An Overview of GEO

(Global Energy Optimization)

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GEO Project Scope and Goals

- GEO is an open source, scalable, extensible runtime and framework for power management in HPC systems
  - Provides extensibility via plug-ins + advanced default functionality
- Developing GEO through CORAL NRE project with potential deployment on Aurora system at Argonne
- Goal1: unlock more performance in power-limited systems
- Goal2: accelerate innovation in HPC power management
  - Enables researchers to focus effort on algorithms (via plug-ins) not re-engineering distributed runtime infrastructure
  - Provides a streamlined path for deploying new ideas
    - Product-grade framework w/ development+hardening backed by Intel
  - Drives codesign of power and performance management features in Intel processors for better results w/ runtimes like GEO

Acknowledgements

GEO Core Team (Intel)

- Fede Ardanaz
- Chris Cantalupo
- Jonathan Eastep
- Richard Greco
- Stephanie Labasan
- Steve Sylvester
- Reza Zamani
- … and hiring!

Collaborators (Intel)

- David Lombard
- Tryggve Fossum
- Al Gara

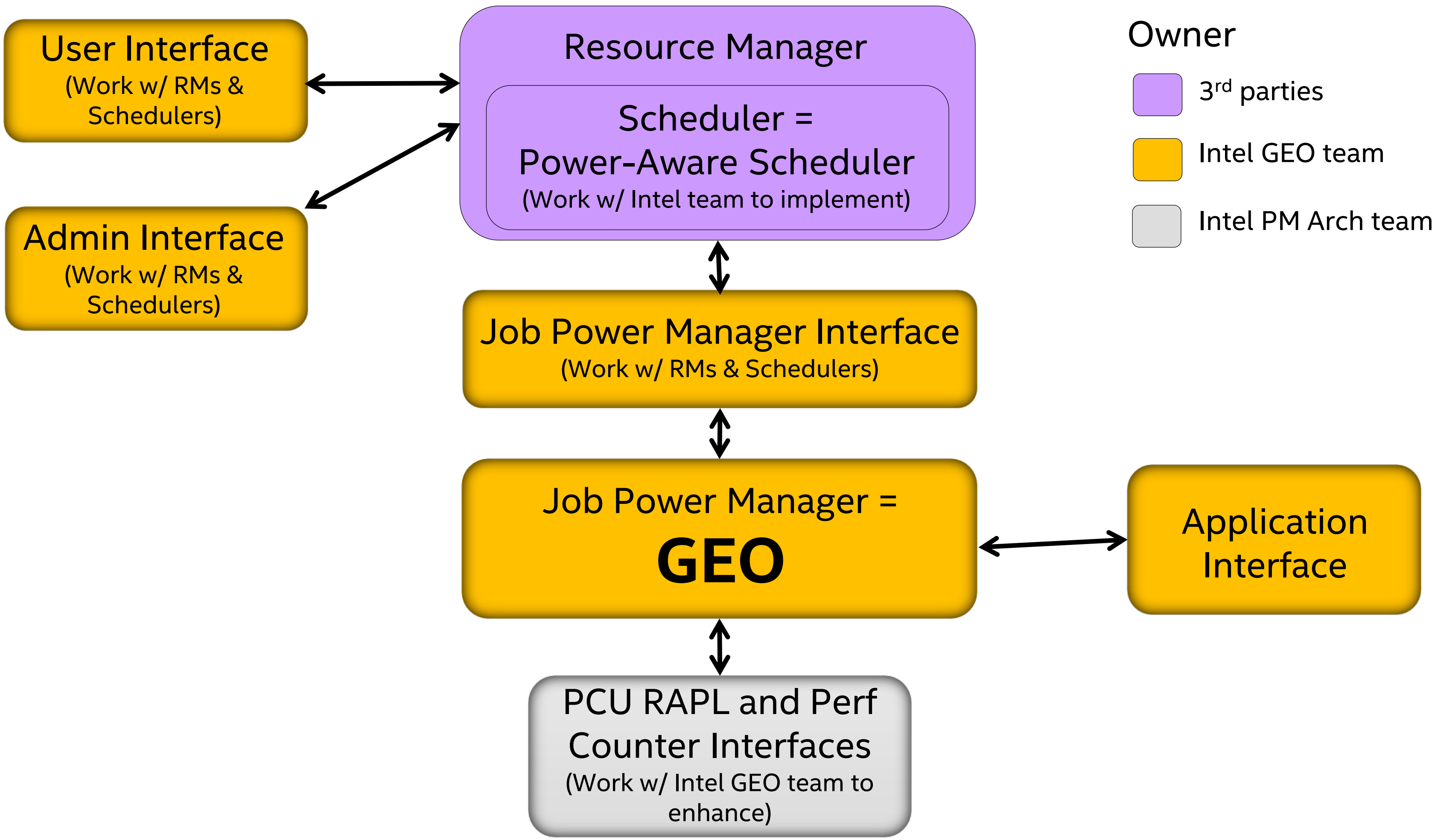
Collaborators (External)

