the globus project™
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GRAM: Grid Resource Allocation & Management

Globus Toolkit™ Developer Tutorial

The Globus Project™

Argonne National Laboratory

USC Information Sciences Institute

http://www.globus.org/

Components of Resource Management

- Resource Specification Language (RSL) is used to communicate requirements
- The Globus Resource Allocation Manager (GRAM) API allows programs to be started on remote resources
- A layered architecture allows application-specific resource brokers and co-allocators (e.g. DUROC) to be defined in terms of GRAM services

GRAM is responsible for

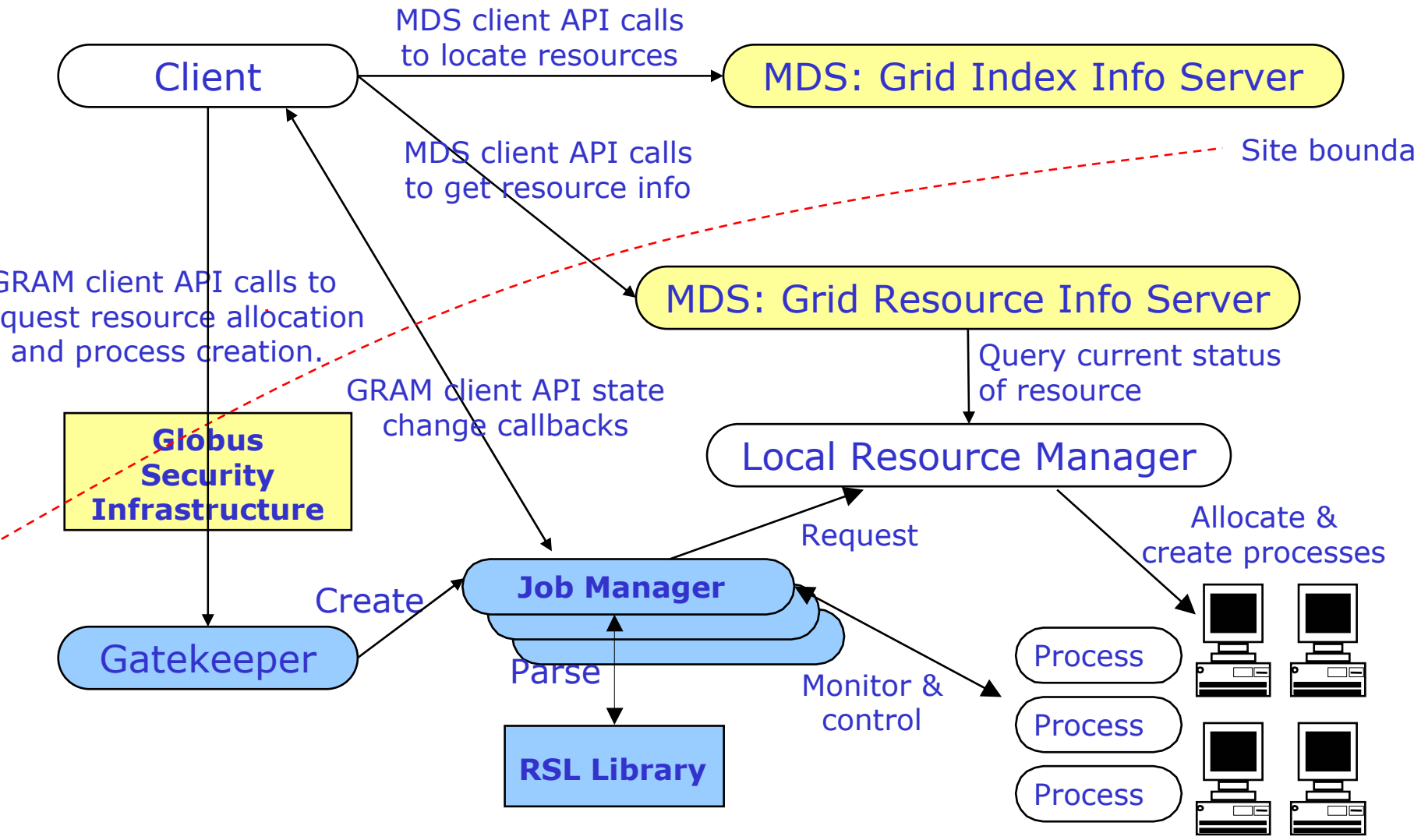
- Parsing and processing the RSL specifications
- Enabling remote monitoring and managing of jobs
- Updating MDS with information regarding the availability of the resources it manages

Functionalities of GRAM

- GRAM allows you to run jobs remotely
- Provides an API for
  - Submitting
  - Monitoring
  - Terminating

  your job

GRAM Components



How GRAM works?

- To run a job remotely,
  - a GRAM gatekeeper server must be running on a remote computer, listening at port 2119
  - The application must be compiled on that remote machine
- The execution begins:
  - When a GRAM user application runs on the client machine
  - Sending a job request to the remote site
  - A job is submitted using the client API and creating an RSL specification
- Job request contains:
  - Executable, stdin, stdout
  - Name and port of the remote computer

How GRAM works?

- The request is sent to the GRAM gatekeeper server of the remote computer which:
  - Checks globus certificate
  - Creates a job manager for the job
- The job manager:
  - Parses RSL
  - Starts and monitors the remote program
  - Communicates state changes to the client
  - Terminates when the job terminates

Components of GRAM

- Job request – a request to gatekeeper to create one or more job processes, expressed in the RSL
- This request guides:
  - **Resource selection** (when and where to create the job processes)
  - **Job process creation** (what job processes to create)
  - **Job control** (how the processes should execute)

Components of GRAM

- Gatekeeper – a process, running as root, which begins the process of handling allocation requests
- Its tasks:
  - Mutually authenticates with the client
  - Maps the requestor to a local user
  - Starts a job manager on the local host as the local user
  - Passes the allocation arguments to the newly created job manager

Components of GRAM

- Job Manager – one process for each job, to fulfill every request submitted to the gatekeeper
- Its tasks:
  - Starts the job on the local system (e.g. by any local resource manager like Condor, SGE, etc.)
  - Handles all further communication with the client

Two Components of the Job Manager

- Common Component
  - Translates messages received from the gatekeeper and client into an internal API
  - Translates callback requests from the machine specific components into messages to the application manager
- Machine-Specific Component
  - Implements the internal API in the local environment that includes
    - > Calls to the local system
    - > Message to the resource monitor
    - > Inquiries to the MDS

Resource Management APIs

- Globus Toolkit has APIs for RSL, GRAM, and DUROC:
  - globus_rsl
  - globus_gram_client
  - globus_gram_myjob
  - globus_duroc_control
  - globus_duroc_runtime

Resource Specification Language

- Much of the power of GRAM is in the RSL
- Common language for specifying job requests
  - GRAM service translates this common language into scheduler specific language
- GRAM service constrains RSL to a conjunction of (attribute=value) pairs
  - E.g. &(executable="/bin/ls")(arguments="-l")
- GRAM service understands a well defined set of attributes

globus_rsl

- Module for manipulating RSL expressions
  - Parse an RSL string into a data structure
  - Functions to manipulate the data structure
  - Unparse the data structure into a string
- Can be used to assist in writing brokers or filters which refine an RSL specification

globus_rsl

- Contains three main parts:
  - Information about the application program
  - Information about the remote computer
  - Control information (e.g. job_state_mask)

RSL Attributes for the Program

- (executable=string)
  - Program to run
  - A file path (absolute or relative) or URL
- (directory=string)
  - Directory in which to run (default is $HOME)
- (arguments=arg1 arg2 arg3...)
  - List of string arguments to program
- (environment=(E1 v1)(E2 v2))
  - List of environment variable name/value pairs

RSL Attributes for the Program

- (stdin=string)
  - Stdin for program
  - A file path (absolute or relative) or URL
- (stdout=string)
  - Stdout for program
  - A file path (absolute or relative) or URL
- (stderr=stderr)
  - Stderr for program
  - A file path (absolute or relative) or URL

RSL Attributes for Control

- (count=integer)
  - Number of processes to run (default is 1)
- (hostCount=integer)
  - On SMP multi-computers, number of nodes to distribute the "count" processes across
- (project=string)
  - Project (account) against which to charge
- (queue=string)
  - Queue into which to submit job

