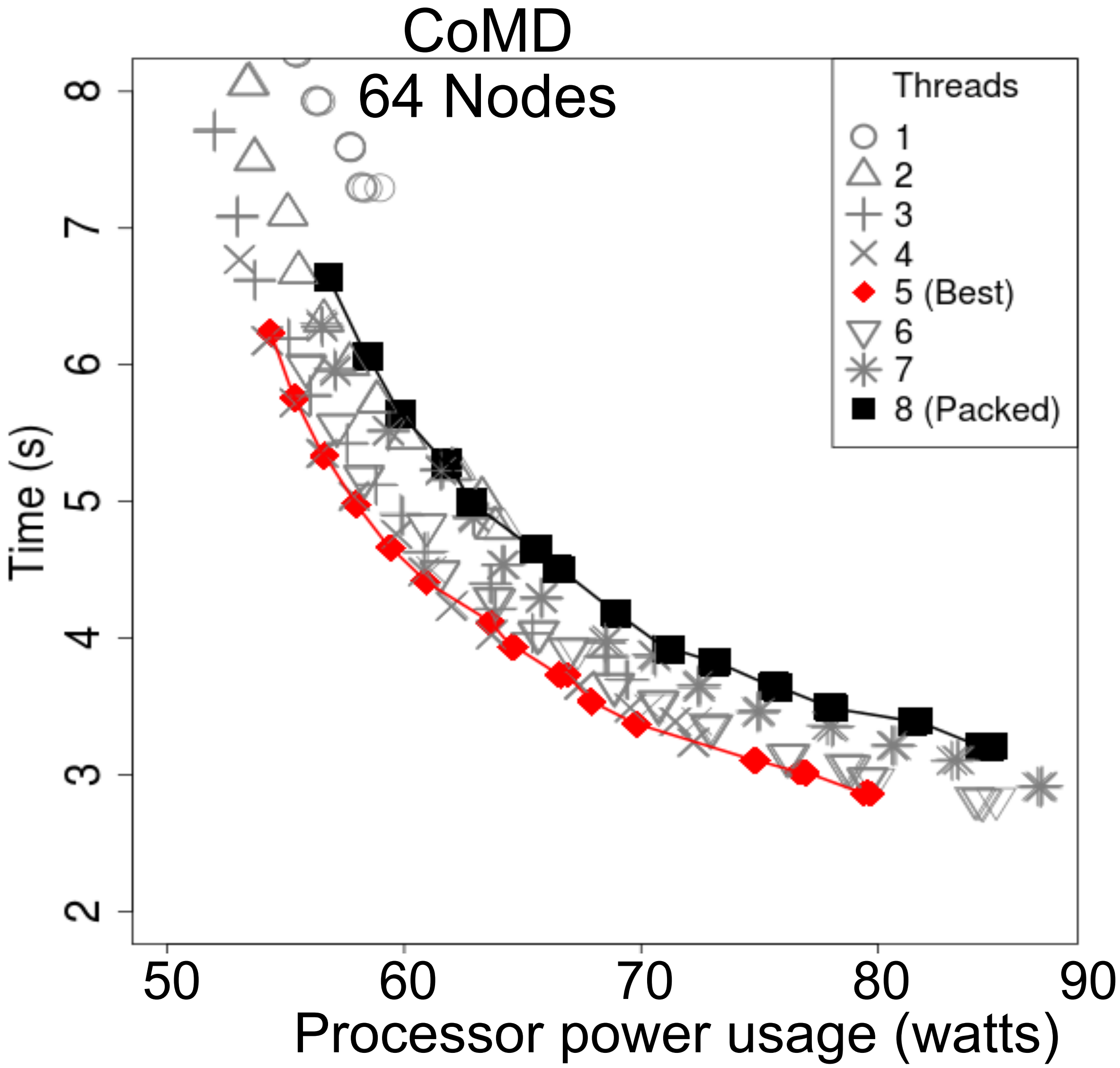

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   Input: {# cores, frequency/power limit}

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- Up to 30% slower than the optimal configuration
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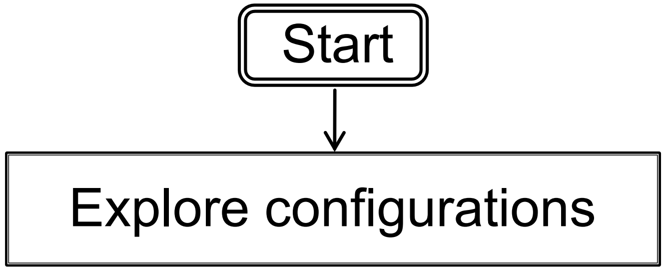
2. Portion of power left unused with load-imbalanced applications (up to 40%)

