Toward Loosely Coupled Programming on Petascale Systems

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University of Chicago

In Collaboration with:
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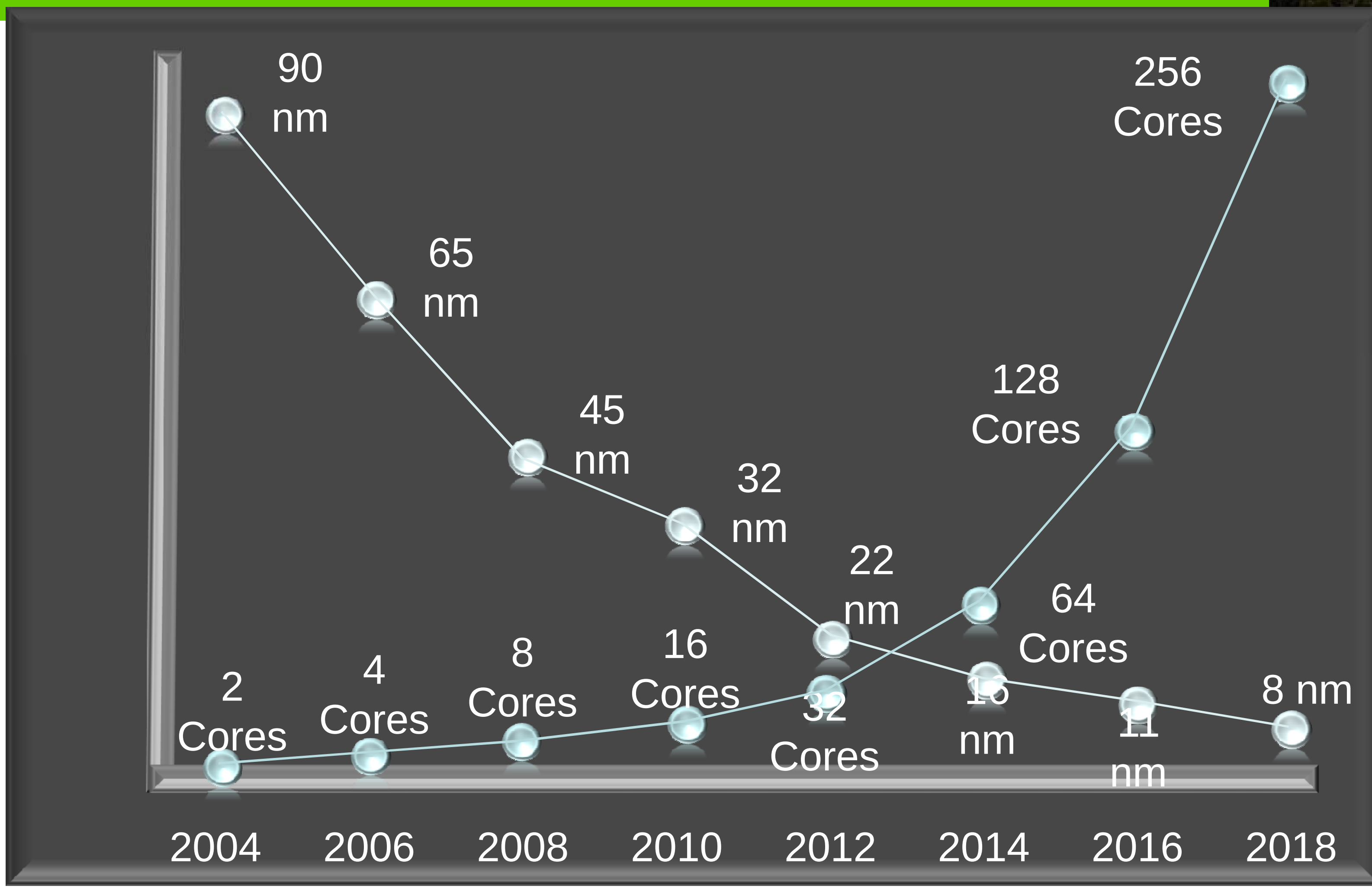
Mike Wilde & Ian Foster, Univ. of Chicago and Argonne National Lab.
Pete Beckman & Kamil Iskra, Argonne National Lab.

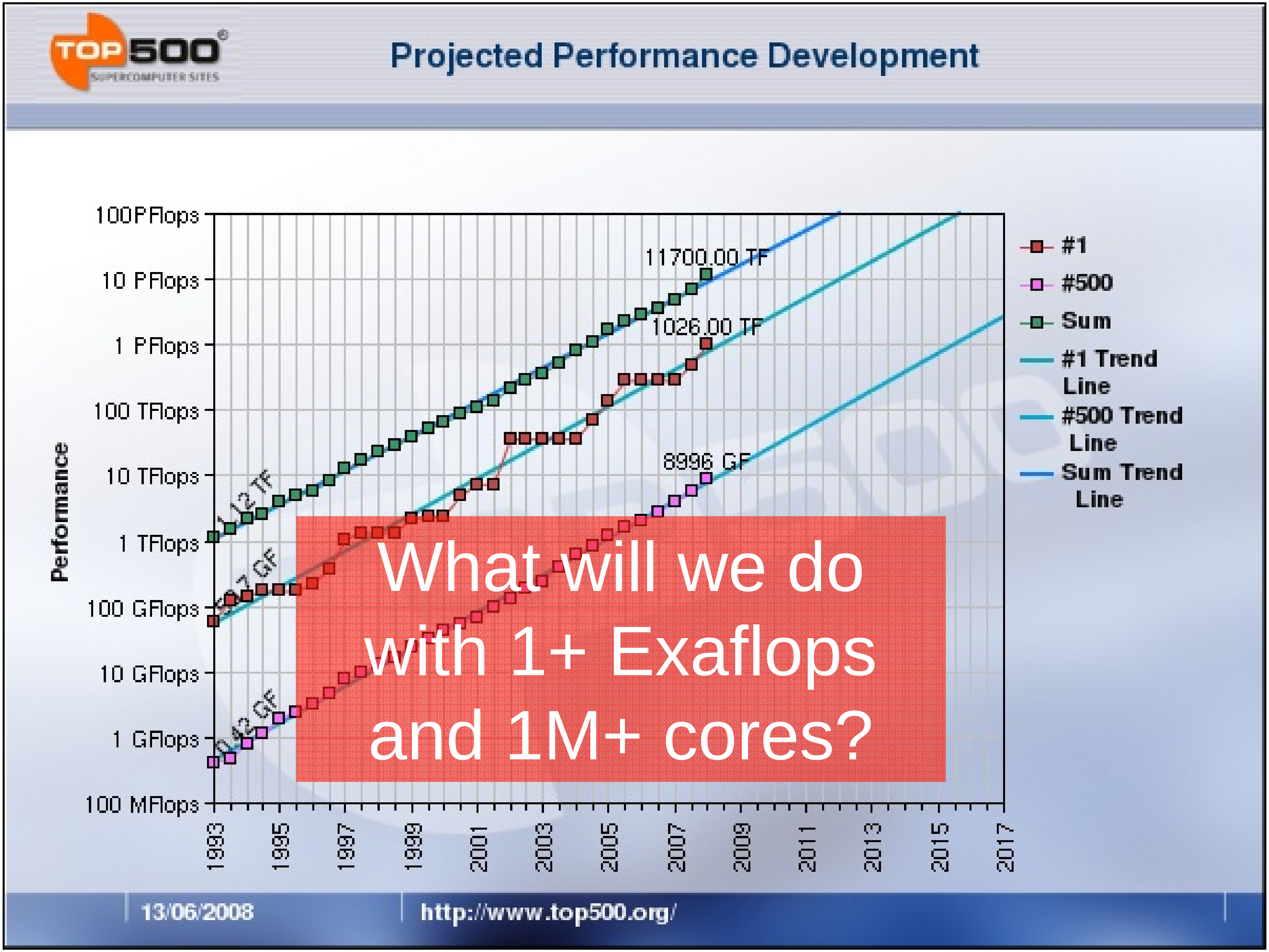
IEEE/ACM Supercomputing 2008
November 18th, 2008

PART I

Motivation

Many-Core Growth Rates

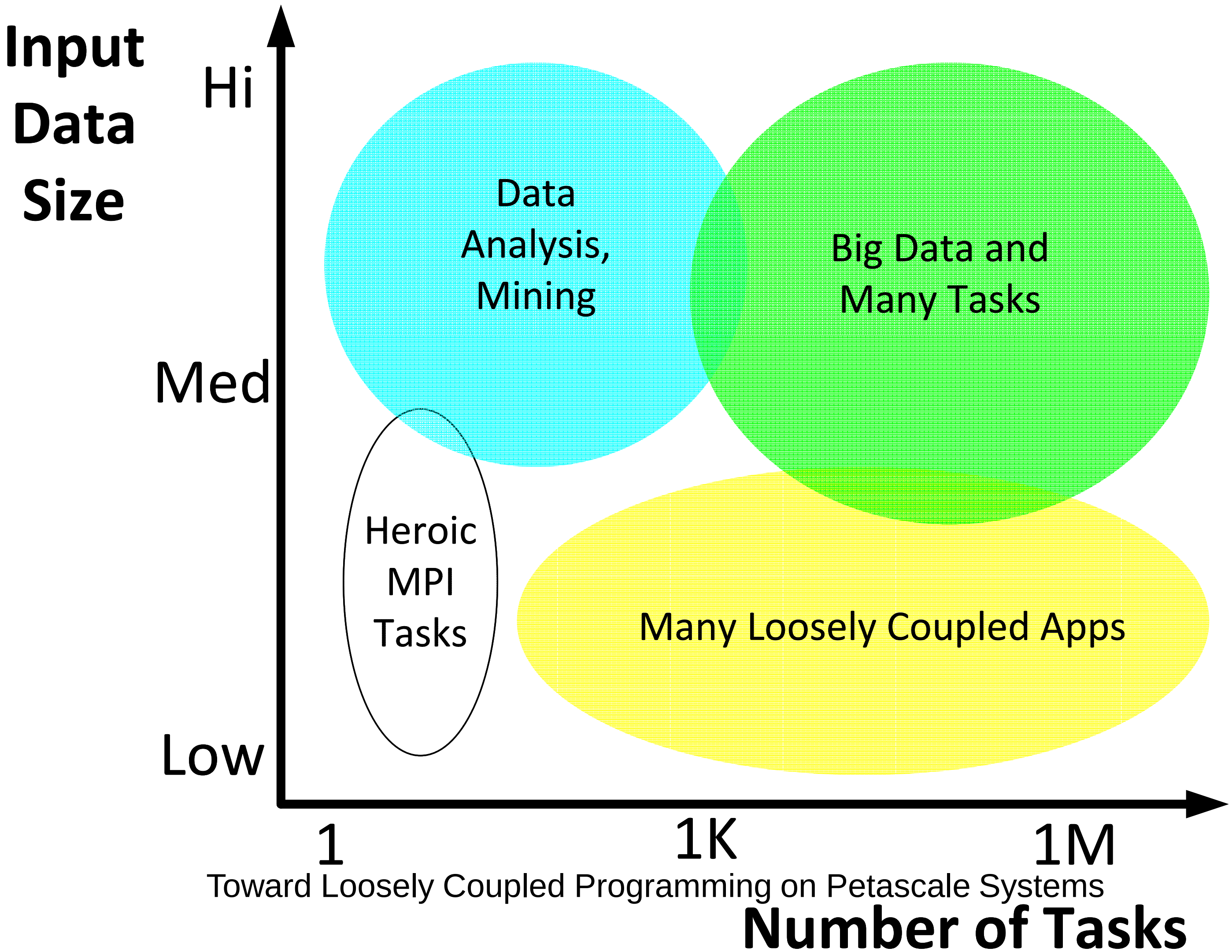



Projected Performance Development
100 PFlops
10 PFlops
1 PFlops
100 TFlops
10 TFlops
1 TFlops
100 GFlops
10 GFlops
1 GFlops
100 MFlops
Performance
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017
11700.00 TF
1026.00 TF
8996 GF
1.12 TF
0.42 GF
#1
#500
Sum
#1 Trend Line
#500 Trend Line
Sum Trend Line
What will we do with 1+ Exaflops and 1M+ cores?
13/06/2008
http://www.top500.org/

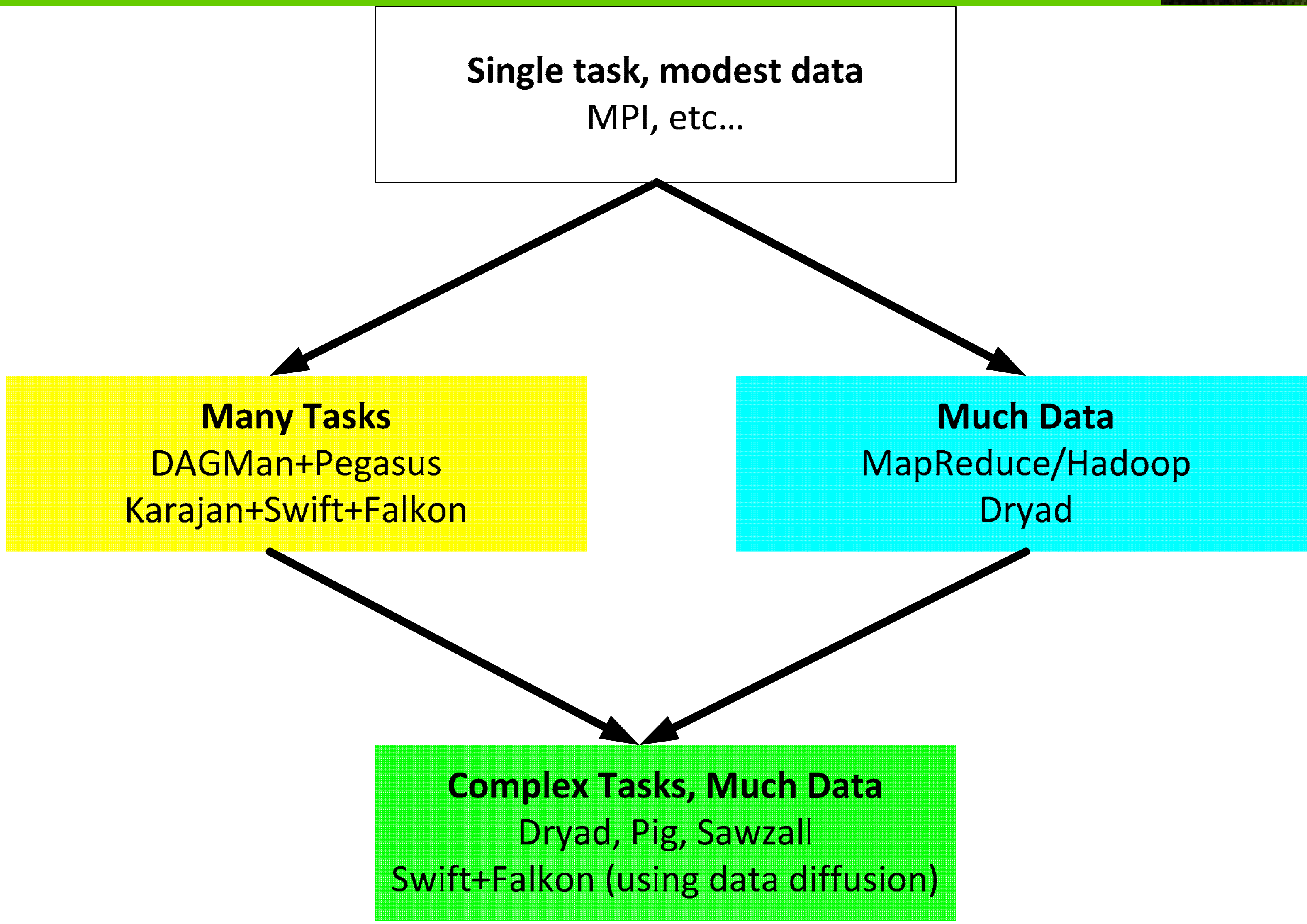
Programming Model Issues

- **Multicore/Manycore** processors
- Massive **task parallelism**
- Massive **data parallelism**
- Integrating **black box applications**
- Complex **task dependencies** (task graphs)
- **Failure**, and other execution management issues
- **Dynamic task graphs**
- Documenting **provenance** of data products
- **Data management**: input, intermediate, output
- **Dynamic data access** over large amounts of data