- Argonne (CORAL)
- LLNL (Rountree)
- … and expanding!

Relationship to Standard Power APIs

- GEO is a job-level power management framework
  - Manages the compute nodes in a job to a job power bound
  - … while maximizing performance or other objective functions
- With work, GEO could fit under/above other power APIs
  - GEO currently interacts with other SW components through its own interfaces (next slide)
  - We're not positioning our external interfaces as standards
- Emphasis on providing an extensible framework and advanced out-of-the-box power management strategies
  - Builds on "Auto-Tuner" machine learning, control system, and optimization technology Intel has been researching for 4 years

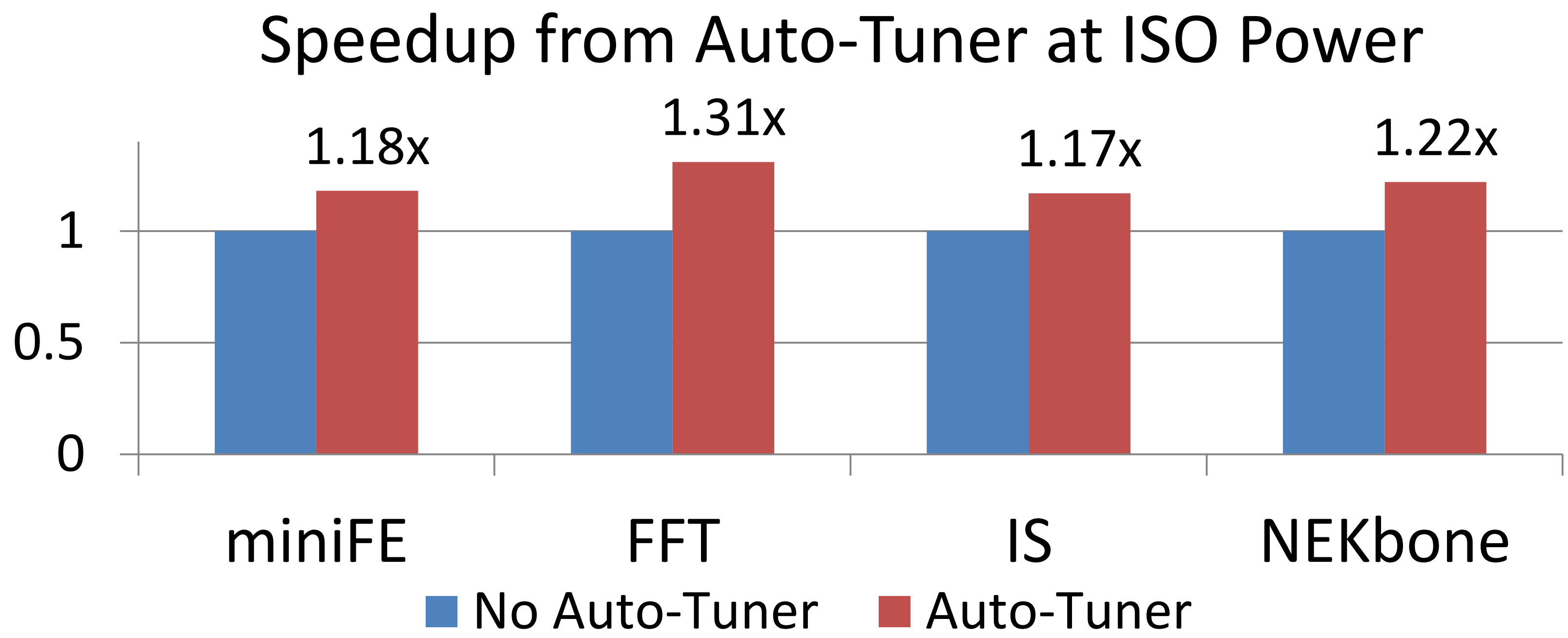
GEO Interfaces / Integration Architecture