RSL Attributes for Control

- (maxTime=integer)
  - Maximum wall clock or cpu runtime (schedulers's choice) in minutes
- (maxWallTime=integer)
  - Maximum wall clock runtime in minutes
- (maxCpuTime=integer)
  - Maximum CPU runtime in minutes

RSL Attributes for Control

- (maxMemory=integer)
  - Maximum amount of memory for each process in megabytes
- (minMemory=integer)
  - Minimum amount of memory for each process in megabytes

RSL Attributes for Control

- (jobType=value)
  - Value is one of “mpi”, “single”, “multiple”, or “condor”
    - > mpi: Run the program using “mpirun -np <count>”
    - > single: Only run a single instance of the program, and let the program start the other count-1 processes.
    - > multiple: Start <count> instances of the program using the appropriate scheduler mechanism
    - > condor: Start a <count> Condor processes running in “standard universe”

RSL Attributes for Control

- (gramMyjob=value)
  - Value is one of "collective", "independent"
  - Defines how the globus_gram_myjob library will operate on the <count> processes
    - collective: Treat all <count> processes as part of a single job
    - independent: Treat each of the <count> processes as an independent uniprocessor job
- (dryRun=true)
  - Do not actually run job

Constraints: "&"

- For example:

  "Create 5-10 instances of myprog, each on a machine with at least 64 MB memory that is available to me for 4 hours"

  ```
  & (count>=5) (count<=10)
     (max_time=240) (memory>=64)
     (executable=myprog)
  ```

Disjunction: "|"

- For example:
- Create 5 instances of myprog on a machine that has at least 64MB of memory, or 10 instances on a machine with at least 32MB of memory

```
& (executable=myprog)
   ( | (&(count=5)(memory>=64))
       (&(count=10)(memory>=32)))
```

RSL Attributes for Control

- (save_state=yes)
  - Causes the jobmanager to save job state/information to a persistent file on disk
  - Recover from a jobmanager crash
  - New in Globus Toolkit v2.0
- (two_phase=<int>)
  - Implement a two-phase commit for job submission and completion
  - <int>=seconds to wait before job times out
  - New in Globus Toolkit v2.0

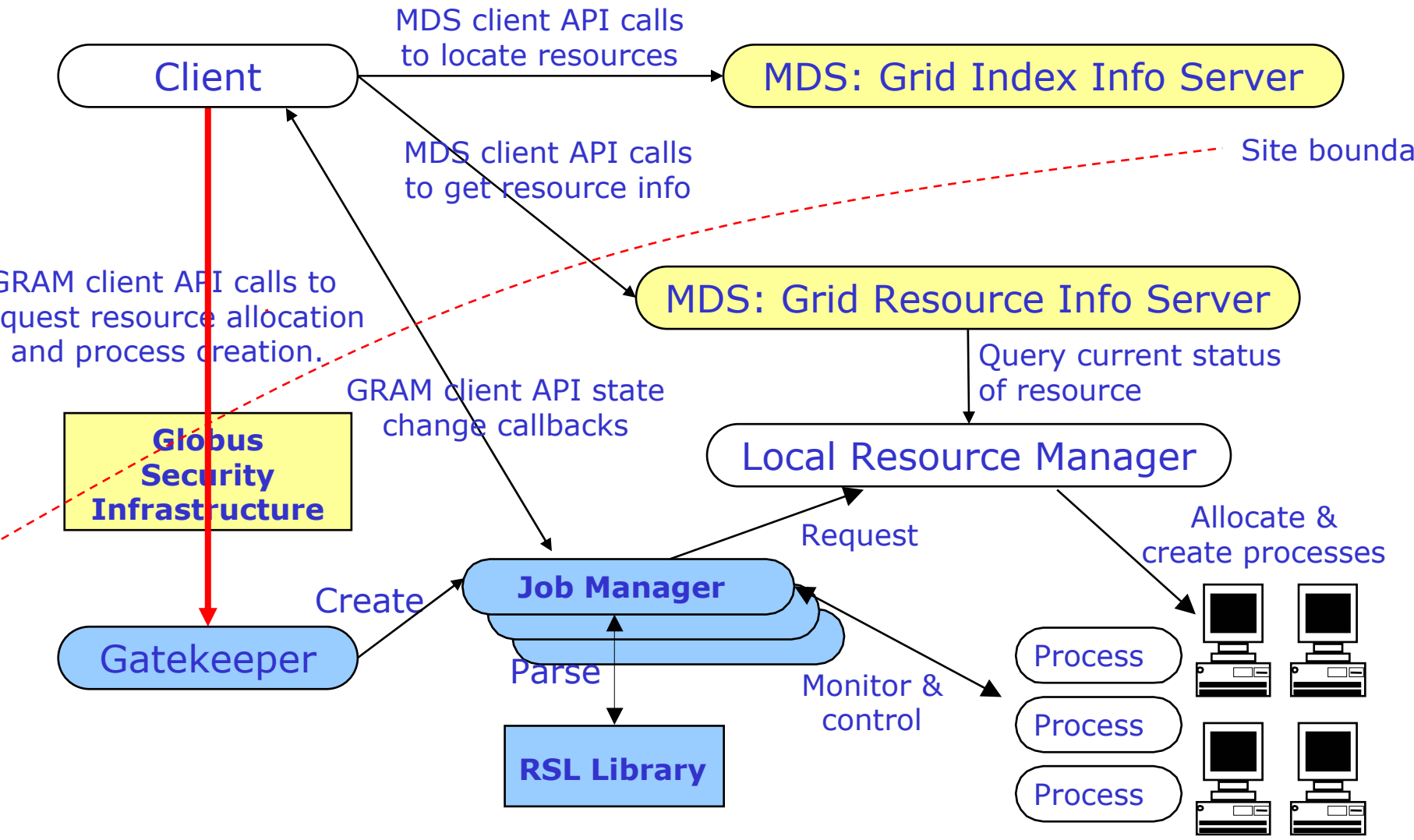
RSL Attributes for Control

- (restart=<old jm contact>)
  - Start a new jobmanager but instead of submitting a new job, start watching over an existing job.
  - New in Globus Toolkit v2.0
- (stdout_position=<int>)
- (stderr_position=<int>)
  - specified as part of a job restart
  - restart file streaming from this byte
  - New in Globus Toolkit v2.0

globus_gram_client

- globus_gram_client_job_request()
  - Submit a job to a remote resource
  - Input:
    - Resource manager contact string
    - RSL specifying the job to be run
    - Callback contact string, for notification
  - Output:
    - Job contact string

GRAM Components



Finding The Gatekeeper

- globus_gram_client_job_request() requires a resource manager contact string to find the gatekeeper