Problem Types

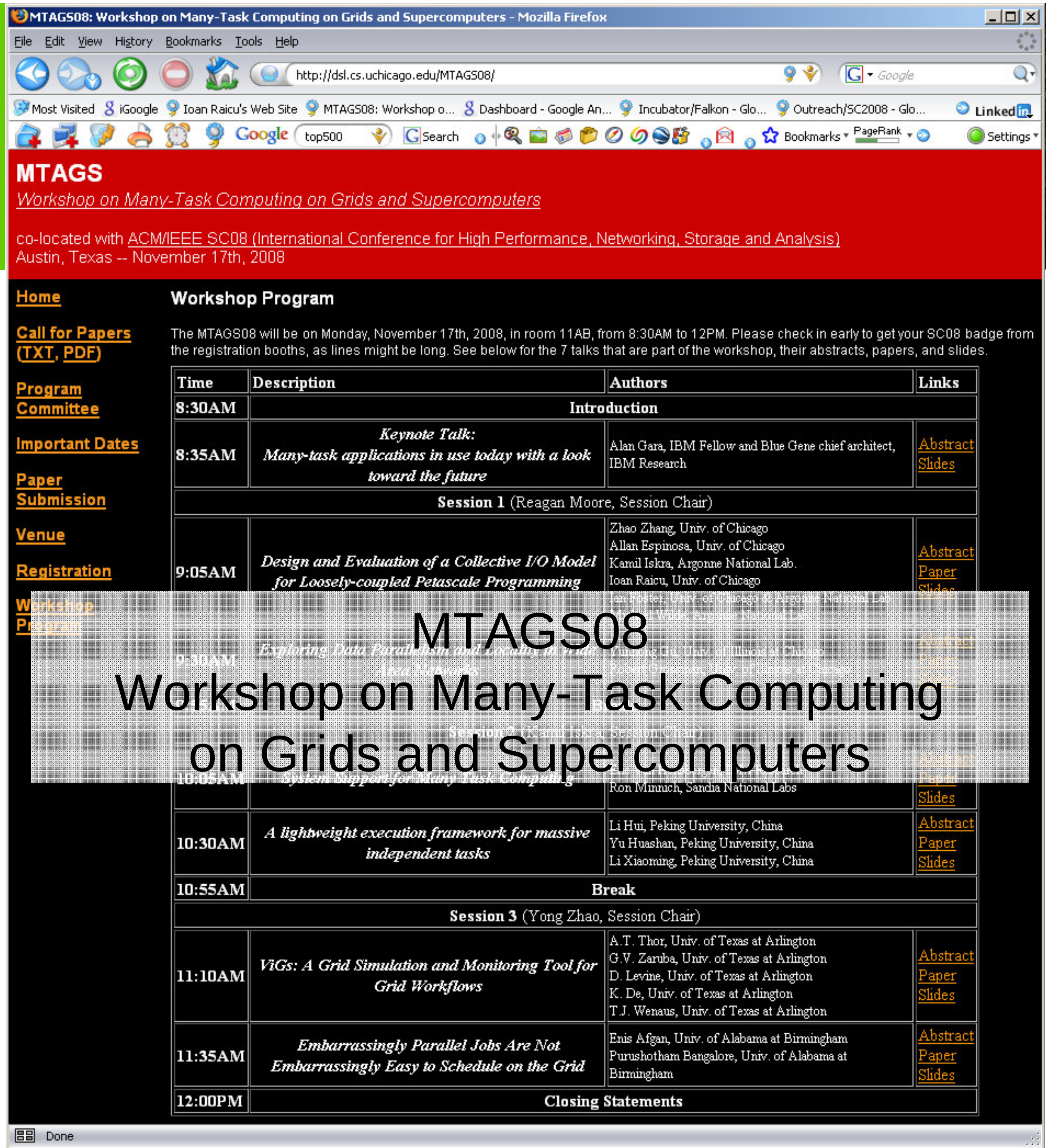
An Incomplete and Simplistic View of Programming Models and Tools



MTC: Many Task Computing

- Bridge the gap between HPC and HTC
- Loosely coupled applications with HPC orientations
- HPC comprising of multiple distinct activities, coupled via file system operations or message passing
- Emphasis on many resources over short time periods
- Tasks can be:
  - small or large, independent and dependent, uniprocessor or multiprocessor, compute-intensive or data-intensive, static or dynamic, homogeneous or heterogeneous, loosely or tightly coupled, large number of tasks, large quantity of computing, and large volumes of data…

MTAGS08
Workshop on Many-Task Computing on Grids and Supercomputers


MTAGS08: Workshop on Many-Task Computing on Grids and Supercomputers - Mozilla Firefox

http://dsl.cs.uchicago.edu/MTAGS08/

MTAGS

Workshop on Many-Task Computing on Grids and Supercomputers

co-located with ACM/IEEE SC08 (International Conference for High Performance, Networking, Storage and Analysis)
Austin, Texas -- November 17th, 2008

Home
Call for Papers (TXT, PDF)
Program Committee
Important Dates
Paper Submission
Venue
Registration
Workshop Program

Workshop Program

The MTAGS08 will be on Monday, November 17th, 2008, in room 11AB, from 8:30AM to 12PM. Please check in early to get your SC08 badge from the registration booths, as lines might be long. See below for the 7 talks that are part of the workshop, their abstracts, papers, and slides.

Time	Description	Authors	Links
8:30AM	**Introduction**		
8:35AM	*Keynote Talk: Many-task applications in use today with a look toward the future*	Alan Gara, IBM Fellow and Blue Gene chief architect, IBM Research	Abstract Slides
	Session 1 (Reagan Moore, Session Chair)		
9:05AM	*Design and Evaluation of a Collective I/O Model for Loosely-coupled Petascale Programming*	Zhao Zhang, Univ. of Chicago Allan Espinosa, Univ. of Chicago Kamil Iskra, Argonne National Lab. Ioan Raicu, Univ. of Chicago Ian Foster, Univ. of Chicago & Argonne National Lab Michael Wilde, Argonne National Lab.	Abstract Paper Slides
9:30AM	*Exploring Data Parallelism and Locality in Wide Area Networks*	Yunhong Gu, Univ. of Illinois at Chicago Robert Grossman, Univ. of Illinois at Chicago	Abstract Paper Slides
	Break		
	Session 2 (Kamil Iskra, Session Chair)		
10:05AM	*System Support for Many Task Computing*	Ron Minnich, Sandia National Labs	Abstract Paper Slides
10:30AM	*A lightweight execution framework for massive independent tasks*	Li Hui, Peking University, China Yu Huashan, Peking University, China Li Xiaoming, Peking University, China	Abstract Paper Slides
10:55AM	**Break**		
	Session 3 (Yong Zhao, Session Chair)		
11:10AM	*ViGs: A Grid Simulation and Monitoring Tool for Grid Workflows*	A.T. Thor, Univ. of Texas at Arlington G.V. Zaruba, Univ. of Texas at Arlington D. Levine, Univ. of Texas at Arlington K. De, Univ. of Texas at Arlington T.J. Wenaus, Univ. of Texas at Arlington	Abstract Paper Slides
11:35AM	*Embarrassingly Parallel Jobs Are Not Embarrassingly Easy to Schedule on the Grid*	Enis Afgan, Univ. of Alabama at Birmingham Purushotham Bangalore, Univ. of Alabama at Birmingham	Abstract Paper Slides
12:00PM	**Closing Statements**		

Growing Interest on enabling HTC/MTC on Supercomputers

- Project Kittyhawk
  - IBM Research
- HTC-mode in Cobalt/BG
  - IBM
- Condor on BG
  - University of Wisconsin at Madison, IBM
- Grid Enabling the BG
  - University of Colorado, National Center for Atmospheric Research
- Plan 9
  - Bell Labs, IBM Research, Sandia National Labs
- Falkon/Swift on BG/P and Sun Constellation
  - University of Chicago, Argonne National Laboratory

Many Large Systems available for Open Science Research

- Jaguar (#2) *[to be announced in 90 minutes]*
  - DOE, Oak Ridge National Laboratory
- Intrepid (#5)
  - DOE, Argonne National Laboratory
- Ranger (#6)
  - University of Texas / NFS TeraGrid

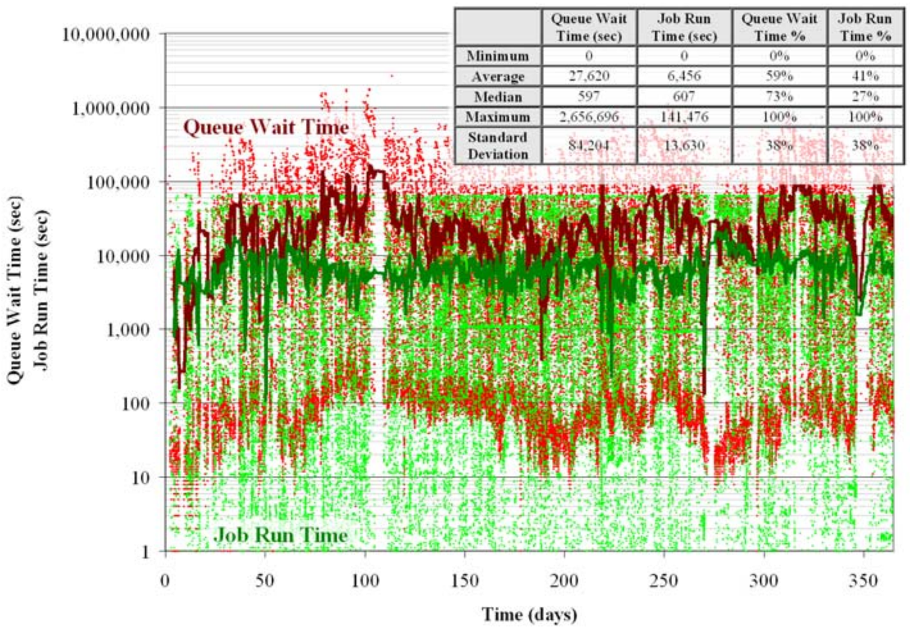
Why Petascale Systems for MTC Applications?

1. The I/O subsystem of petascale systems offers unique capabilities needed by MTC applications
2. The cost to manage and run on petascale systems is less than that of conventional clusters or Grids
3. Large-scale systems that favor large jobs have utilization issues
4. Some problems are intractable without petascale systems

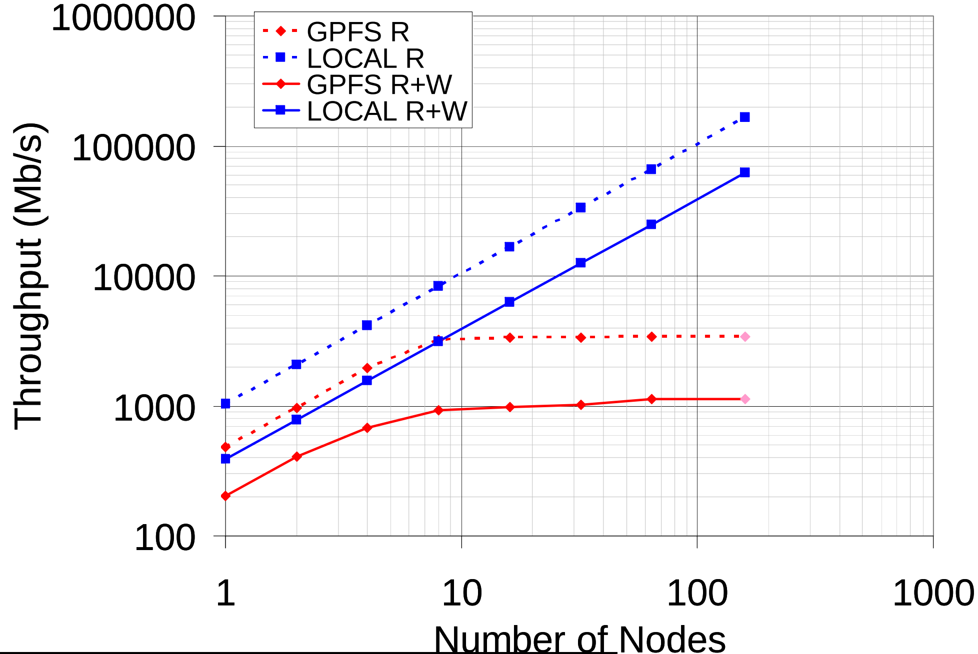
PART II

Some context on systems we used as building blocks

Obstacles running MTC apps in Clusters/Grids



	Queue Wait Time (sec)	Job Run Time (sec)	Queue Wait Time %	Job Run Time %
Minimum	0	0	0%	0%
Average	27,620	6,456	59%	41%
Median	597	607	73%	27%
Maximum	2,656,696	141,476	100%	100%
Standard Deviation	84,204	13,630	38%	38%

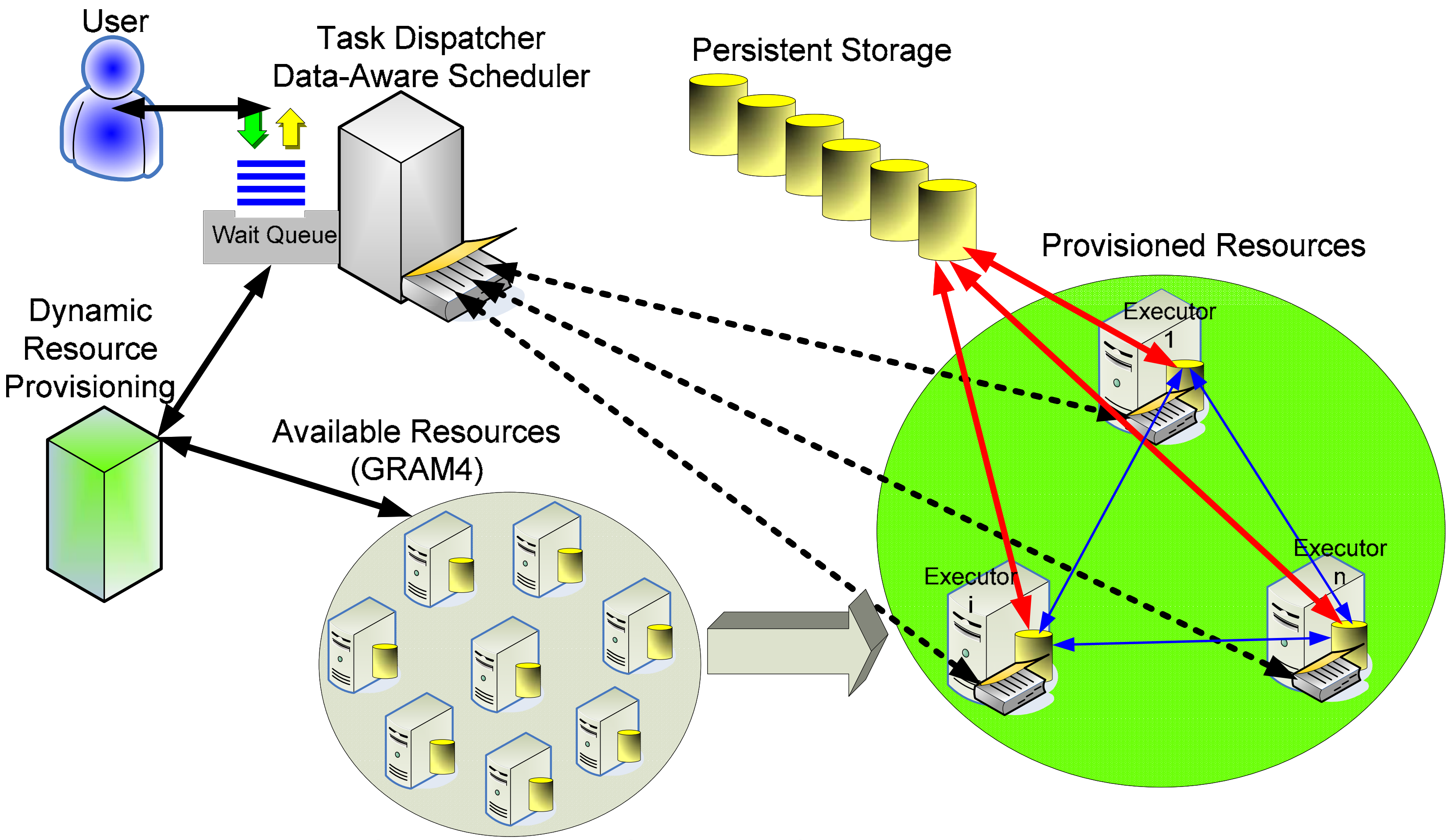


System	Comments	Throughput (tasks/sec)
Condor (v6.7.2) - Production	Dual Xeon 2.4GHz, 4GB	0.49
PBS (v2.1.8) - Production	Dual Xeon 2.4GHz, 4GB	0.45
Condor (v6.7.2) - Production	Quad Xeon 3 GHz, 4GB	2
Condor (v6.8.2) - Production		0.42
Condor (v6.9.3) - Development		11
Condor-J2 - Experimental	Quad Xeon 3 GHz, 4GB	22

