An Example Grid Middleware
-
The Globus Toolkit

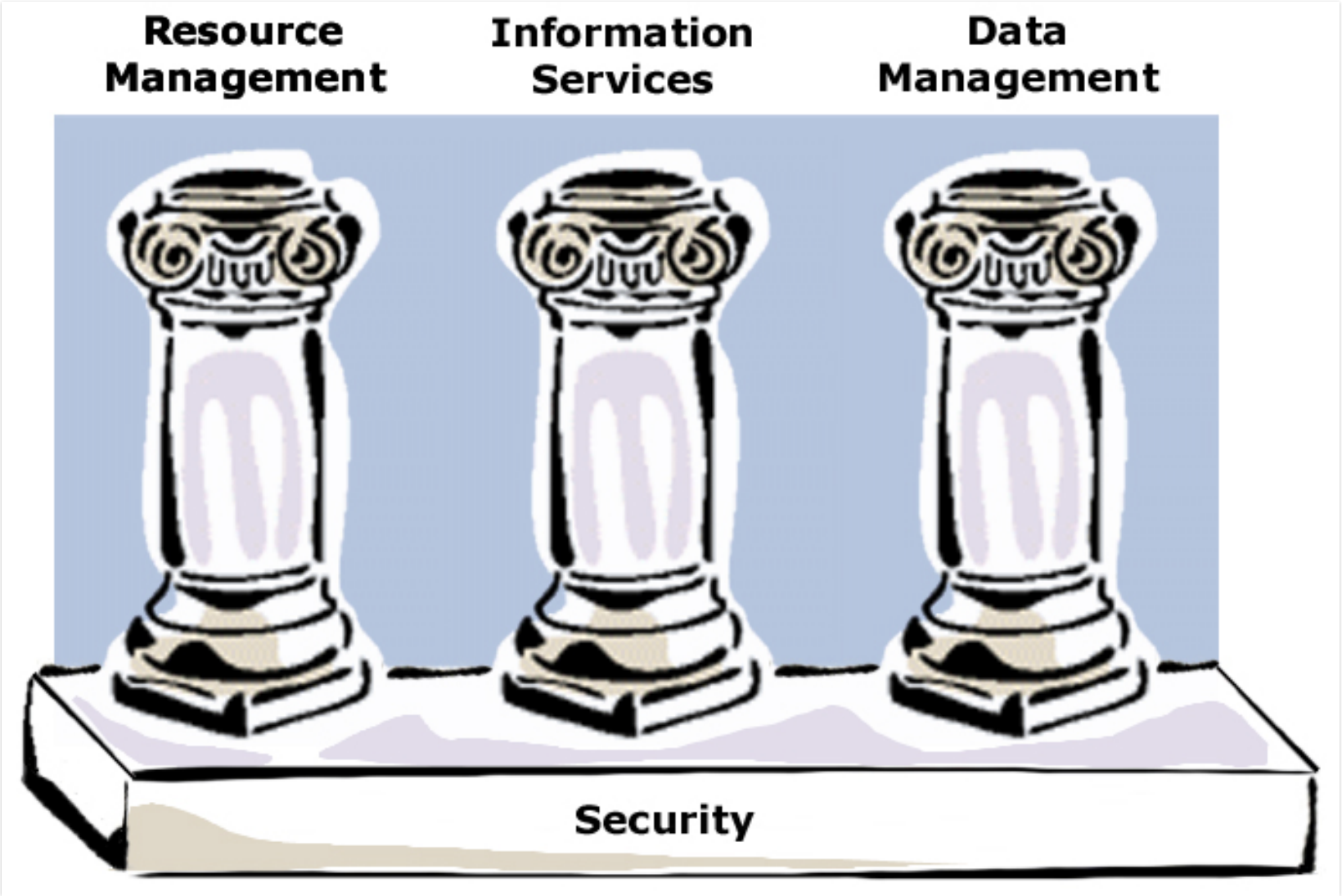
Globus Toolkit™

- A software toolkit addressing key technical problems in the development of Grid enabled tools, services, and applications
  - Offer a modular "bag of technologies"
  - Enable *incremental* development of Grid-enabled tools and applications
  - Implement standard Grid protocols and APIs (the "core" of the hourglass)
  - Is available under liberal open source license

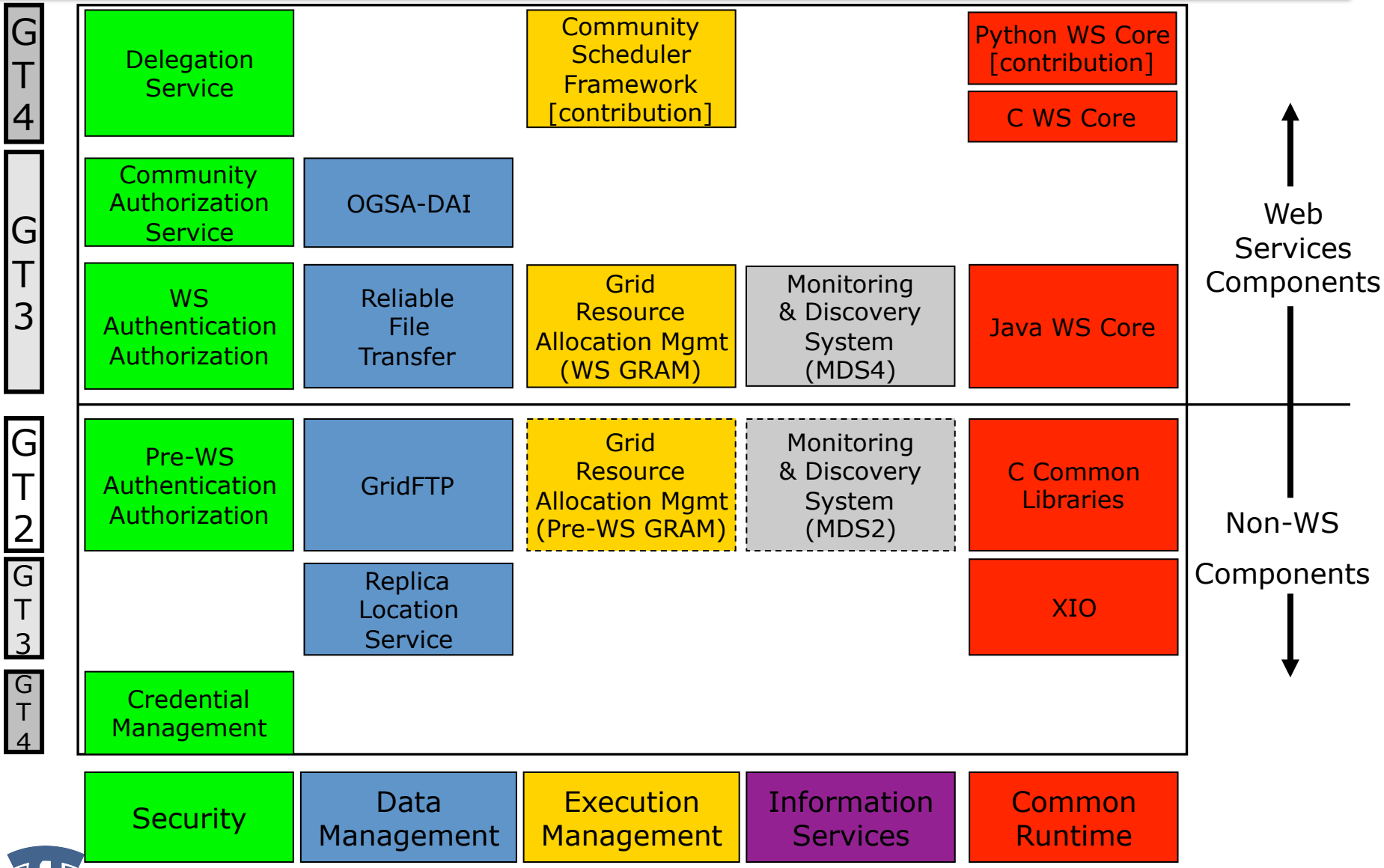
General Approach

- Define Grid protocols & APIs
  - Protocol-mediated access to remote resources
  - Integrate and extend existing standards
  - "On the Grid" = speak "intergrid" protocols
- Develop a reference implementation
  - Open source Globus Toolkit
  - Client and server SDKs, services, tools, etc.
- Grid-enable wide variety of tools
  - Globus Toolkit, FTP, SSH, Condor, SRB, MPI, …
- Integrate user experience gathered through deployment and application integration

Four Key Protocols



Globus Open Source Grid Software



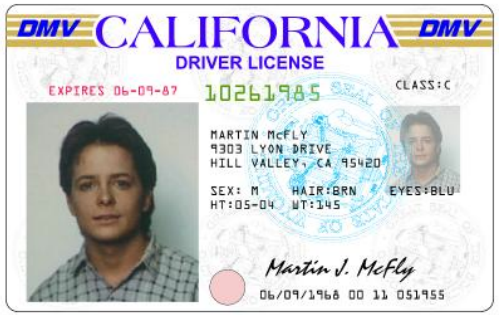
Grid Security

Terminology

- **Authentication**
- **Authorization**
- **Integrity**
- **Confidentiality**
- **Non-repudiation**
- **Delegation**
- **Single Sign On**
- **Digital Signature**

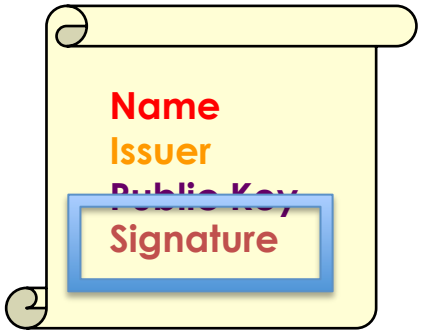
Public Key Infrastructure

- PKI allows you to know that a given public key belongs to a given user
- PKI builds upon asymmetric encryption:
  - Each entity has two keys: public and private
  - Data encrypted with one key can only be decrypted with the other
  - The private key is known only to the owner
- The public key is given to the world encapsulated in a X.509 certificate
  - Similar to passport or driver's license



Certificate Authorities

- A small set of trusted entities known as Certificate Authorities (CAs) are established to sign certificates
- A Certificate Authority is an entity that exists only to sign user certificates
- The CA signs it's own certificate which is distributed in a trusted manner
- Examples: Verisign, DFN, …
- The public key from the CA certificate can then be used to verify other certificates



Certificate Issuance

- To request a certificate a user starts by generating a key pair
- The private key is stored encrypted with a pass phrase the user gives
- The public key is put into a certificate request
- The user then takes the certificate to the CA
- The CA usually includes a Registration Authority (RA) which verifies the request:
  - The name is unique with respect to the CA
  - It is the real name of the user (through ID/passport check)
- The CA then signs the certificate request and issues a certificate for the user

Why Grid Security is Hard

- Resources being used may be valuable & the problems being solved sensitive
- Resources are often located in distinct administrative domains
  - Each resource has own policies & procedures
- Set of resources used by a single computation may be large, dynamic, and unpredictable
  - Not just client/server, requires delegation
- It must be broadly available & applicable
  - Standard, well-tested, well-understood protocols; integrated with wide variety of tools

