Dynamic Fractional Resource Scheduling Practical Issues and Future Directions

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Outline

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Dynamic Fractional Resource Scheduling

- HPC Scheduling Problem:
  - homogeneous nodes with high-speed interconnect
  - network file system
  - release date and number of tasks known at submission
  - computation time known only after completion
  - goal: minimize maximum stretch
- approach:
  - based on virtual machine technology
    - fractional resource allocations
    - preemption / migration
  - on-line scheduling problem $\rightarrow$ sequence of off-line resource allocation problems
  - computable, on-line performance metric related to max stretch
  - heuristics for task placement/resource allocation

Task Placement and Resource Allocation Problem

- nodes comprise a number of resources (CPU cores, memory, bandwith, etc...)
- tasks have rigid requirements and fluid needs
  - job tasks have the same requirements and needs
  - rigid requirements specify minimum resource allocations
  - fluid needs specify minimum allocations without performance degradation
- yield of a job is a value between 0 and 1
  - correlated with performance
  - jobs allocated product of yield and need in each resource
- Goal: find an allocation that maximizes the minimum yield

Task Placement Heuristics

- **Greedy Task Placement** – incremental, puts each task on the node with the lowest computational load on which it can fit without violating memory constraints
- **MCB Task Placement** – global, iteratively applies multi-capacity (vector) bin-packing heuristics during a binary search for the maximized minimum yield
  - achieves higher minimum yield values than Greedy
  - can *potentially* cause lots of migration
- what if the system is oversubscribed?
  - use a priority function to decide which jobs to run

Priority Function?

- Virtual Time: subjective time experienced by a job
- first idea: $\frac{1}{\text{VIRTUAL TIME}}$
  - informed by ideas about fairness
  - lead to good results
  - theoretically prone to starvation
- second idea: $\frac{\text{FLOW TIME}}{\text{VIRTUAL TIME}}$
  - addresses starvation problem
  - lead to poor performance
- Third Idea: $\frac{\text{FLOW TIME}}{(\text{VIRTUAL TIME})^2}$
  - combines idea #1 and idea #2
  - addresses starvation
  - performs about the same as first priority function

When to apply Heuristics

We consider a number of different options:

- Job Submission – heuristics can use greedy or bin packing approaches
- Job Completion – as above, can help with throughput when there are lots of short running jobs
- Periodically – some heuristics periodically apply vector packing to improve overall job placement

