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Falkon: a Fast and Light-weight tasK executiON framework for Grid Environments

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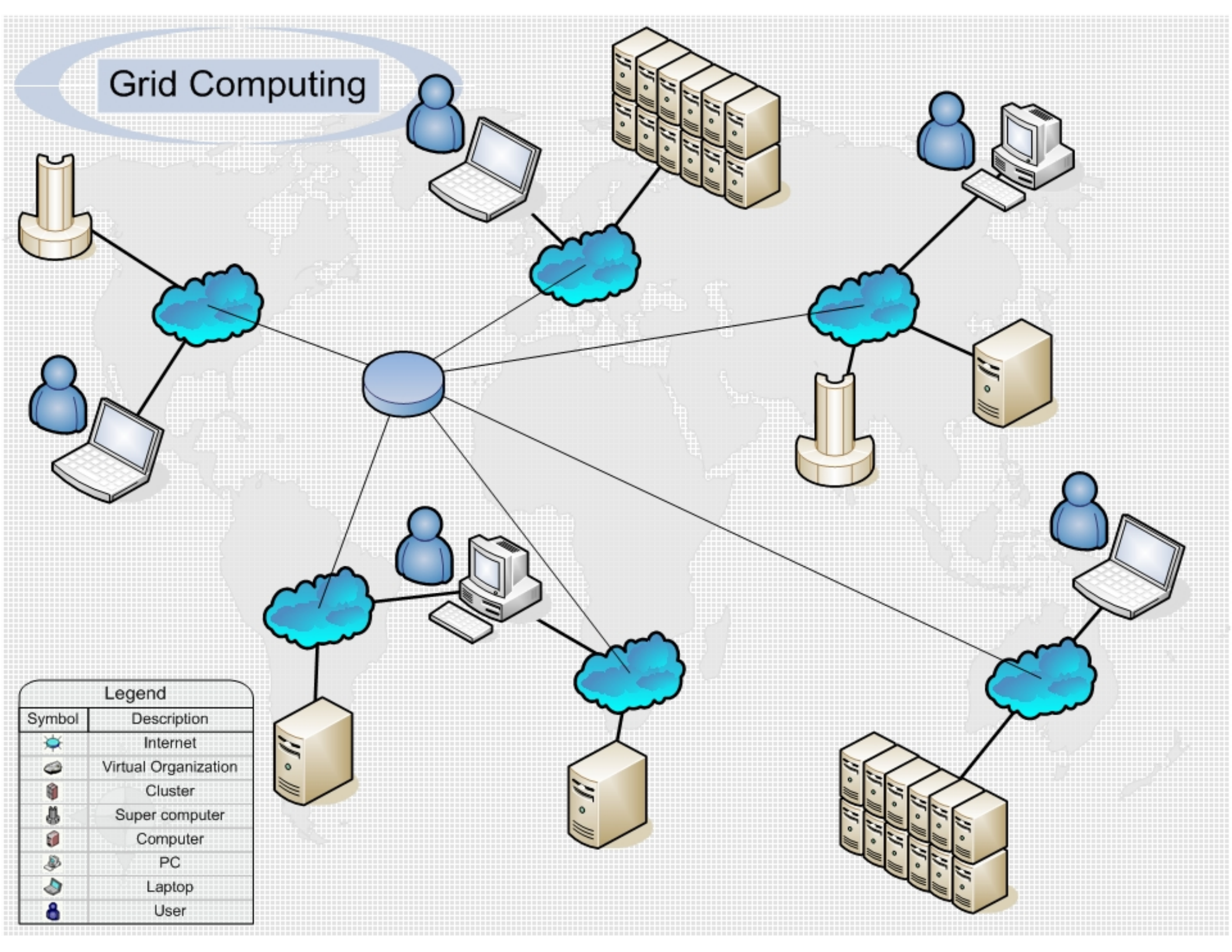

Grid Computing
Legend
Symbol
Description
Internet
Virtual Organization
Cluster
Super computer
Computer
PC
Laptop
User

Grid Computing

- Grid Computing's focus:
  - **large-scale resource sharing:** direct access to computers, software, data
  - innovative applications
  - high-performance orientation
- The 'Grid problem':
  - **Definition:** flexible, secure, and ***coordinated resource sharing among dynamic collections of individuals, institutions, and resources***
  - **Challenges:** Security (Authentication, Authorization), ***resource management (resource access, resource discovery, scheduling, data management)***