Grid Security Requirements

User View

1) Easy to use
2) Single sign-on
3) Run applications
   FTP, SSH, MPI, Condor, Web, …
4) User based trust model
5) Proxies/agents (delegation)

Resource Owner View

1) Specify local access control
2) Auditing, accounting, etc.
3) Integration w/ local system
   Kerberos, AFS, license mgr.
4) Protection from compromised resources

Developer View

1) API/SDK with authentication, flexible message protection, flexible communication, delegation, …
   a) Direct calls to various security functions (e.g. GSS-API)
   b) Security integrated into higher-level SDKs

Grid Security Infrastructure (GSI)

- Extensions to standard protocols & APIs
  - Standards: SSL/TLS, X.509 & CA, GSS-API
  - Extensions for single sign-on and delegation
- Globus Toolkit reference implementation of GSI
  - SSLeay/OpenSSL + GSS-API + single sign-on/delegation
  - Tools and services to interface to local security
    - Simple ACLs; SSLK5/PKINIT for access to K5, AFS, …
  - Tools for credential management
    - Login, logout, etc.
    - Smartcards
    - MyProxy: Web portal login and delegation
    - K5cert: Automatic X.509 certificate creation

Delegation: proxies (I)

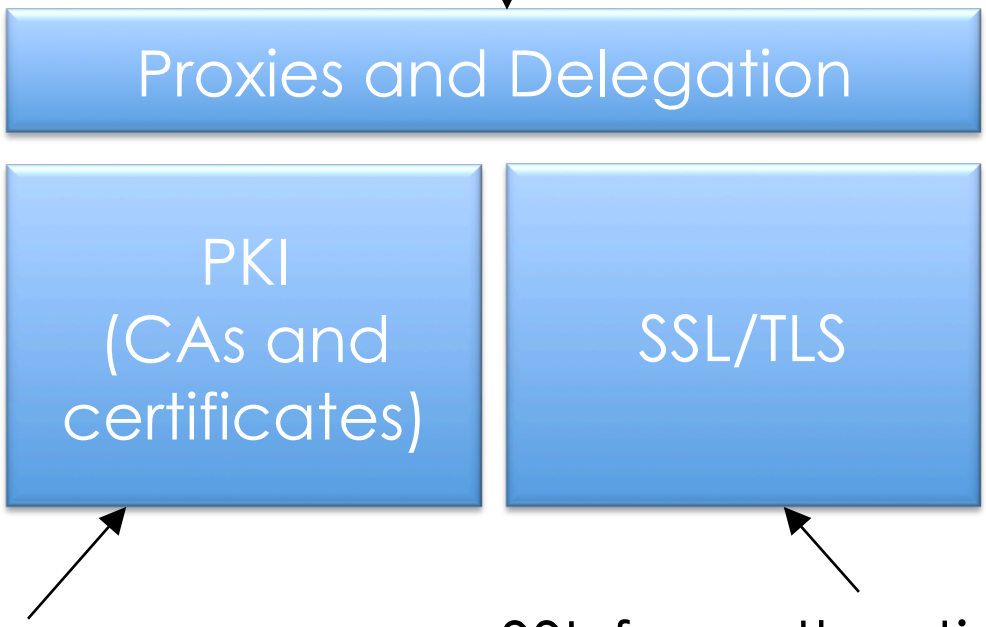
- Delegation = remote creation of a (second level) proxy credential
  - New key pair generated remotely on server
  - Proxy cert and public key sent to client
  - Clients signs proxy cert and returns it
  - Server (usually) puts proxy in temp dir
- Allows remote process to authenticate on behalf of the user
  - Remote process "impersonates" the user

Delegation: proxies (II)

- During delegation, the client can elect to delegate only a **limited proxy**, rather than a "full" proxy (no process creation allowed)
  - Job submission client does this
- Each service decides whether it will allow authentication with a limited proxy
  - Job manager service requires a full proxy
  - File server allows either full or limited proxy to be used
- A **restricted proxy** is a generalization of the simple limited proxies
  - Desirable to have fine-grained restrictions
  - Reduces exposure from compromised proxies
- Embed restriction policy in proxy certificates
  - Policy is evaluated by resource upon proxy use
  - Reduces rights available to the proxy to a subset of those held by the user
    - A proxy no longer grants full impersonation rights

Grid Security Infrastructure is …

Proxies and delegation (GSI extensions) for secure single sign-on

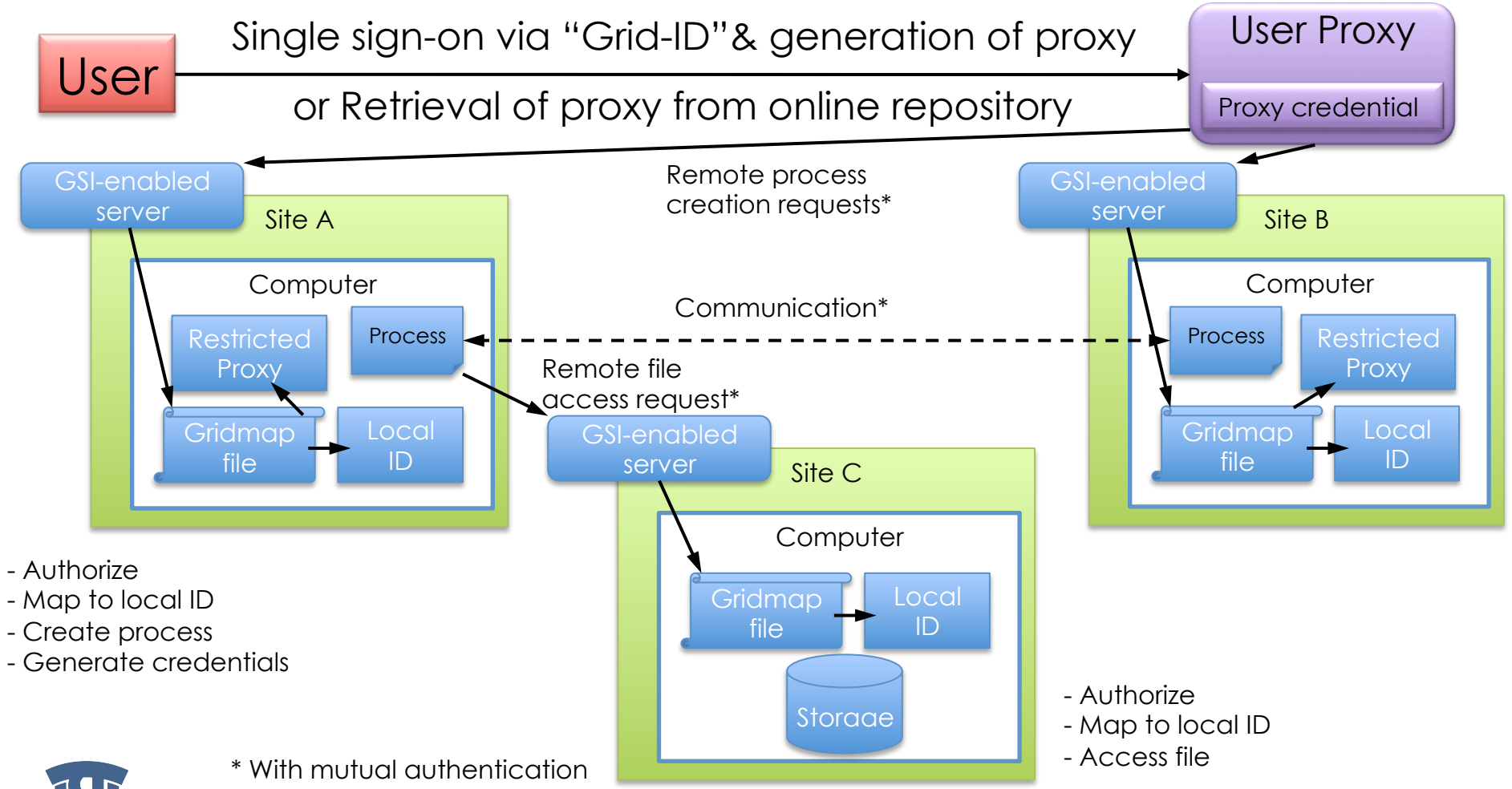


PKI for credentials

SSL for authentication and message protection

GSI in action

"Create Processes at A and B that Communicate & Access Files at C"



Grid Security in Globus

1. Obtaining a Certificate

- The program grid-cert-request is used to create a public/private key pair and unsigned certificate:
  - usercert_request.pem: Unsigned certificate file
  - userkey.pem: Encrypted private key file
- Mail usercert_request.pem to ca@globus.org
- Receive a Globus-signed certificate
- Other organizations use different approaches
  - NCSA, NPACI, NASA, etc. have their own CA

Your New Certificate

```
Certificate:
    Data:
        Version: 3 (0x2)
        Serial Number: 28 (0x1c)
        Signature Algorithm: md5WithRSAEncryption
        Issuer: C=US, O=Globus, CN=Globus Certification Authority
        Validity
            Not Before: Apr 22 19:21:50 1998 GMT
            Not After : Apr 22 19:21:50 1999 GMT
        Subject: C=US, O=Globus, O=NACI, OU=SDSC, CN=Richard Frost
        Subject Public Key Info:
            Public Key Algorithm: rsaEncryption
            RSA Public Key: (1024 bit)
                Modulus (1024 bit):
                    00:bf:4c:9b:ae:51:e5:ad:ac:54:4f:12:52:3a:69:
                    <snip>
                    b4:e1:54:e7:87:57:b7:d0:61
                Exponent: 65537 (0x10001)
Signature Algorithm: md5WithRSAEncryption
        59:86:6e:df:dd:94:5d:26:f5:23:c1:89:83:8e:3c:97:fc:d8:
        <snip>
        8d:cd:7c:7e:49:68:15:7e:5f:24:23:54:ca:a2:27:f1:35:17:
```

NTP is highly recommended

2. “Logging on” to the Grid

- To run programs, authenticate to Globus:

  % grid-proxy-init

  Enter PEM pass phrase: ******
- Creates a temporary, local, short-lived proxy credential for use by our computations (RFC 3820) grid-proxy-init creates the local proxy file.
- User enters pass phrase, which is used to decrypt private key.
- Private key is used to sign a proxy certificate with its own, new public/private key pair.
  - User’s private key not exposed after proxy has been signed
- Proxy placed in temp dir, read-only by user
- NOTE: *No* network traffic!