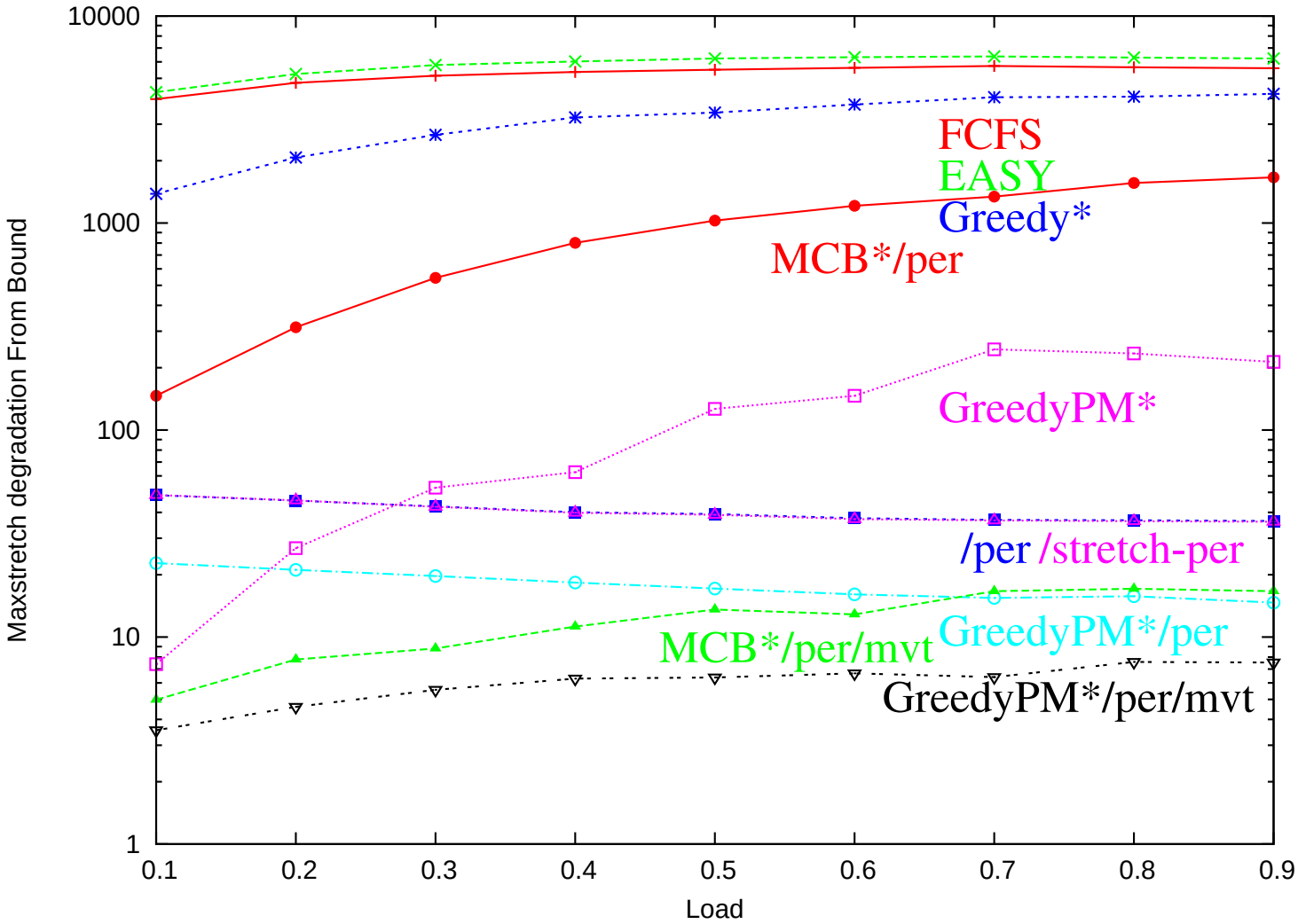
Methodology

- experiments conducted using discrete event simulator
- mix of synthetic and real trace data
- considered only memory requirements and CPU needs
- preemption/migration of jobs causes 300 second penalty to runtime
- periodic approaches use a 600 second (10 minute) period
- absolute bound on max stretch computed for each instance
- performance comparison based on degradation from max stretch bound

