Exploring the Trade-off Space of Hierarchical Scheduling for Very Large HPC Centers

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Motivation

- On the path to a next-generation HPC center lies a significant increase in scale and diversity of resources
- Single, monolithic scheduling already lacks scalability and flexibility for today's large HPC centers
- Hierarchical scheduling is becoming an attractive alternative
  - A lack of trade-off studies precludes the development of effective techniques

	2010	2018	Change
System Size (nodes)	20 K nodes	1 M nodes	50x
Power	6 MW	20 MW	3x
Storage	15 PB	300 PB	20x
Interconnect BW	1.5 GB/s	50 GB/s	33x
Total Concurrency	225 K	1 B	4,444x

DOE Exascale Initiative Roadmap, Architecture and Technology Workshop, San Diego, December, 2009.

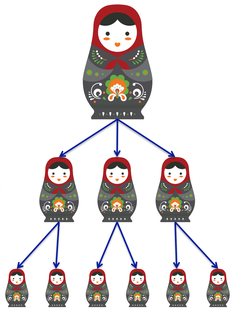
We need systematic trade-off studies to be able to develop effective hierarchical scheduling techniques

Goal

- Quantify the advantages and disadvantages of a hierarchical, multilevel scheduling scheme against a monolithic scheme
- In particular, explore the trade-off space between scheduling complexity and resource utilization

Hierarchical Scheduling under Flux

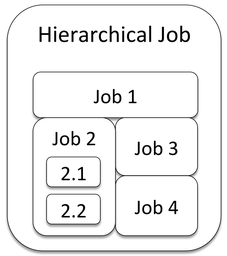
- Flux is a resource and job management system (RJMS) currently being developed to enable hierarchical, multi-level scheduling for large HPC centers [1]
- Its hierarchical scheduling rules:
  - *Parent bounding rule* – parent grants and confines the allocation of its children
  - *Child empowerment rule* – children are solely responsible for the most efficient use of their resources
- Major scalability and policy requirements
  - Provide higher levels of scheduler parallelism and thus scalability
  - Distribute load across the schedulers in this hierarchy
  - Provide the ability to impose a stricter policy enforcement



Source: eftours.com/worldmap

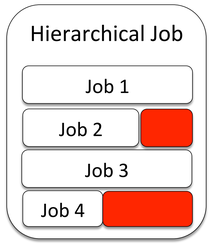
Realistic Hierarchical Workload Creation

- Under hierarchical scheduling, any job can instantiate a scheduler to schedule its sub-jobs
- A hierarchical workload is non-existent to be used for our trade-off exploration
- Use novel job-aggregation techniques to generate hierarchical workloads from real HPC workloads
  - Jobs submitted within a short window of time with similar characteristics are aggregated together into a larger job
  - This emulates an important mode in which users will use hierarchical schedulers under Flux

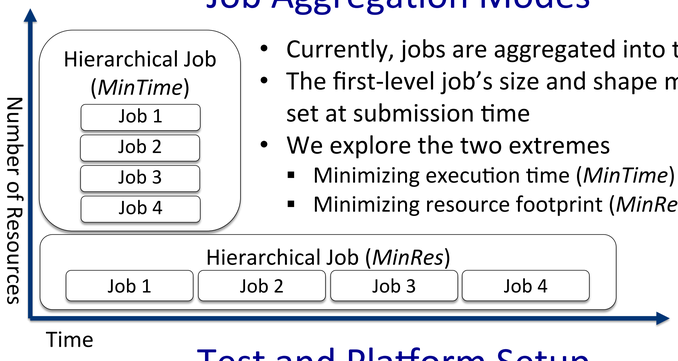


Metrics

- Scheduling complexity
  - Is a function of the number resources items and jobs to be considered at each level in the hierarchy
  - Increases as compute resources increase in scale and diversity
  - Decreases when the number of jobs are reduced by job aggregation at each level in the hierarchy
- Resource utilization
  - Hierarchical scheduling can decrease utilization when resources within an allocation go idle
  - Typically caused by small or short-running jobs



Job Aggregation Modes



- Currently, jobs are aggregated into two levels
- The first-level job's size and shape must be set at submission time
- We explore the two extremes
  - Minimizing execution time (*MinTime*)
  - Minimizing resource footprint (*MinRes*)

Test and Platform Setup

- Evaluate with a scheduling emulator built on top of Flux
- Use job logs from Rzmerl & Rzzeus, clusters at LLNL, as input to the emulator
  - Logs were collected over 2.5 months and contain 32,046 jobs
- Aggregate jobs that are submitted by the same user and within 30 seconds of each other

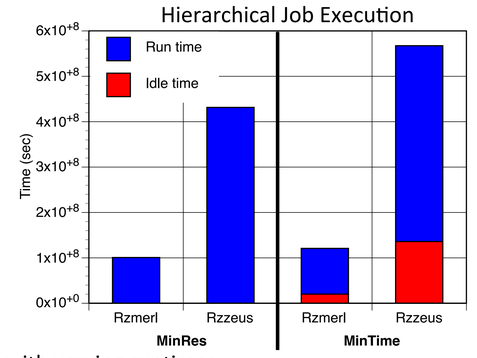
Scheduling Complexity Results

Machine	Pre-Aggregation	Post-Aggregation	Ratio
Rzmerl	6,737 jobs	5,688 jobs	1.18x
Rzzeus	25,309 jobs	7,073 jobs	3.58x

- Introducing only one additional level to scheduling leads to a reduction of **3.58x** in scheduling complexity for Rzzeus workloads
  - The preliminary results show each additional level will become a significant reduction factor for scheduling complexity
- Rzmerl has a lower ratio since its submission rate is less
  - Lower probability that a user submits jobs back-to-back

Resource Utilization Results

- *MinRes* results in virtually no idle time and thus no decrease in resource utilization compared to monolithic scheduling
  - Idleness caused by sub-jobs with varying sizes
- *MinTime* results in a large decrease in utilization compared to monolithic scheduling
  - Idleness caused by sub-jobs with varying runtimes



Conclusion and Future Work

Hierarchical scheduling offers a sizable reduction in scheduling complexity

- Job submission patterns suggest users can group together their jobs to take advantage of hierarchical scheduling
- Larger and busier HPC centers can reduce their scheduling complexity with hierarchical scheduling at deeper levels
- Sub-jobs with diverse time and resource requirements can leave center resources underutilized
- Our study motivates the development of dynamic scheduling as a way to complement hierarchical scheduling

References and Acknowledgements

[1] D. Ahn, J. Garlick, M. Grondona, D. Lipari, B. Springmeyer, and M. Schulz. Flux: A next-generation resource management framework for large hpc centers. In Proceedings of the 43rd International Conference on Parallel Processing Workshops, ICCPW'14, Sept 2014.

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