3. “Logging off” from the Grid

- To destroy your local proxy that was created by grid-proxy-init:

  % grid-proxy-destroy

- This does *NOT* destroy any proxies that were delegated from this proxy.
  - You cannot revoke a remote proxy
  - Usually proxies with short lifetimes are created

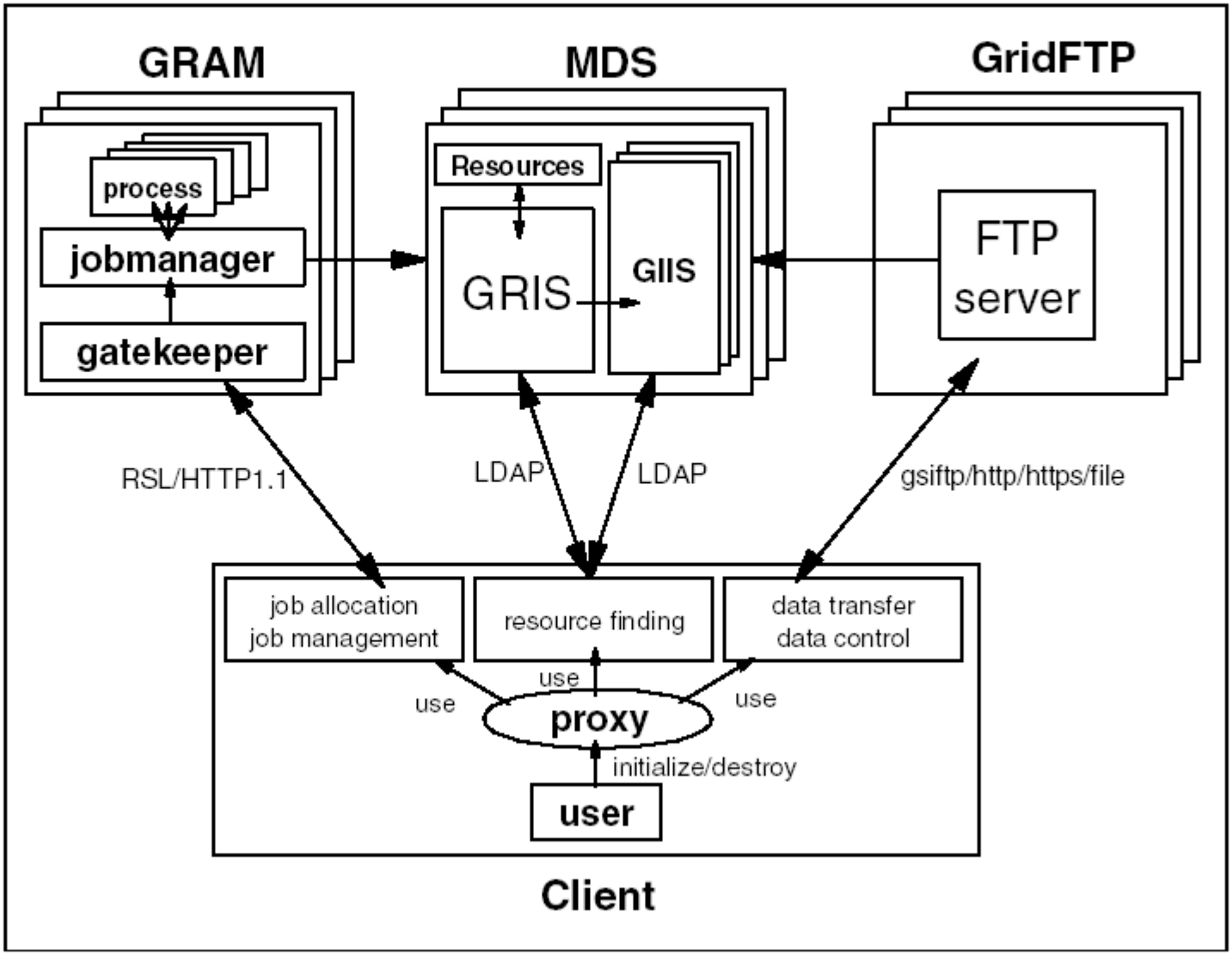
Important Files (I)

- /etc/grid-security
  - hostcert.pem: certificate used by the server in mutual authentication
  - hostkey.pem: private key corresponding to the server's certificate (read-only by root)
  - grid-mapfile: maps grid subject names to local user accounts (really part of gatekeeper)
- /etc/grid-security/certificates
  - CA certificates: certs that are trusted when validating certs, and thus need not be verified
  - ca-signing-policy.conf: defines the subject names that can be signed by each CA

Important Files (II)

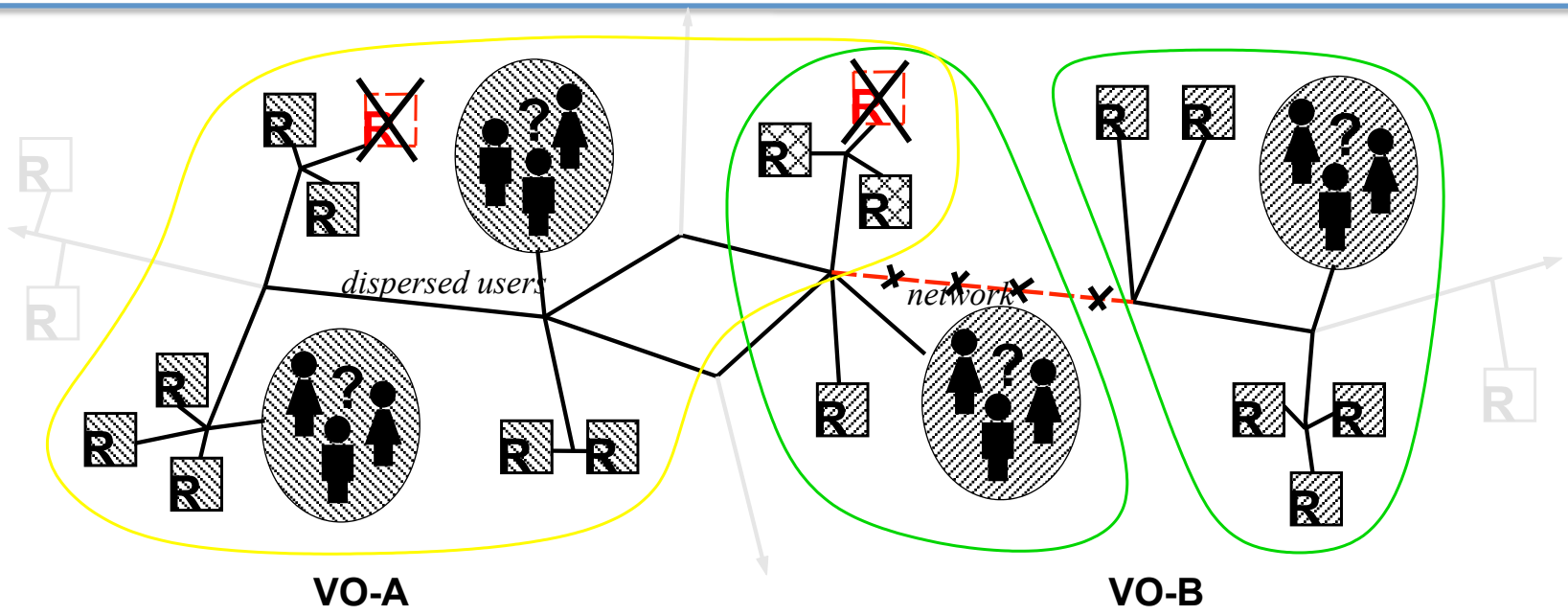
- $HOME/.globus
  - usercert.pem: User's certificate (subject name, public key, CA signature)
  - userkey.pem: User's private key (encrypted using the user's pass phrase)
- /tmp
  - Proxy file(s): Temporary file(s) containing unencrypted proxy private key and certificate (readable only by user's account)

Globus Toolkit 2



Grid Information Services

Resource Discovery/Monitoring



- Distributed resources and/or clients
- Resources status subject to change
- Dynamically variable connectivity and VOs

Grid "discovery"

- Resource *Discovery*
  - "What kind of resources could I use?"
  - Search status
- Resource *Inquiry*
  - "How can I compare resources (now)?"
  - Select status
- Resource *Control*
  - "How can I 'take control' of resources"
  - Acquisition status
  - **It is not part of an information service!**

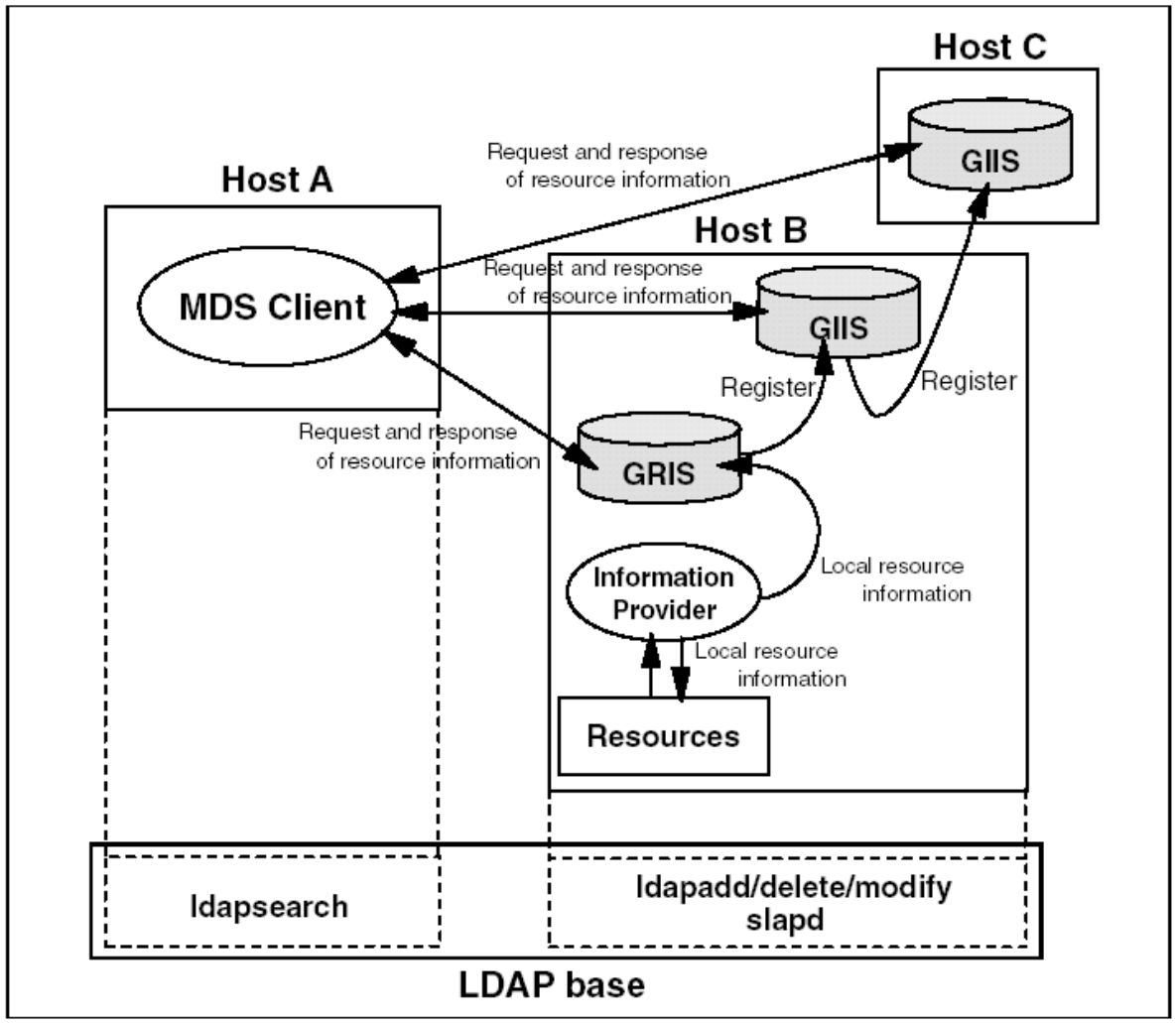
Grid Information Service

- Provide access to static and dynamic information regarding system components
- A basis for configuration and adaptation in heterogeneous, dynamic environments
- Resource Description Services
  - Supplies information about a specific resource
- Aggregate Directory Services
  - Supplies collection of information which was gathered from multiple resource description services
  - Customized naming and indexing