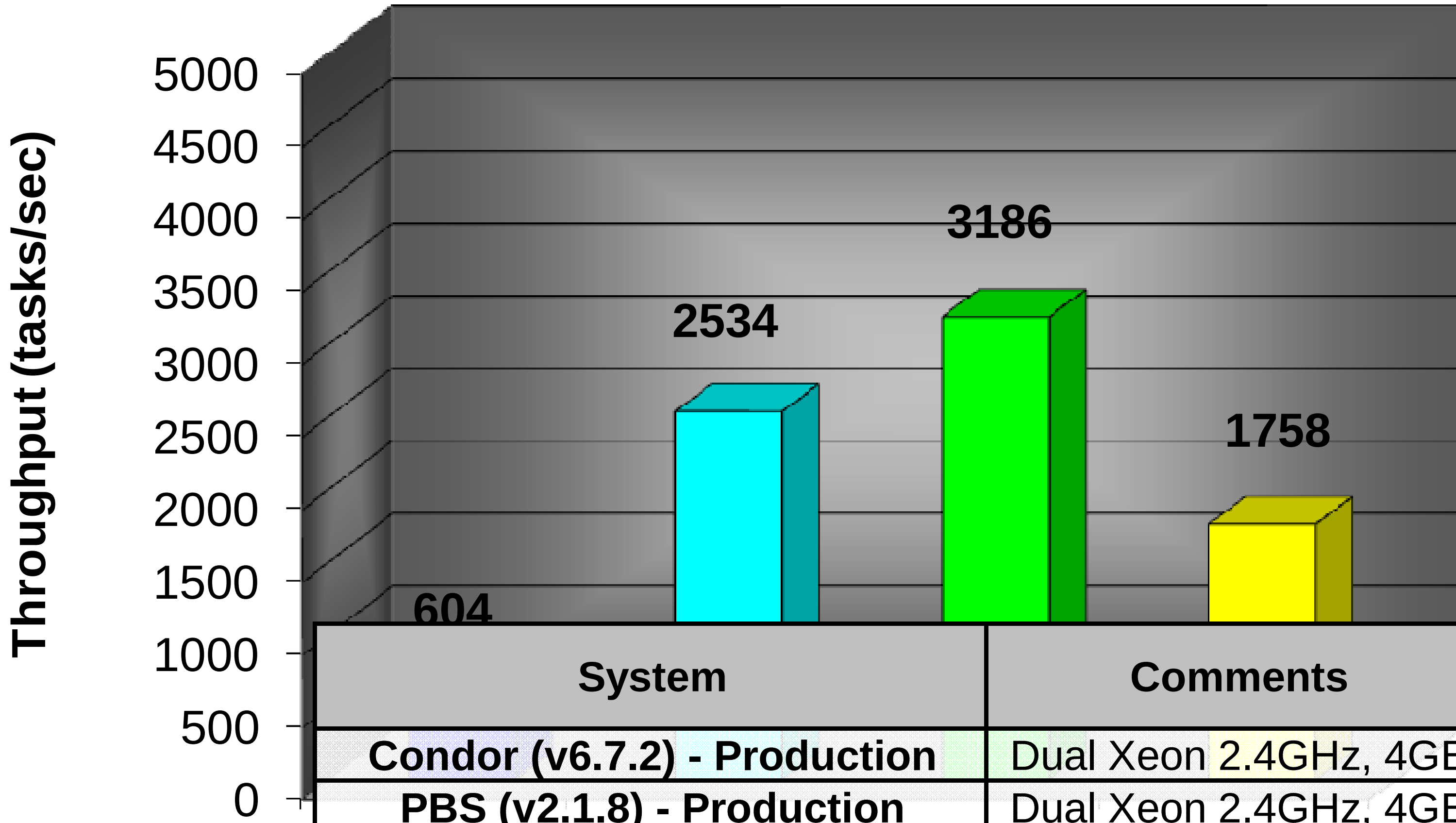
Solutions

- Falkon: A Fast and Light-weight tasK executiON framework
  - ***Goal:*** enable the ***rapid and efficient*** execution of many independent jobs on large compute clusters
  - Combines three components:
    - A ***streamlined task dispatcher***
    - ***Resource provisioning*** through multi-level scheduling techniques
    - ***Data diffusion*** and data-aware scheduling to leverage the co-located computational and storage resources
- Swift: A parallel programming system for loosely coupled applications
  - Applications cover many domains: Astronomy, astro-physics, medicine, chemistry, economics, climate modeling, data analytics

Falkon Overview



Dispatch Throughput



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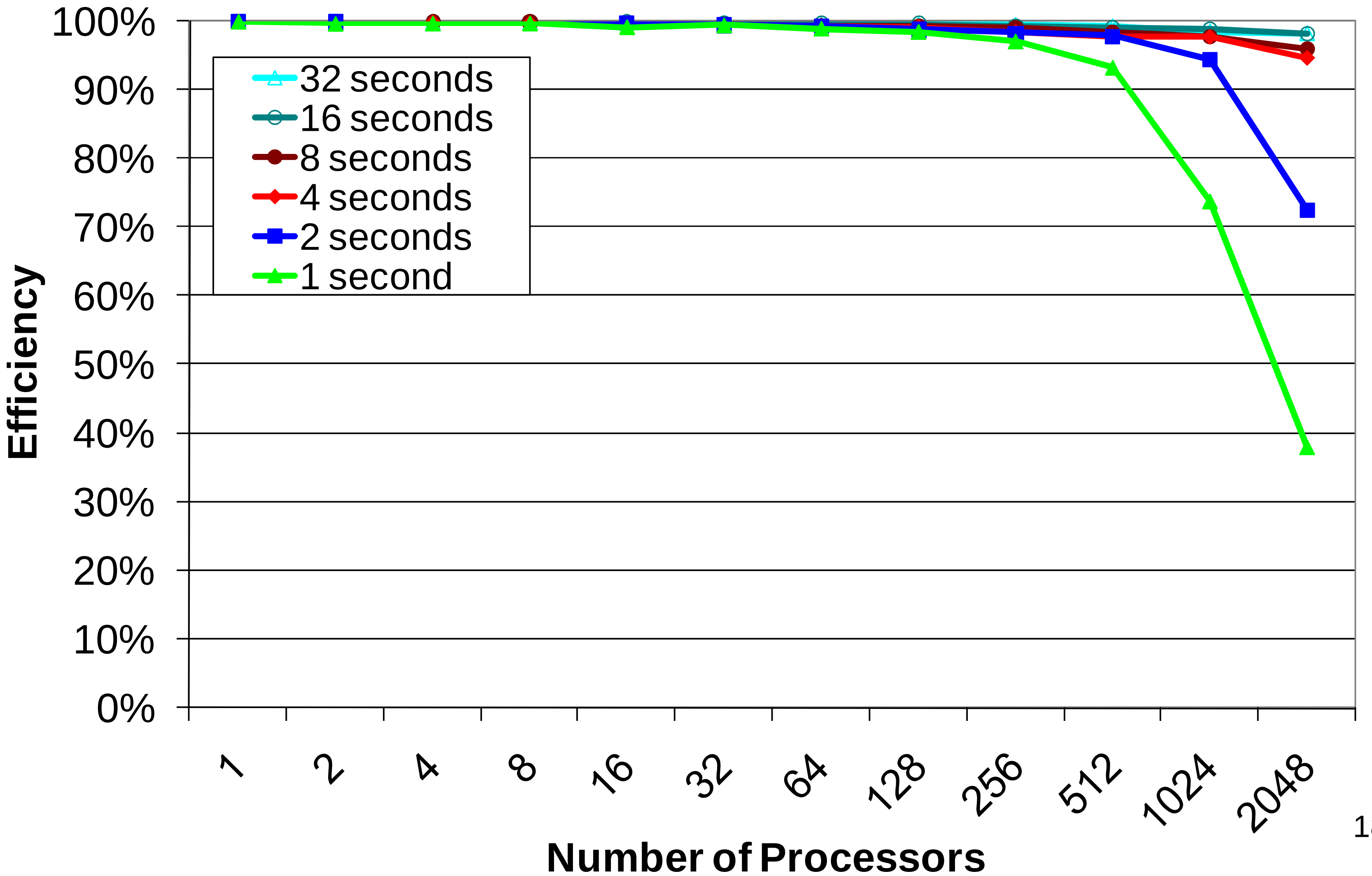
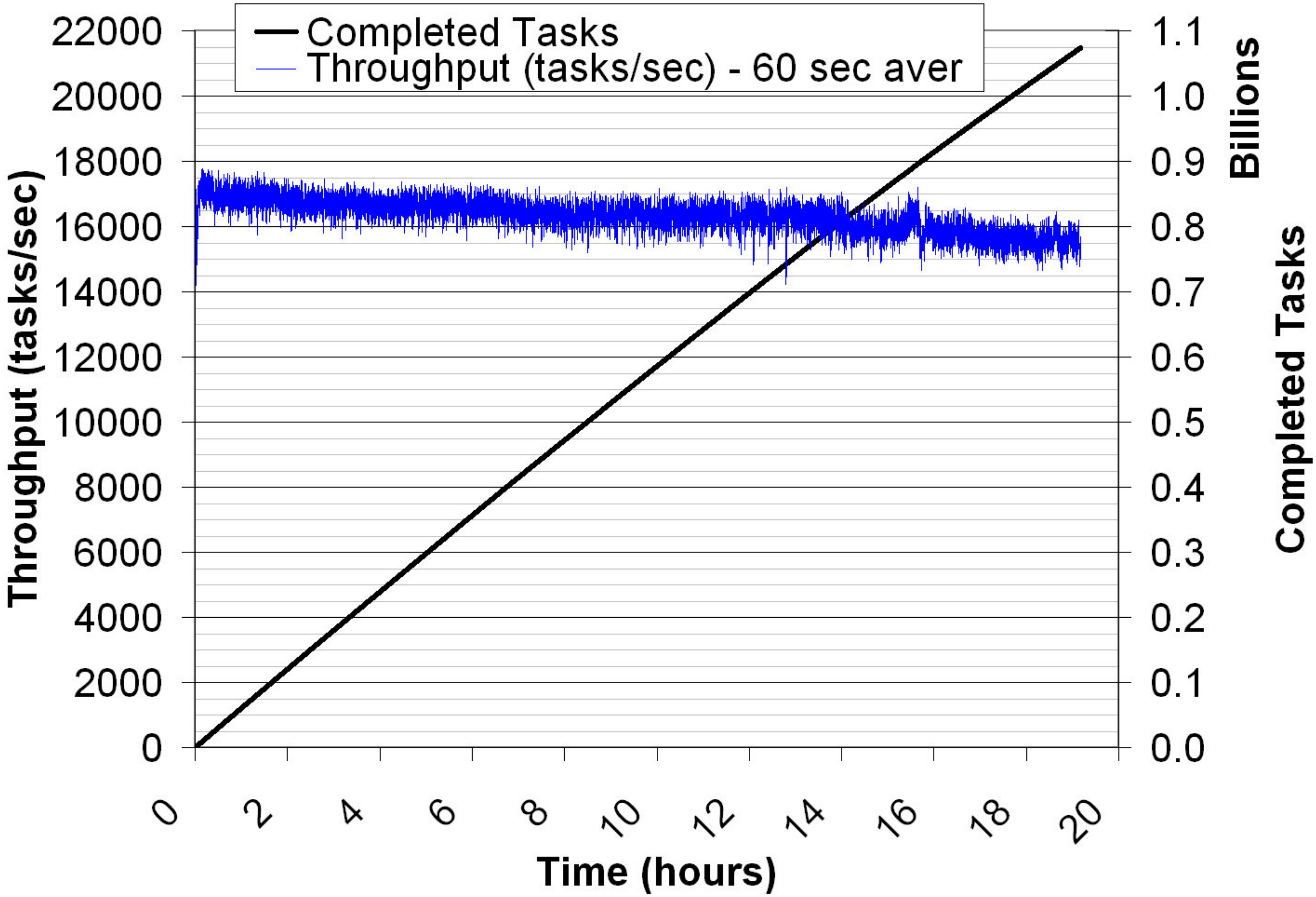
Condor-J2 - Experimental	Quad Xeon 3 GHz, 4GB	22

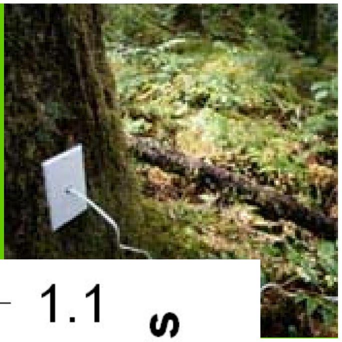
Efficiency



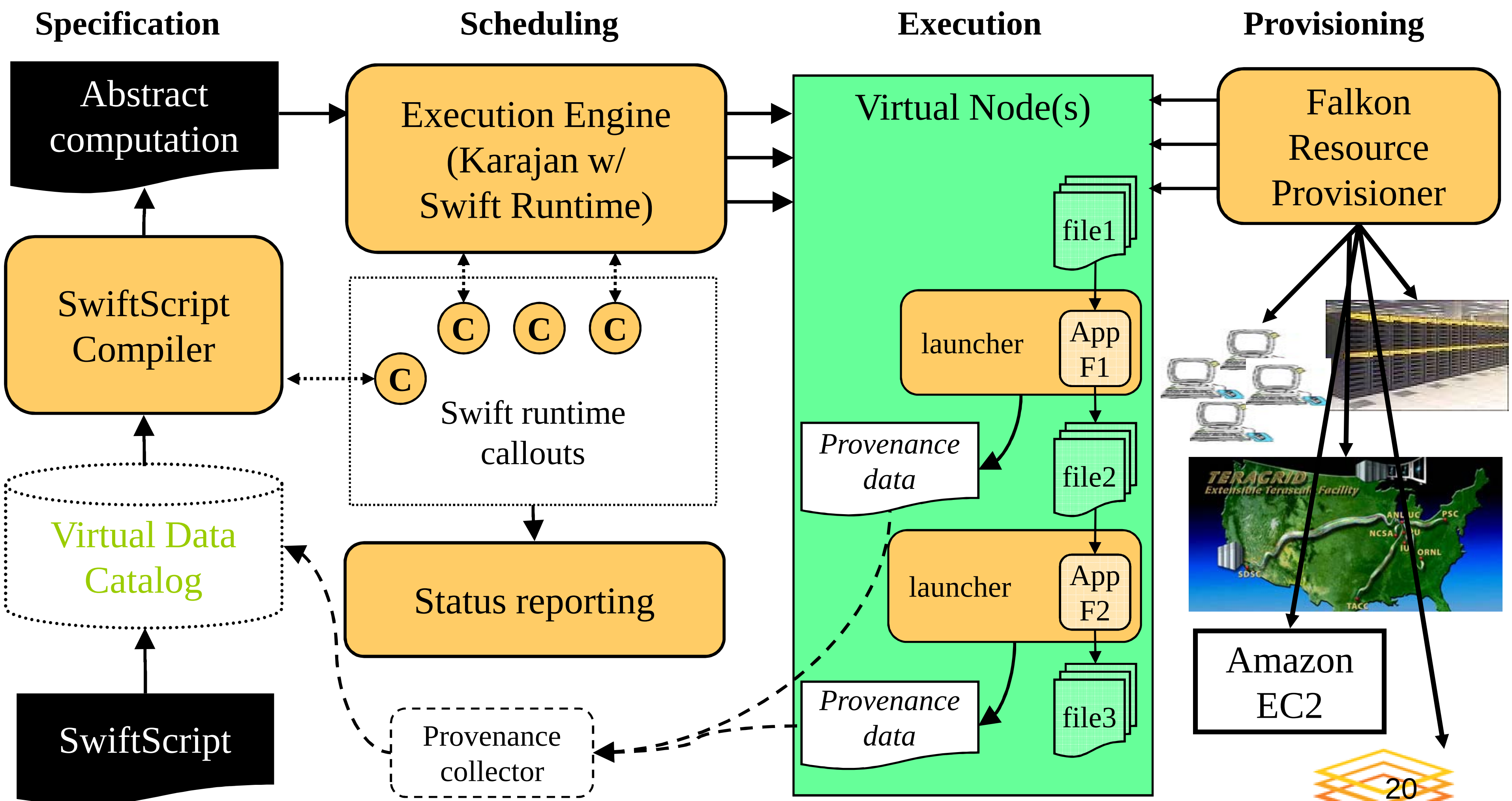
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Efficiency
32 seconds
16 seconds
8 seconds
4 seconds
2 seconds
1 second
1
2
4
8
16
32
64
128
256
512
1024
2048
Number of Processors