Advanced Auto-Tuner Capabilities

- Comprehend and mitigate dynamic load imbalance by globally coordinating frequency and power allocations across nodes
- Leverage application-awareness and learning to recognize patterns in application (phases), then exploit patterns to optimize decisions
- React to phase changes at aggressive time scales (low milliseconds) and rapidly redistribute limited power to performance-critical resources
- Tackle the scale challenges prior techniques have swept under the rug to enable holistic joint optimization of power policy across the job

Auto-Tuner Prototype Results Summary



Speedup derives from two factors: correcting load imbalance across nodes and node-local spatio-temporal energy scheduling optimizations exploiting phases

Bars represent average results over a range of assumptions about how much power the job is allocated and how much load imbalance is present

Experimental setup carefully emulates large-cluster load imbalance on a small cluster

Results collected while running on Xeon hardware (not simulation)

Presentation Outline

- GEO Project Overview
- GEO Architecture Overview
- Open Source Project Details (if time allows)
- Deep Dive: Application Feedback Interface

GEO Architecture Overview

GEO Hierarchical Architecture

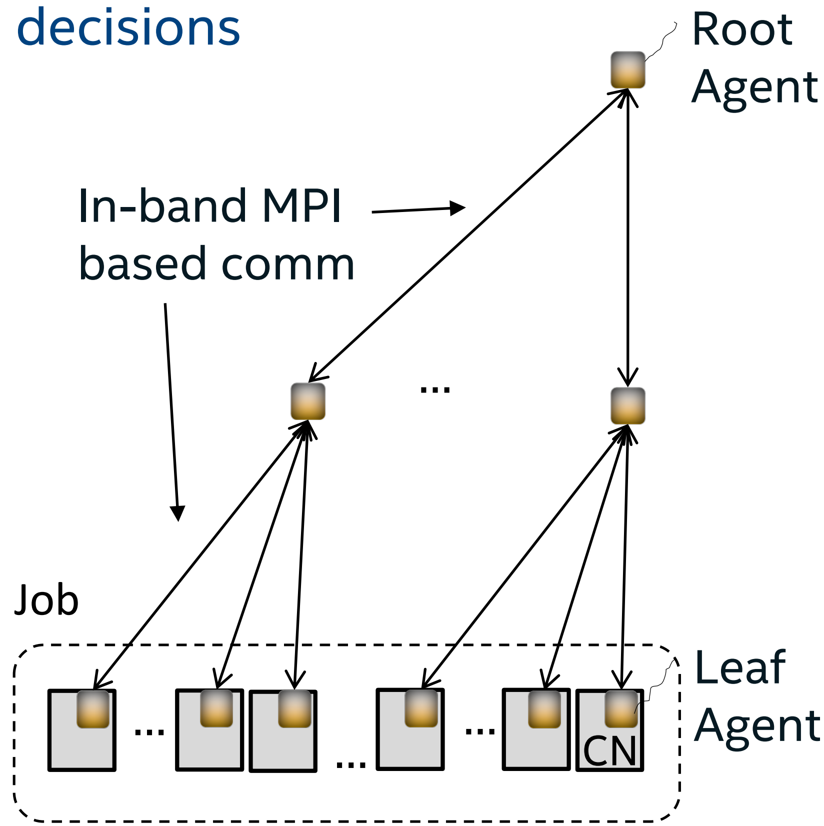
GEO manages job to a power budget and globally coordinates frequency & power allocation decisions

Scaling challenge is addressed via tree-hierarchical design & hierarchical policy

- Each agent owns sub-problem: decide how to divide/balance power among children
- Power/perf telemetry is scalably aggregated so network traffic is minimal
- Tuning is globally optimized despite distributed tuning: achieved through Hierarchical-POMDP learning techniques