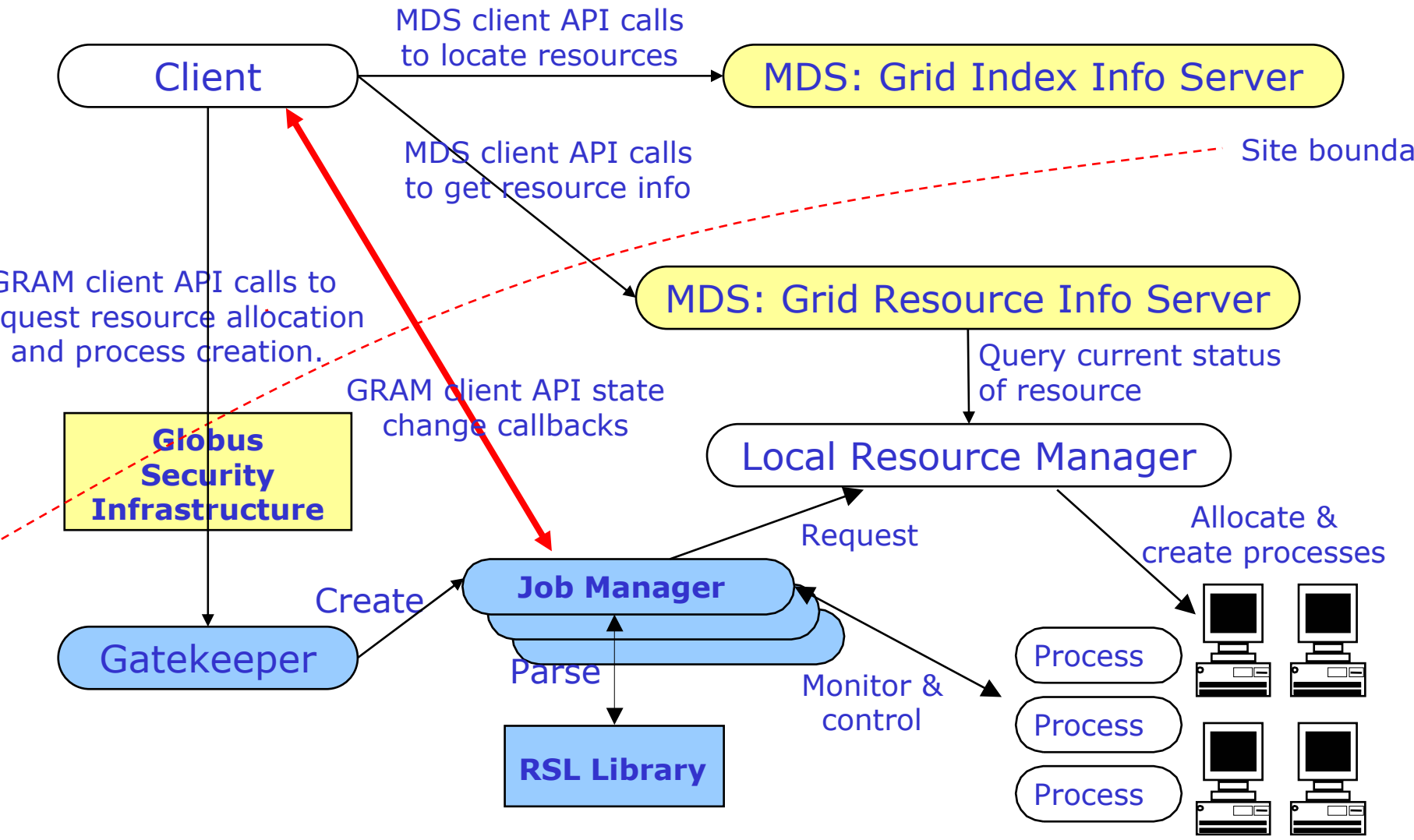
  hostname[:port][/service][:subject]

  - hostname – host of gatekeeper
    - > required
  - port – port on which gatekeeper is listening
    - > defaults to well known port = gsigatekeeper = 2119
  - service – gatekeeper service to invoke
    - > defaults to "jobmanager"
  - subject – security subject name of gatekeeper
    - > Defaults to standard host cert form: "…/cn=host/hostname"
    - > Applies fuzzy match to deal with interface names, etc.

Job Contact

- globus_gram_client_job_request() returns a job contact
  - Opaque string
  - Other globus_gram_client_*() functions use the job contact to find the right job manager to which requests are made
  - Job contact string can be passed between processes, even on different machines

GRAM Components



globus_gram_client

- globus_gram_client_job_status()
  - Check the status of the job
    - > UNSUBMITTED, PENDING, ACTIVE, FAILED, DONE, SUSPENDED
  - Can also get job status through callbacks
    - > globus_gram_client_callback_{allow,disallow,check}()
- globus_gram_client_job_cancel()
  - Cancel/kill a pending or active job

globus_gram_client

- globus_gram_client_job_signal()
  - Controls the jobmanager
  - COMMIT_REQUEST*
    - > submit job
  - COMMIT_END*
    - > Cleanup job
  - COMMIT_EXTEND*
    - > Wait additional N seconds
  - * when jobs have "(two_phased=yes)"

globus_gram_client

- globus_gram_client_job_signal(), continued
  - STDIO_UPDATE
    - > Allows client to submit an RSL that changes some I/O attributes of the job
      - stdout, stderr, stdout_position, stderr_position, remote_io_url
  - STDIO_SIZE
    - > verify that streamed I/O has been completely received
  - STOP_MANAGER
    - > Tells JM to exit, but leave the job running

State Change Callbacks

- GRAM managed job can be in the states:
  - Unsubmitted, Pending, Active, Failed, Done, Suspended
- GRAM client can register for asynchronous state change callbacks
  - Registration can be done during submission
    - > Globus_gram_client_job_request()
  - Registration can be done later by any process, using the job contact
    - > globus_gram_client_job_callback_register()

globus_gram_client

- globus_gram_client_callback_allow()
  globus_gram_client_callback_disallow()
  globus_gram_client_callback_check()
  - Create/destroy a client port to listen for asynchronous state change callbacks
  - Callback to local function on state change
- globus_gram_client_job_callback_register()
  globus_gram_client_job_callback_unregister()
  - Register with job manager to receive callbacks

globus_gram_myjob

- When a set of processes in a single job startup, they may need to self organize
  - How many processes in the job?
  - What is my rank within the job?
  - Simple send/receive between job processes.
- This API is a minimal set of functions to allow this self organization
- This is a bootstrapping library. It is NOT meant to be a general purpose message passing library for use by applications

DUROC Review

- Simultaneous allocation of a resource set
  - Handled via optimistic co-allocation based on free nodes or queue prediction
  - In the future, advance reservations will also be supported
- globusrun will co-allocate specific multi-requests
  - Uses a Globus component called the **Dynamically Updated Request Online Co-allocator** (DUROC)

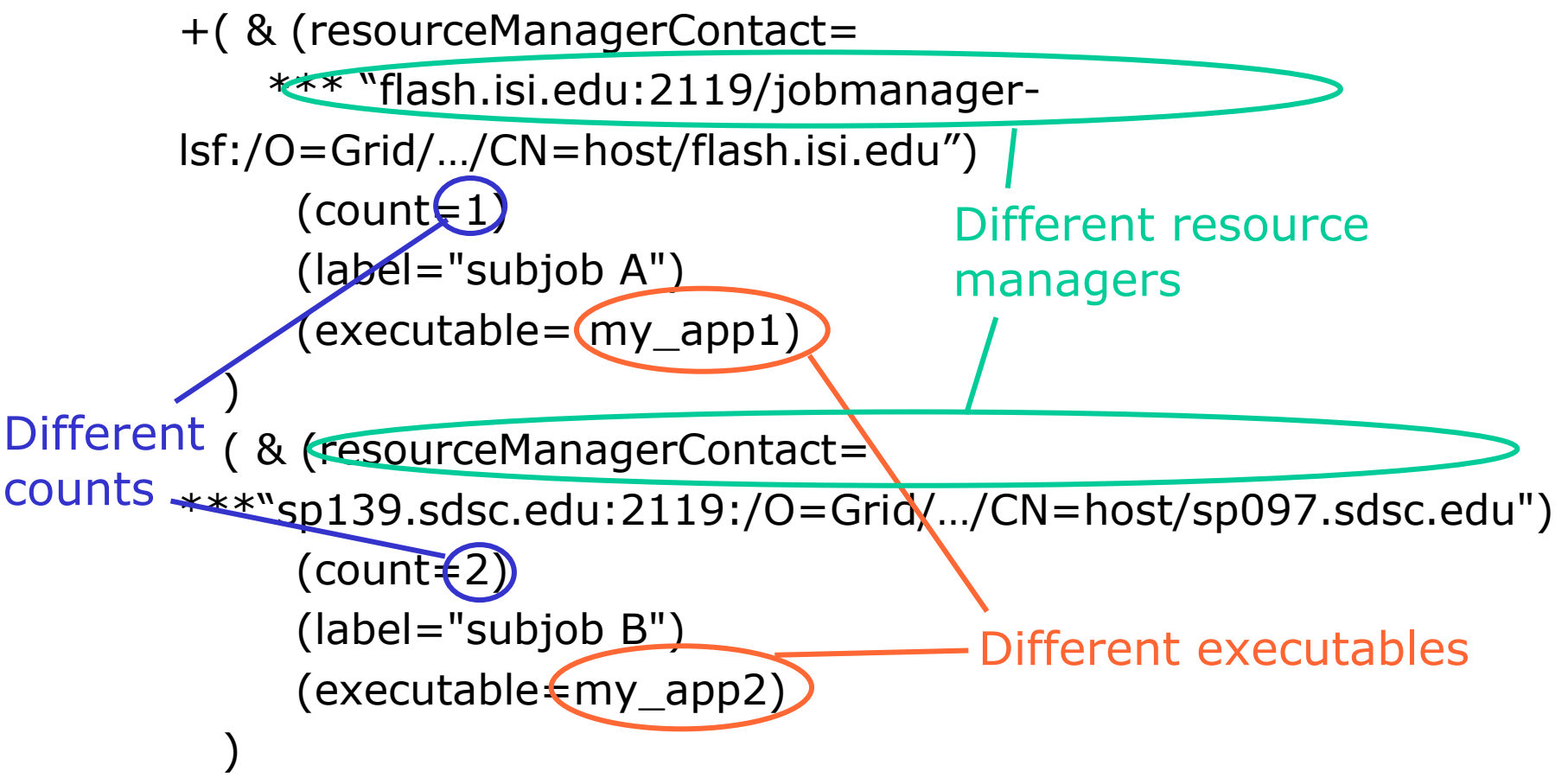
Multirequest: "+"