Conductor: Dynamic Configuration and Power Management

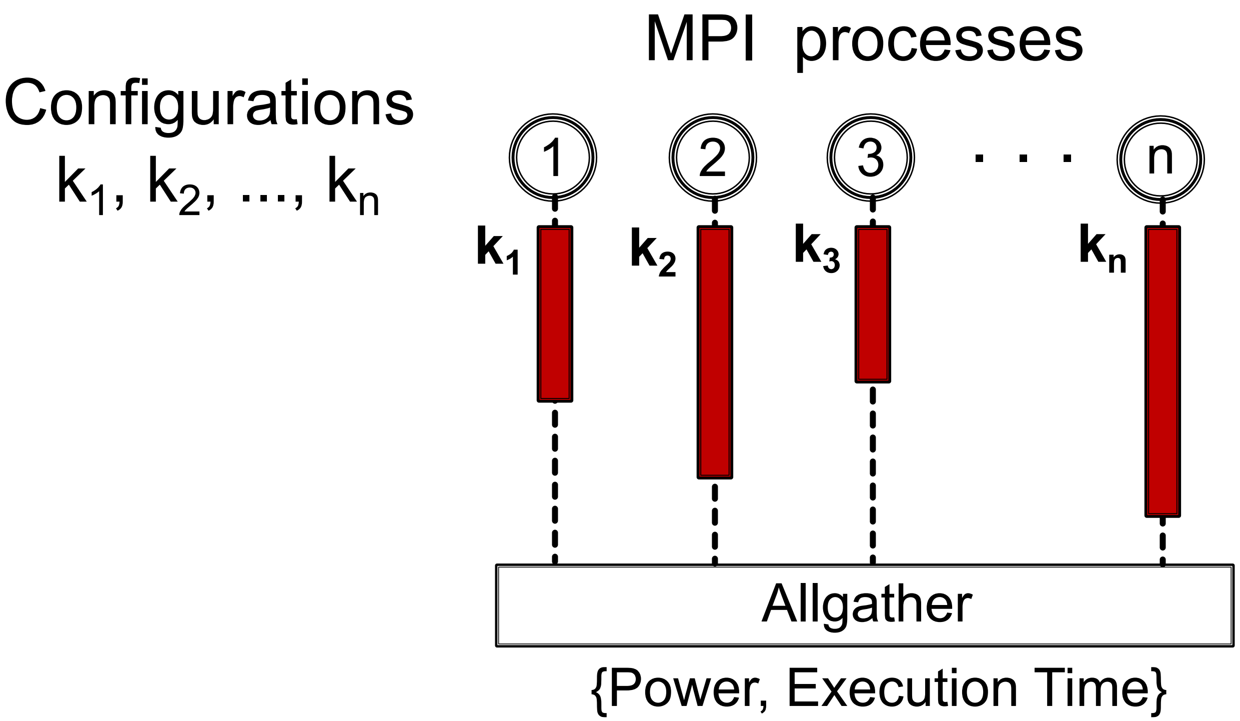
- Goals of ConductorAgent
  - Speed up computation on the critical path
  - Use power-efficient configuration

- Need to *dynamically* identify
  - Computation region potentially on the critical path
  - {execution time, power usage} profile for every computation on every processor

ConductorAgent Algorithm



Step 1: Configuration Exploration



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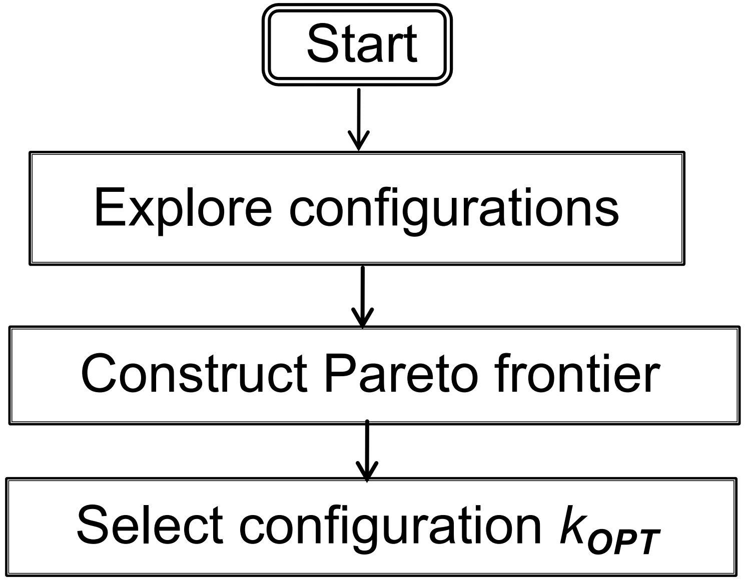