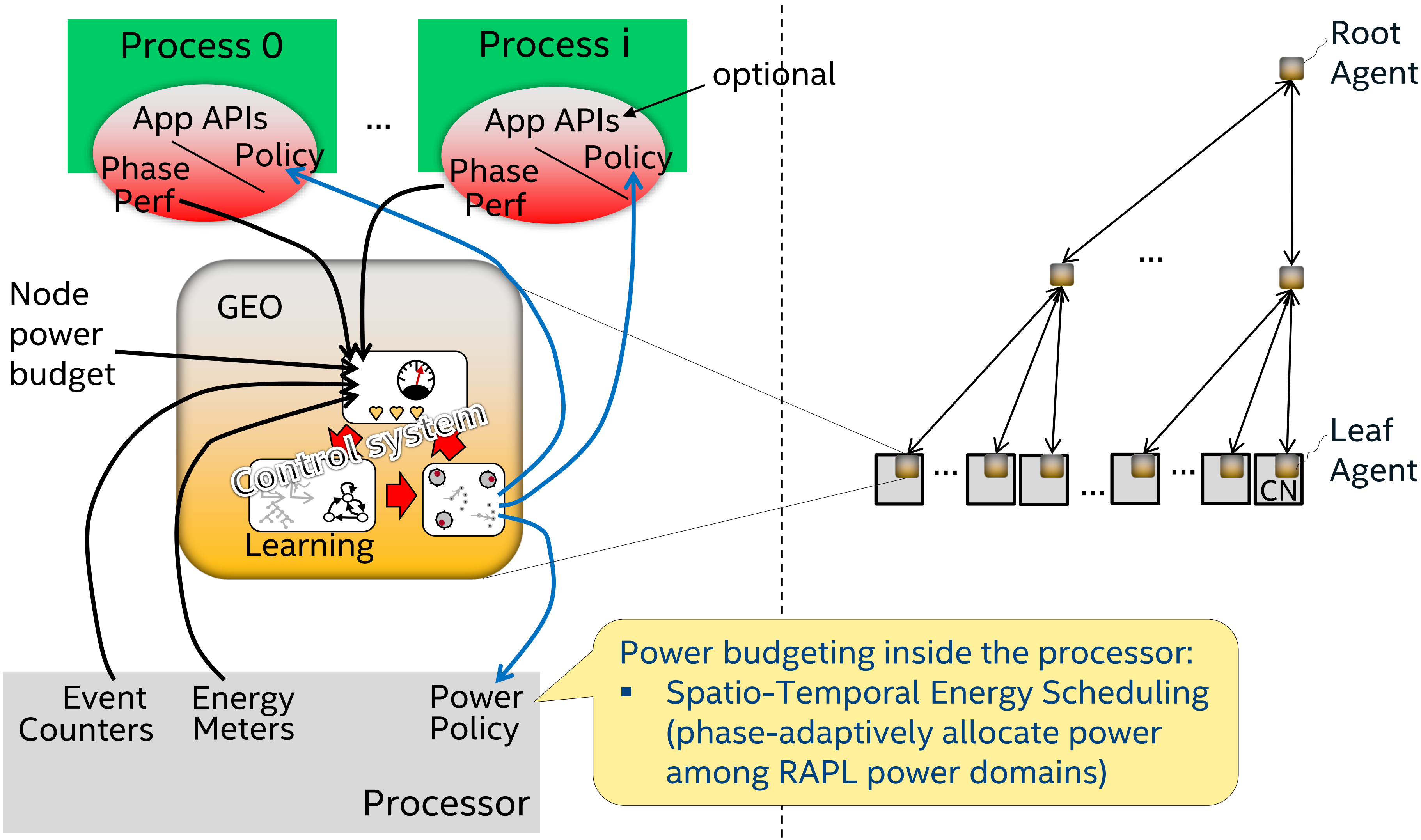
GEO tree runs in 1 reserved core per CN

- Leaf & non-leaf agents run in these cores
- Enables fast reaction times, deep analysis
- Overhead is negligible in manycore chips
- Designing for minimal memory footprint



CN ≡ Compute Node
(in compute node racks)

Zoom-In on Leaf Agent



Power budgeting inside the processor:

- Spatio-Temporal Energy Scheduling (phase-adaptively allocate power among RAPL power domains)

Open Source Project Details

GEOPM Open Source Release

Team just completed first open source release on github

- Package Name: geopm (GEO power management)
- Release Goal: publish docs and interfaces for community review
- Non-Goal: feature-completeness
- Compatibility: Red Hat RHEL7 and SUSE SLES12 Linux distros
- Repository: view project and source code via http://geopm.github.io/geopm/