Falkon Endurance Test





Swift Architecture



PART III

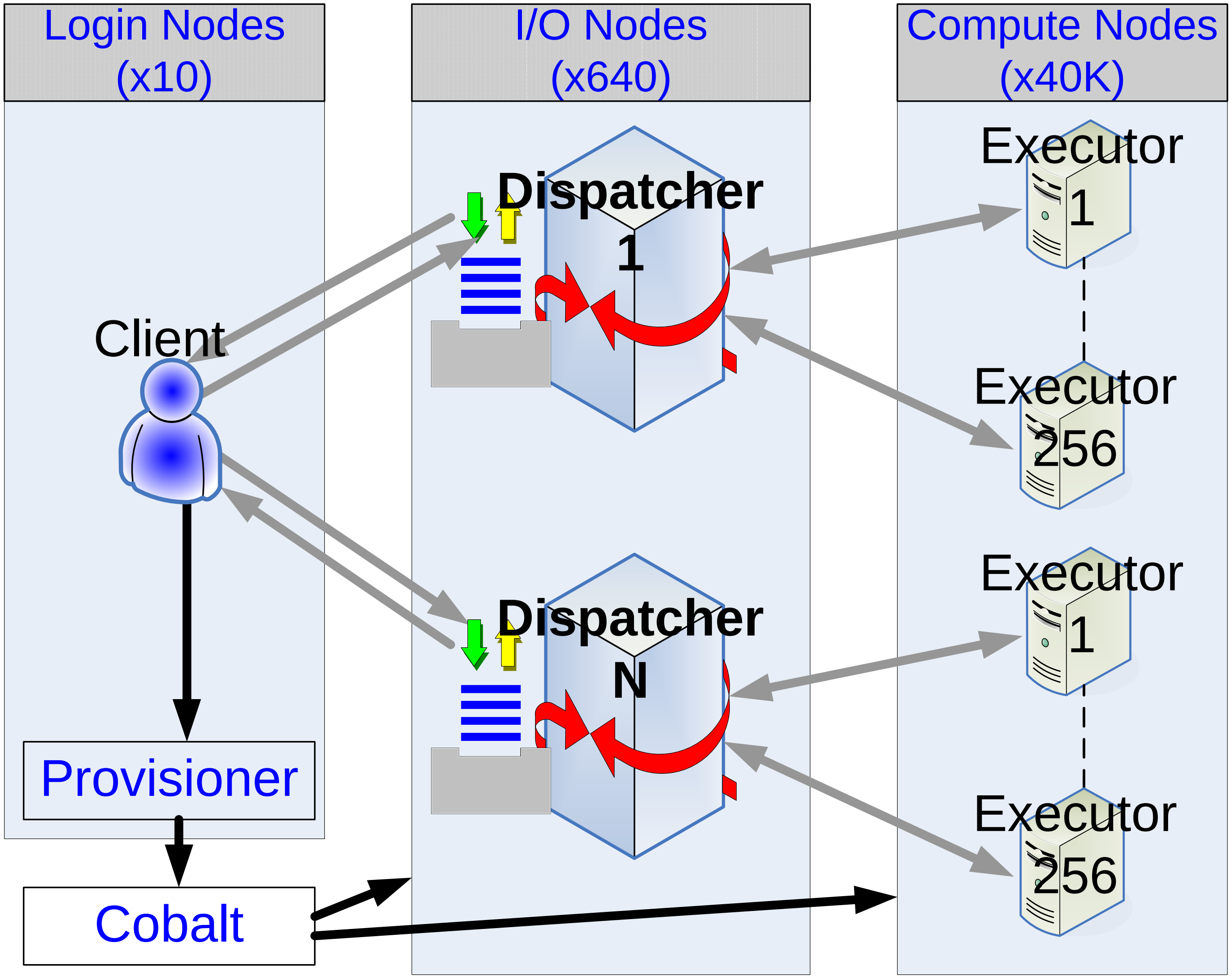
Contributions:

Proposed Changes & Results

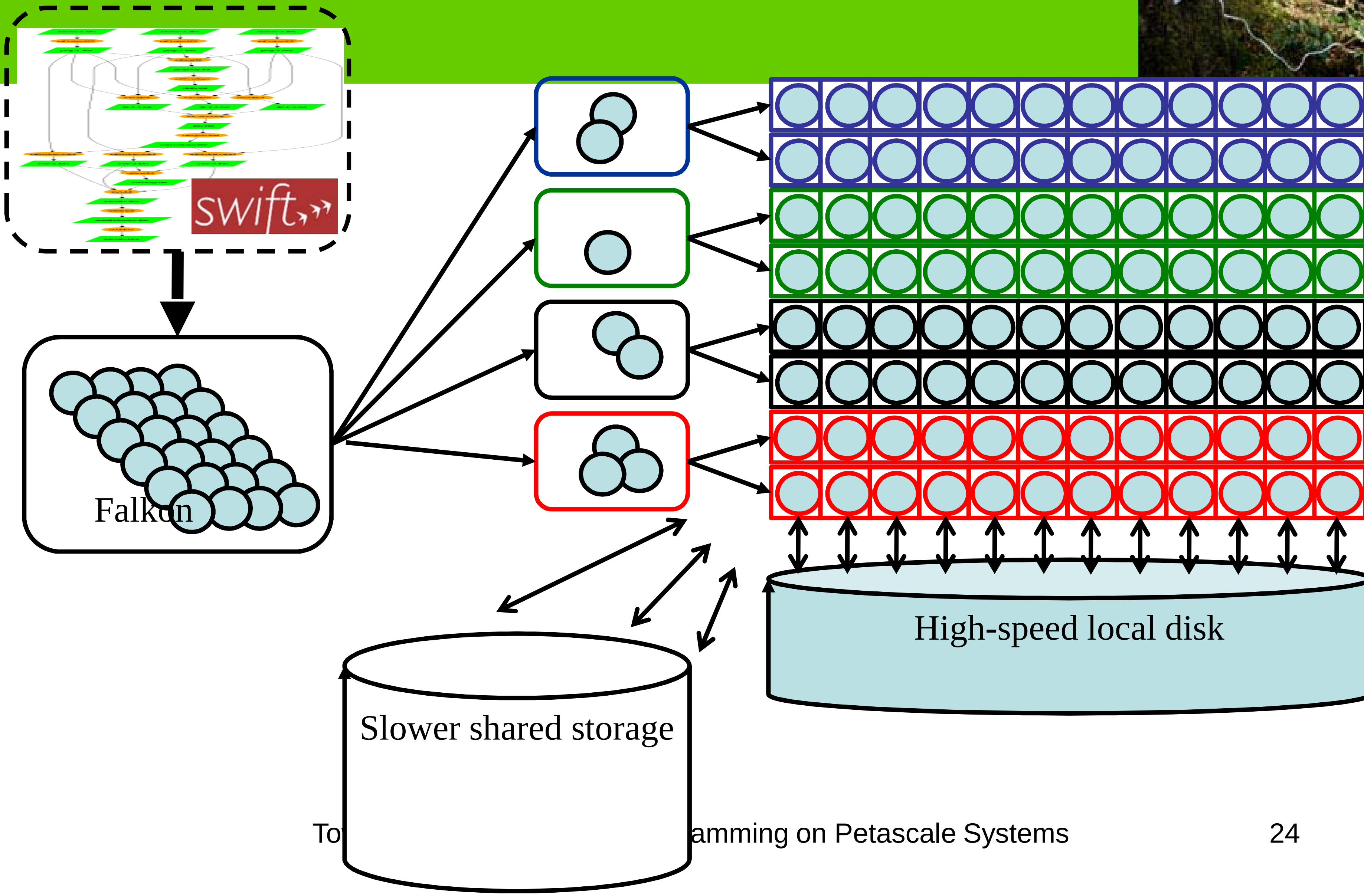
Scaling from 1K to 100K CPUs

- At 1K CPUs:
  - 1 Server to manage all 1K CPUs
  - Use shared file system extensively
    - Invoke application from shared file system
    - Read/write data from/to shared file system
- At 100K CPUs:
  - N Servers to manage 100K CPUs (1:256 ratio)
  - Don’t trust the application I/O access patterns to behave optimally
    - Copy applications and input data to RAM
    - Read input data from RAM, compute, and write results to RAM
    - Archive all results in a single file in RAM
    - Copy 1 result file from RAM back to GPFS
  - Use collective I/O primitives to make app logic simpler
  - Leverage all networks (Ethernet, Tree, and Torus) for high aggregate bandwidth