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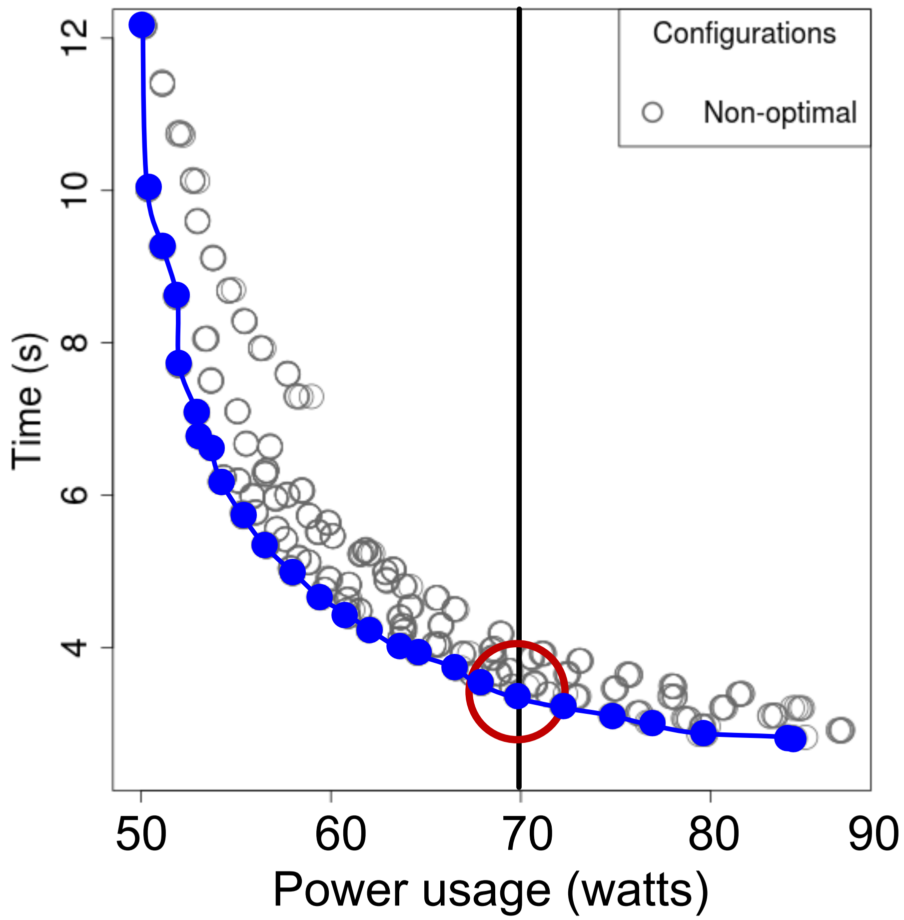