- A multirequest allows us to specify multiple resource needs, for example

```
+ (& (count=5)(memory>=64)
       (executable=p1))
   (&(network=atm) (executable=p2))
```

  - Execute 5 instances of p1 on a machine with at least 64M of memory
  - Execute p2 on a machine with an ATM connection
- Multirequests are central to co-allocation

A Co-allocation Multirequest



RSL Attributes For DUROC

- (subjobStartType=value)
  - Alters the startup barrier mechanism
  - values are “strict-barrier”, “loose-barrier”, “no-barrier”
- (subjobCommsType=value)
  - values are “blocking-join” and “independent”
  - if value is set to “independent”, the subjob won’t be seen from the other subjobs when doing inter-subjob communication.

RSL Attributes For DUROC

- (label=string)
  - Identifier for this subjob
- (resourceManagerContact=string)
  (resourceManagerName=string)
  - Resource manager to which to submit a subjob

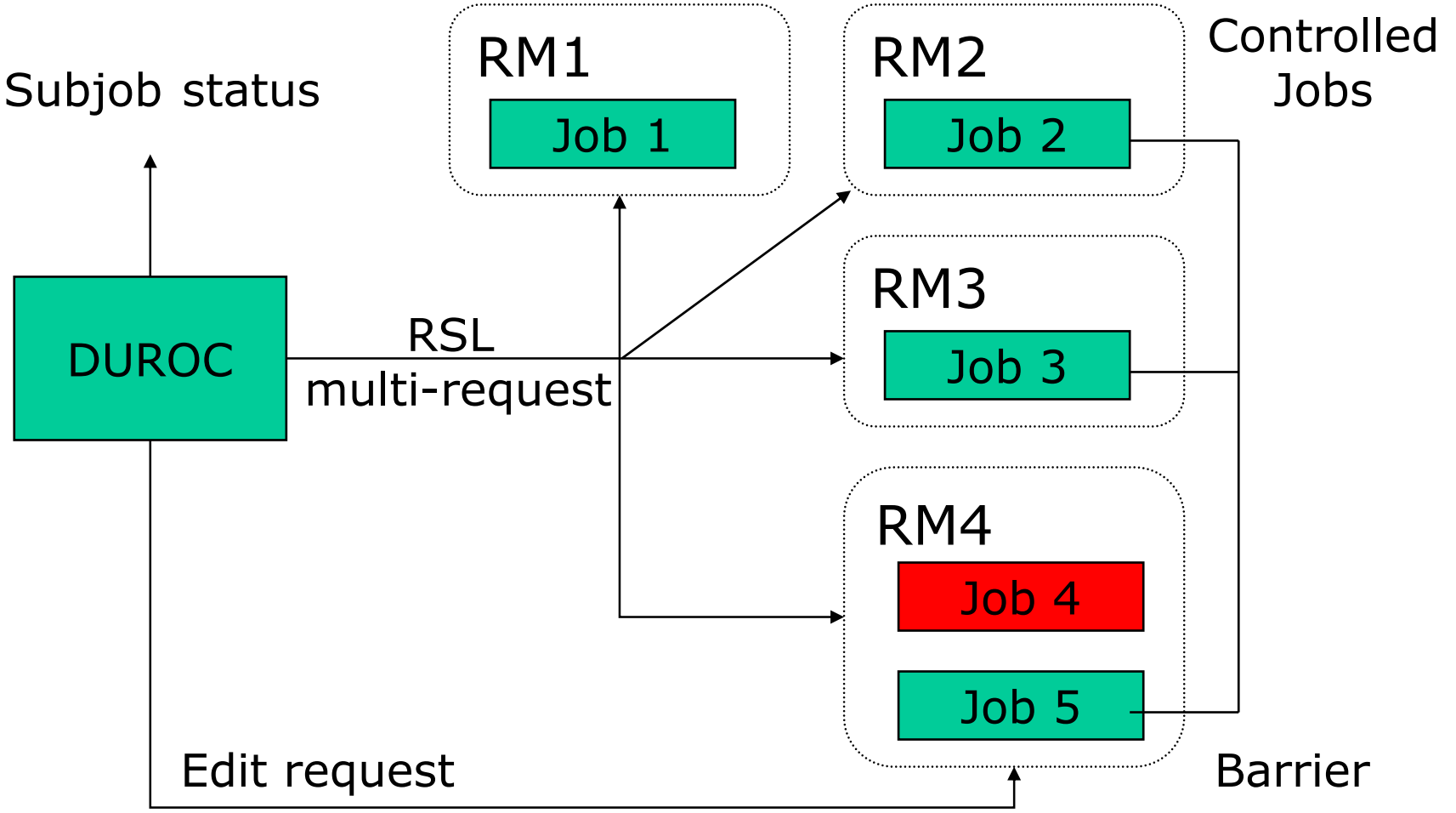
globus_duroc_control Module

- Submit a multi-request
- Edit a pending request
  - Add new nodes, edit out failed nodes
- Commit to configuration
  - Delay to last possible minute
  - Barrier synchronization
- Initialize computation
  - Bootstrap library
- Monitor and control collection