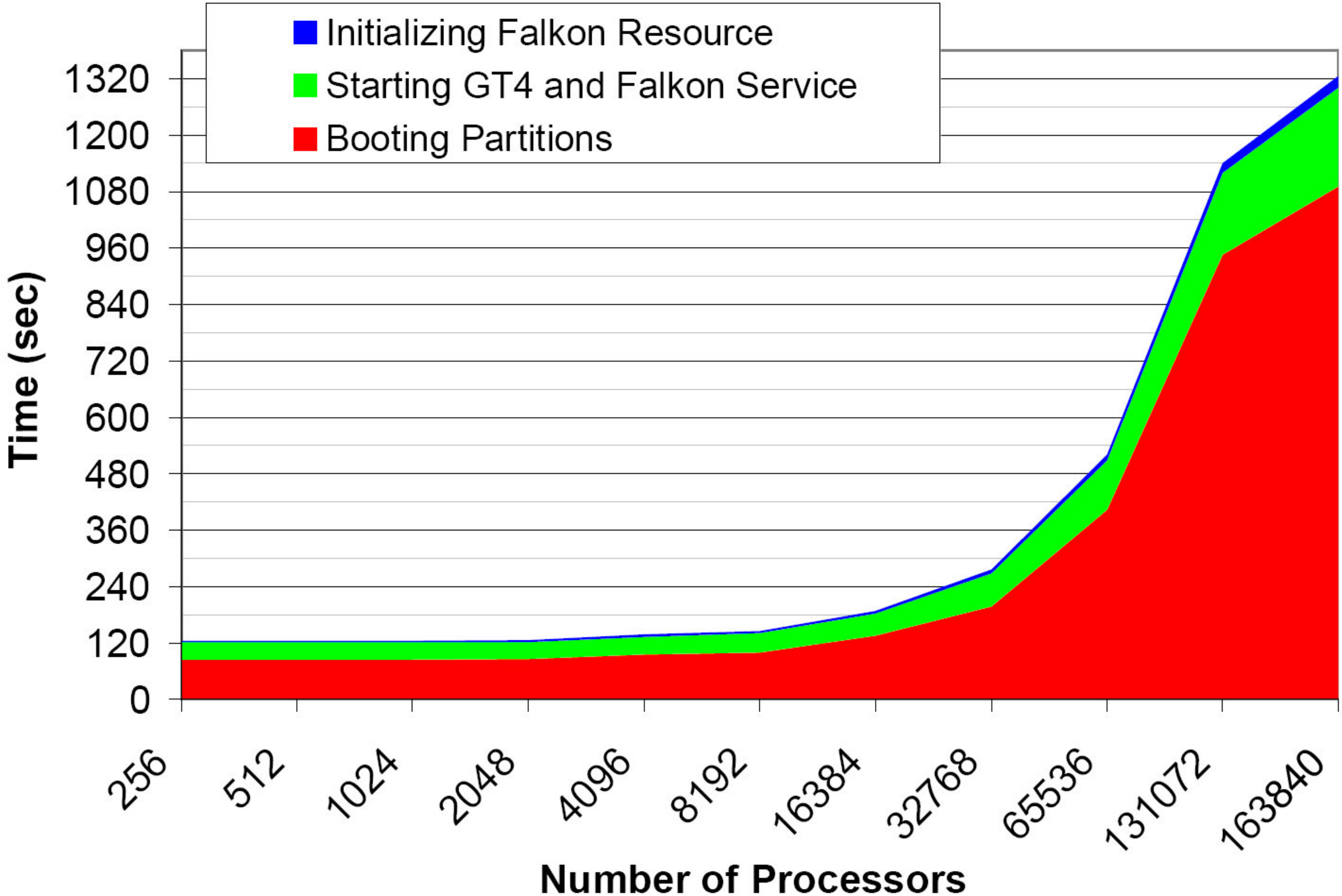
Distributed Falkon Architecture



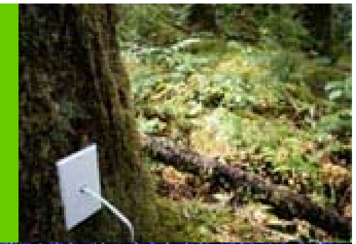
Managing 160K CPUs

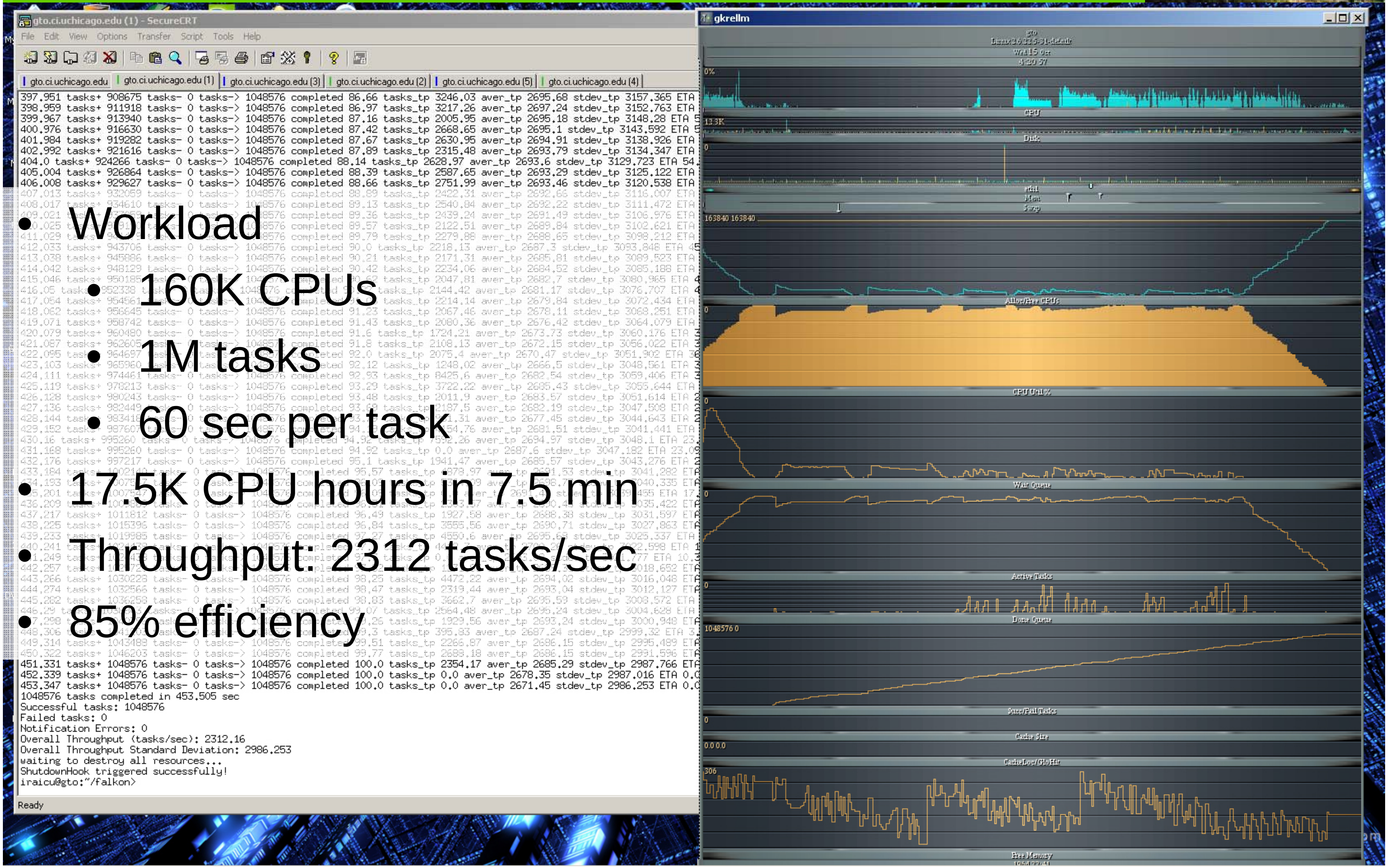


Falkon Bootstrapping



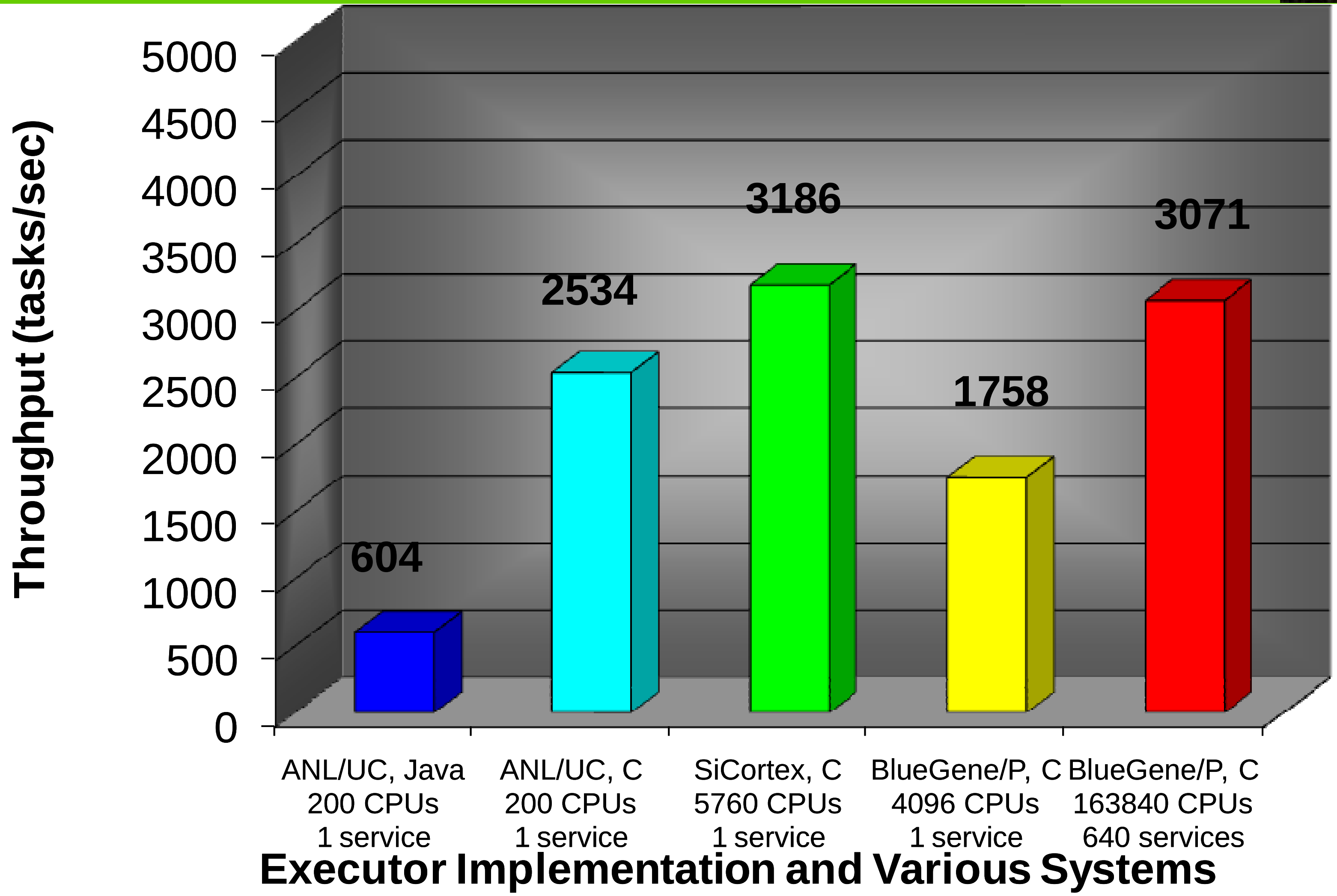
Falkon Monitoring



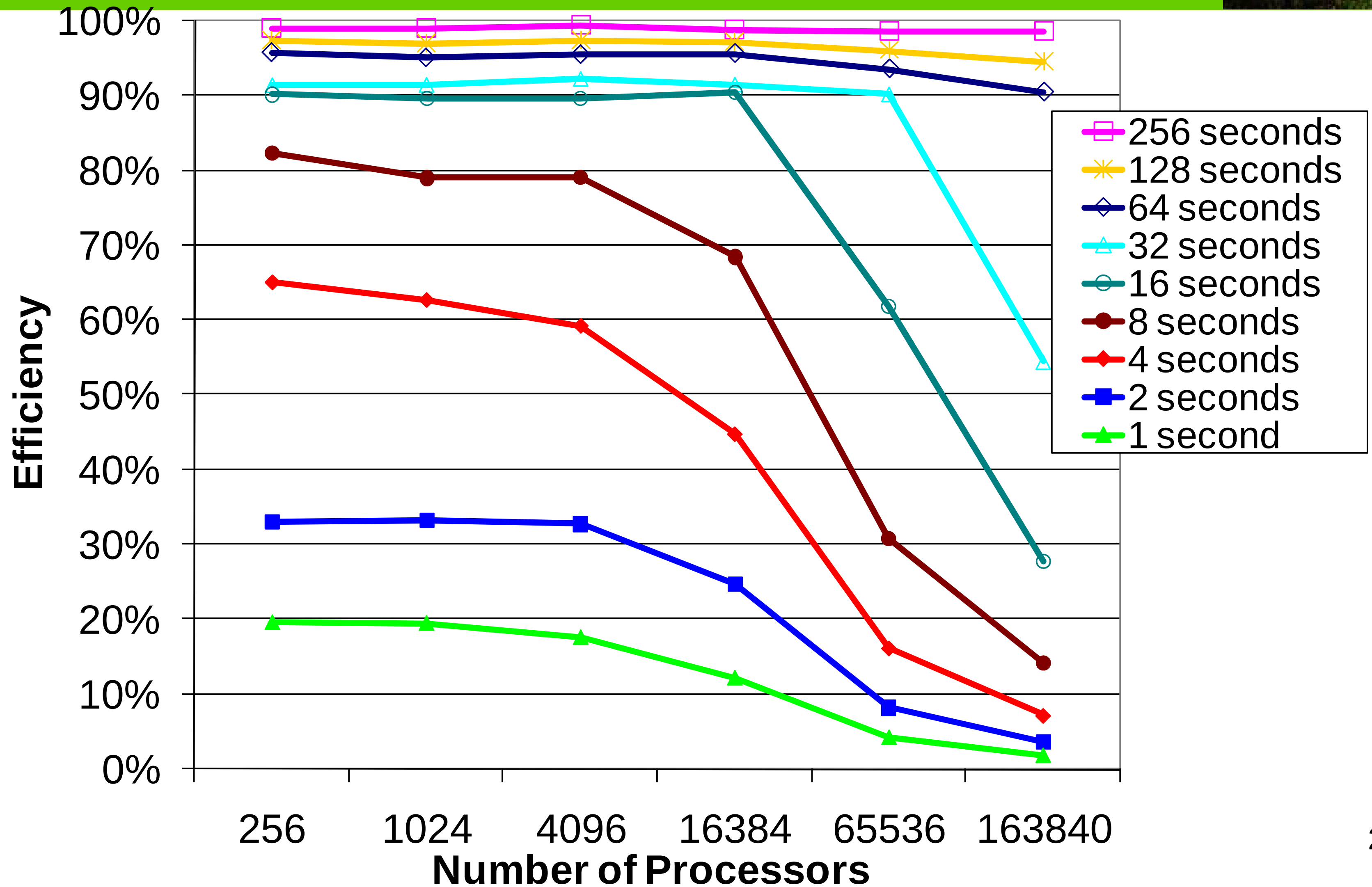


- Workload
  - 160K CPUs
  - 1M tasks
  - 60 sec per task
- 17.5K CPU hours in 7.5 min
- Throughput: 2312 tasks/sec
- 85% efficiency

Dispatch Throughput



Efficiency

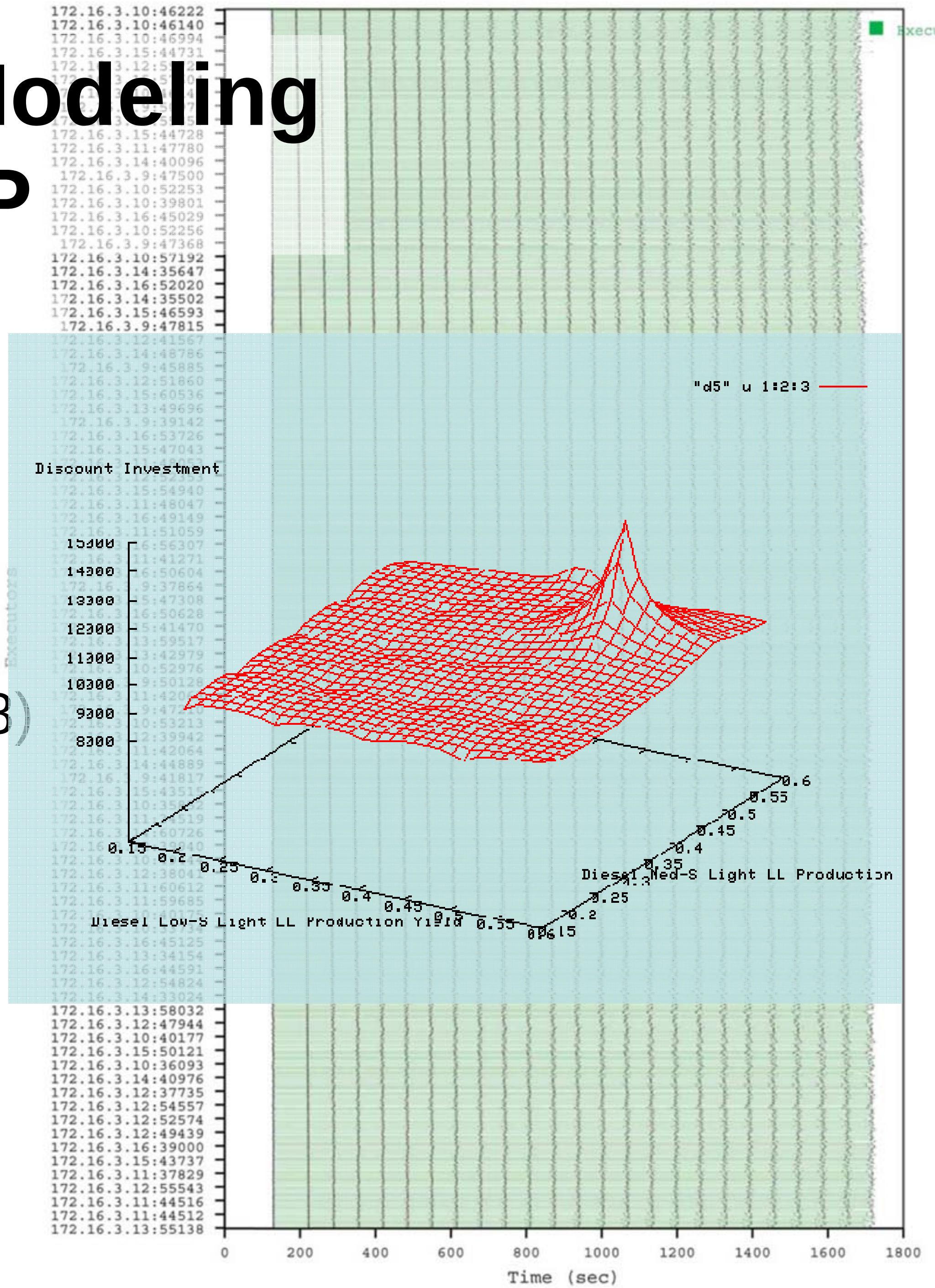


100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Efficiency
256
1024
4096
16384
65536
163840
Number of Processors
256 seconds
128 seconds
64 seconds
32 seconds
16 seconds
8 seconds
4 seconds
2 seconds
1 second

MARS Economic Modeling on IBM BG/P

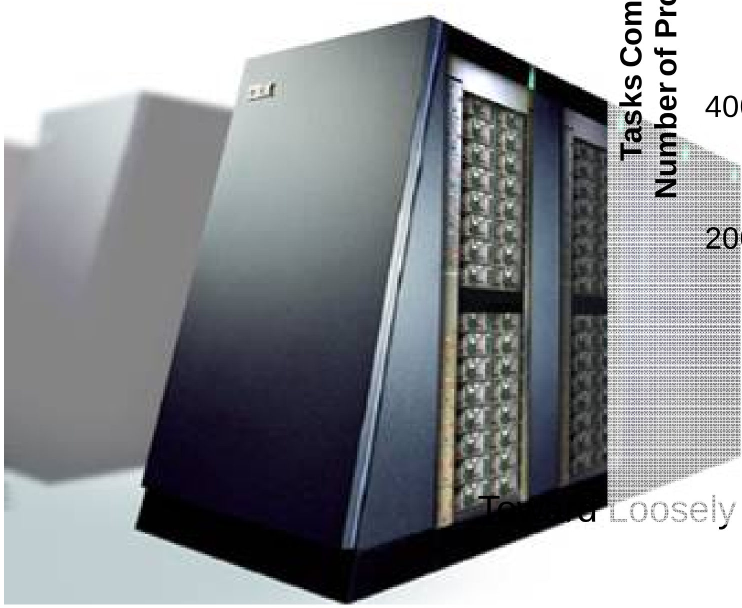
- CPU Cores: 2048
- Tasks: 49152
- Micro-tasks: 7077888
- Elapsed time: 1601 secs
- CPU Hours: 894
- Speedup: 1993X (ideal 2048)
- Efficiency: 97.3%

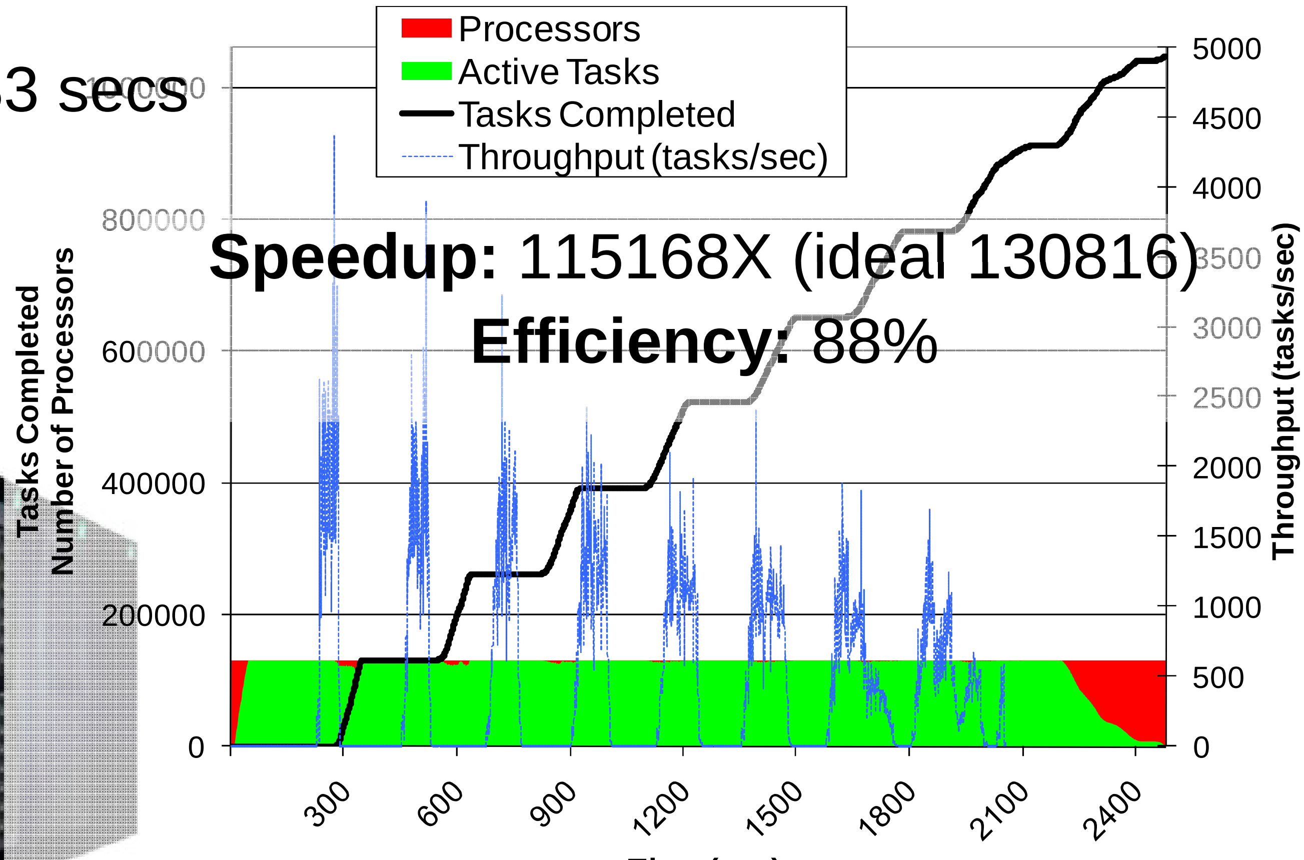
Couplec



MARS Economic Modeling on IBM BG/P (128K CPUs)