Falkon: a Fast and Light-weight tasK executiON framework

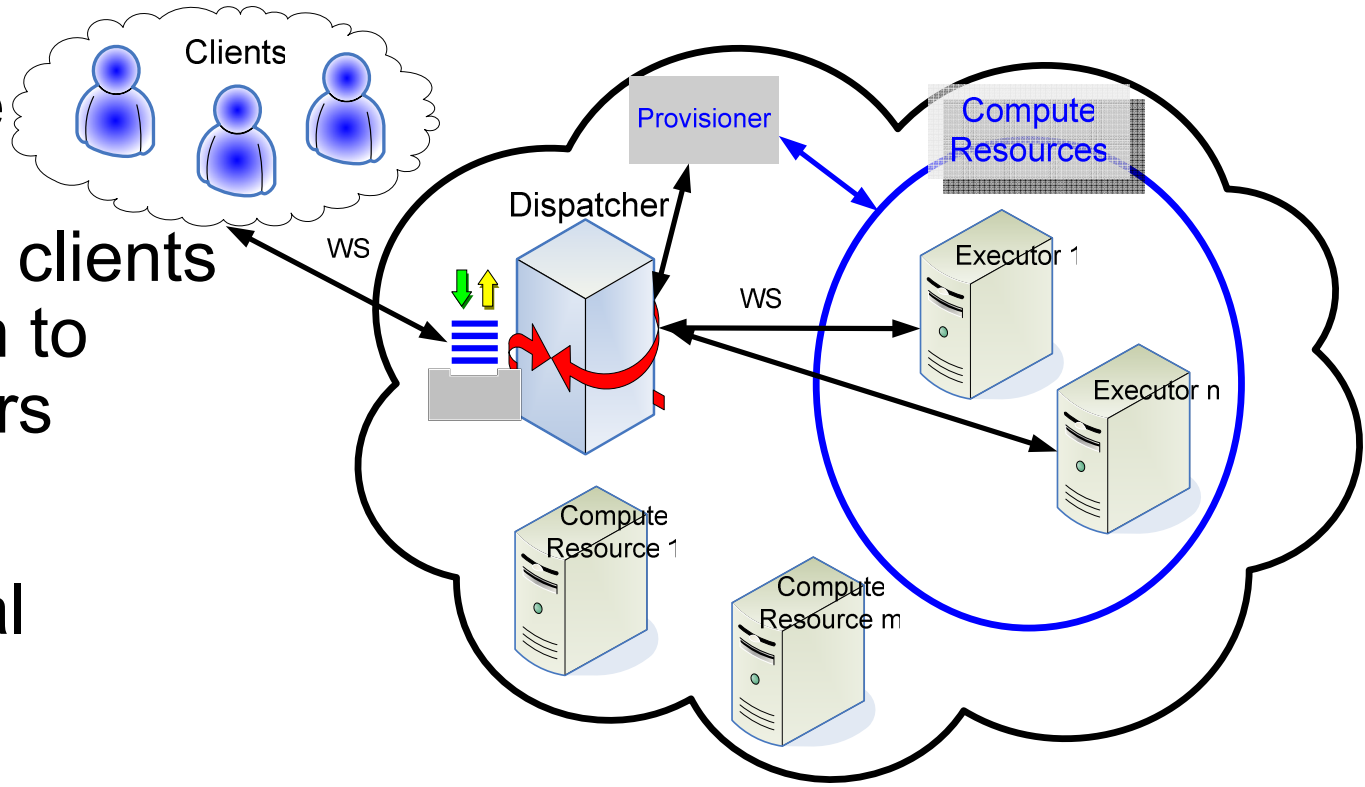
- ***Goal:*** enable the rapid and efficient execution of many independent jobs on large compute clusters
- Combines two techniques:
  - ***multi-level scheduling*** techniques to enable separate treatments of resource provisioning
  - a ***streamlined task dispatcher*** able to achieve order-of-magnitude higher task dispatch rates than conventional schedulers

Execution Model

- **Dispatch policy**
  - Round-robin
- **Replay policy**
- **Resource Acquisition Policy**
  - One-at-a-time
  - Additive
  - Exponential
  - All-at-once
  - Optimal
- **Resource Release Policy**
  - Centralized
  - Distributed

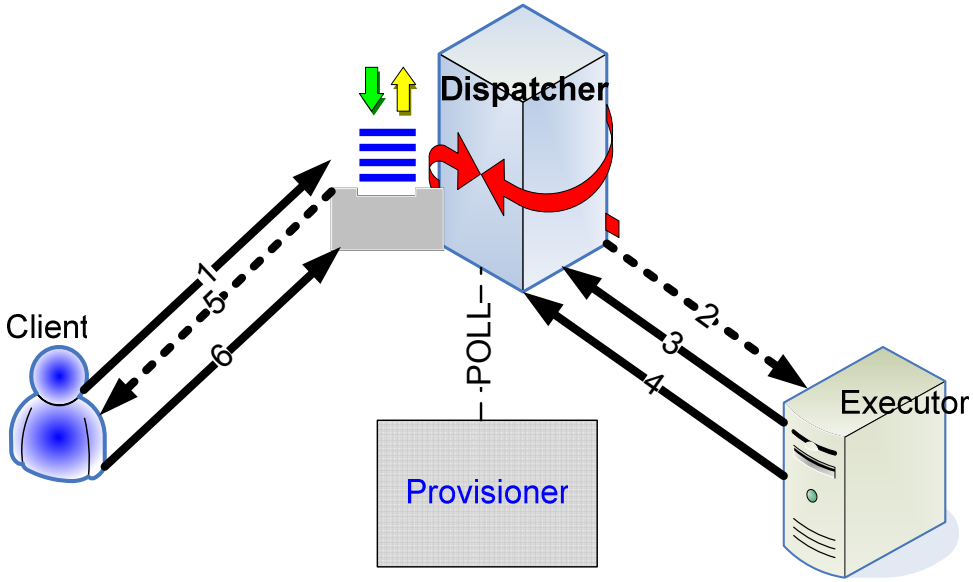
Falkon 2-Tier Architecture

- Tier 1: Dispatcher
  - GT4 Web Service accepting task submissions from clients and sending them to available executors
- Tier 2: Executor
  - Run tasks on local resources
- Provisioner
  - Static and dynamic resource provisioning