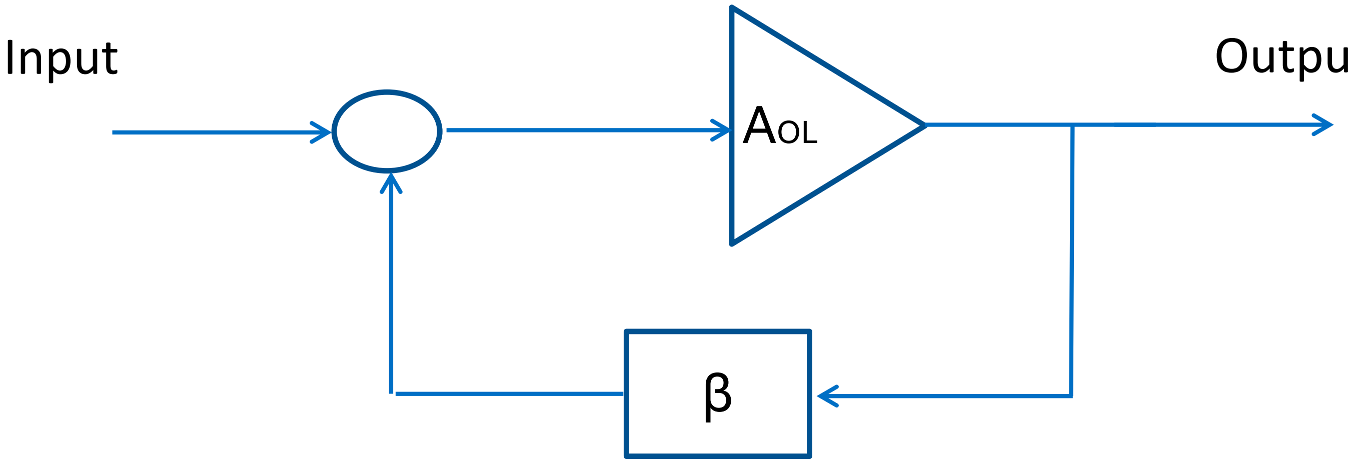
Release Notes

- Defined interfaces and architecture for integration in HPC SW stacks
- Nailed down our modular object-oriented design in C++11 (with C interfaces to external components / application)
- Developed solid autotools build system and gtest/gcov test infrastructure
- Delivered support for basic static power management functionality
  - E.g. Uniform Frequency Static mode
  - E.g. Hybrid Frequency Static mode (Pseudo Big Core / Little Core)
- No dynamic power management yet (still under construction)
  - No Auto-Tuner load balancing modes yet

Next Steps (Through Q1'16)

- WIP on community adoption of GEO
  - [DONE] Spin up collaborations with Argonne and LLNL
  - [WIP] Spin up collaborations with other national labs and universities
  - [WIP] Pursue community feedback on interfaces and documentation
  - [WIP] Joint research / publications with collaborators building on GEO
- WIP on the runtime for dynamic power management
  - [DONE] MPI communications between levels of GEO runtime hierarchy
  - [DONE] SLURM plug-in (initial development vehicle)
  - [DONE] Application feedback interface implementation
    - Recall: application markup is initially required for dynamic power mgmt modes
    - Long-term goal is for GEO to automatically infer the info without the API
  - [DONE] Extensibility in support for processor features
  - [WIP] Extensibility in decision algorithms

Deep Dive: Application Feedback Interface



Overview

- C interfaces provided in a lib that the app links against
  - They resemble typical profiler interfaces
- Consist of annotation functions for programmers to provide GEO info about app critical path and phases:
  - Indicate where bulk synchronizations occur (points where load imbalance results will result in degraded performance)
  - Indicate where phase changes occur in an MPI rank (i.e. phase entry and exit)
  - Indicate hints specifying whether phases will be compute-, memory-, or communication-intensive
  - Indicate how much progress each MPI rank has made toward completing the current phase (identify critical path)

Profiler Management / Reporting

```
int geopm_prof_create(
    const char *name,
    size_t table_size,
    const char *sample_key,
    MPI_Comm comm,
    struct geopm_prof_c **prof);

int geopm_prof_destroy(
    struct geopm_prof_c *prof);
```

```
int geopm_prof_region(
        struct geopm_prof_c *prof,
        const char *region_name,
        long policy_hint,
        uint64_t *region_id);

int geopm_prof_print(
        struct geopm_prof_c *prof,
        const char *file_name,
        int depth);
```