- CPU Cores: 130816
- Tasks: 1048576
- Elapsed time: 2483 secs
- CPU Years: 9.3



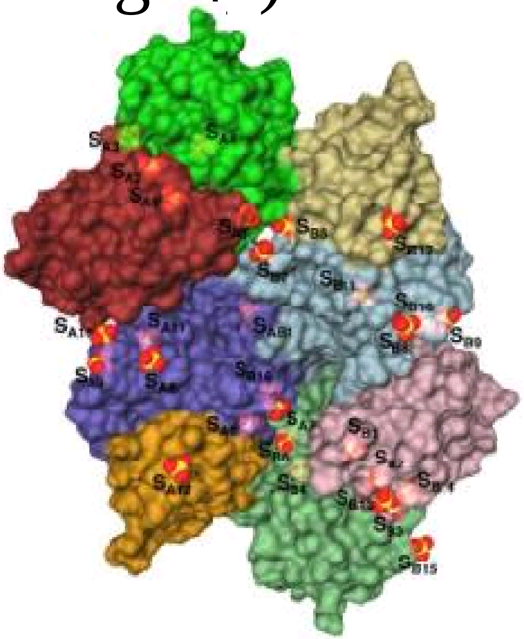


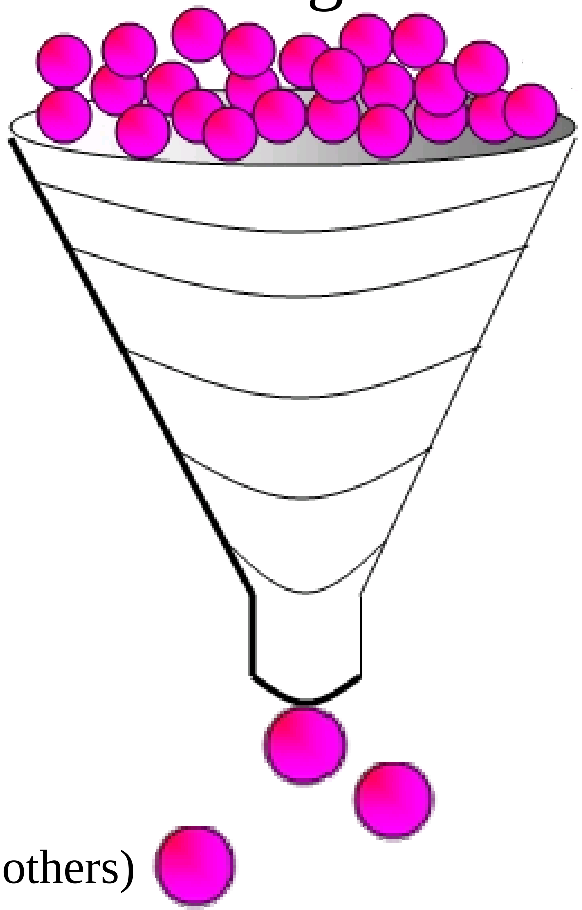
Speedup: 115168X (ideal 130816)

Efficiency: 88%

Many Many Tasks: Identifying Potential Drug Targets

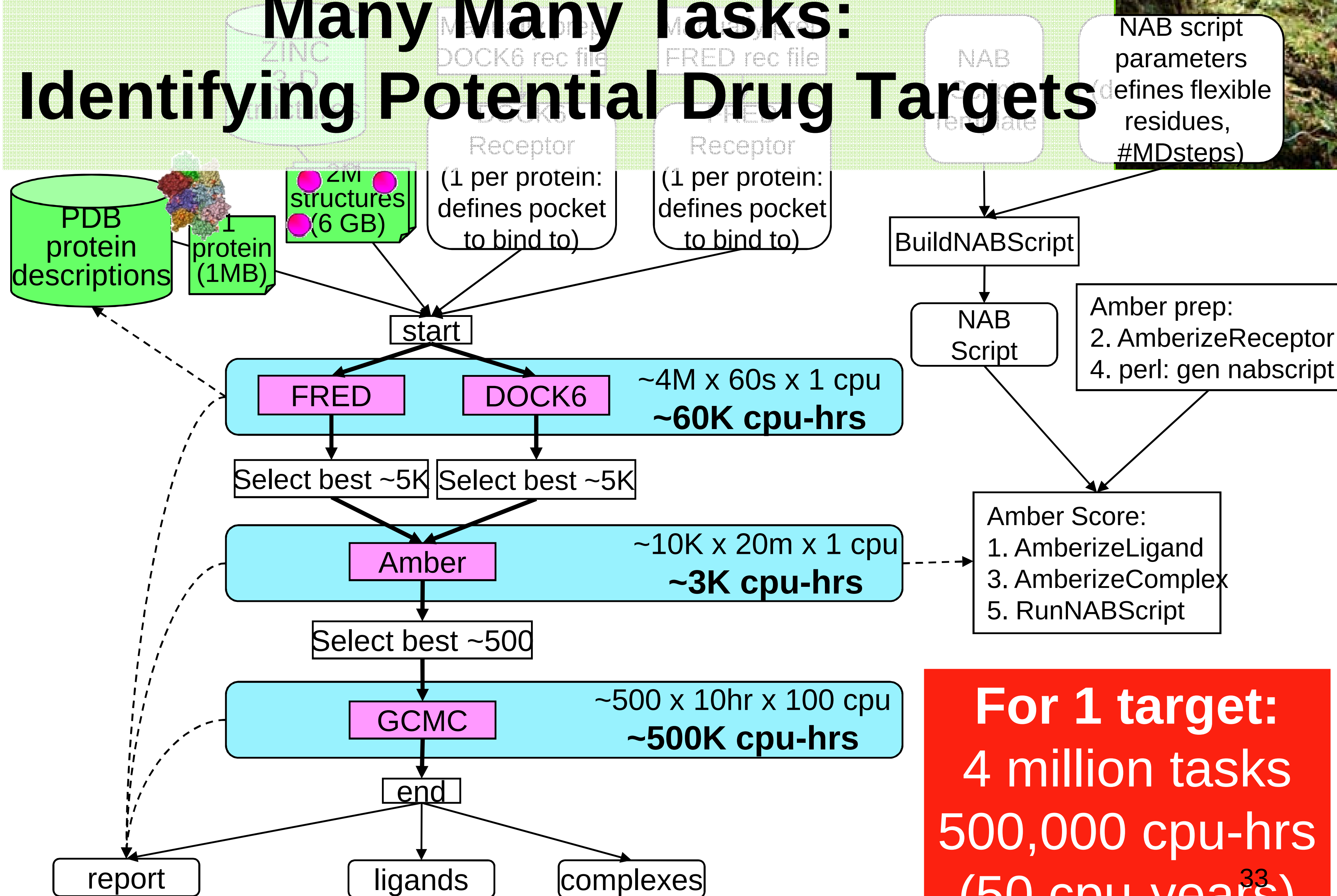
Protein target(s) x 2M+ ligands





(Mike Kubal, Benoit Roux, and others)

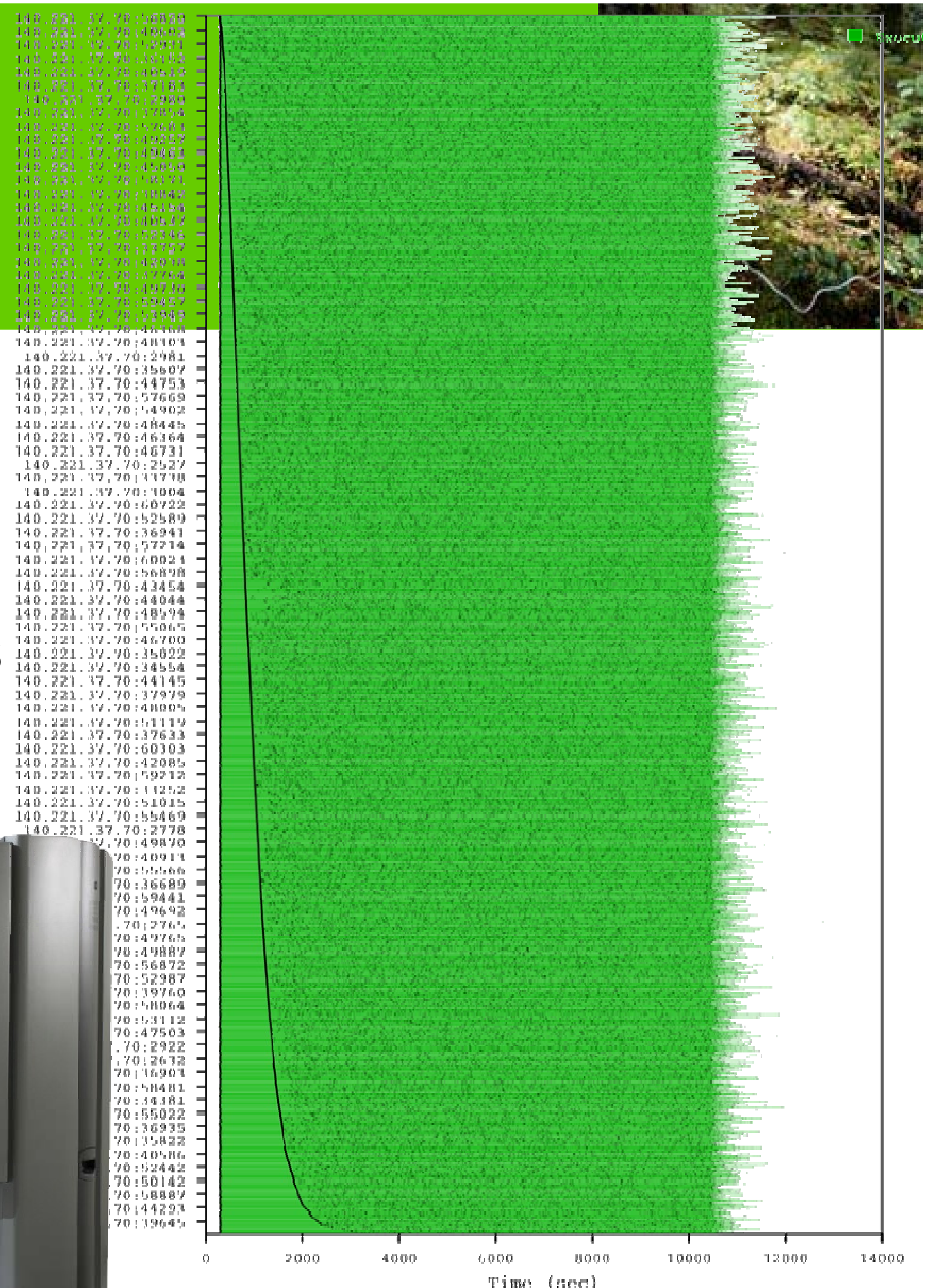
Many Many Tasks: Identifying Potential Drug Targets



For 1 target:
4 million tasks
500,000 cpu-hrs
(50 cpu-years)

DOCK on SiCortex

- CPU cores: 5760
- Tasks: 92160
- Elapsed time: 12821 sec
- Compute time: 1.94 CPU years
- Average task time: 660.3 sec
- Speedup: 5650X (ideal 5760)
- Efficiency: 98.2%



DOCK on the BG/P

CPU cores: 118784

Tasks: 934803

Elapsed time: 2.01 hours

Compute time: 21.43 CPU years

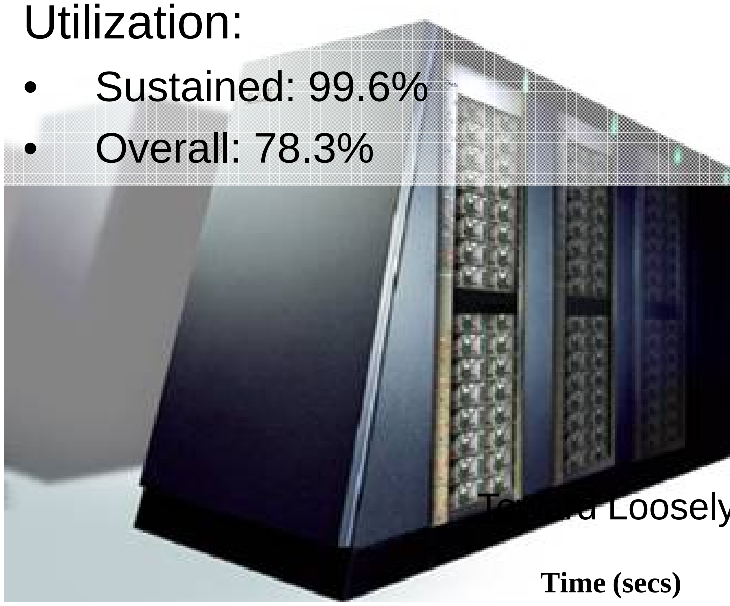
Average task time: 667 sec

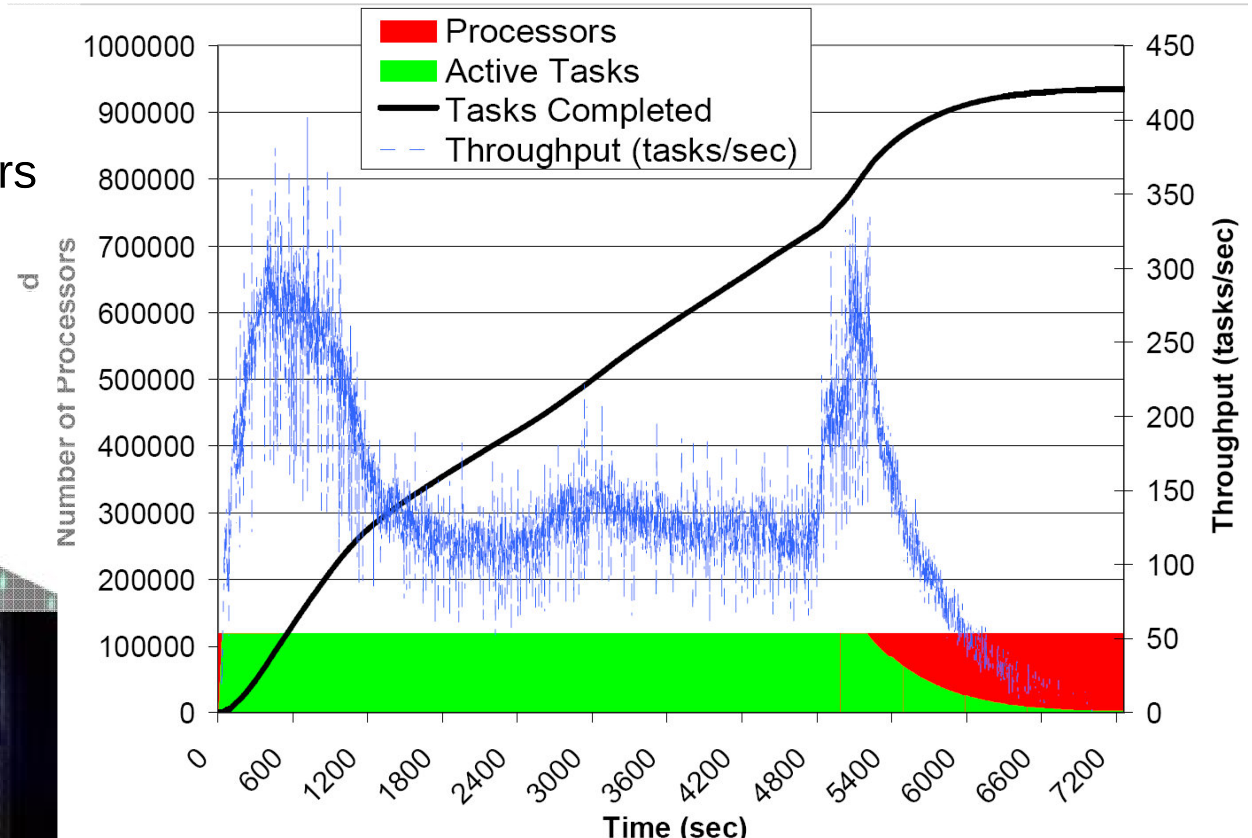
Relative Efficiency: 99.7%

(from 16 to 32 racks)

Utilization:

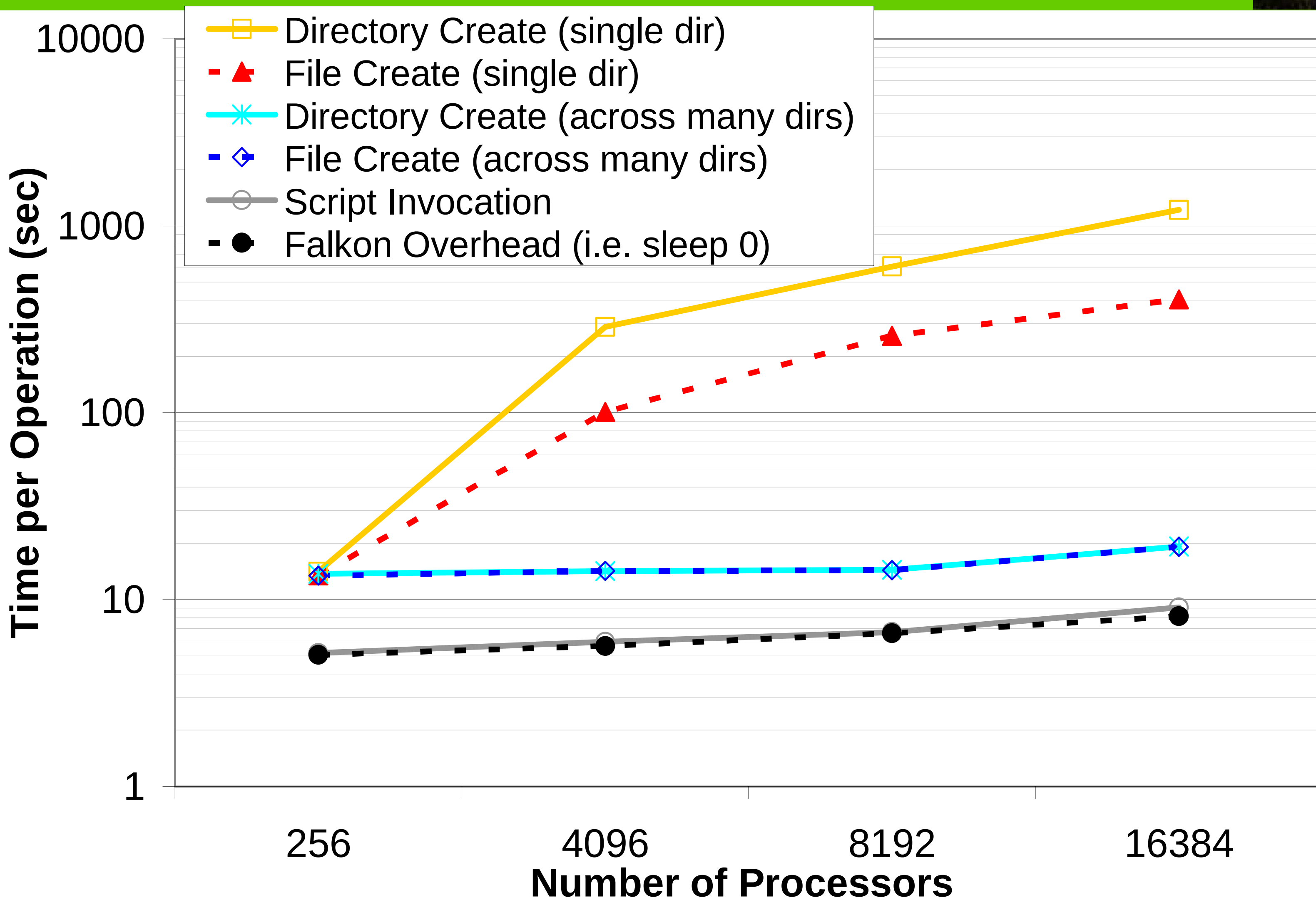
- Sustained: 99.6%
- Overall: 78.3%



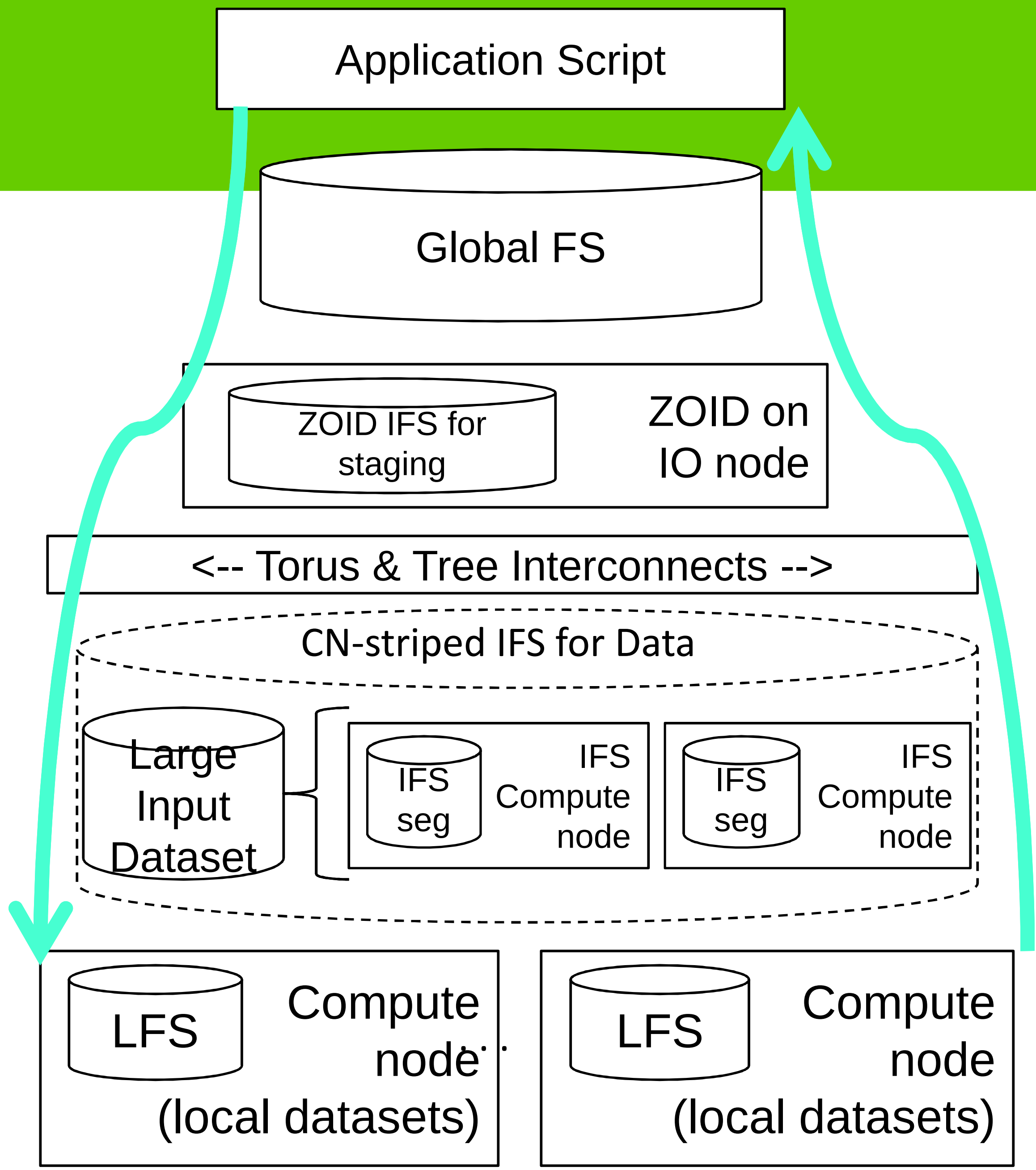


Time (secs)

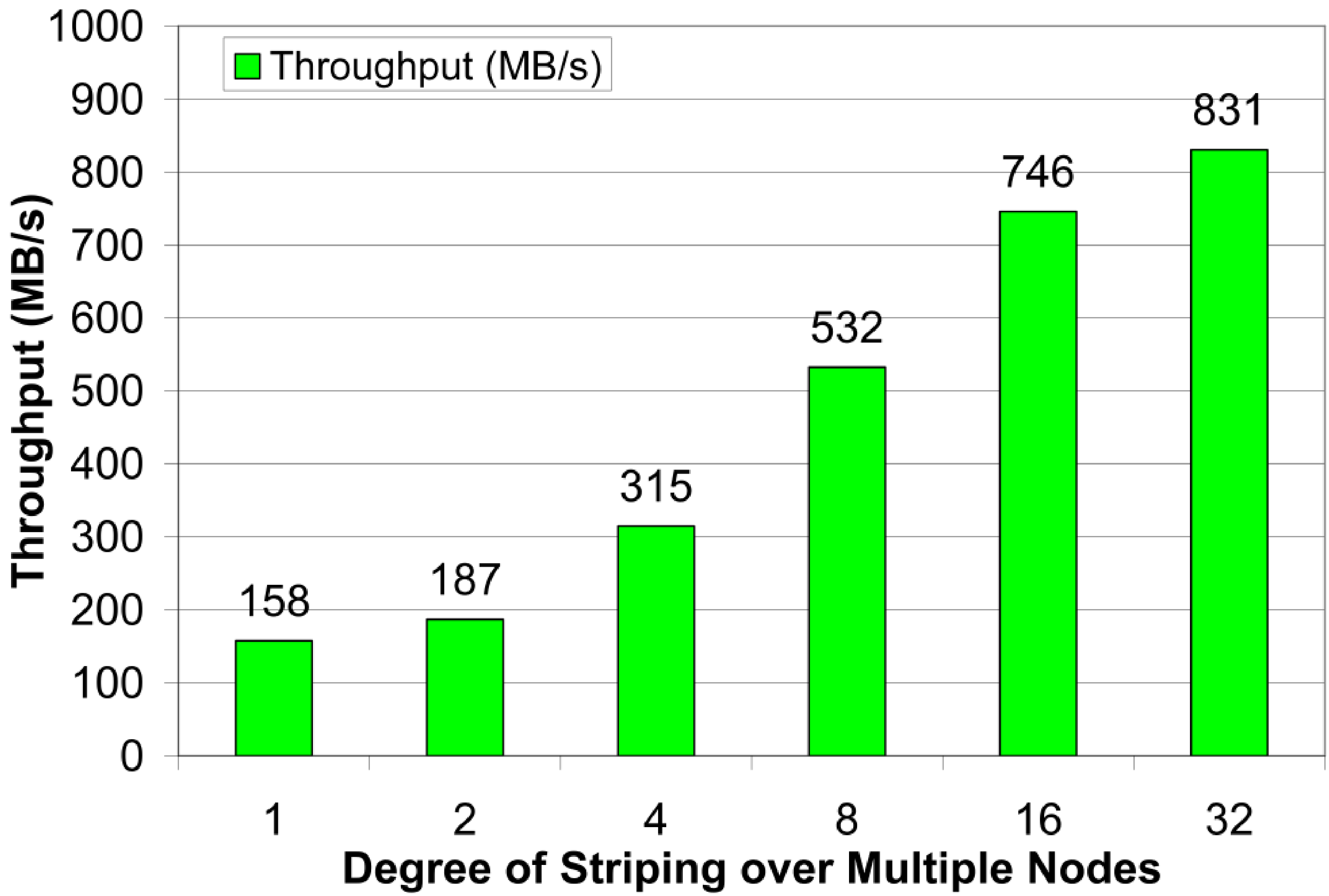
Costs to interact with GPFS



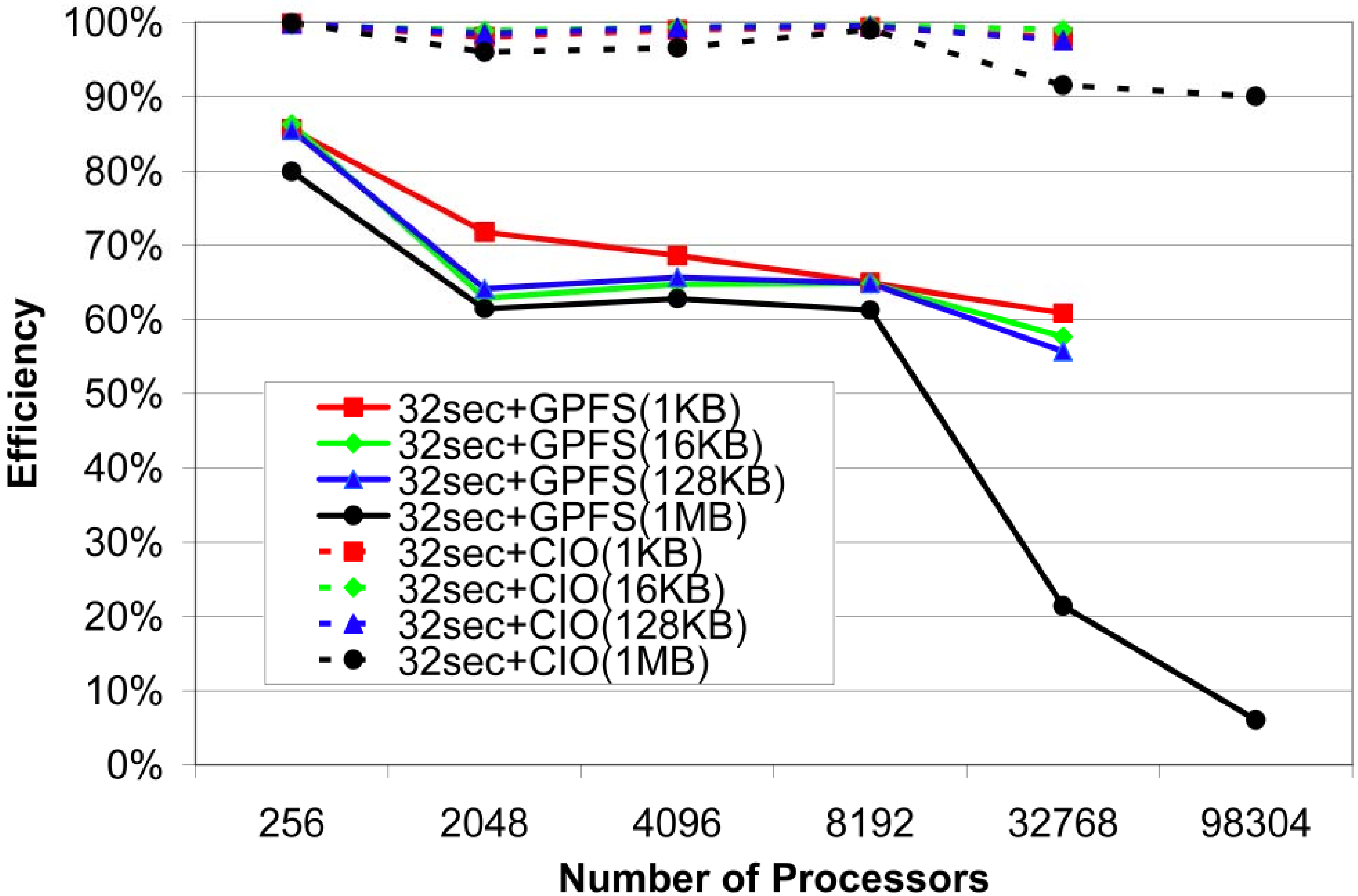
LCP Collective IO Model



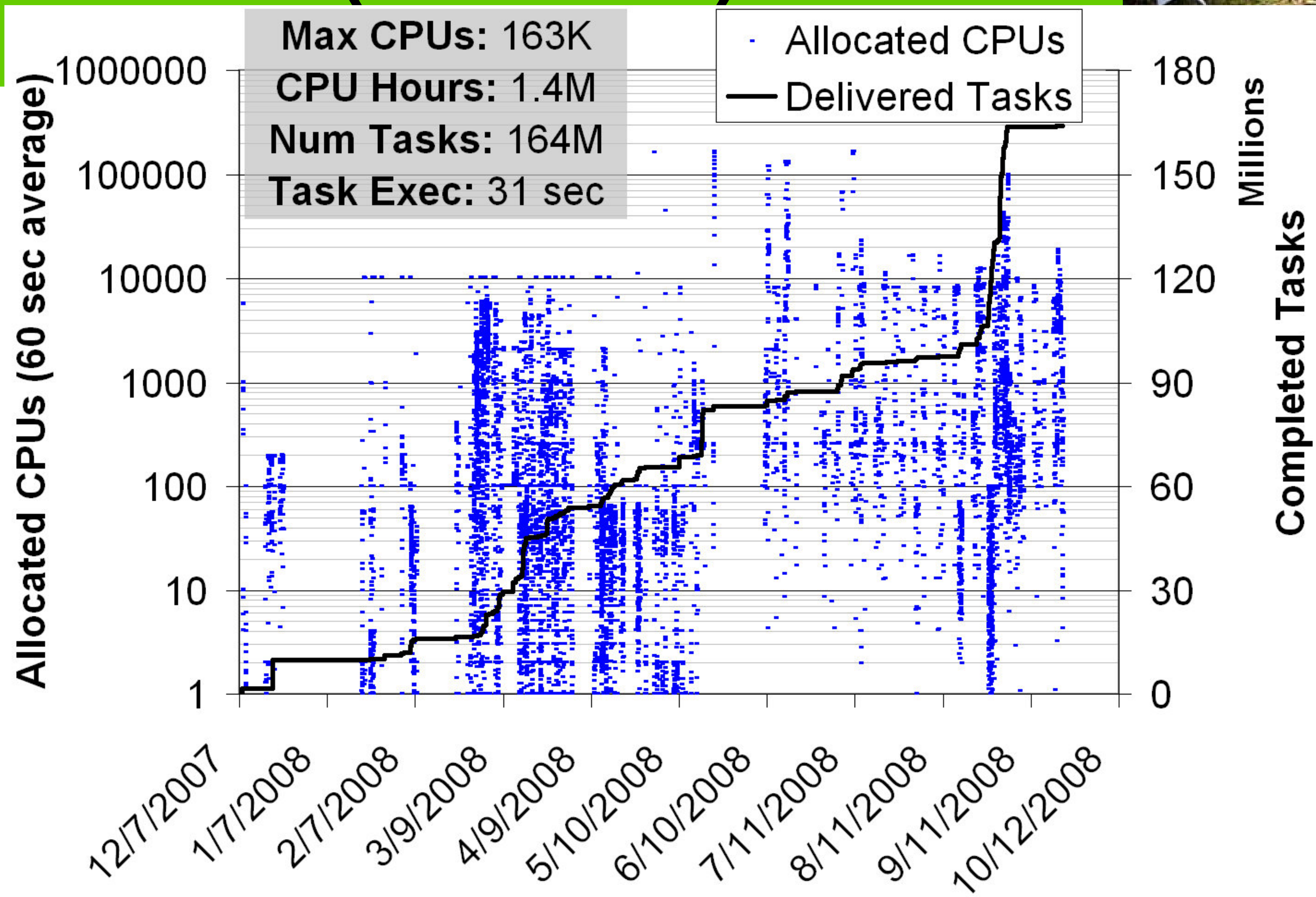
Read performance from IFS



Write Performance
CIO vs. GFS efficiency



Falkon Activity History (10 months)