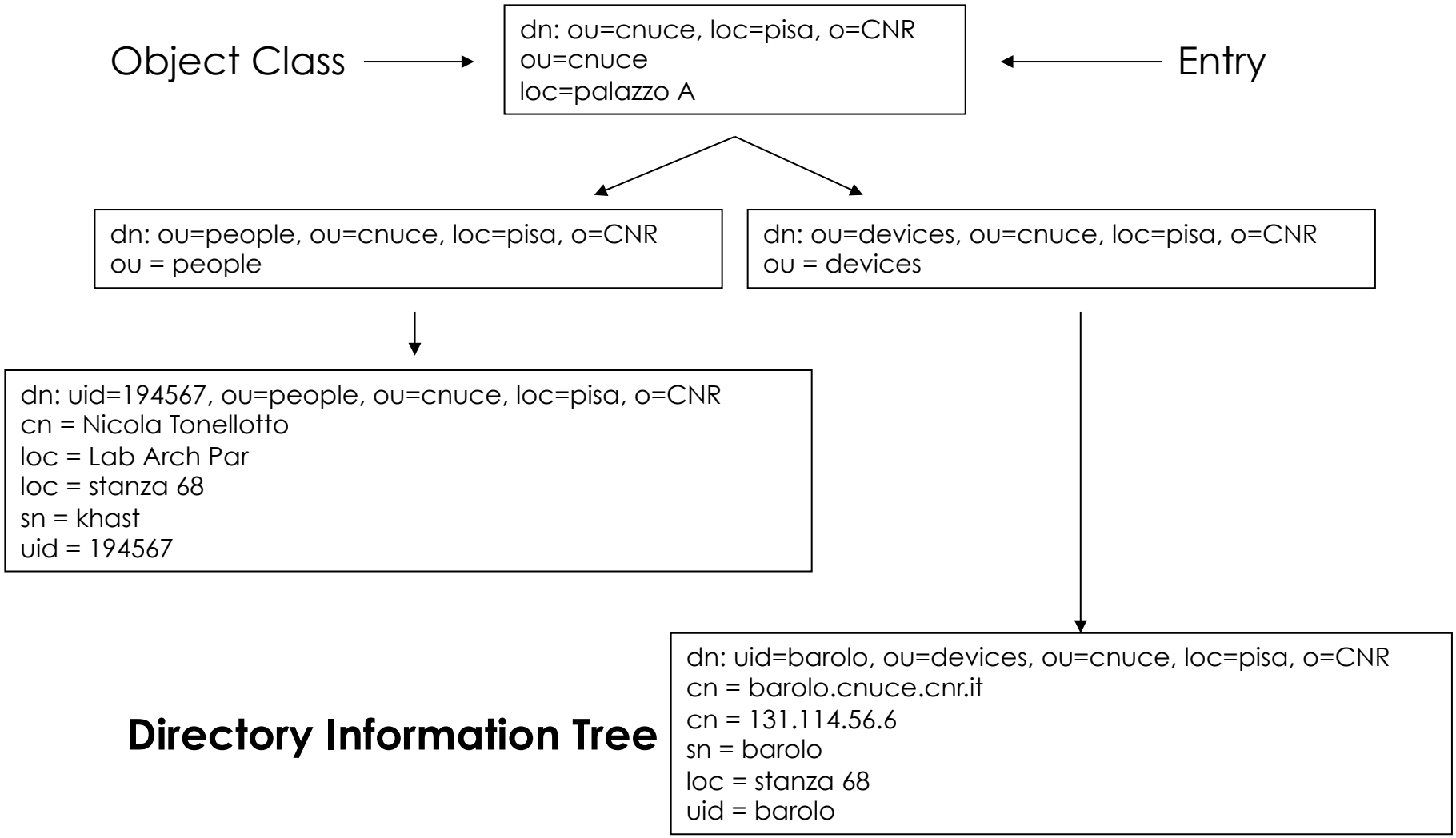
Requirements

- Performance
- Scalability
- Cost
- Uniformity
- Expressiveness
- Extensibility
- Multiple information sources
- Dynamic data
- Access flexibility
- Security
- Easy to employ
- Decentralized maintainability

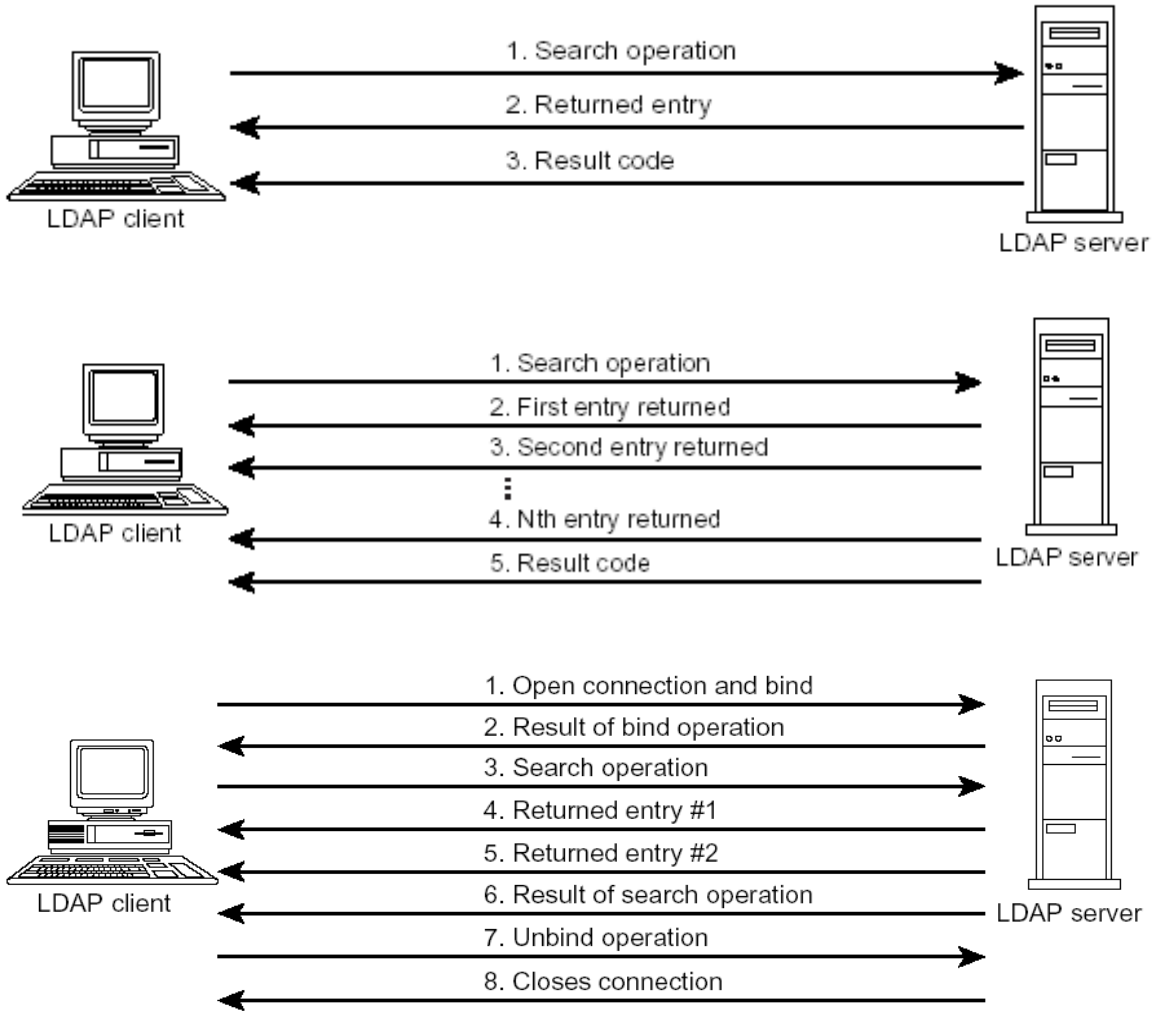
Monitoring and Discovery Service



MDS-2 Information Model



MDS-2 Functional Model



MDS-2 Data Representation (I)