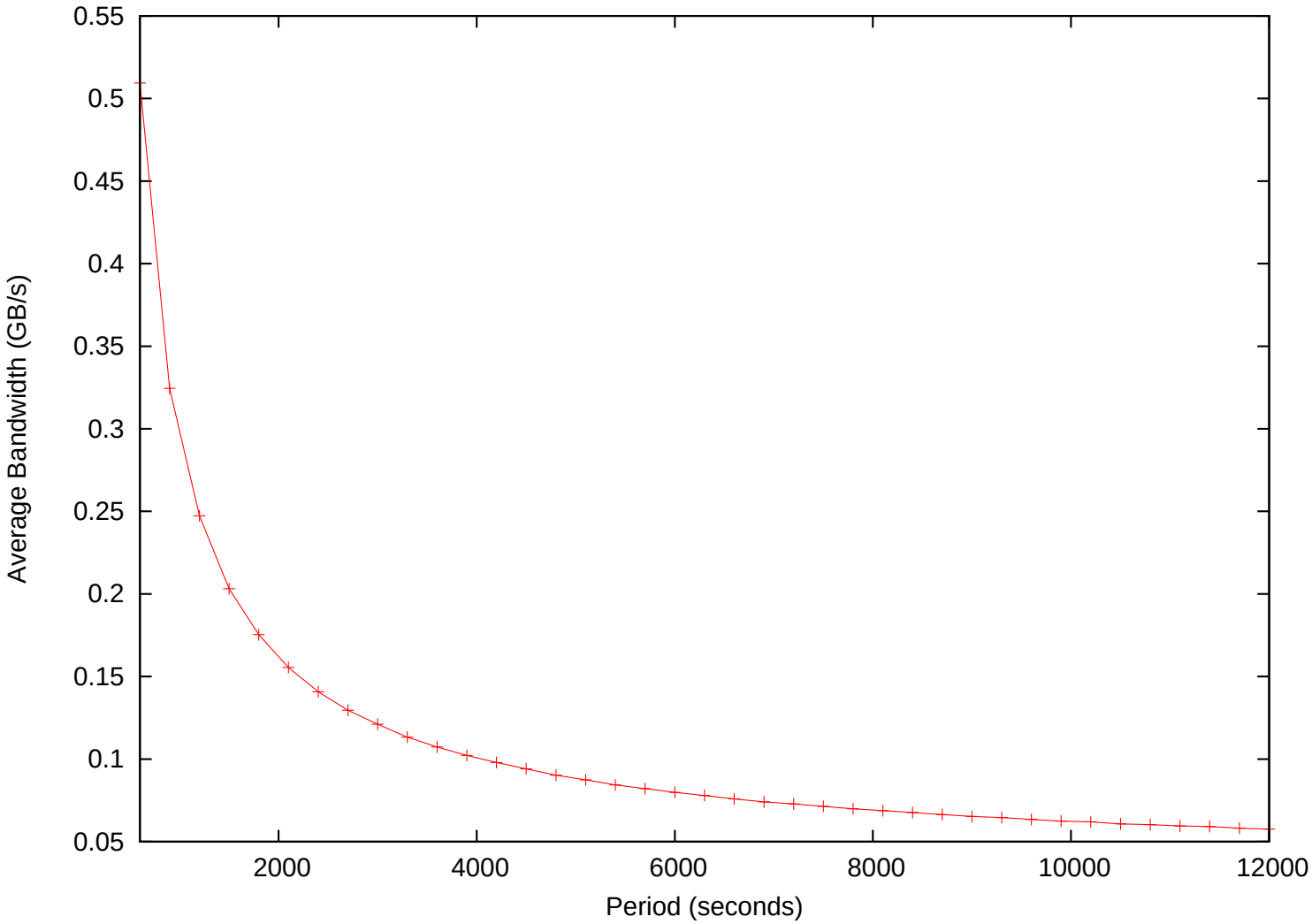
Simulation Algorithms

- FCFS
- EASY
- Greedy*
- GreedyPM*
- /per
- GreedyPM*/per
- MCB*/per
- GreedyPM*/per/mvt
- MCB*/per/mvt
- /stretch-per