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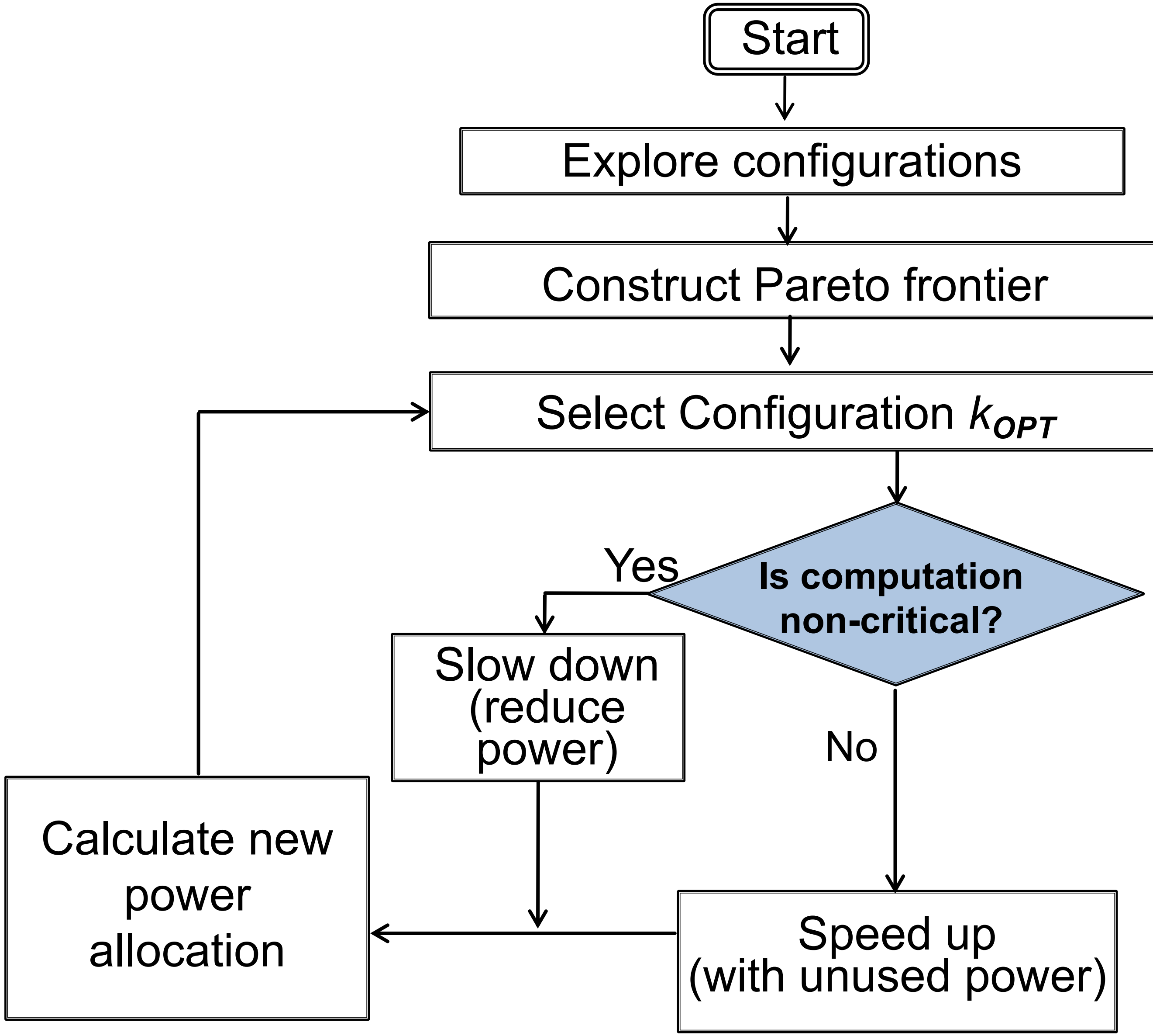
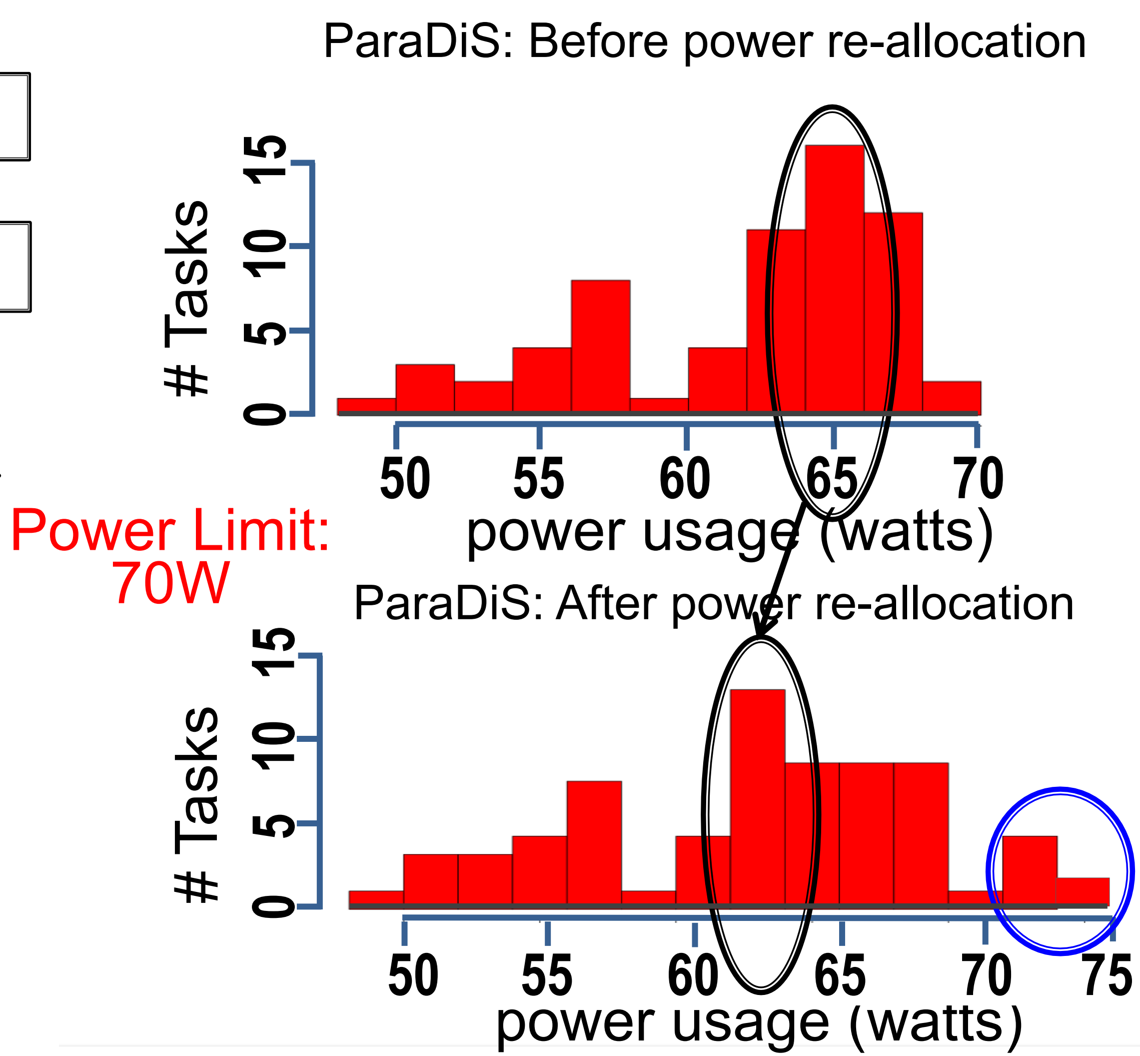