Resource

Entry

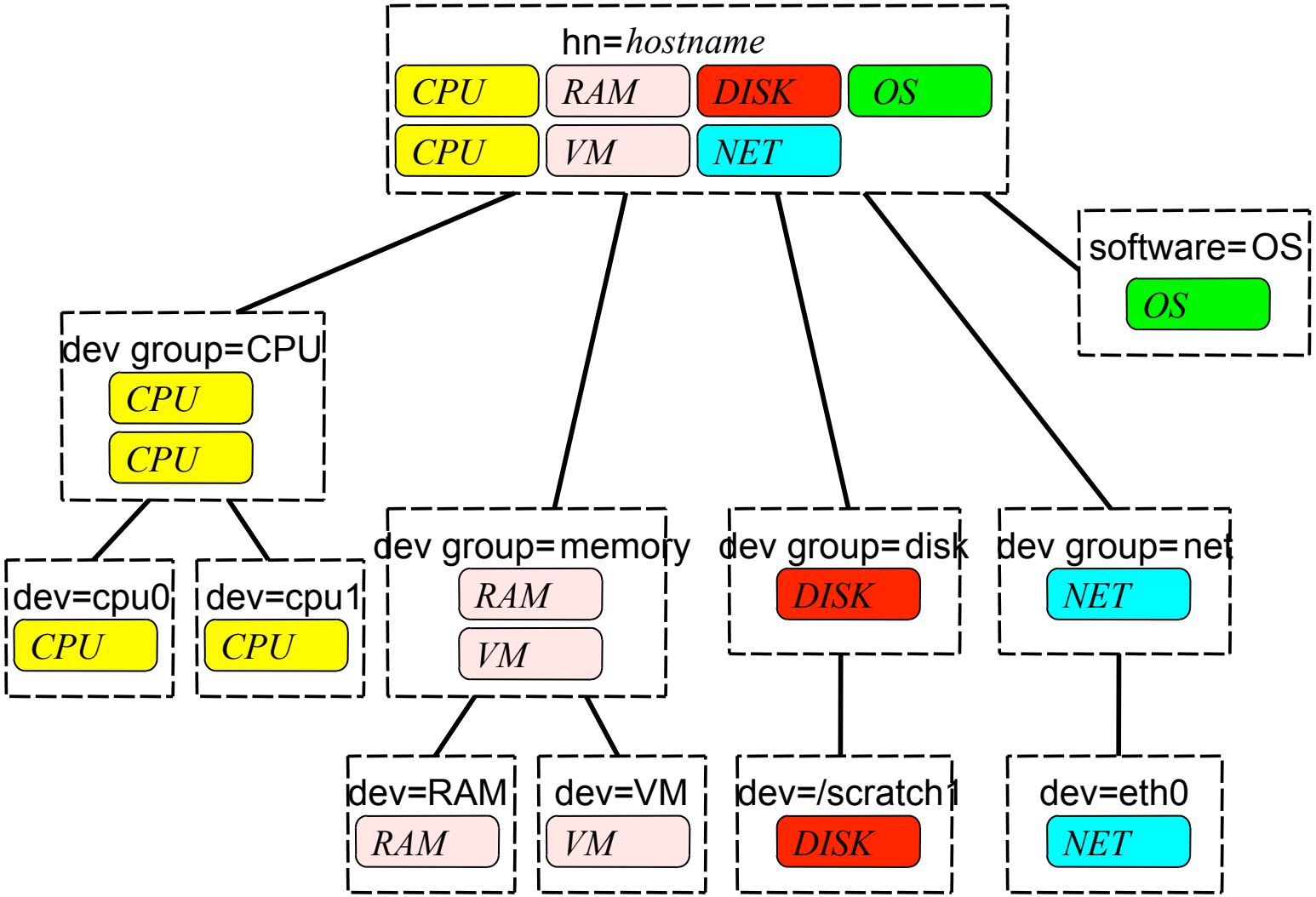
< hn = backus.di.unipi.it

ou = Dip. Informatica

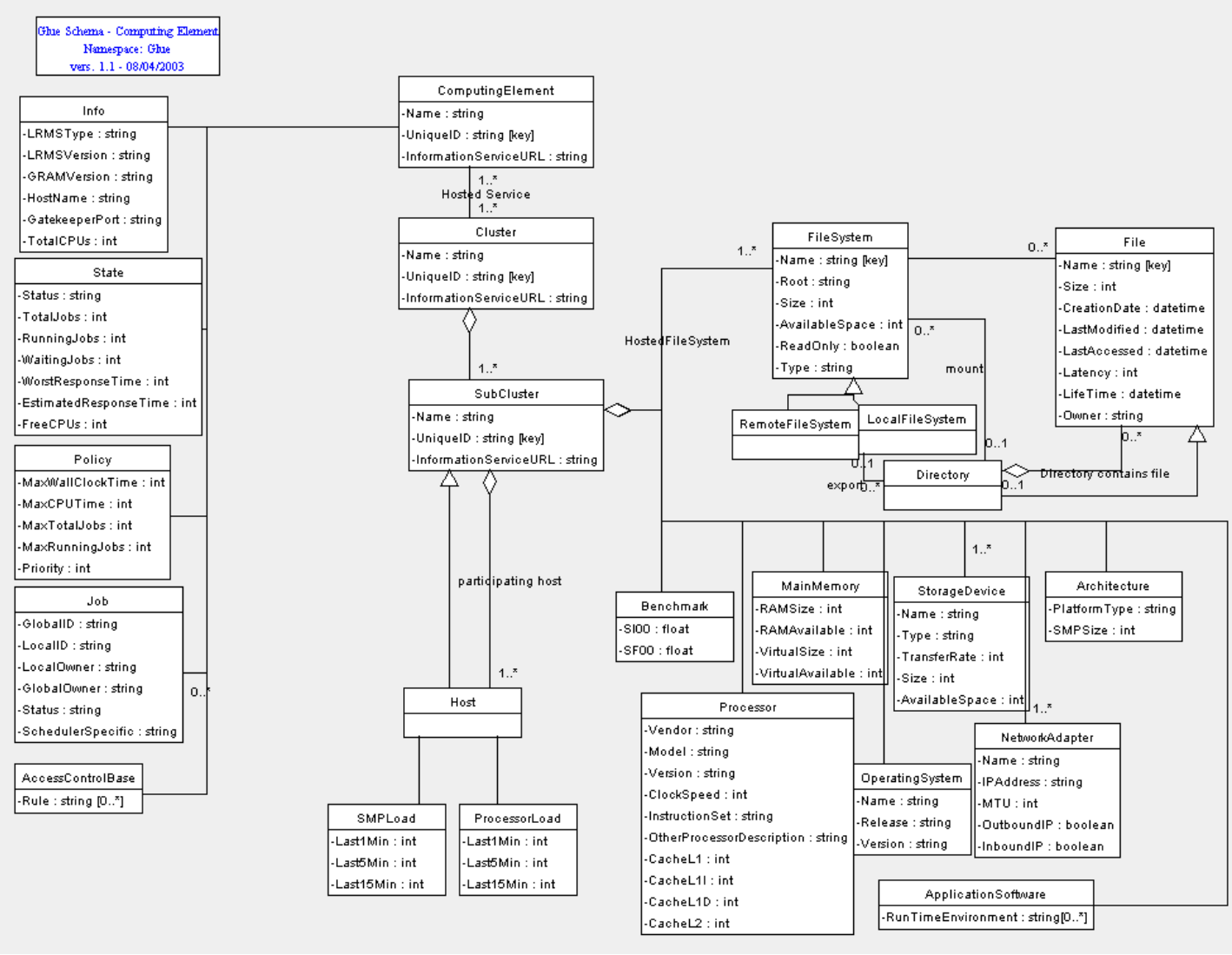
o = Università di Pisa

c = Italia >

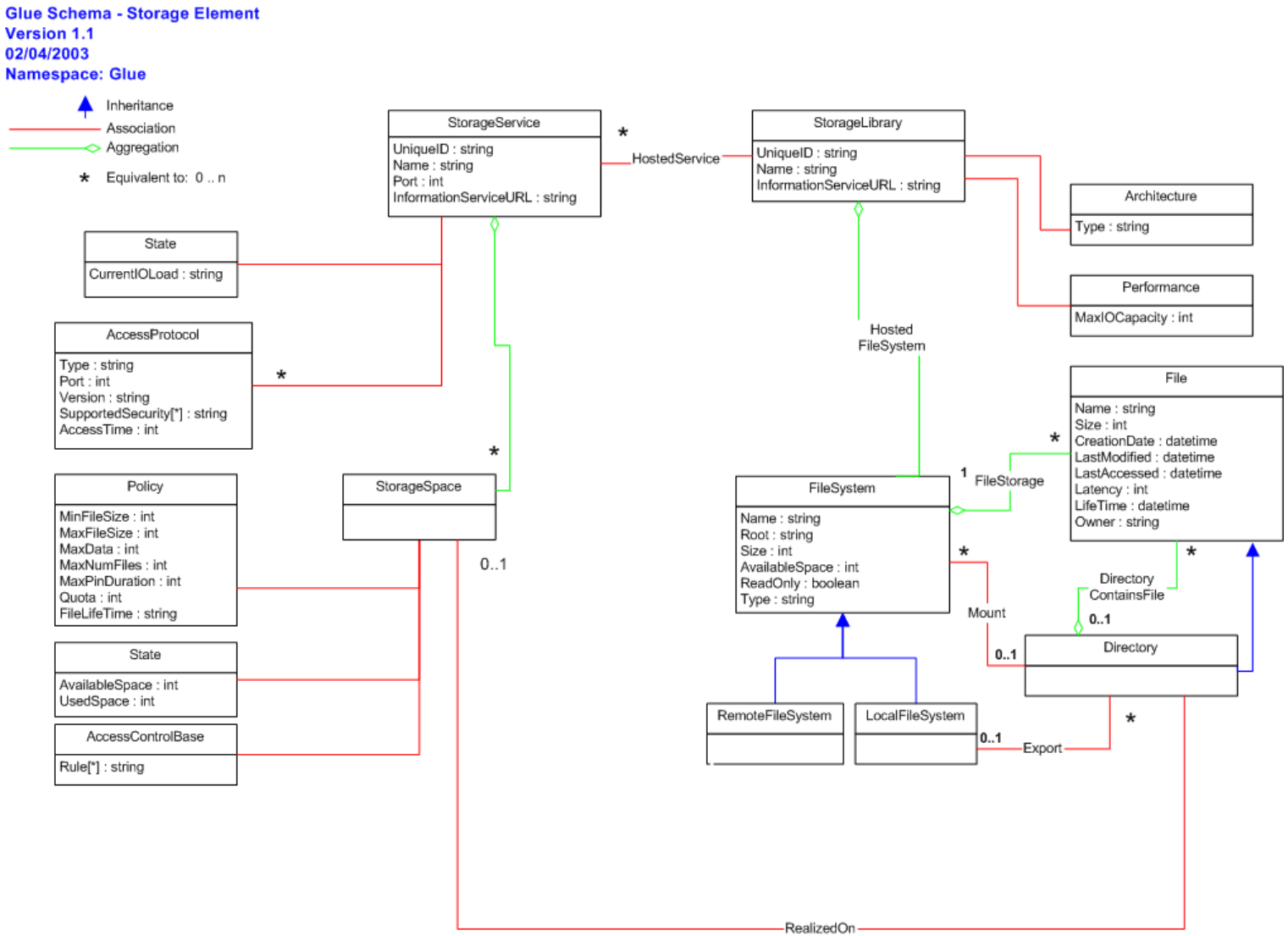
MDS-2 Data Representation (II)



GLUE Schema: Computing Element



GLUE Schema: Storage Element



Grid Resource Management

Resource Management on HPC Resources

- HPC resources are usually parallel computers or large scale clusters

- The local resource management systems (RMS) for such resources includes:
  - configuration management
  - monitoring of machine state
  - job management

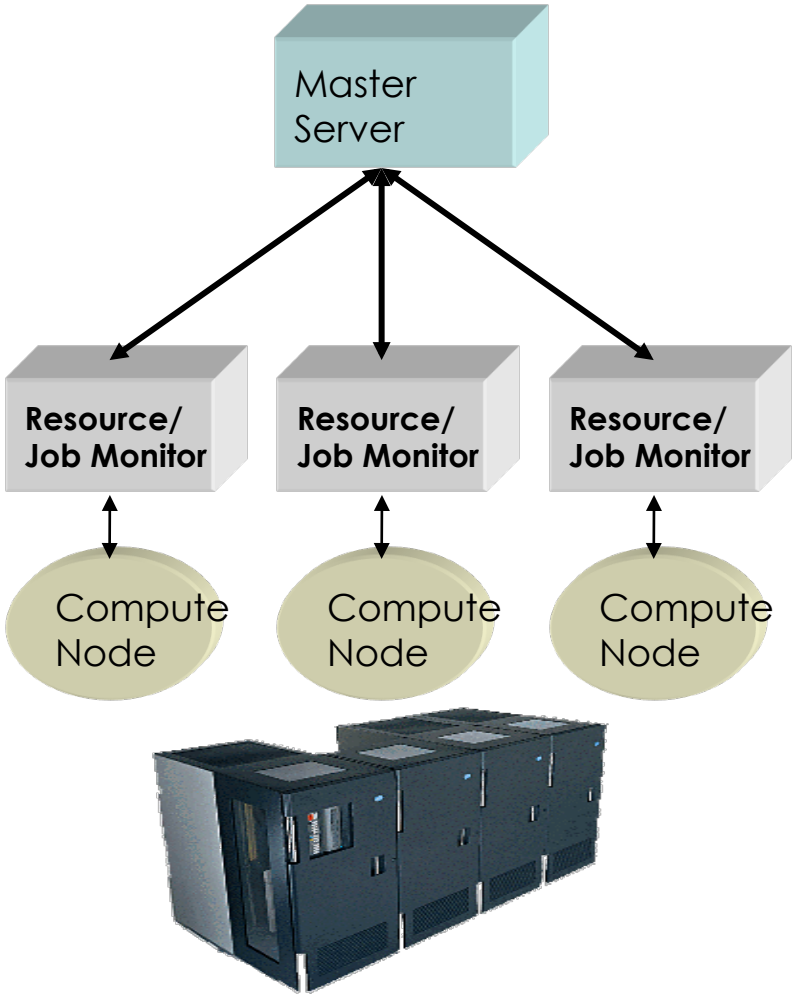
- There is no standard for this resource management
- Several different proprietary solutions are in use
- Examples for job management systems:
  - PBS, LSF, NQS, LoadLeveler, Condor