Falkon Message Exchanges

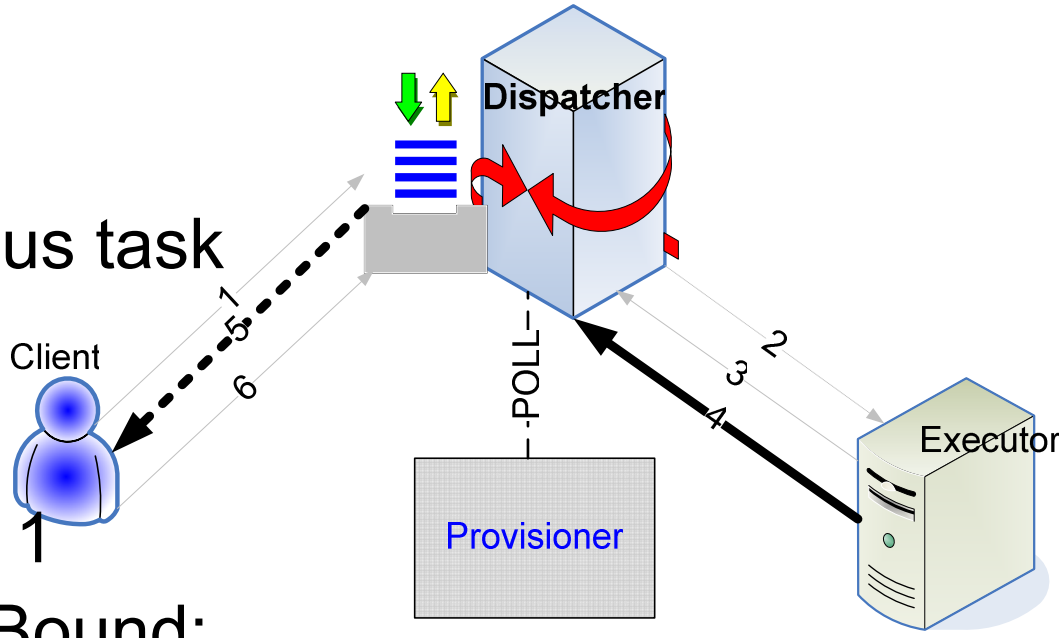
- Description:
  1. task(s) submit
  2. notification for work
  3. pick up task(s)
  4. deliver task(s) results
  5. notification for task result
  6. pick up task(s) results



- Worst case:
  - 4 WS messages (1, 3, 4, 6) and 2 notifications (2, 5) per task
- Best case:
  - 1 WS message (4) and 1 notification (5) message per task

Enhancements

- Bundling
  - Include multiple tasks per communication message
- Piggy-Backing
  - Attach next task to acknowledgement of previous task
- Message reduction:
  - Now: 6 → 2
  - General Lower Bound: 6 → 1
  - Application Specific Lower Bound: 6 → c, where c is a small positive value close to 0



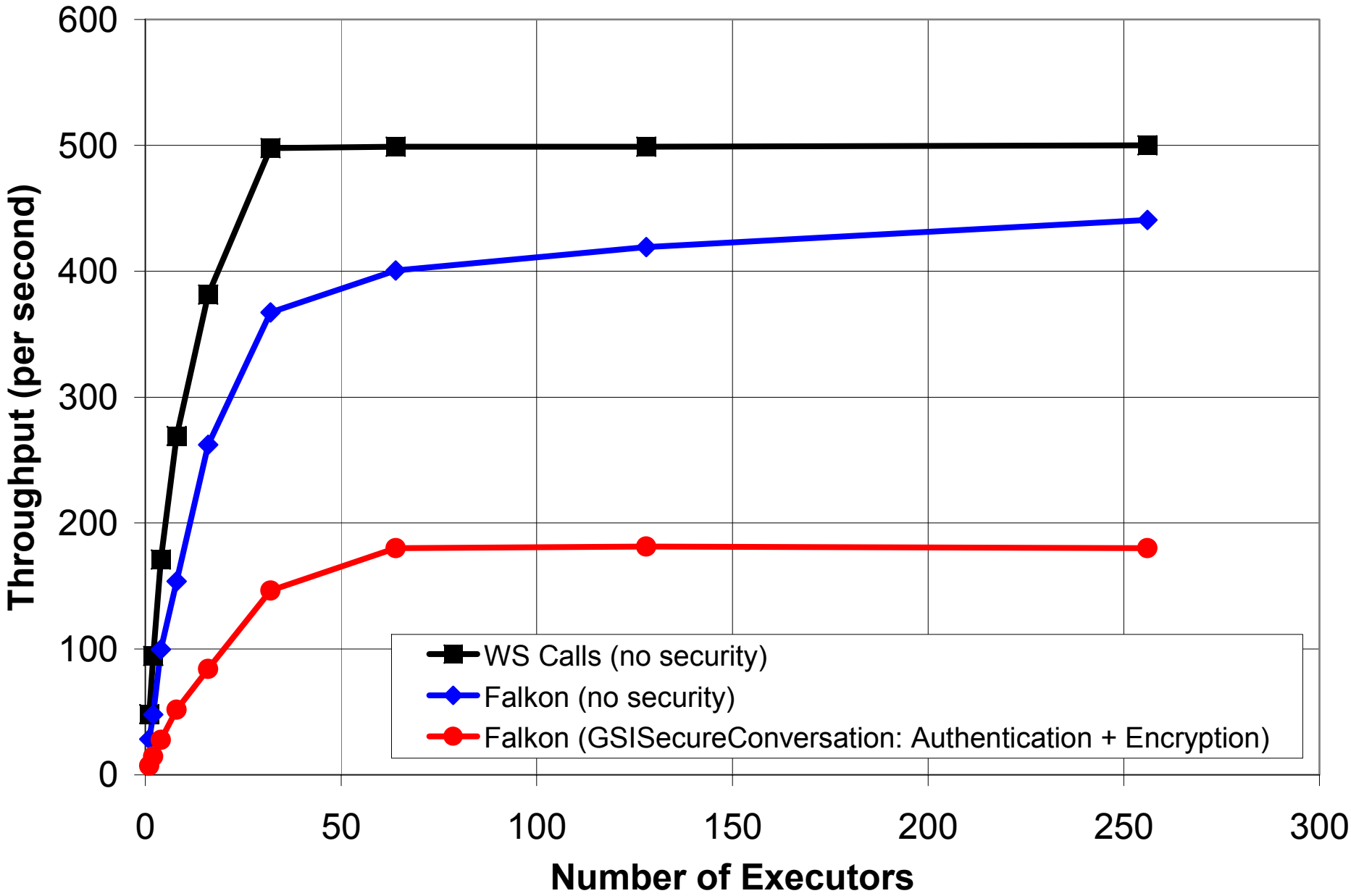
Testbeds

Name	# of Nodes	Processors	Memory	Network
TG_ANL_IA32_CLUSTER	98	Dual Xeon 2.4GHz	4GB	1Gb/s
TG_ANL_IA64_CLUSTER	64	Dual Itanium 1.5GHz	4GB	1Gb/s
TP_UC_x64_CLUSTER	122	Dual Opteron 2.2GHz	4GB	1Gb/s
UC_x64	1	Dual Xeon 3GHz w/ HT	2GB	100 Mb/s
UC_IA32	1	Intel P4 2.4GHz	1GB	100 Mb/s