PART IV

Conclusions and Future Work

Mythbusting

- ~~Embarrassingly~~ Happily parallel apps are trivial to run
  - Logistical problems can be tremendous
- Loosely coupled apps do not require “supercomputers”
  - Total computational requirements can be enormous
  - Individual tasks may be tightly coupled
  - Workloads frequently involve large amounts of I/O
  - Make use of idle resources from “supercomputers” via backfilling
  - Costs to run “supercomputers” per FLOP is among the best
    - BG/P: 0.35 gigaflops/watt **(higher is better)**
    - SiCortex: 0.32 gigaflops/watt
    - BG/L: 0.23 gigaflops/watt
    - x86-based HPC systems: an order of magnitude lower
- Loosely coupled apps do not require specialized system software
- Shared file systems are good for all applications
  - They don’t scale proportionally with the compute resources
  - Data intensive applications don’t perform and scale well

Conclusions & Contributions

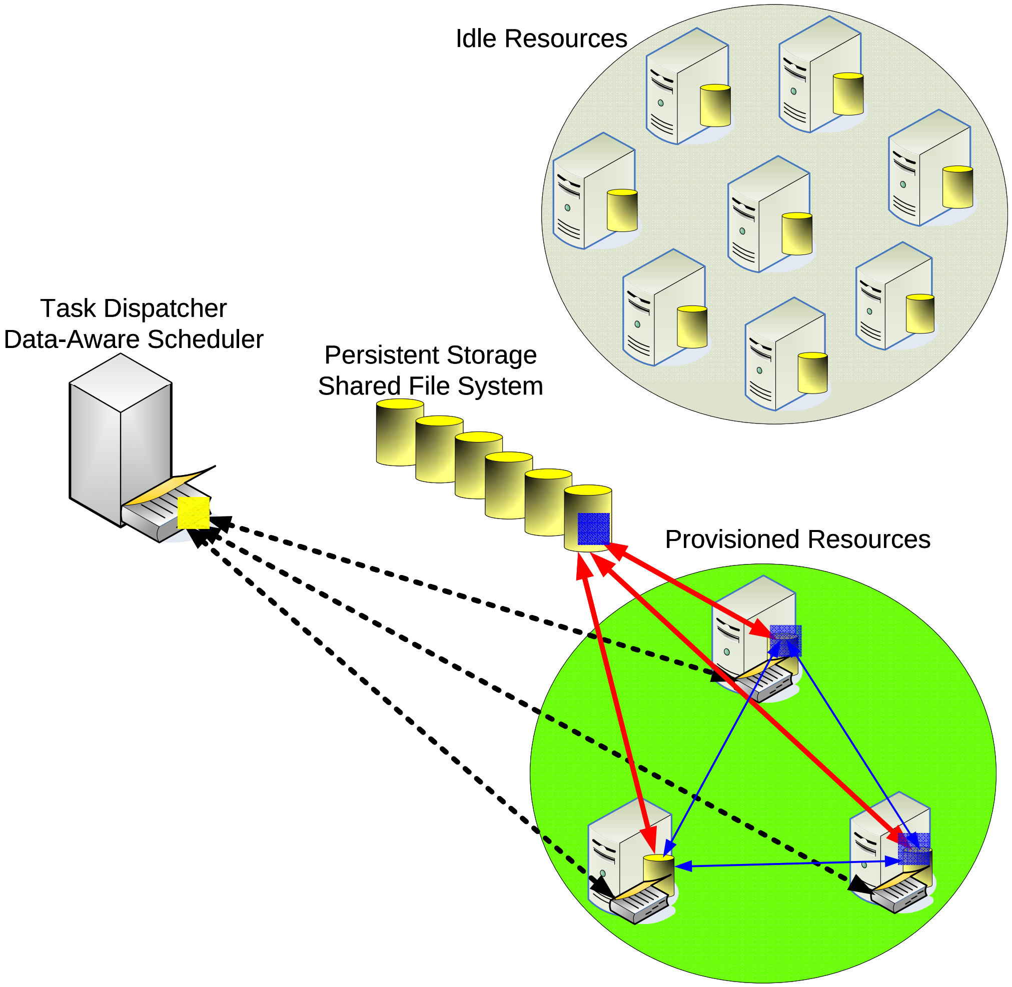
- Defined a new class of applications: MTC
- Proved that MTC applications can be executed efficiently on supercomputers at full scale
- Extended Falkon by distributing the dispatcher/scheduler
- Falkon installed and configured on the BG/P for anyone to use

Future Work: Other Supercomputers

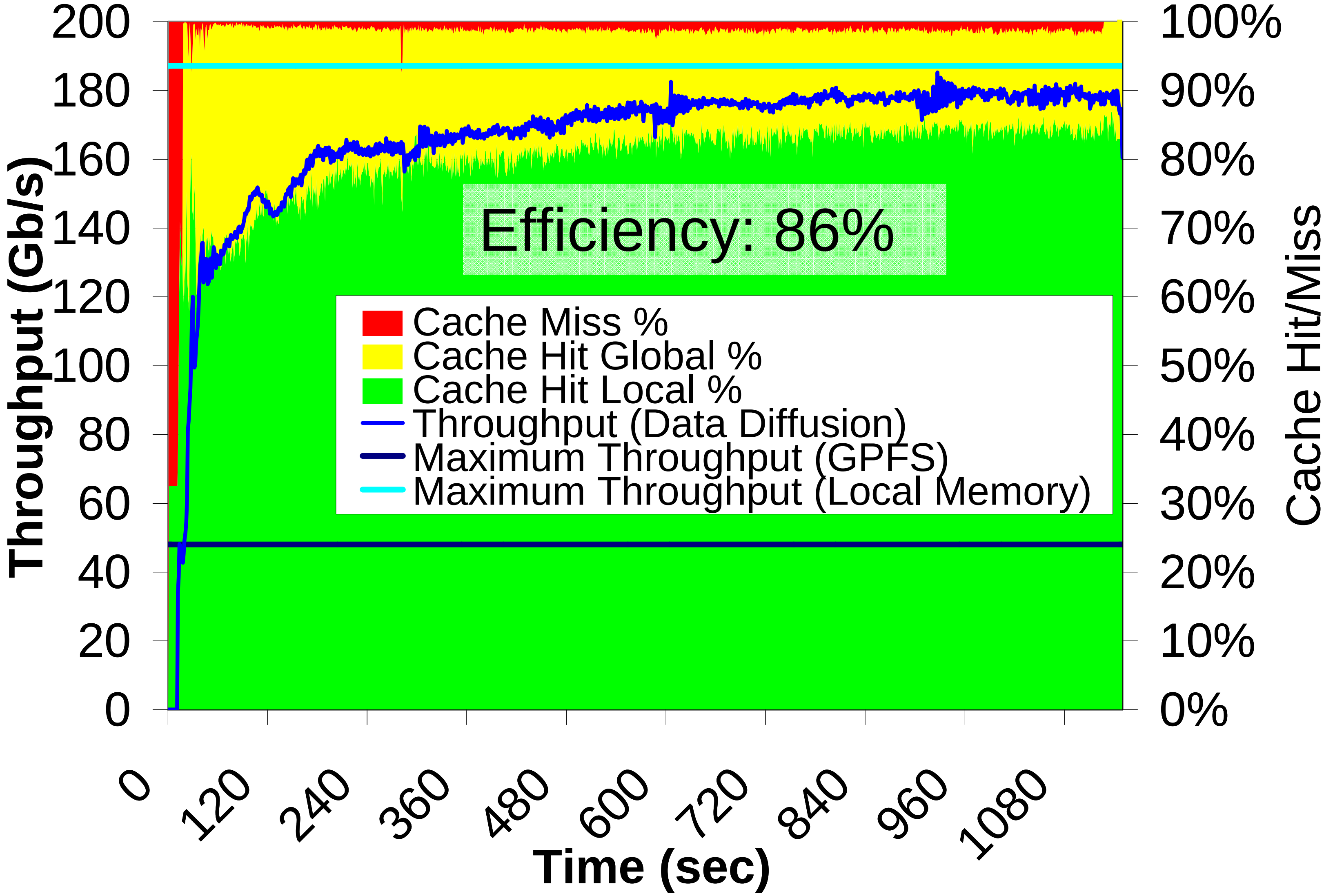
- Ranger: Sun Constellation
  - Basic mechanisms in place, and have started testing
- Jaguar: Cray
  - Plan to get accounts on machine as soon as its online
- Future Blue Gene machines (Q?)
  - Discussions underway between IBM, ANL and UChicago

Future Work: Data Diffusion

- Resource acquired in response to demand
- Data and applications diffuse from archival storage to newly acquired resources
- Resource “caching” allows faster responses to subsequent requests
  - Cache Eviction Strategies: RANDOM, FIFO, LRU, LFU
- Resources are released when demand drops

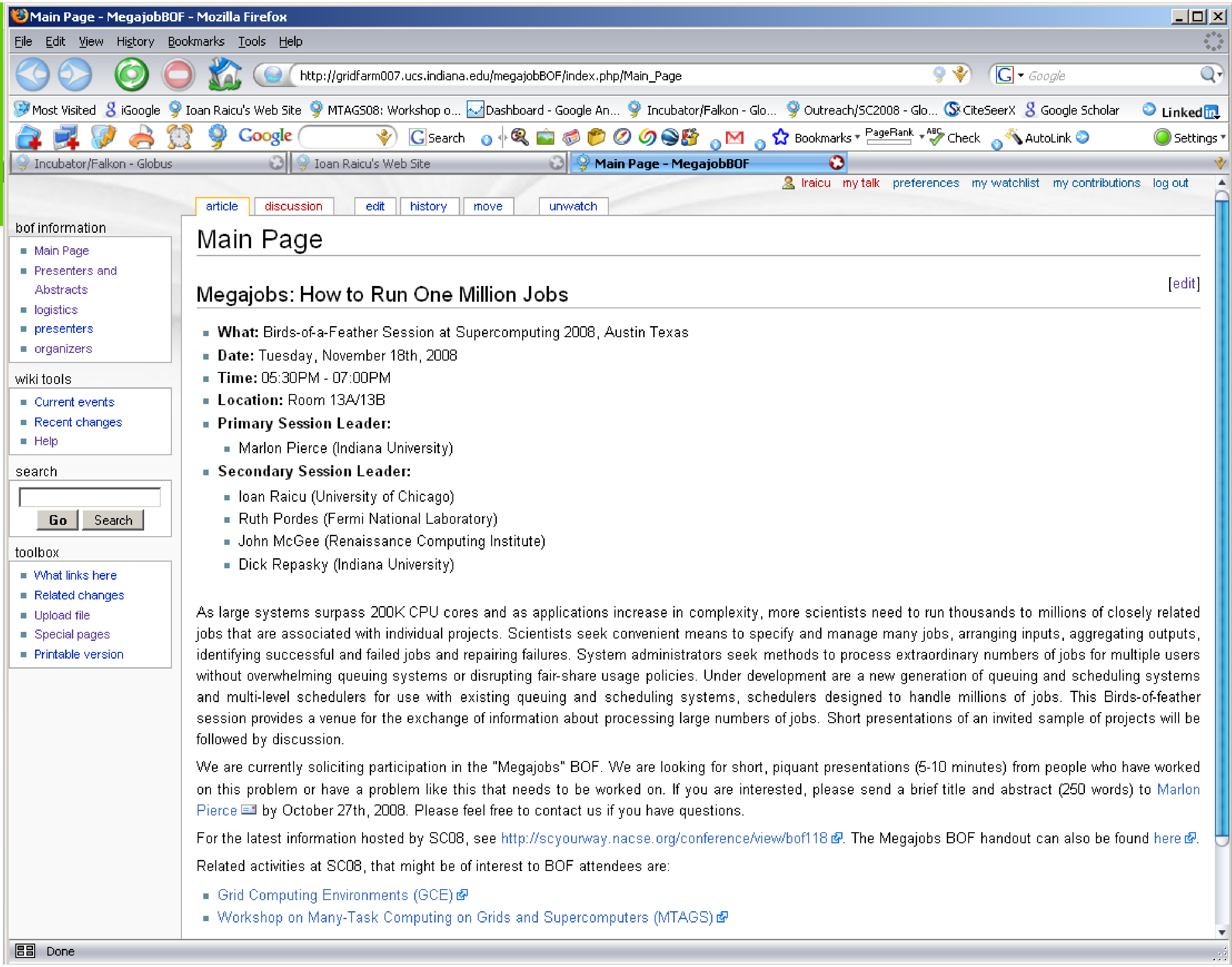


All-Pairs Workload
1000x1000 on 4K emulated CPUs



More Information

- More information: http://people.cs.uchicago.edu/~iraicu/
- Related Projects:
  - Falkon: http://dev.globus.org/wiki/Incubator/Falkon
  - Swift: http://www.ci.uchicago.edu/swift/index.php
- Funding:
  - **NASA**: Ames Research Center, Graduate Student Research Program
    - Jerry C. Yan, NASA GSRP Research Advisor
  - **DOE**: Mathematical, Information, and Computational Sciences Division subprogram of the Office of Advanced Scientific Computing Research, Office of Science, U.S. Dept. of Energy
  - **NSF**: TeraGrid



Main Page

Megajobs: How to Run One Million Jobs

[edit]

- **What:** Birds-of-a-Feather Session at Supercomputing 2008, Austin Texas
- **Date:** Tuesday, November 18th, 2008
- **Time:** 05:30PM - 07:00PM
- **Location:** Room 13A/13B
- **Primary Session Leader:**
  - Marlon Pierce (Indiana University)
- **Secondary Session Leader:**
  - Ioan Raicu (University of Chicago)
  - Ruth Pordes (Fermi National Laboratory)
  - John McGee (Renaissance Computing Institute)
  - Dick Repasky (Indiana University)

As large systems surpass 200K CPU cores and as applications increase in complexity, more scientists need to run thousands to millions of closely related jobs that are associated with individual projects. Scientists seek convenient means to specify and manage many jobs, arranging inputs, aggregating outputs, identifying successful and failed jobs and repairing failures. System administrators seek methods to process extraordinary numbers of jobs for multiple users without overwhelming queuing systems or disrupting fair-share usage policies. Under development are a new generation of queuing and scheduling systems and multi-level schedulers for use with existing queuing and scheduling systems, schedulers designed to handle millions of jobs. This Birds-of-feather session provides a venue for the exchange of information about processing large numbers of jobs. Short presentations of an invited sample of projects will be followed by discussion.

We are currently soliciting participation in the "Megajobs" BOF. We are looking for short, piquant presentations (5-10 minutes) from people who have worked on this problem or have a problem like this that needs to be worked on. If you are interested, please send a brief title and abstract (250 words) to Marlon Pierce by October 27th, 2008. Please feel free to contact us if you have questions.

For the latest information hosted by SC08, see http://scyourway.nacse.org/conference/view/bof118. The Megajobs BOF handout can also be found here.

Related activities at SC08, that might be of interest to BOF attendees are:

- Grid Computing Environments (GCE)
- Workshop on Many-Task Computing on Grids and Supercomputers (MTAGS)