HPC Management Architecture in General

Control Service
Job Master

Resource and Job Monitoring and Management Services

Compute Resources/ Processing Nodes



Computational Job

- A job is a computational task
  - that requires processing capabilities (e.g. 64 nodes) and
  - is subject to constraints (e.g. a specific other job must finish before the start of this job)

- The job information is provided by the user
  - resource requirements
    - CPU architecture, number of nodes, speed
    - memory size per CPU
    - software libraries, licenses
    - I/O capabilities
  - job description
  - additional constraints and preferences

- The format of job description is not standardized, but usually very similar

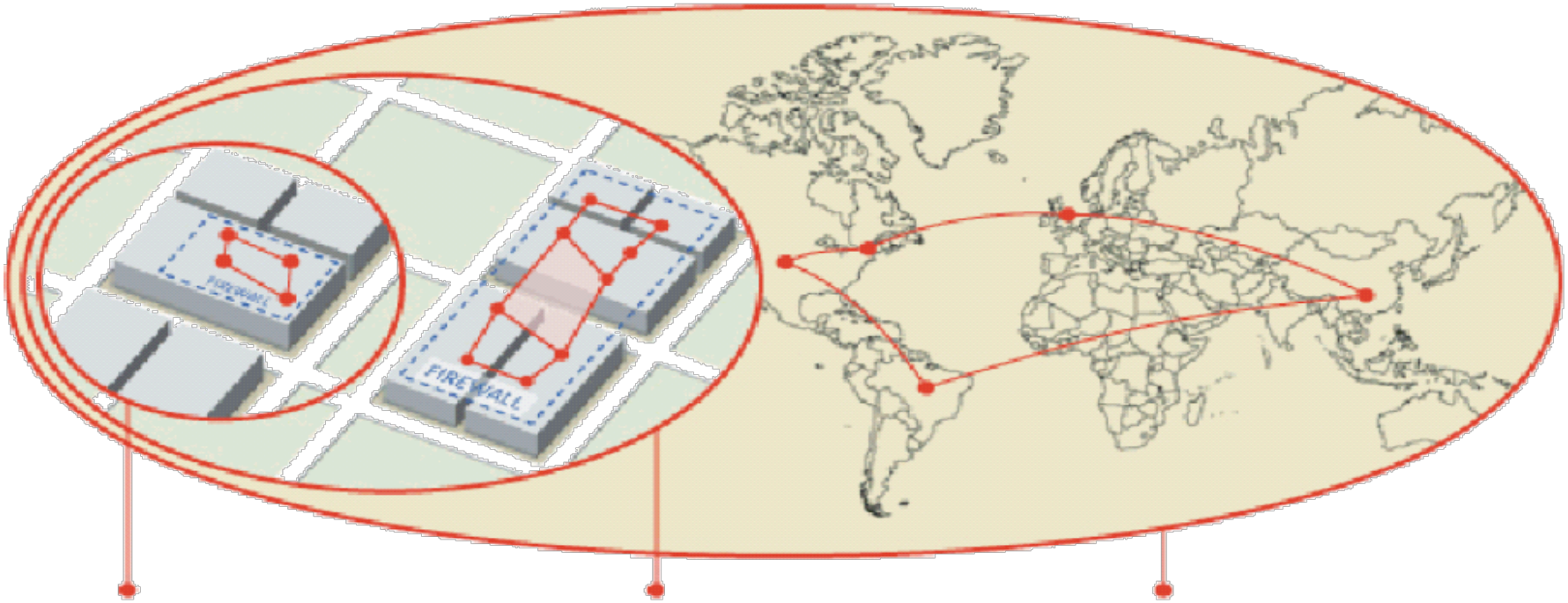
Transition to the Grid

More resource types come into play:

- Resources are any kind of entity, service or capability to perform a specific task
  - processing nodes, memory, storage, networks, experimental devices, instruments
  - data, software, licenses
  - people
- The task/job/activity can also be of a broader meaning
  - a job may involve different resources and consists of several activities in a workflow with according dependencies
- The resources are distributed and may belong to different administrative domains
- HPC is still the key application for Grids. Consequently, the main resources in a Grid are the previously considered HPC machines with their local RMS

Scope of Grids

Source: Ian Foster



Cluster Grid Enterprise Grid Global Grid

Implications to Grid Resource Management

- Several security-related issues have to be considered: authentication, authorization, accounting
  - who has access to a certain resource?
  - what information can be exposed to whom?

- There is lack of global information:
  - what resources are when available for an activity?

- The resources are quite heterogeneous:
  - different RMS in use
  - individual access and usage paradigms
  - administrative policies have to be considered

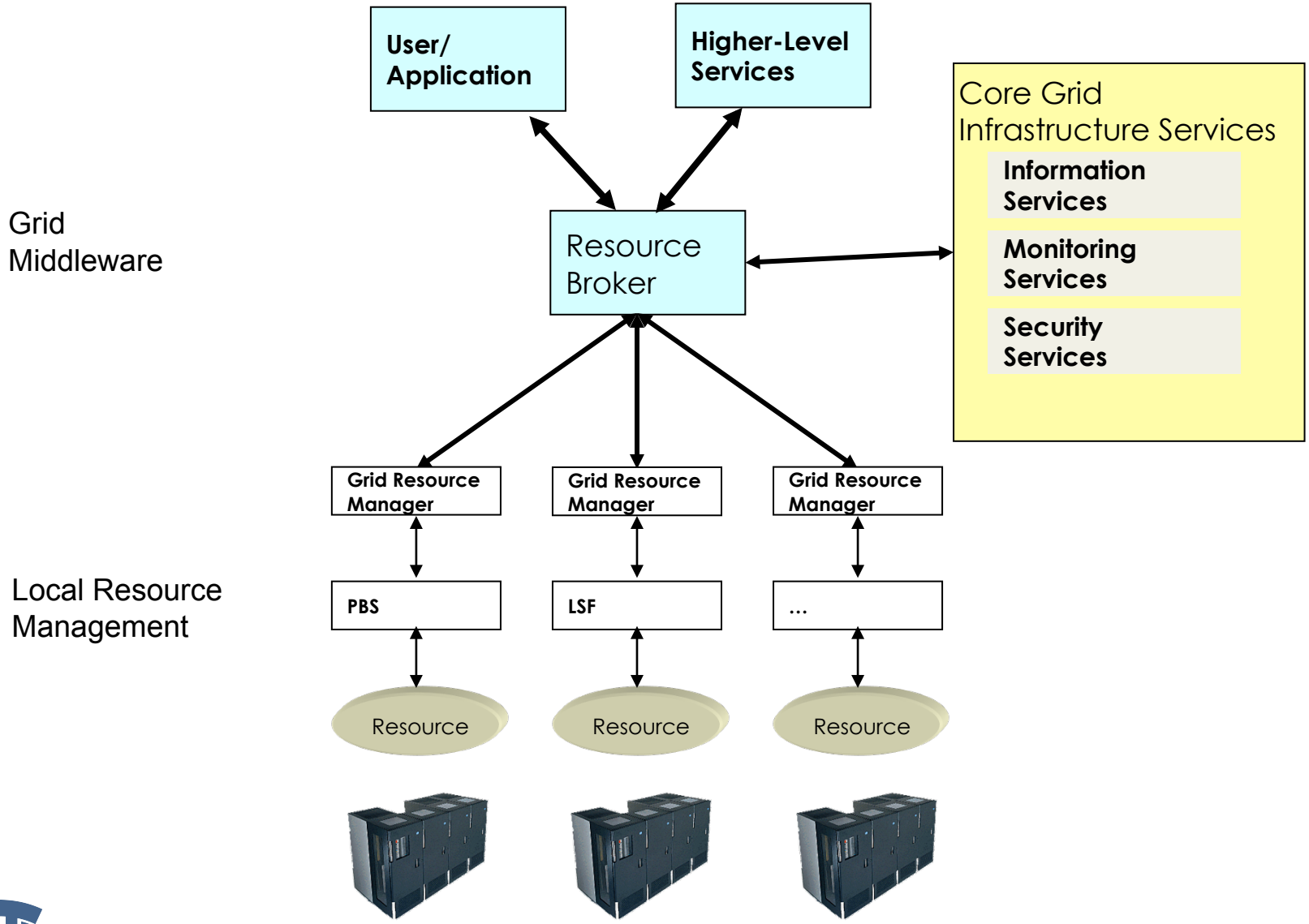
Resource Management Layer

Grid Resource Management System consists of :

- ***Local resource management system (Resource Layer)***
  - Basic resource management unit
  - Provide a standard interface for using remote resources
  - Grid Resource Allocation Manager (GRAM)

- ***Global resource management system (Collective Layer)***
  - Coordinate all Local resource management system within multiple or distributed Virtual Organizations (VOs)
  - Provide high-level functionalities to efficiently use all of resources
    - Job Submission
    - Resource Discovery and Selection
    - Scheduling
    - Co-allocation
    - Job Monitoring, etc.
  - e.g. Meta-scheduler, Resource Broker, etc.