Max Stretch Degradation vs. Load, 5 minute penalty



Bandwidth vs. Period



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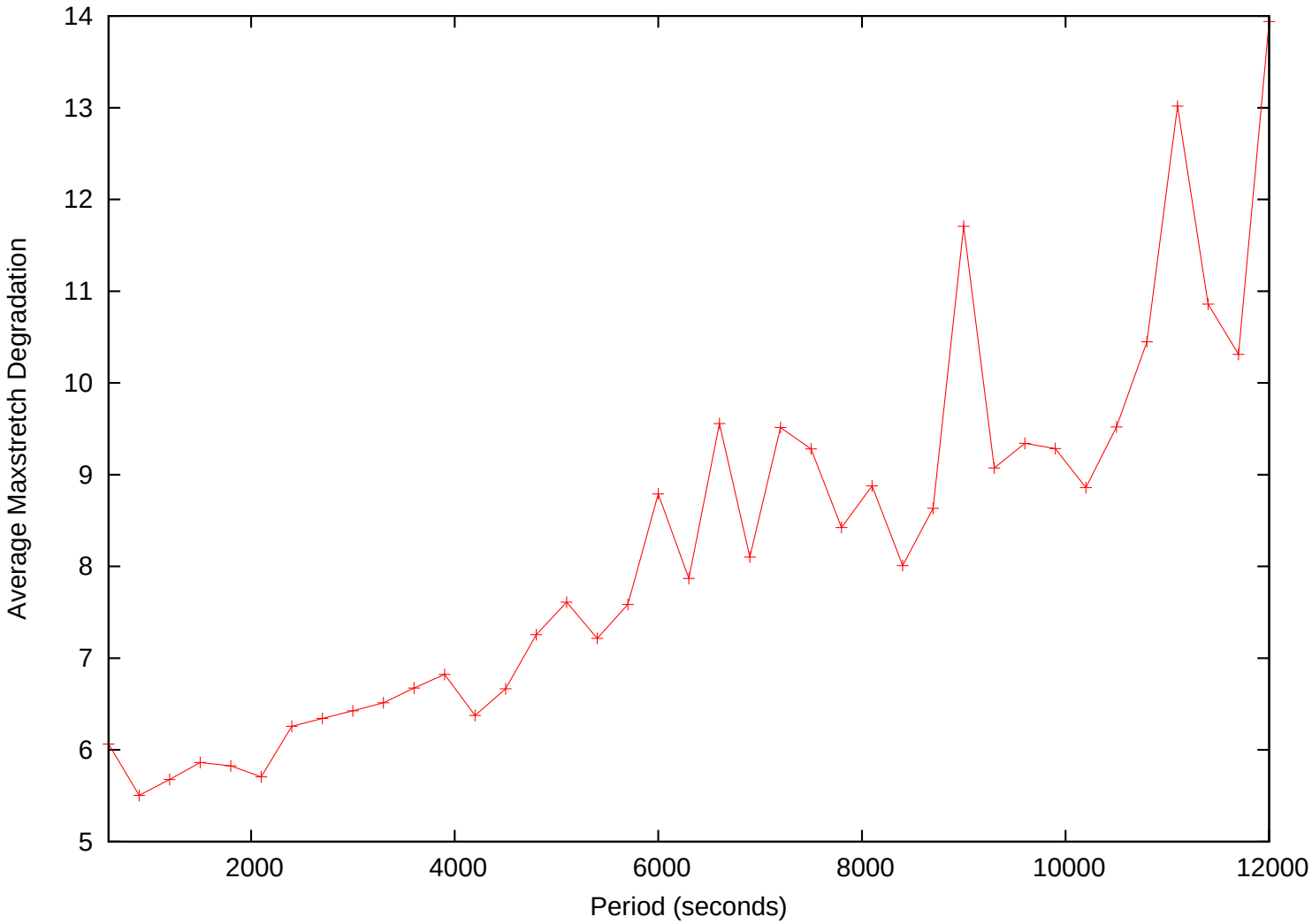

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Development Platform

- Grid5000 (`http://www.grid5000.fr`)
  - Kadeploy images
  - Genepi Nodes: Quad Core Xeon 2.5GHz w/ 8GB ram
- Open-Source Software
  - Xen 4.0
  - Debian Squeeze / Linux 2.6.32

Goals

- “small” experiment topics:
  - VM overhead
  - resource requirement/needs estimation
  - time sharing performance impact
  - preemption/migration costs
    - bandwidth consumption
    - performance impact
  - migration planning strategies
- “large” experiment topic: DFRS in practice

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Estimating Resource Needs

- Techniques:
  - repeated runs for benchmarking / model building
  - online model building
  - introspection / configuration variation
- Models:
  - constant values
  - time-varying values
  - random variables / probability distributions
- Questions:
  - how accurate can we be?
  - how accurate do we need to be?