Performance Metrics

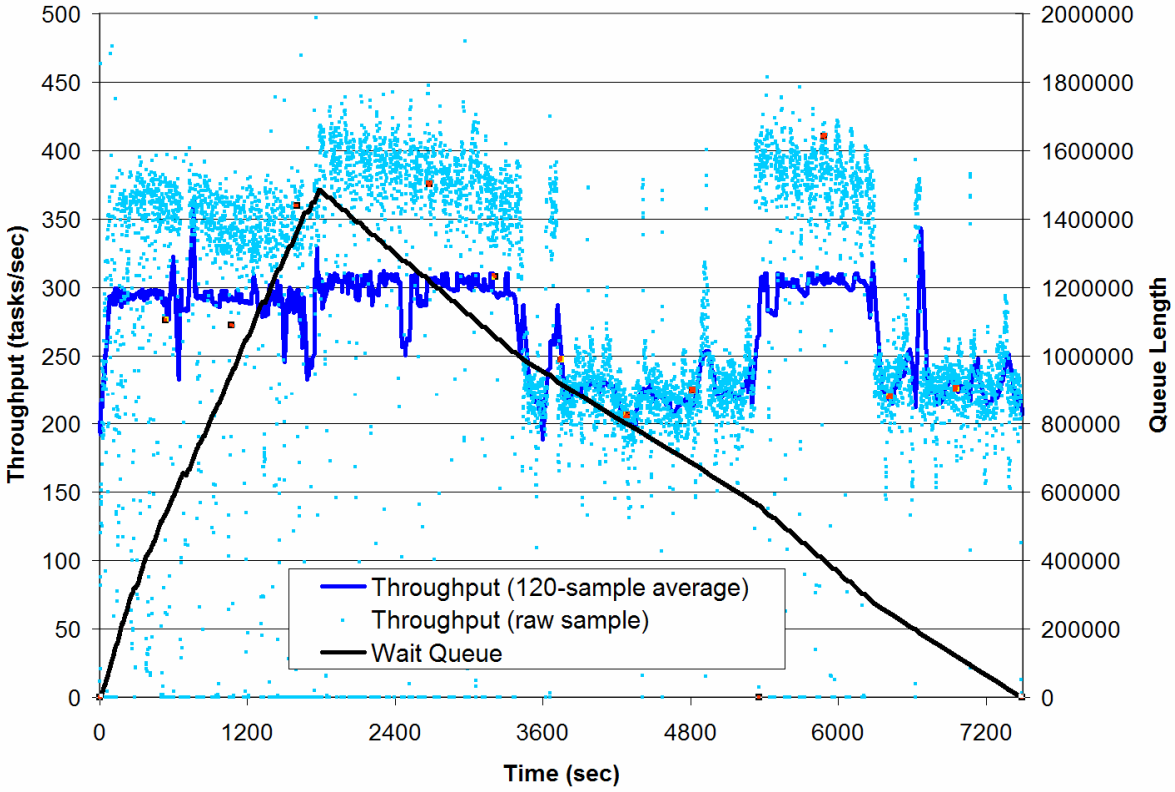
- Throughput (tasks/sec)
- Time to execute per task (ms)
- Execution time for a given set of tasks
- Speedup
- Efficiency

Throughput


Throughput (per second)
600
500
400
300
200
100
0
0
50
100
150
200
250
300
Number of Executors
WS Calls (no security)
Falkon (no security)
Falkon (GSISecureConversation: Authentication + Encryption)