Grid Resource Management



Definitions

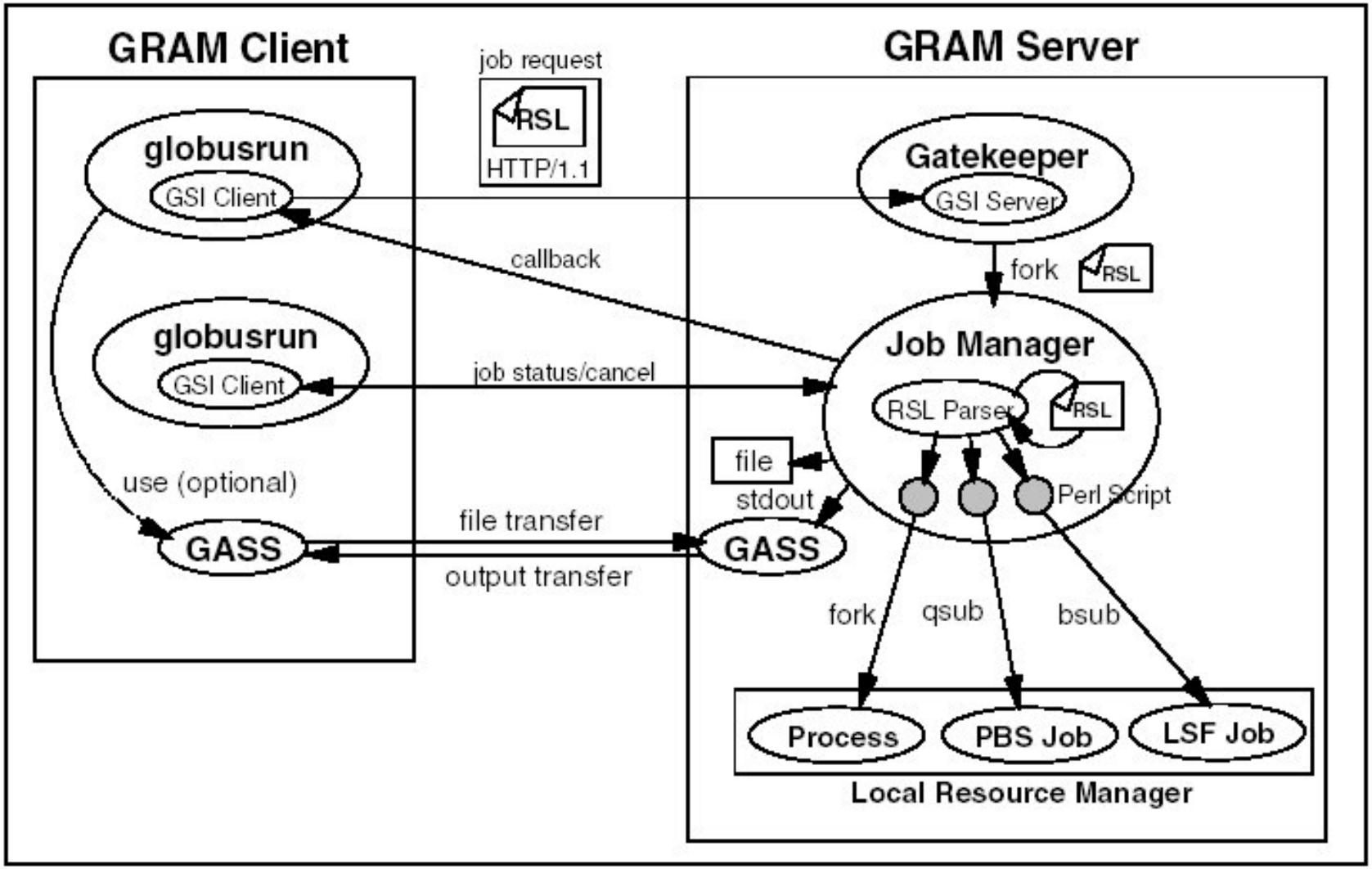
- **Resource**: entity able to execute one or more jobs on the behalf of the user
- **Client**: process using GRAM protocol to submit a job request
- **Job**: one or more processes being part of a job request
- **Job request**: a message containing the request and the specification for a job execution on a remote resource. A typical job request specifies:
  - When and where processes should be created
  - How and what processes to create
  - How to execute and terminate processes
- **Gatekeeper**: remote resources service managing incoming job requests (GT2)
- **Job Manager**: service instantiated by the gatekeeper to manage the execution and monitor the job's processes (GT2)

Gatekeeping (GT2)

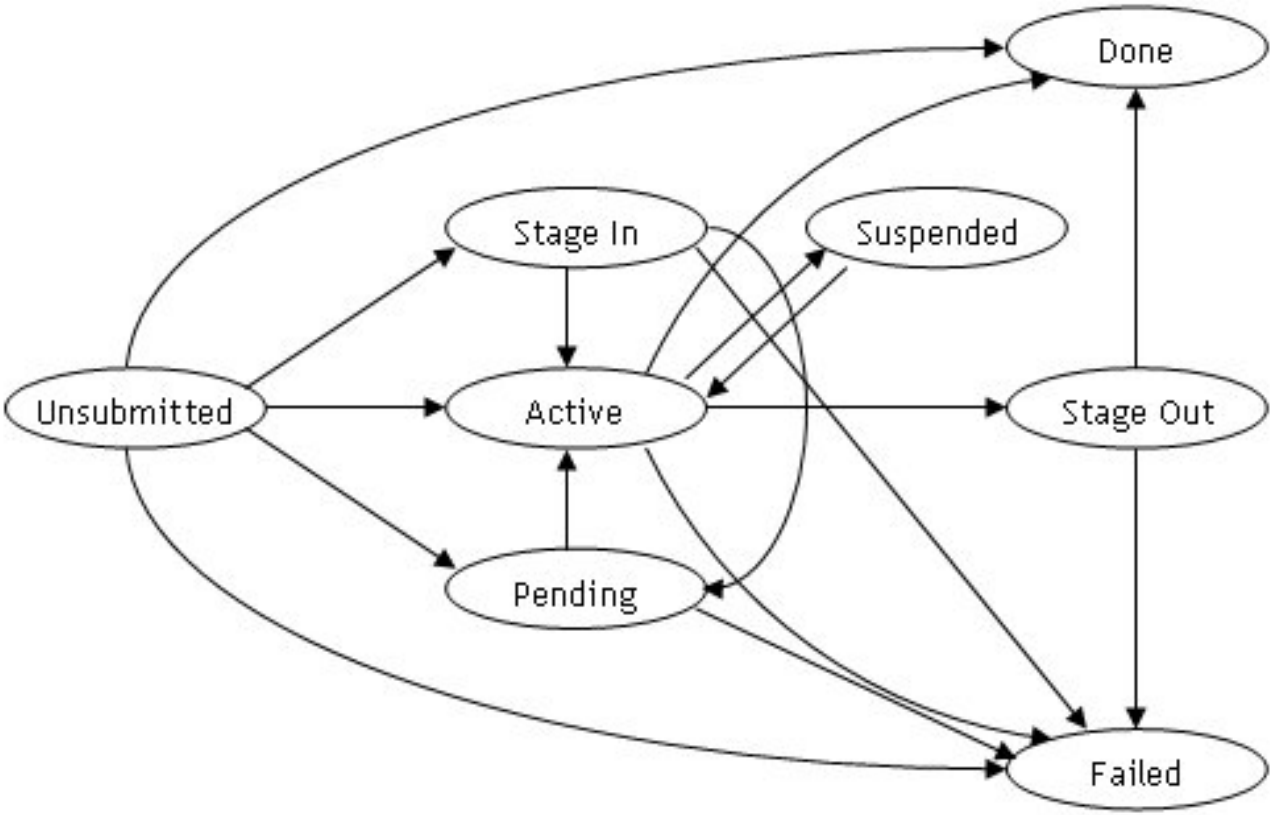
The gatekeeper is a daemon process running with root privileges on each computational resource on the Grid. When it receives a job request from a client it executes the following operations:

- Performs mutual authentication
- Maps the client in a local user
- Instantiates a job manager process with local user rights
- Sends required arguments to allocate job's processes to the job manager

GRAM components



Job Status



job status != process status

RSL Examples

```
'&(executable=/bin/ls)
  (directory=/tmp)
  (arguments=-l)
  (environment=(COLUMNS 40))'

'&(executable=/bin/ls)
  (count=3)(project=GlobusTeach)
  (mAxCpUtImE=10)(max_Memory=30)'

'&(executable=https://barolo.cnuce.cnr.it::65092/bin/ls)'

'&(executable=/bin/ls)
  (stdout=$(HOME)/ls.out)
  (stderr=$(HOME)/ls.err)'
```

Problem: Job Submission Descriptions differ

The deliverables of the OGF Working Group JSDL:

- A specification for an abstract standard Job Submission Description Language (JSDL) that is independent of language bindings, including;
  - the JSDL feature set and attribute semantics,
  - the definition of the relationship between attributes,
  - and the range of attribute values.
- A normative XML Schema corresponding to the JSDL specification.
- A document of translation tables to and from the scheduling languages of a set of popular batch systems for both the job requirements and resource description attributes of those languages, which are relevant to the JSDL.

JSDL Attribute Categories

- The job attribute categories will include:
  - Job Identity Attributes
    - ID, owner, group, project, type, etc.
  - Job Resource Attributes
    - hardware, software, including applications, Web and Grid Services, etc.
  - Job Environment Attributes
    - environment variables, argument lists, etc.
  - Job Data Attributes
    - databases, files, data formats, and staging, replication, caching, and disk requirements, etc.
  - Job Scheduling Attributes
    - start and end times, duration, immediate dependencies etc.
  - Job Security Attributes
    - authentication, authorization, data encryption, etc.

And the collective layer?

- The GRAM protocol provides a standard interfaces to access local resources
- At collective layer:
  - Resource brokers
  - Metaschedules
- We will speak about scheduling in desktop computers, clusters and Grids in subsequent lectures

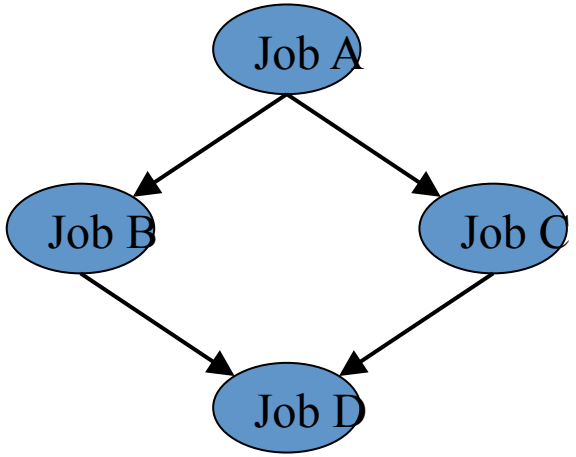
Metascheduler Example

Directed Acyclic Graph Manager

Source: Miron Livny

- DAGMan allows you to specify the *dependencies* between your Condor-G jobs, so it can *manage* them automatically for you.
- (e.g., "Don't run job "B" until job "A" has completed successfully.")
- A DAG is defined by a *.dag file*, listing each of its nodes and their dependencies:

```
# diamond.dag
Job A a.sub
Job B b.sub
Job C c.sub
Job D d.sub
Parent A Child B C
Parent B C Child D
```



- each node will run the Condor-G job specified by its accompanying Condor submit file

Grid Data Management

Data Management Services

- Data access and transfer
  - **GASS:** Simple multi-protocol tool to transfer 'normal' files; integrated in GRAM
  - **GridFTP:** Reliable and high-performance file transfer protocol for 'big' files in computer networks
- Replica Management
  - **Replica Catalog:** Service to keep updated information on sets of replicated data
  - **Replica Management:** Service to create and manage sets of replicated data