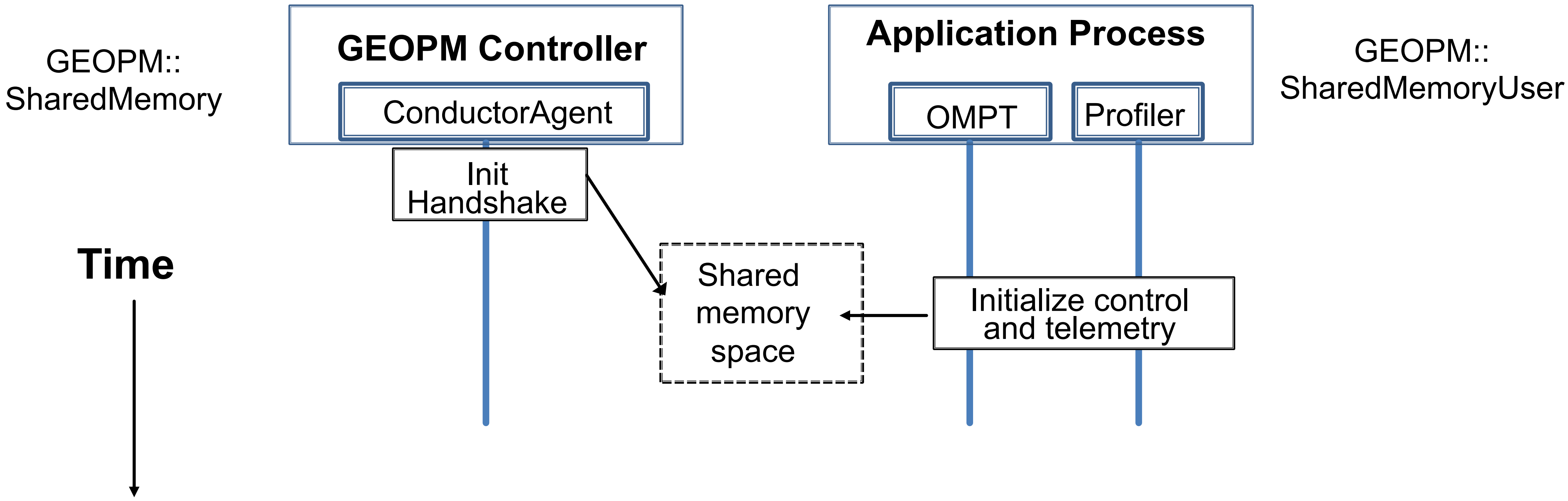
Step 2: Power Re-allocation



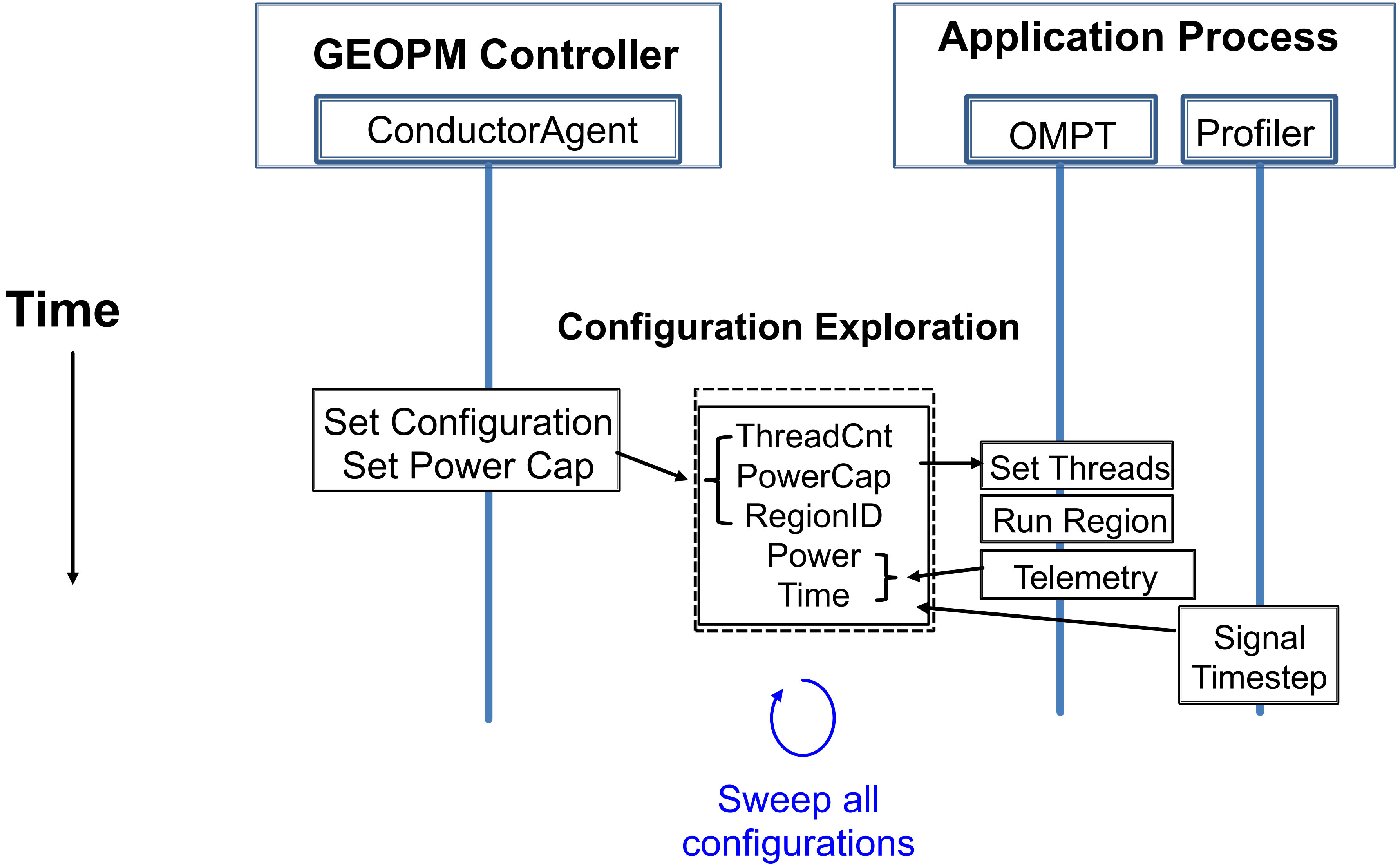
Conductor: Integration into GEOPM

- **OMPT class**
  - Explore {OMP, Pcap} configurations during the exploration phase
  - Select power-efficient configuration during regular execution.
- **Profile class**