Phase Markup / Bulk Sync Point

```
int geopm_prof_enter(
        struct geopm_prof_c *prof,
        uint64_t region_id);

int geopm_prof_exit(
        struct geopm_prof_c *prof,
        uint64_t region_id);

int geopm_prof_outer_sync(
        struct geopm_prof_c *prof,
        uint64_t region_id);
```

Progress Reporting (1)

- Interfaces provide two options for reporting progress:
  - Special case (direct determination of critical path):
    - Assume: MPI+OpenMP w/ statically scheduled parallel regions
    - Assume: Total work for each individual thread is known
    - API computes rank's progress as the min progress any thread made toward completing its total work (this is a %)
  - General case (estimation of critical path):
    - Assume: MPI+X
    - Assume: Total work is not known for each individual thread but the total work across all threads is known
    - API computes rank's progress as sum of work completed on all threads / total work all threads will perform (this is a %)

Progress Reporting (2)

```
int geopm_prof_progress(
    struct geopm_prof_c *prof,
    uint64_t region_id,
    double fraction);

int geopm_omp_sched_static_norm(
    int num_iter,
    int chunk_size,
    int num_thread,
    double *norm);
```

```
double geopm_progress_threaded_min(
        int num_thread,
        size_t stride,
        const uint32_t *progress,
        const double *norm);

double geopm_progress_threaded_sum(
        int num_thread,
        size_t stride,
        const uint32_t *progress,
        double norm);
```

Example of Application Markup (1)

```
max_threads = omp_get_max_threads();
posix_memalign((void **)&progress, cache_line_size,
               cache_line_size * max_threads);
memset(progress, 0, cache_line_size * max_threads);
norm = (double *)malloc(sizeof(double) * max_threads);
geopm_omp_sched_static_norm(num_iter, chunk_size,
                            max_threads, norm);
geopm_prof_region(prof, "main-loop",
                  GEOPM_POLICY_HINT_UNKNOWN, &region_id);
#pragma omp parallel default(shared) private(i, progress_ptr)
{
    progress_ptr = progress + stride * omp_get_thread_num();
    #pragma omp for schedule(static, chunk_size)
    for (i = 0; i < num_iter; ++i) {
        x += do_something(i);
        (*progress_ptr)++;
        if (omp_get_thread_num() == 0) {
            thread_progress = geopm_progress_threaded_min(
                omp_get_num_threads(), stride, progress, norm);
            geopm_prof_progress(prof, region_id, thread_progress);
        }
    }
}
```

Example of Application Markup (2)

```
max_threads = omp_get_max_threads();
posix_memalign((void **)&progress, cache_line_size,
               cache_line_size * max_threads);
memset(progress, 0, cache_line_size * max_threads);
norm =  1.0 / num_iter;


geopm_prof_region(prof, "main-loop",
                  GEOPM_POLICY_HINT_UNKNOWN, &region_id);
#pragma omp parallel default(shared) private(i, progress_ptr)
{
    progress_ptr = progress + stride * omp_get_thread_num();
    #pragma omp for schedule(static, chunk_size)
    for (i = 0; i < num_iter; ++i) {
        x += do_something(i);
        (*progress_ptr)++;
        if (omp_get_thread_num() == 0) {
            thread_progress = geopm_progress_threaded_sum(
                omp_get_num_threads(), stride, progress, norm);
            geopm_prof_progress(prof, region_id, thread_progress);
        }
    }
}
```

Coming Soon: Plug-In Interfaces

- Completion targeted for Q1’16 (hopefully early Q1)
- Platform plug-ins
  - Provides high-level abstraction of low-level processor interfaces for power & performance monitoring and control
    - E.g. control registers for RAPL, P-states, event counters, etc.
  - Simplifies porting to new Intel processors with new features (or processors from other vendors)
- Decider plug-ins
  - Enables researchers to extend GEO’s control algorithms
    - E.g. site-specific power management strategies
    - E.g. application-specific power management strategies