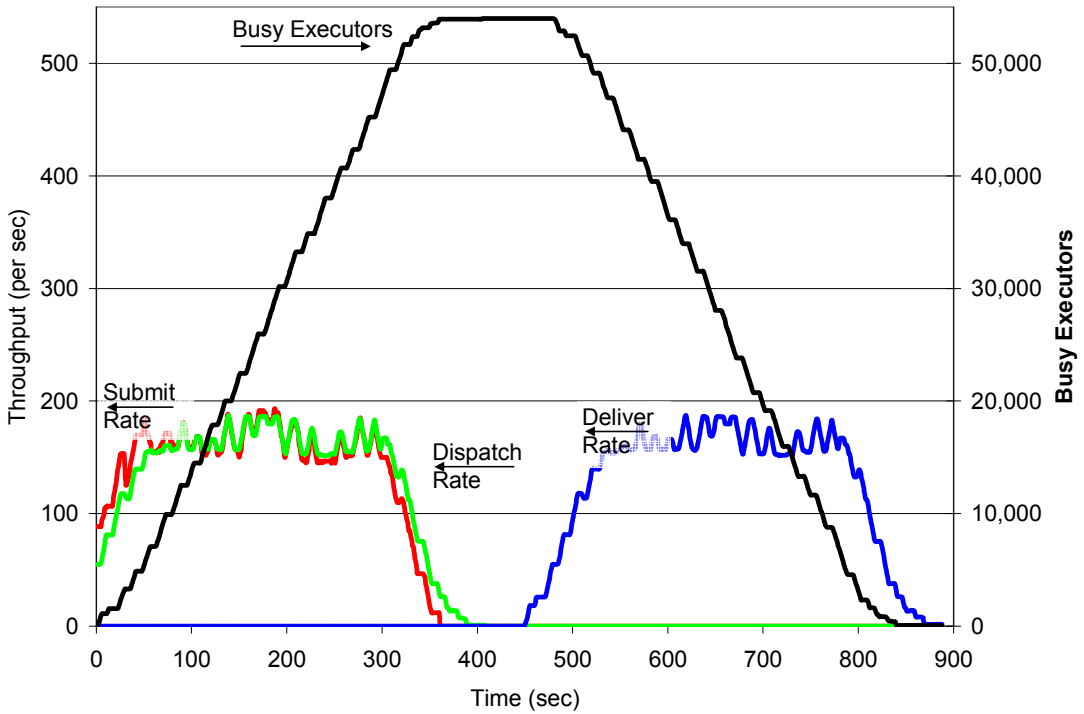
Falkon Scalability

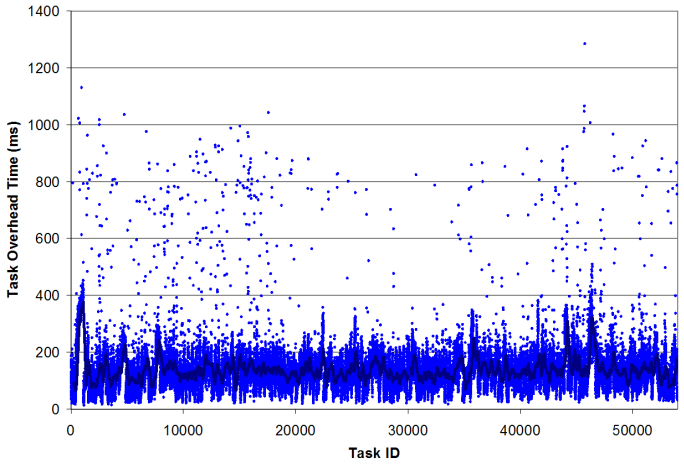
- 2M tasks processed (sleep 0) on 16 machines (32 executors)
- 7490 seconds ~ 267 tasks/sec
- Queue Length ~ 1.5M
- Sun JDK 1.4.2 with 1.5GB Heap
- Throughput variations → issues with GC



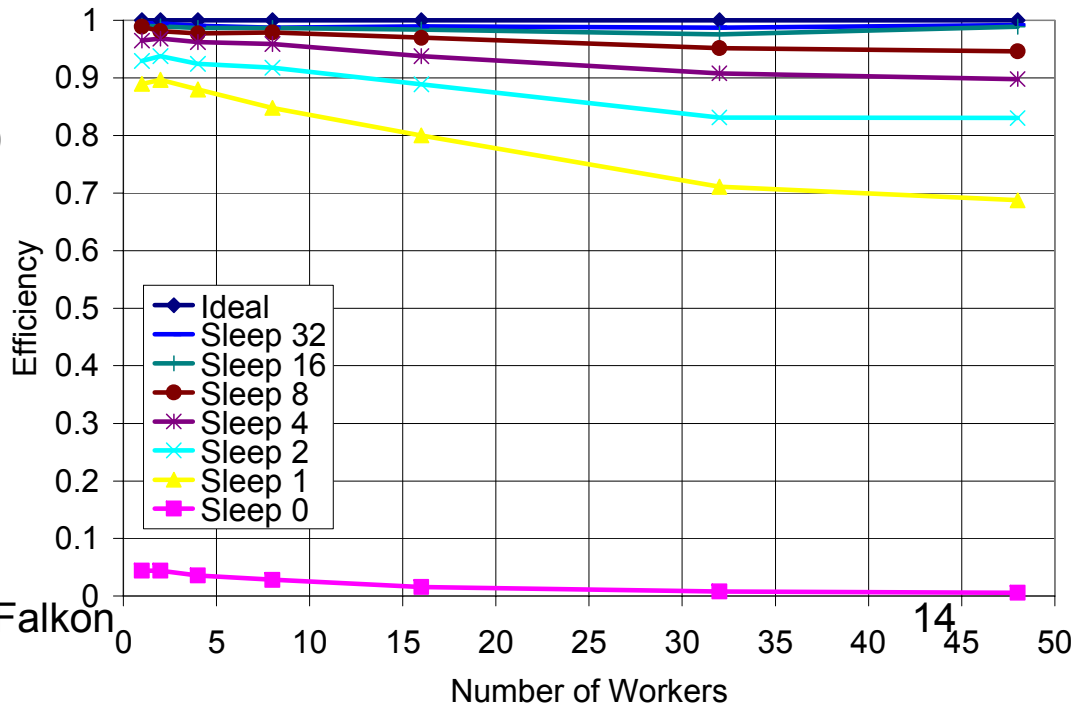
Falkon Scalability

- 54K tasks processed (sleep 480) on 60 machines (54K executors)
- 888 seconds ~ 61 tasks/sec
- Per task overhead: 127 ms, standard deviation 76ms
- Sun JDK 1.4.2 with 1.5GB Heap





Speedup & Efficiency



Security Overhead

- Experiment:
  - 1 client, 1 dispatcher, 1 executor
  - 30 tasks of sleep 60
  - Security:
    - None
    - GSITransport with authentication and encryption
    - GSISecureConversation with authentication and encryption
- MyCluster Comparison
  - Condor: 5%
  - SGE: 25%

	Exec Time (sec)	Exec Overhead %
Ideal Tasks Execution	1800.00	0.00%
No Security	1803.46	0.19%
GSI Transport (Authentication + Encryption)	1817.37	0.96%
GSI Secure Conversation (Authentication + Encryption)	1815.58	0.87%