  - Report end of timestep (i.e., ‘epoch’), application and system telemetry to enable sweep of configuration at runtime.
- **ConfigApp class**
  - Perform profiling, generate pareto-optimal configurations.
- **ConfigAgent class**
  - Share telemetry with PowerBalancer agent, send configuration to OMPT.

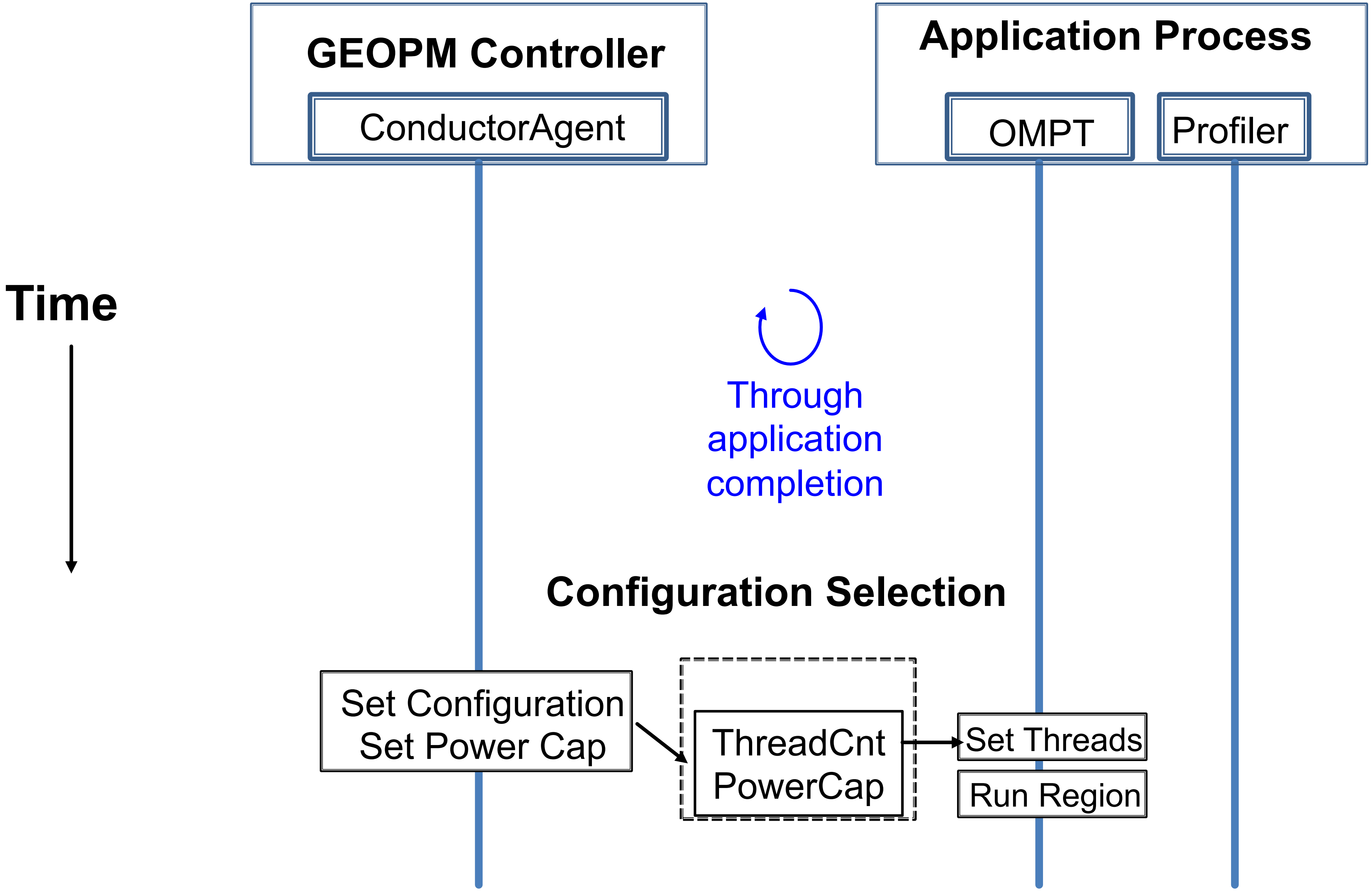
Initialization: GEOPM, Application Handshake