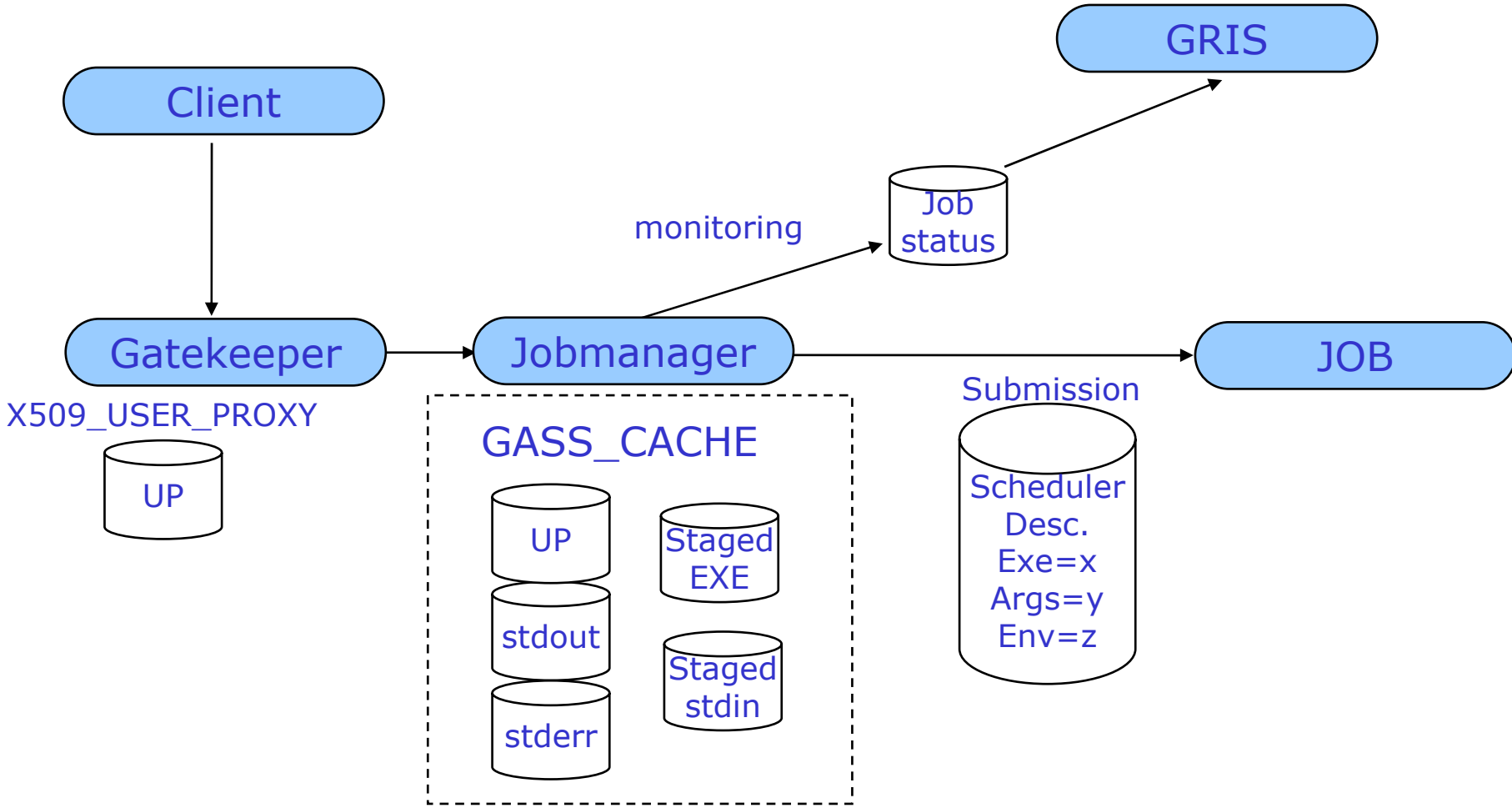
globus_duroc_runtime Module

- globus_duroc_runtime_barrier()
  - All processes in DUROC job must call this
  - It will wait until the DUROC control module releases all processes from the barrier
- globus_duroc_runtime_inter_subjob_*()
  - Bootstrap library between subjobs
- globus_duroc_runtime_intra_subjob_*()
  - Bootstrap library within a subjob

DUROC Architecture



Job Manager Files



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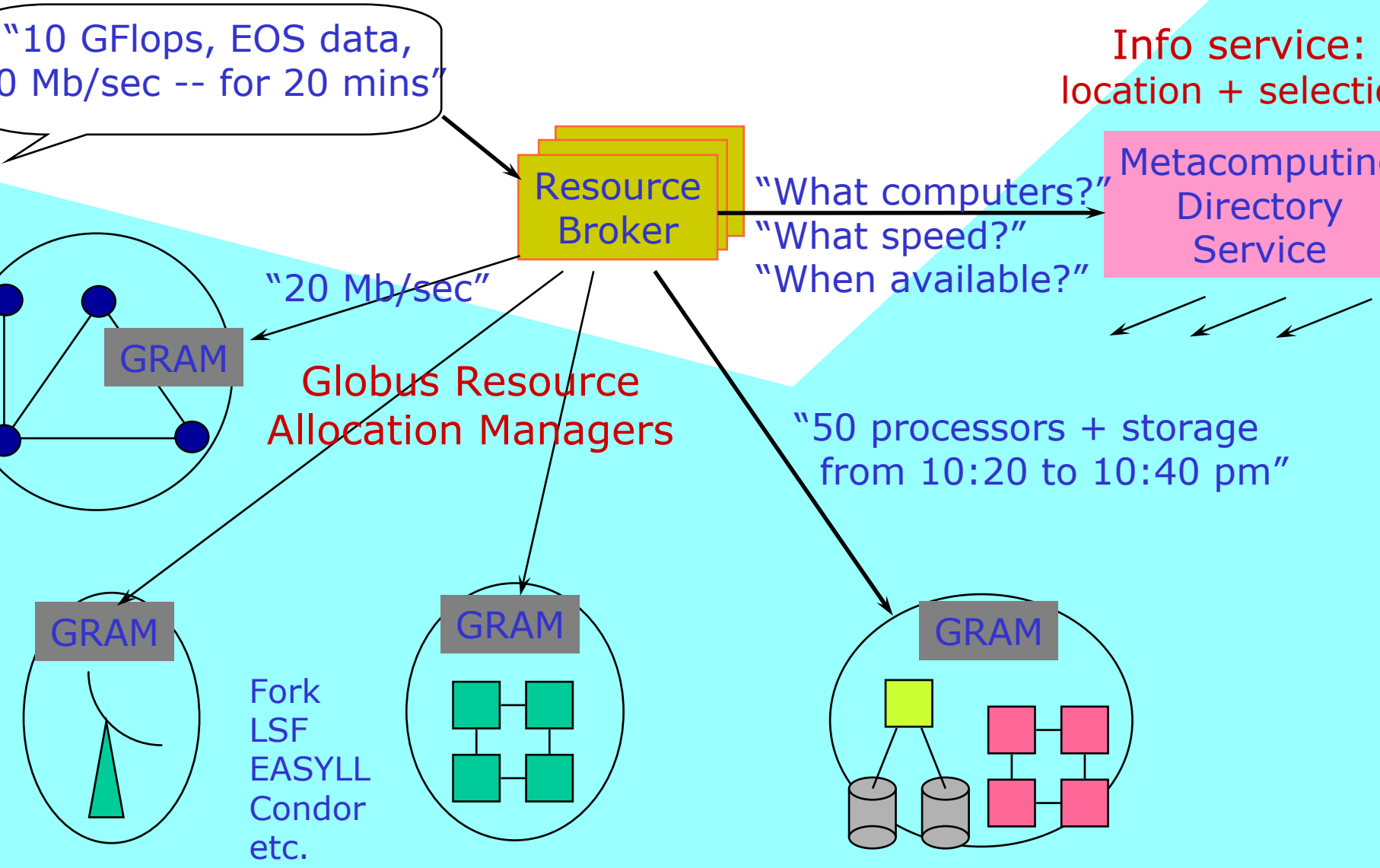
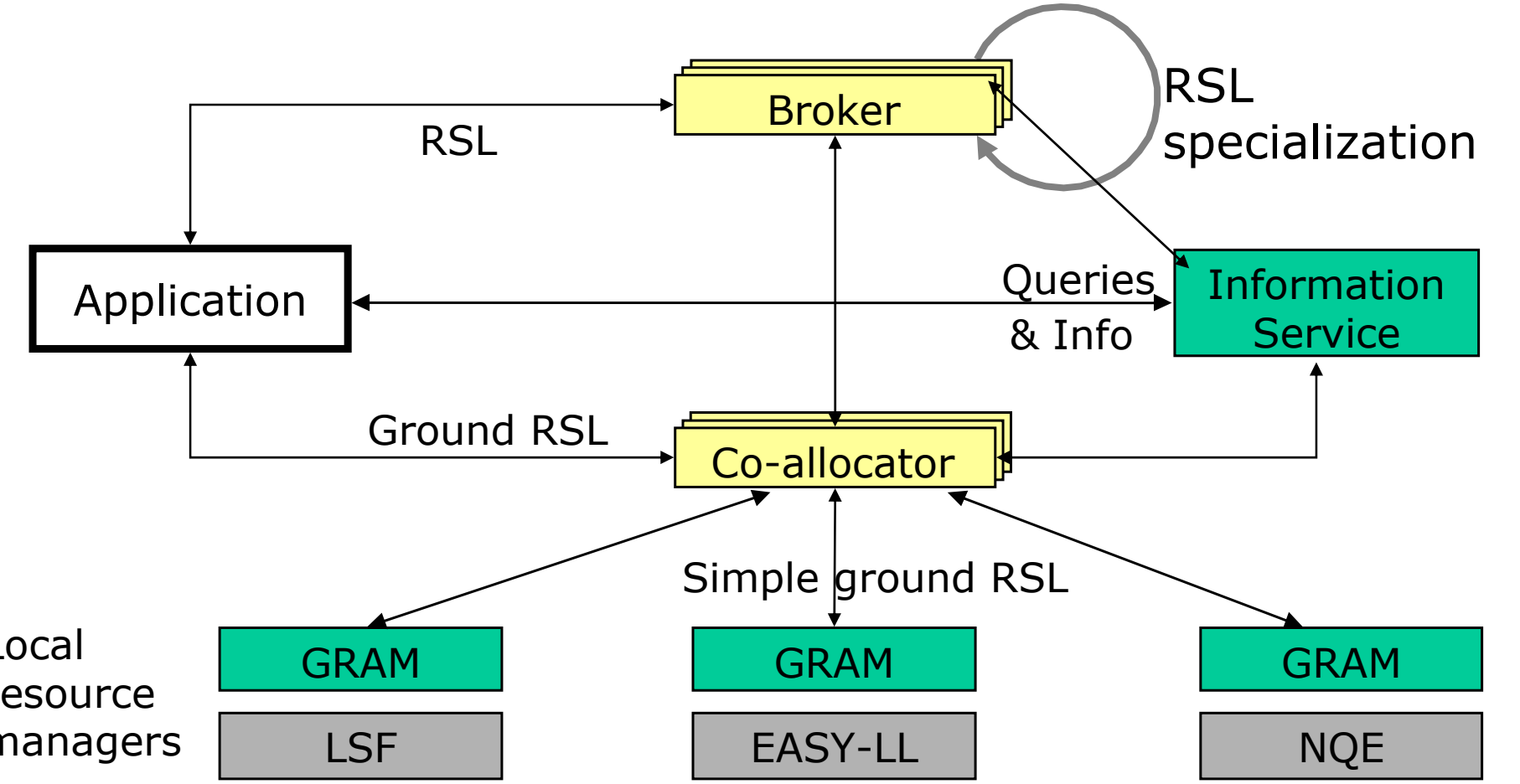
Using Information for Resource Brokering