Dynamic Resource Provisioning

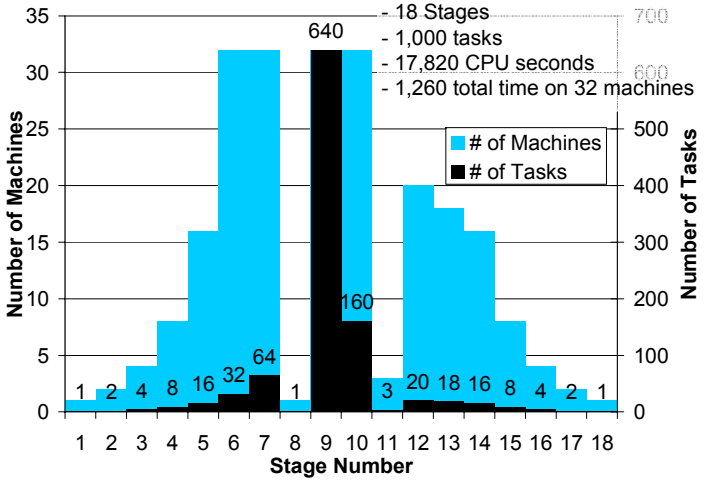
- Synthetic Workload
  - 18 stages
  - 1000 tasks
  - 17,820 CPU seconds
  - 1,260 seconds total time on 32 machines

Stage #	# of Tasks	Task Time (sec)	Stage Time (32 machines)	# Machines (32 max)
1	1	60	60	1
2	2	60	60	2
3	4	60	60	4
4	8	60	60	8
5	16	60	60	16
6	32	60	60	32
7	64	60	120	32
8	1	120	120	1
9	640	6	120	32
10	160	12	60	32
11	3	60	60	3
12	20	60	60	20
13	18	60	60	18
14	16	60	60	16
15	8	60	60	8
16	4	60	60	4
17	2	60	60	2
18	1	60	60	1

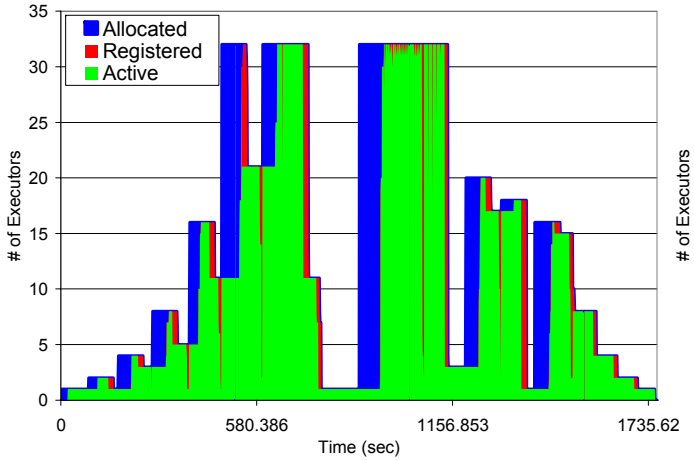
Dynamic Resource Provisioning

- Compared:
  - GRAM+PBS: 1 job per task
  - Falkon-15, -60, -120, -180: dynamic resource provisioning – 15, 60, 120, and 180 seconds idle time before resource de-allocation, and with 32 maximum machines
  - Falkon-∞: static resource provisioning with 32 maximum machines
  - Ideal with 32 maximum machines
- Falkon-15 / Falkon-180:
  - Allocated (blue): LRM wait queue
  - Registered (red): idle executors
  - Active (green): executors processing tasks

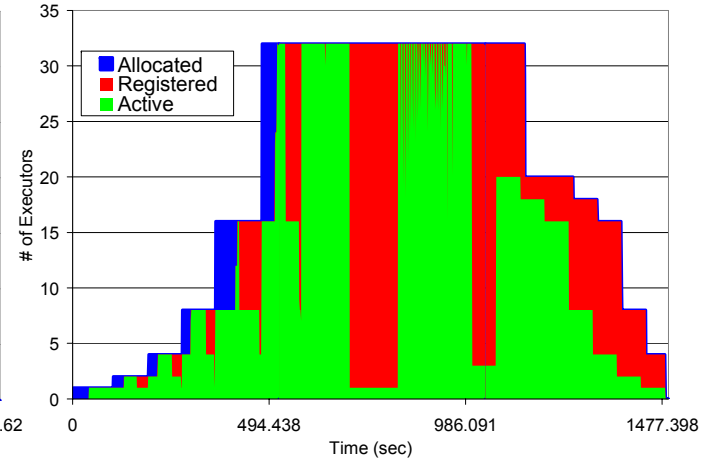
Ideal



Falkon-15



Falkon-180



Dynamic Resource Provisioning

- End-to-end execution time:
  - 1260 sec in ideal case
  - 4904 sec → 1276 sec
- Average task queue time:
  - 42.2 sec in ideal case
  - 611 sec → 43.5 sec
- Trade-off:
  - Resource Utilization for Execution Efficiency

	GRAM +PBS	Falkon-15	Falkon-60	Falkon-120	Falkon-180	Falkon-∞	Ideal (32 nodes)
Queue Time (sec)	611.1	87.3	83.9	74.7	44.4	43.5	42.2
Execution Time (sec)	56.5	17.9	17.9	17.9	17.9	17.9	17.8
Execution Time %	8.5%	17.0%	17.6%	19.3%	28.7%	29.2%	29.7%

	GRAM +PBS	Falkon-15	Falkon-60	Falkon-120	Falkon-180	Falkon-∞	Ideal (32 nodes)
Time to complete (sec)	**4904**	**1754**	**1680**	**1507**	**1484**	**1276**	**1260**
Resouce Utilization	30%	89%	75%	65%	59%	44%	100%
Execution Efficiency	26%	72%	75%	84%	85%	99%	100%
Resource Allocations	1000	11	9	7	6	0	0