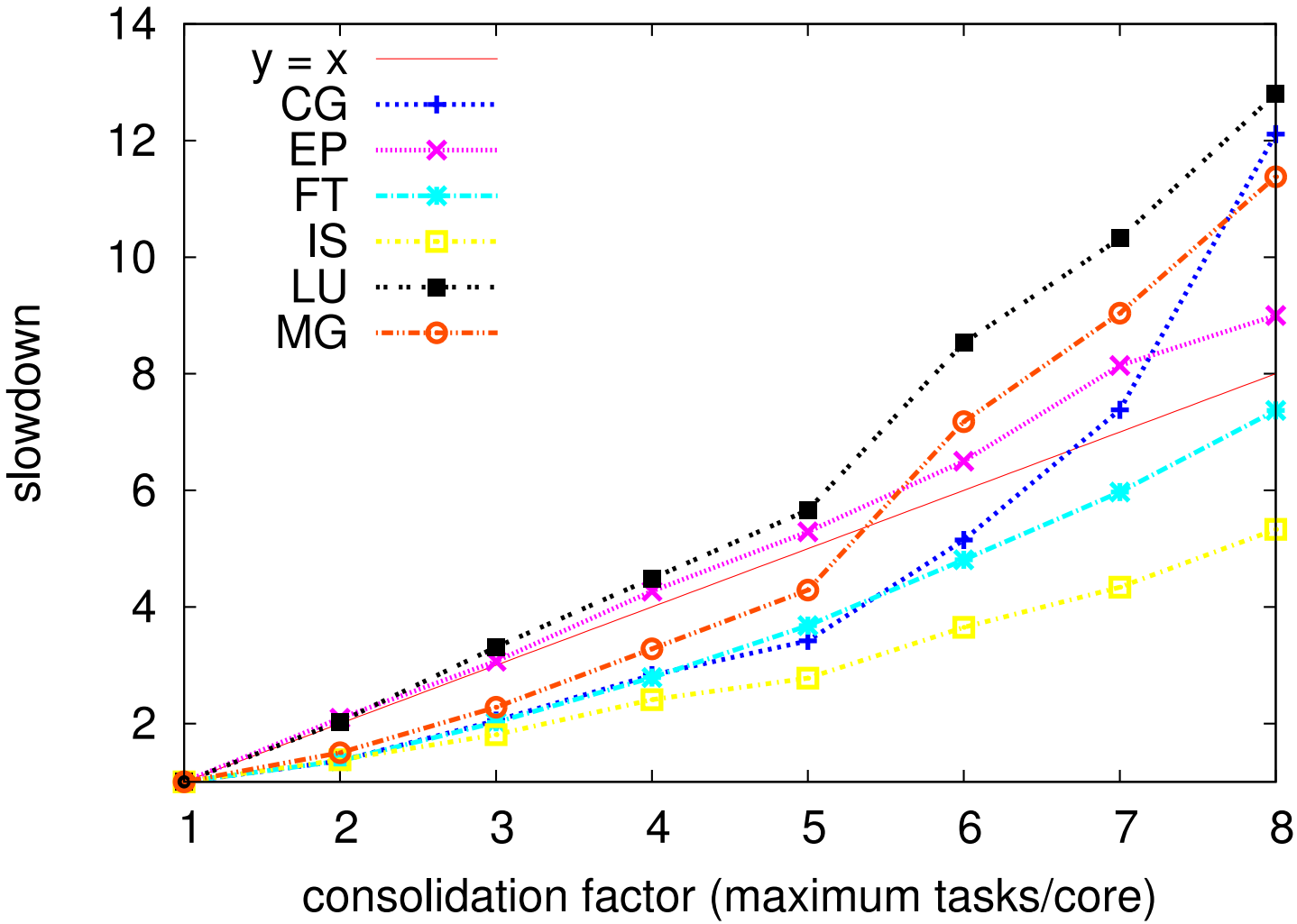
Benchmark Task VM Memory Requirements

bench/tasks	1	2	3	4
CG	477M	251M	–	147M
EP	<64M	<64M	<64M	<64M
FT	1930M	977M	–	499M
IS	637M	329M	–	176M
LU	218M	125M	–	80M
MG	485M	259M	–	147M
SP	369M	–	–	123M

Time Sharing Performance Impact

- Process thrashing!!!
  - Gang Scheduling
  - Flexible Co-scheduling
- Uncoordinated might not be so bad...