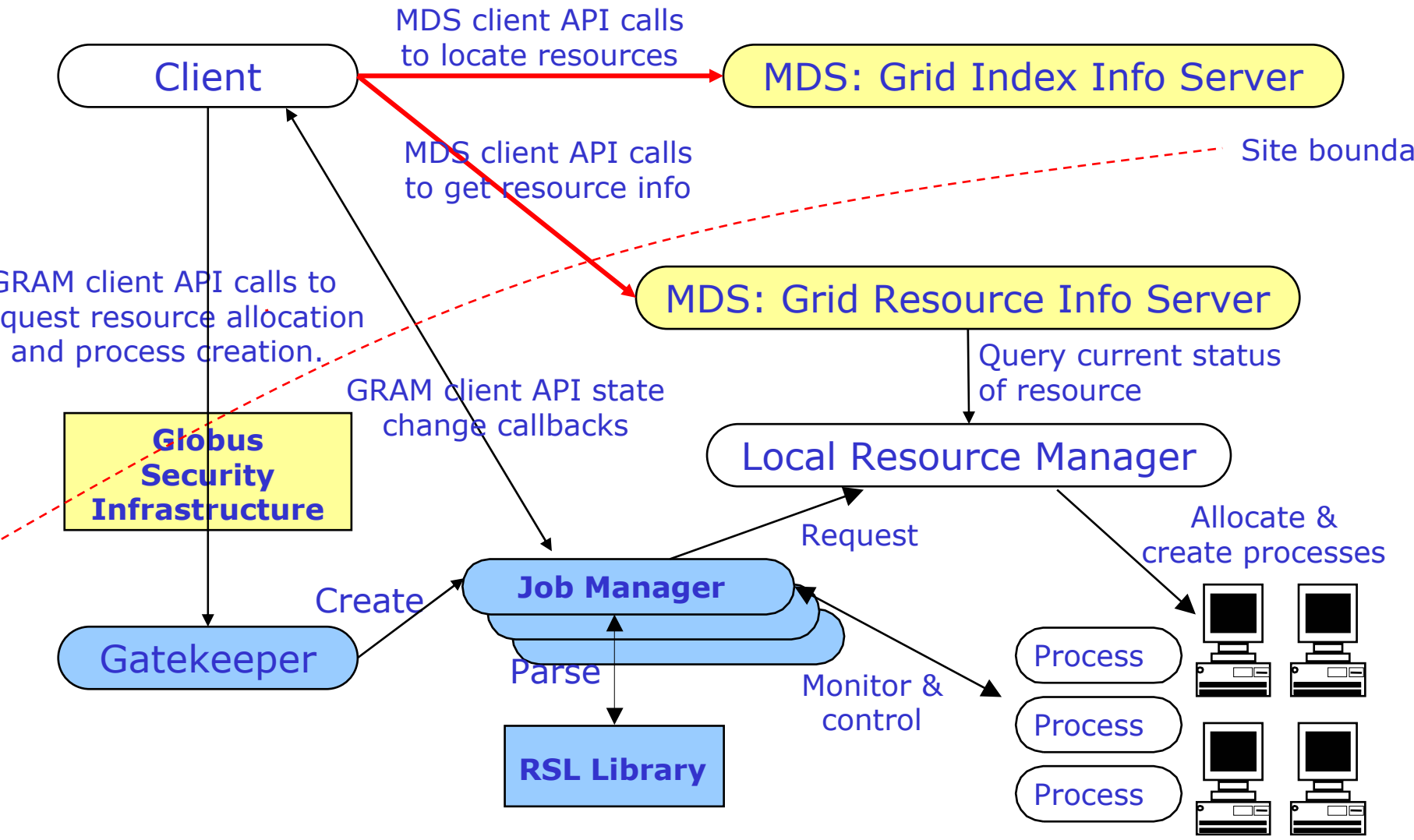
Resource Management Architecture



Resource Broker

- The Globus Toolkit does not include a resource broker or a metascheduler!
- It is the task of the user to access MDS (GIIS and GRIS) and select the remote site where the program should run

GRAM Components



Resource Broker

- The Globus team helped many people to build brokers using GRAM and MDS services
- Several brokers now exist:
  - Condor-G, DRM, PUNCH, Nimrod/G, Cactus, AppLeS,

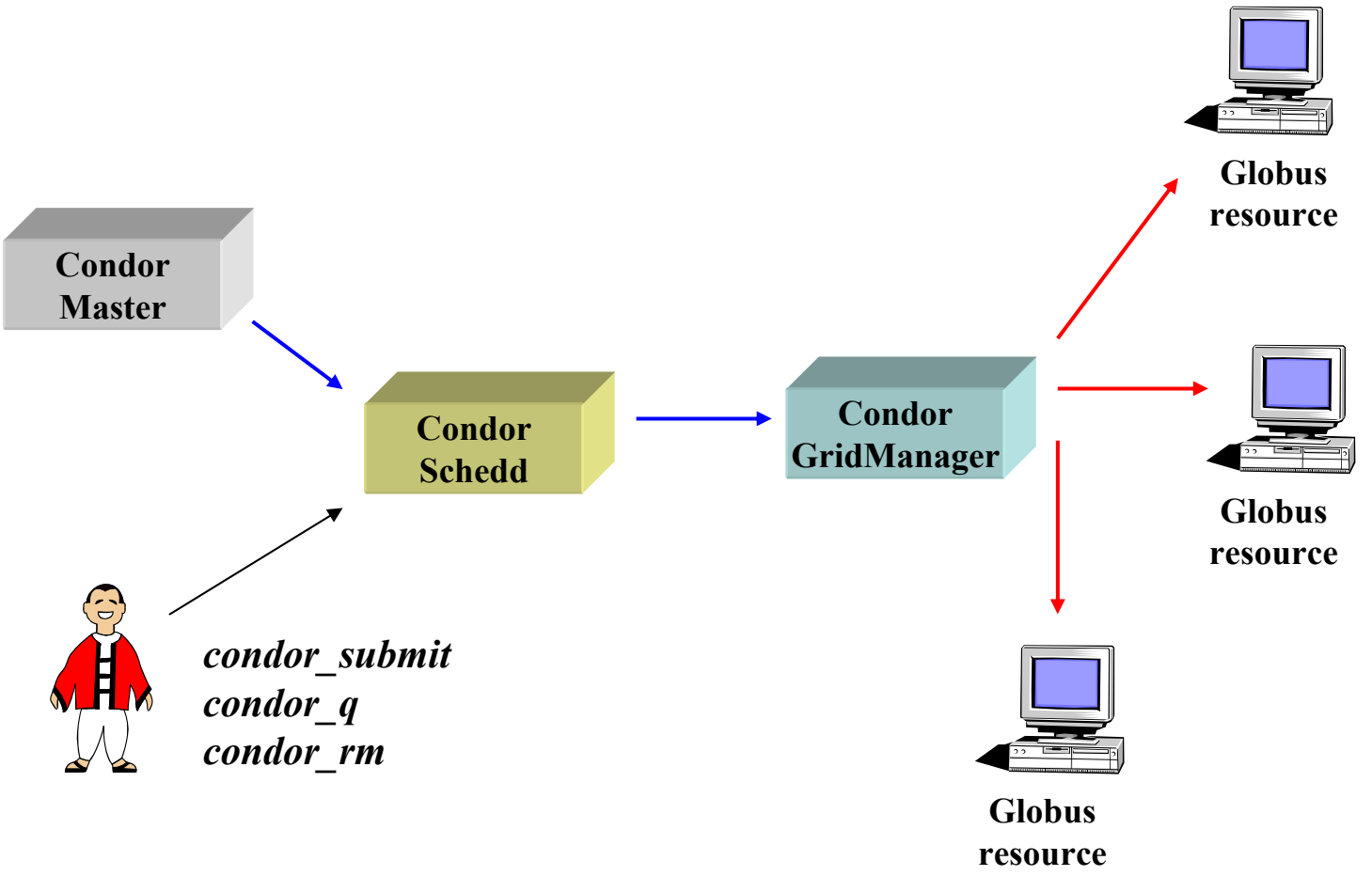
What is Condor-G?