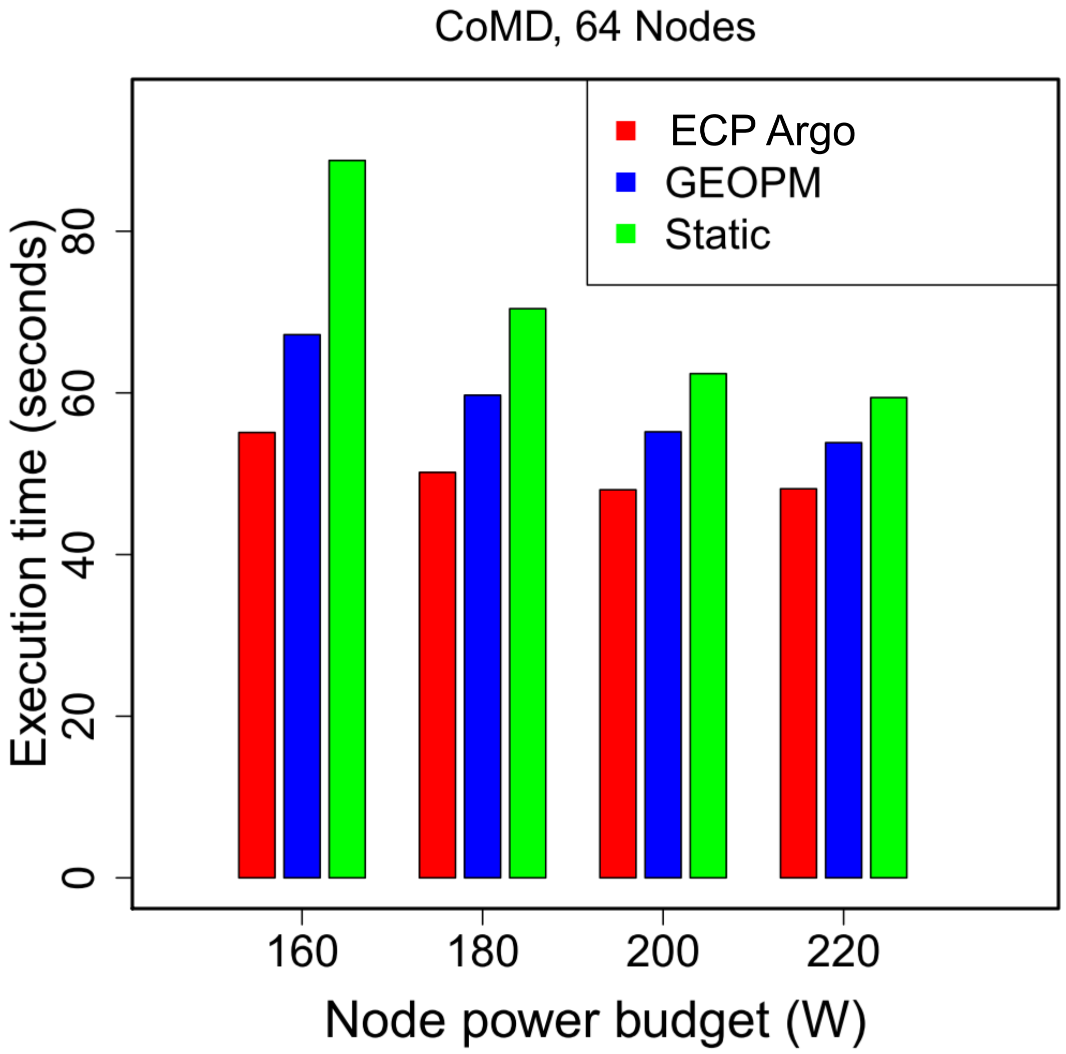
Configuration Exploration: Set Configuration, Collect Telemetry