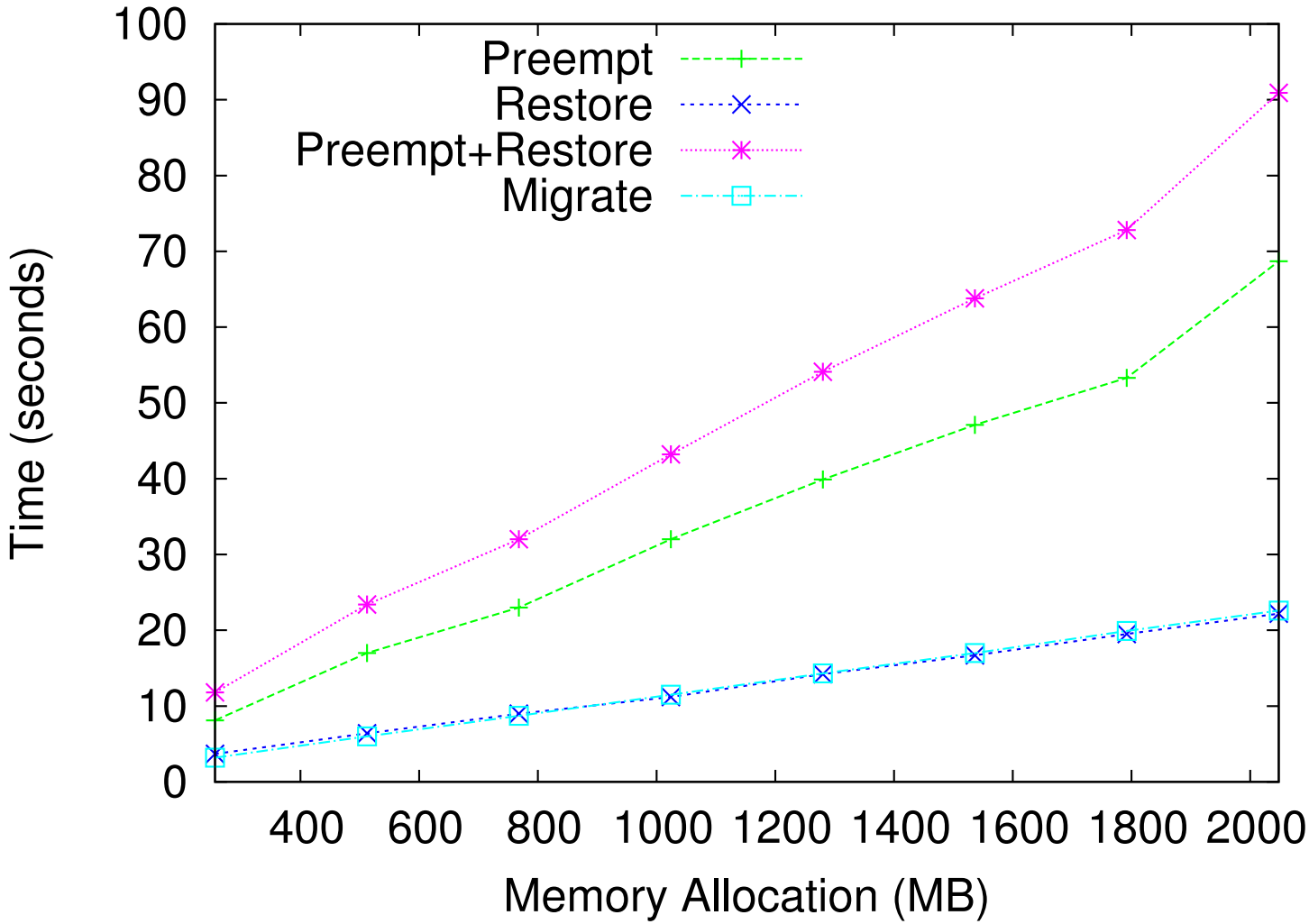
VM Consolidation



Parallel Task Preemption/Migration

- preemption of parallel distributed jobs is theoretically difficult
  - in the general case this may require coordinated shutdown
  - on the target platform everything happens quickly enough that it isn't an issue
- migration can be done by preempt/restore or "live"

Preemption/Migration Timing Results



Migration Planning

- using only live migration is NP-hard
- could fail (circular dependencies)
- heuristic: try to move the highest priority job
  - if it can't move, try next highest
  - if none can move, preempt the lowest priority job scheduled for migration and try again
  - restore any preempted jobs at the end

Planned Implementation Validation Experiment

- generate traces using an accepted model
- annotate them with CPU/memory values
- ”fill in” the traces using benchmarks...
  - NAS parallel benchmarks (HPC)
  - TCPP benchmarks (Service Hosting)

Future Work

- complete development of practical implementation
- extend the model
  - nonlocal resources
  - heterogeneous nodes
  - varying communications delays
- new or arbitrary optimization targets
  - fault tolerance
  - energy or other costs
  - formal definitions of fairness

Summary

- DFRS performs well in simulation
  - orders of magnitude better than batch
  - close to a theoretical bound
- prototype in development
  - preliminary results are promising

References I


Stillwell, M., Schanzenbach, D., Vivien, F., and Casanova, H. (2010).
Resource allocation algorithms for virtualized service hosting platforms.
Journal of Parallel and Distributed Computing, 70(9):962–974.


Stillwell, M., Vivien, F., and Casanova, H. (2011).
Dynamic fractional resource scheduling vs. batch scheduling.
IEEE Transactions on Parallel and Distributed Systems. accepted for publication.