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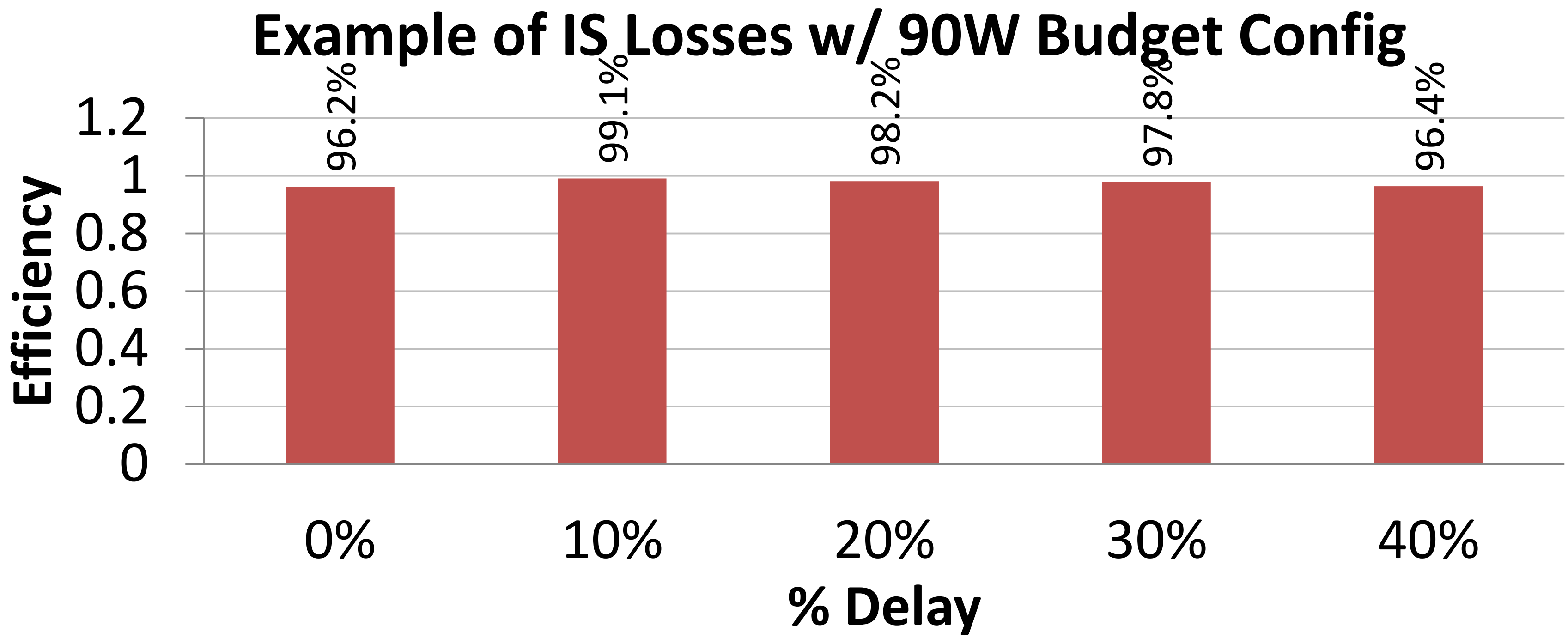
Backup Slides

Power Bounds

- Load imbalance is a big challenge
  - Apps tend to do bulk synchronizations
  - Performance is determined by last node to arrive at bulk synchronization point
- Power is becoming a scarce resource that must be managed carefully
  - Future systems are expected to be power-limited due to site limits
  - Processors are power-limited due to thermal design power limits
- Current strategies for managing power aggravate load imbalance
  - Uniform node power caps expose frequency variation from manufacturing variation
  - Uncoordinated Turbo/throttle decisions on nodes expose frequency variation
  - Results are far from optimal

Comparison Against Theoretical Bounds

- Summary
  - We achieved near-ideal benefits for most workloads with negligible losses vs. bounds
  - But, we note non-negligible losses of benefit for Integer Sort



- X-axis is a parameter for how much load imbalance we inject into the system
- Root-cause of benefit losses: some is initial search time, most is control error due to noise
- IS is considerably noisier than FFT and miniFE; working to improve handling of noise more

GEO Advanced Power Balancing Modes

Can configure objective function for how GEO will dynamically mitigate imbalance

- a) Equalize processor frequency
- b) Equalize node's app progress (steer power to critical path)