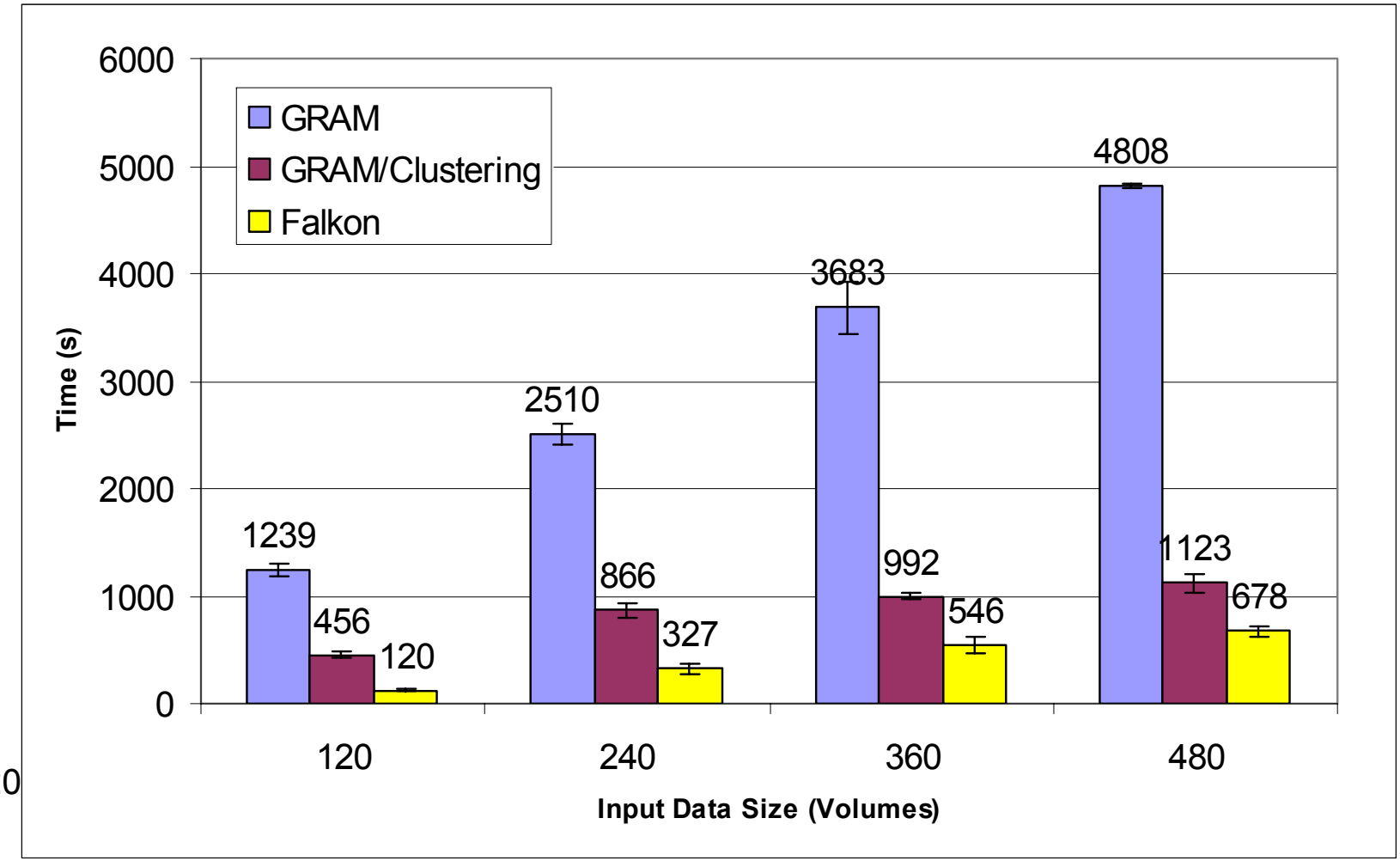
Applications

Application	#Jobs/workflow	#Levels
ATLAS: High Energy Physics Event Simulation	500K	1
fMRI DBIC: AIRSN Image Processing	100s	12
FOAM: Ocean/Atmosphere Model	2000	3
GADU: Genomics	40K	4
HNL: fMRI Aphasia Study	500	4
NVO/NASA: Photorealistic Montage/Morphology	1000s	16
QuarkNet/I2U2: Physics Science Education	10s	3 ~ 6
RadCAD: Radiology Classifier Training	1000s	5
SIDGrid: EEG Wavelet Processing, Gaze Analysis	100s	20
SDSS: Coadd, Cluster Search	40K, 500K	2, 8

- Applications tested:
  - Medicine: fMRI
  - Astronomy: Montage
- Compared:
  - GRAM: Swift submitting each task as a GRAM job
  - GRAM/Clustering: Swift submitting clusters of tasks as GRAM jobs
  - MPI: Executing the entire application as an MPI program
  - Falkon: Swift submitting each task as a task to Falkon