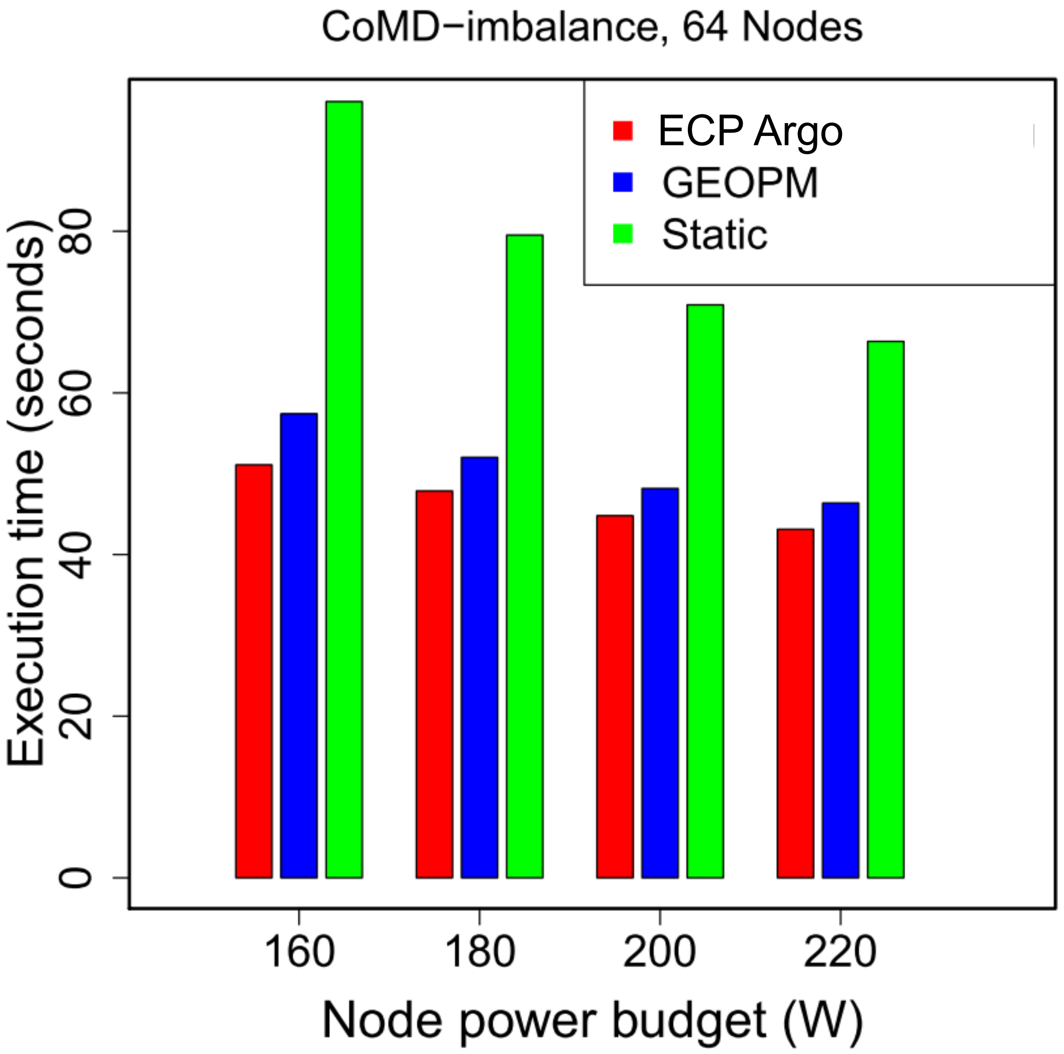


Configuration Selection: Pick Power-Efficient Configurations



ECP Argo: End Result





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GEOPM Port: Migration to New GEOPM IOGroup Interface

Purpose	Old: PlatformImp interface	New: IOGroup interface
Get platform information on POWER9	**PowerPlatformImp:** extends *PlatformImp*	**PowerIOGroup**: extends *IOGroup*
RAPL-like monitoring and control on POWER9	**OCCPlatform**: extends *Platform*	**PowerIO:** Direct CPU monitoring/control interface
Get platform information on GPUs	**NVMLPlatformImp**: extends *PlatformImp*	**NVMLIOGroup**: extends *IOGroup*
RAPL-like monitoring and control on GPUs	**NVMLPlatform**: extends *Platform*	**NVMLIO:** Direct GPU monitoring/control

*Additional modifications in GEOPM Agent implementations to fully support GEOPM power management on POWER9 dual socket + Nvidia Volta with NVLink

GEOPM IBM Port: IBM “Witherspoon” Node

System configuration
&
interfaces

- CPU ID: PowerNV 8335-GTH, 2.2
- Number of cores: 160 4-way SMT, 3.7 GHz
- System memory: 66 GB
- GPU: Nvidia Tesla V100-SXM2
- Software: RHEL, GNU C/C++, GNU Fortran, MPICH2

Telemetry	
Control	ent

We use linear regression-based model to predict power usage at a given CPU frequency

$$P_{CPU} = \alpha.F + C$$

where, P_{CPU} : P9 CPU power usage (watts),
F : CPU frequency (GHz)
α : Coefficient of frequency scaling
C : Constant offset base frequency <-> power correlation

ECP Argo: Github Contributions

- Conductor integration and IBM platform plugin:
  - https://github.com/geopm/geopm/pull/757
- GEOPM integration with Caliper:
  - https://github.com/LLNL/Caliper/pull/213

GEOPM Team and Collaborations

GEOPM Core Team (Intel)

Jonathan Eastep (Project Lead)
Chris Cantalupo (Lead Developer)
Fede Ardanaz
Brad Geltz
Brandon Baker
Mohammad Ali
Siddhartha Jana
Diana Guttman

LLNL Team

Aniruddha Marathe
Tapasya Patki
Stephanie Brink
Barry Rountree

Questions?

Github links

Configuration Exploration: https://github.com/amarathe84/geopm/tree/master

IBM Port: https://github.com/amarathe84/geopm/tree/ibm-port

ECP Future Work

Done

- ECP Phase I: GEOPM extensions, Power-aware SLURM, Legion extensions
- ECP Phase II: Power control and monitoring through `variorum`, co-scheduling and workflows

WIP

- Deliver initial version of PowerStack
- Integrate GEOPM and Variorum
- Include node-level power capping after OPAL firmware update

Future

- Extend configuration exploration to include CPU-GPU configuration space
- Power/Performance models for co-scheduling and workflows
- Port variorum to ARM, HPE, and other architectures
- PowerStack Consortium and industry integration

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