- Condor-G is a Personal-Condor enhanced with Globus services
- It knows how to speak to Globus resources via GRAM
- It can be used to submit jobs to remote Globus resources
- It makes Condor keep track of their progress

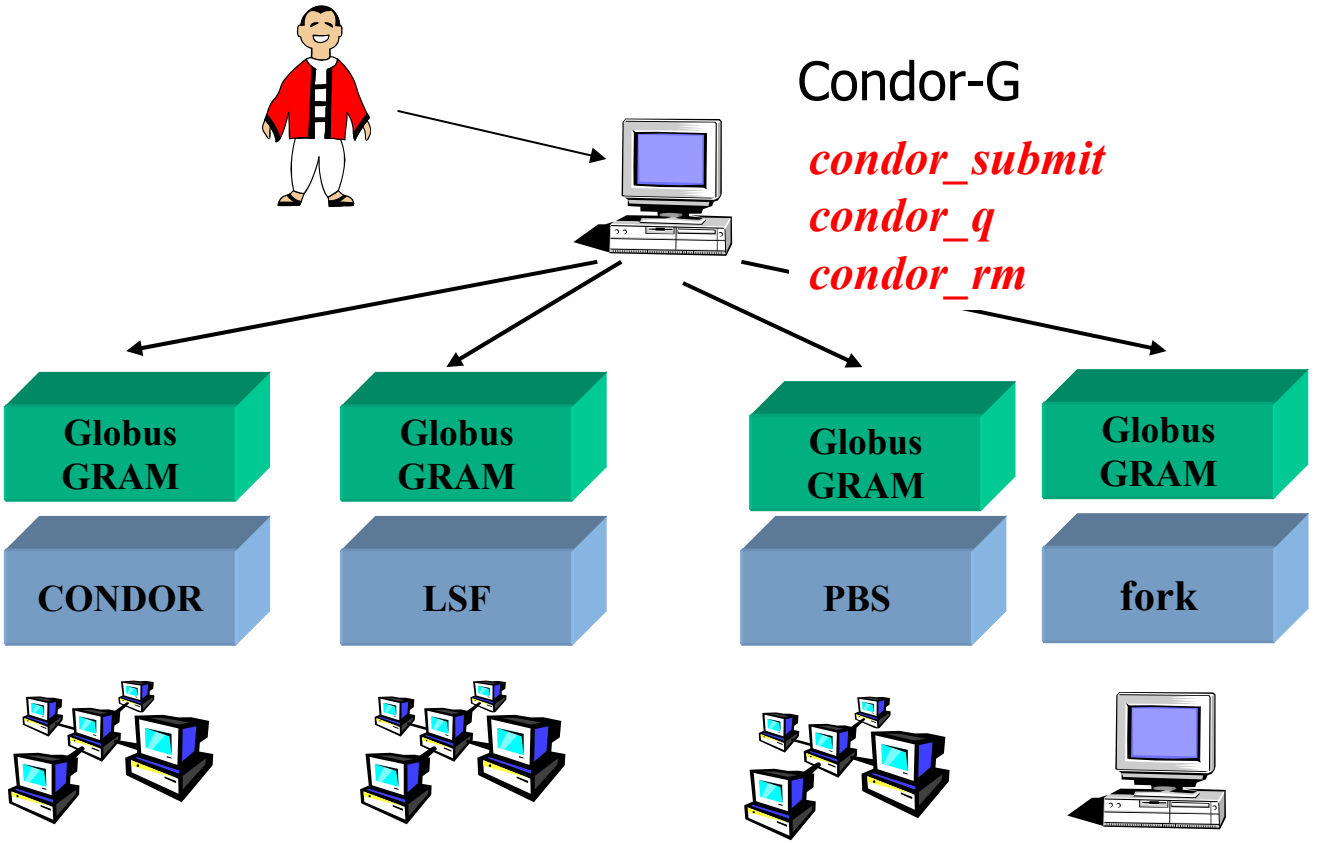
Condor-G: Condor for the Grid

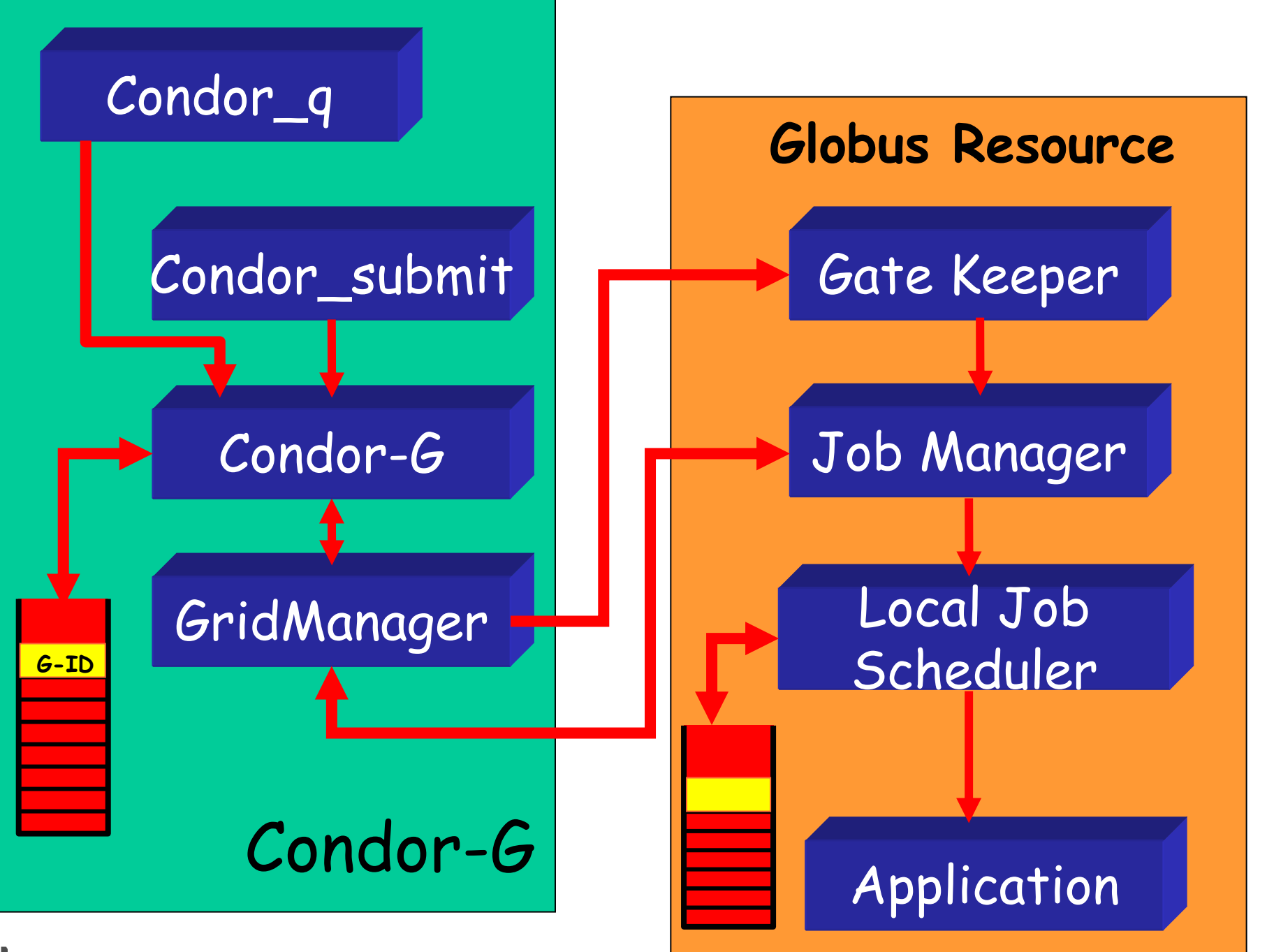
- Condor is a high-throughput scheduler
- Condor-G uses Globus Toolkit libraries for:
  - Security (GSI)
  - Managing remote jobs on Grid (GRAM)
  - File staging & remote I/O (GSI-FTP)
- Grid job management interface & scheduling
  - Robust replacement for Globus Toolkit programs
    - > To implement a reliable, crash-proof, checkpointable job submission service
  - Supports single or high-throughput apps on Grid
    - > Personal job manager which can exploit Grid resources