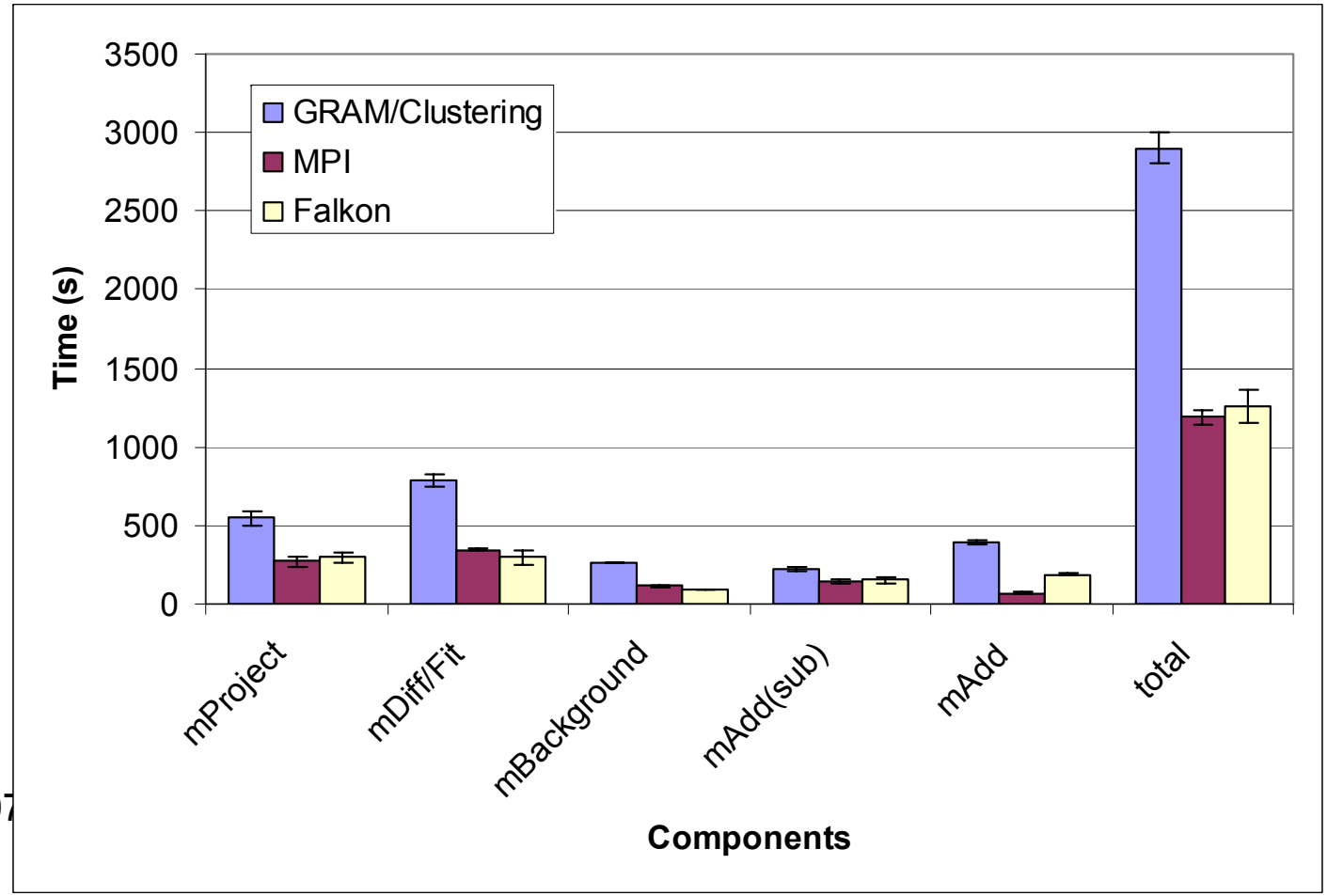
Applications: fMRI

- GRAM vs. Falkon: 85%~90% lower run time
- GRAM/Clustering vs. Falkon: 40%~74% lower run time



Applications: Montage

- GRAM/Clustering vs. Falkon: 57% lower application run time
- MPI* vs. Falkon: 4% higher application run time
- * MPI should be lower bound



Future Work

- Task pre-fetching
  - Overlap communication with computation
- Languages and Technologies
  - Move from Java to C
  - Move from Web Services to proprietary TCP-based protocol on the internals of Falkon
- Data Management
  - Data caching at executor local disk
    - Caching strategies: LRU, FIFO, popularity, …
  - Data replication at Grid site shared file systems
    - Replication strategies to meet a desired QoS

Future Work

- 3-Tier Architecture
  - Overview
    - Tier 1: Forwarder
      - Accept task submission from client(s) and forward them to appropriate dispatcher(s)
    - Tier 2: Dispatcher
      - Same as current Tier 1, but every Grid site (cluster) would have a separate dispatcher
    - Tier 3: Executor
      - Same as current Tier 2, and every executor would only communicate with respective local site dispatcher
  - Increases performance and scalability
  - Ensures that Falkon works with local access policies (firewalls, private IP spaces, etc)

More Information

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  - Ian Foster, Math and Computer Science Div., Argonne National Laboratory & Computer Science Dept., The University of Chicago
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  - Swift Specific: yongzh@cs.uchicago.edu
- Web: http://people.cs.uchicago.edu/~iraicu/research/Falkon/
- Source Code: http://people.cs.uchicago.edu/~iraicu/research/Falkon/Falkon_v0.8.tgz
- Related Projects:
  - Swift: http://www.ci.uchicago.edu/swift/index.php
  - AstroPortal: http://people.cs.uchicago.edu/~iraicu/research/AstroPortal/index.htm
- Documents:
  - Ioan Raicu, Yong Zhao, Catalin Dumitrescu, Ian Foster, Mike Wilde. “Falkon: a Fast and Light-weight tasK executiON framework”, under review at IEEE/ACM SuperComputing 2007.
  - Ioan Raicu, Catalin Dumitrescu, Ian Foster. Dynamic Resource Provisioning in Grid Environments, to appear TeraGrid Conference 2007.
  - Yong Zhao, Mihael Hategan, Ben Clifford, Ian Foster, Gregor von Laszewski, Ioan Raicu, Tiberiu Stef-Praun, Mike Wilde. “Swift: Fast, Reliable, Loosely Coupled Parallel Computation”, to appear at IEEE Workshop on Scientific Workflows 2007.
  - Yong Zhao, Mihael Hategan, Ioan Raicu, Mike Wilde, Ian Foster. “Swift: a Parallel Programming Tool for Large Scale Scientific Computations”, under review at Scientific Programming Journal, Special Issue on Dynamic Computational Workflows: Discovery, Optimization, and Scheduling.