The Use of Condor-G

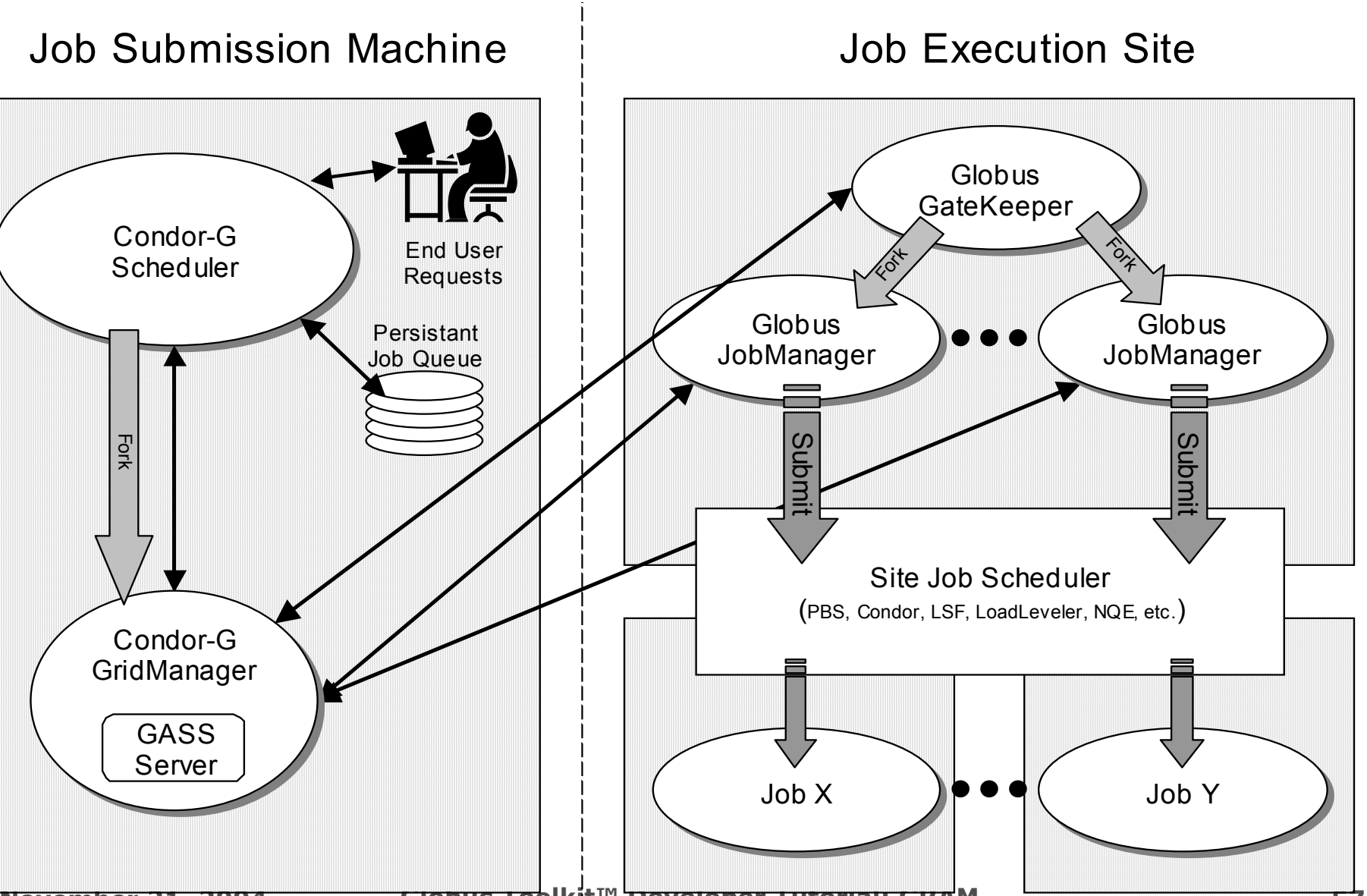


Condor-G as user job submission service




Condor_q
Condor_submit
Condor-G
GridManager
G-ID
Condor-G
Globus Resource
Gate Keeper
Job Manager
Local Job Scheduler
Application

Condor-G

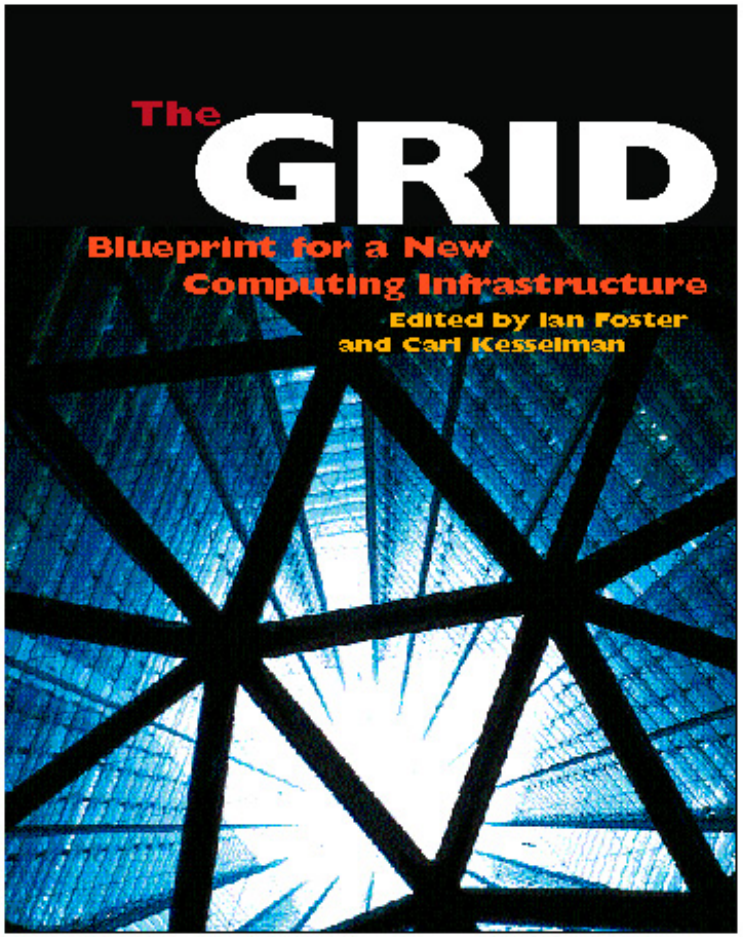

Job Submission Machine
Job Execution Site
Condor-G Scheduler
End User Requests
Persistant Job Queue
Fork
Condor-G GridManager
GASS Server
Globus GateKeeper
Fork
Fork
Globus JobManager
Globus JobManager
Submit
Submit
Site Job Scheduler
(PBS, Condor, LSF, LoadLeveler, NQE, etc.)
Job X
Job Y

The Grid:
Blueprint for a New Computing Infrastructure

I. Foster, C. Kesselman (Eds), Morgan Kaufmann, 1999

- Available July 1998;

  ISBN 1-55860-475-8
- 22 chapters by expert authors including Andrew Chien, Jack Dongarra, Tom DeFanti, Andrew Grimshaw, Roch Guerin, Ken Kennedy, Paul Messina, Cliff Neuman, Jon Postel, Larry Smarr, Rick Stevens, and many others



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