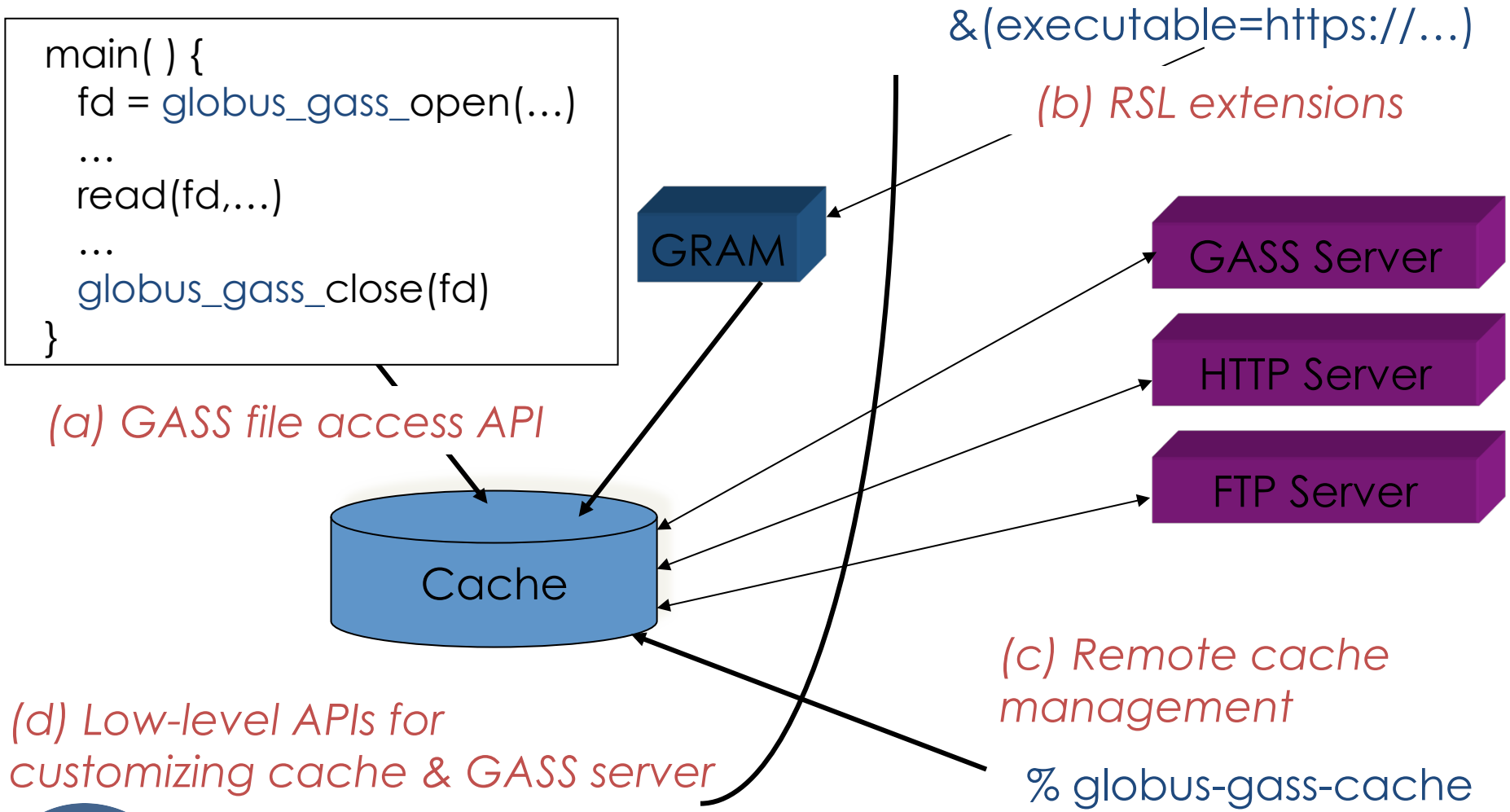
GASS: Global Access to Secondary Storage

- Access to files from remote locations
- Used by GRAM to:
  - Download executables from remote sites (batch)
  - Move stdin/stdout/stderr to/from remote sites (stream)
- Components:
  - GASS file access API:

    OS-spec open/close changed with globus_gass_open/close; Read/write calls automatically managed
  - Job specification language extensions

    Specific URIS used to declate remote executables and stdin/ stdout/stderr
  - Utilities to manage caches for remote data

GASS Architecture



GASS – GRAM Integration

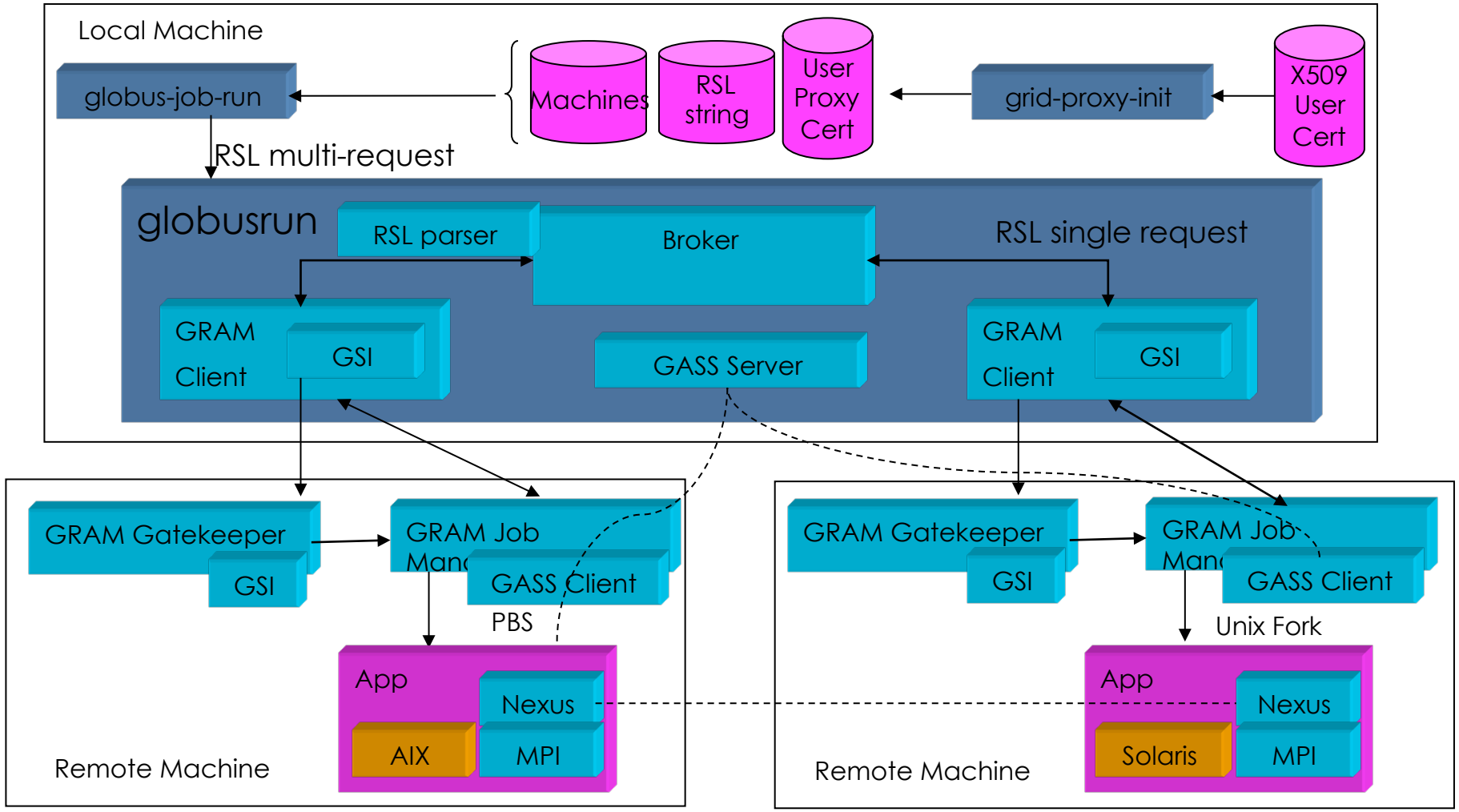
- Resource names coding convention

  https://barolo.cnuce.cnr.it:9991/~khast/myjob

  protocol server address file name

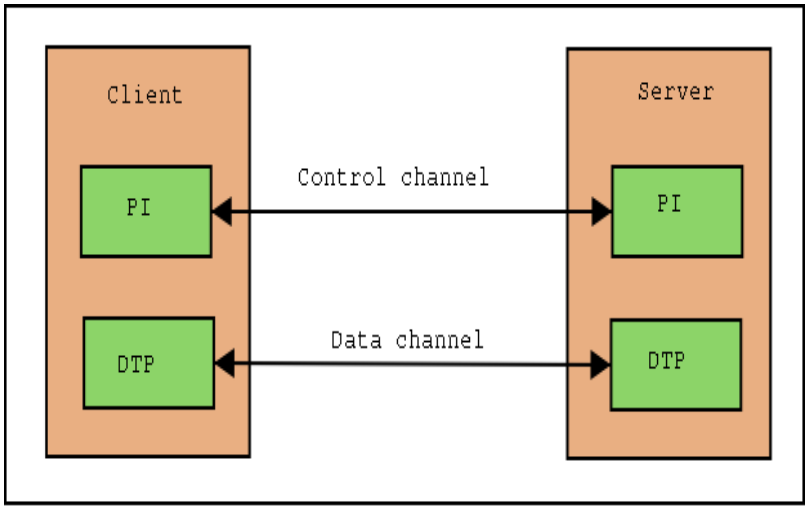
- Supported protocol: http, https, ftp, gsiftp
- Job specification language extensions:
  - executable, stdin, stdout, stderr can be local files or URI
  - Executable and stdin loaded from local cache before job run
  - stdout, stderr managed by GASS in append mode
  - Cache flushed at job end

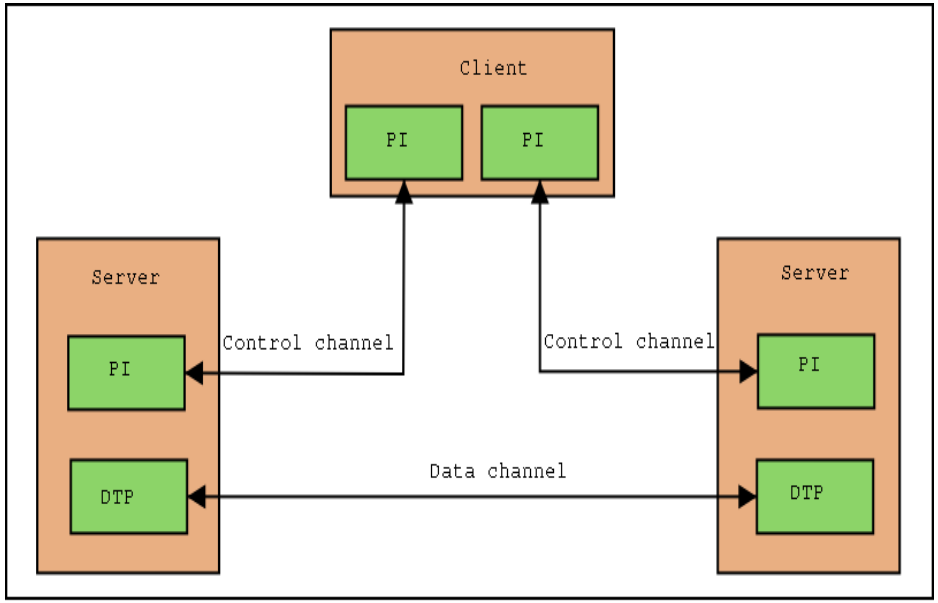
Globus components in action



FTP protocol in a nutshell

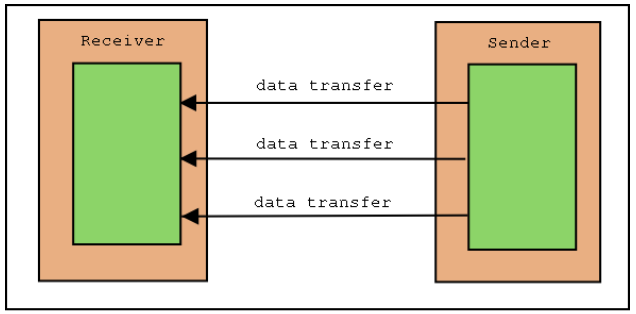
- Control and data channel
- Transfers: client- server and e third party



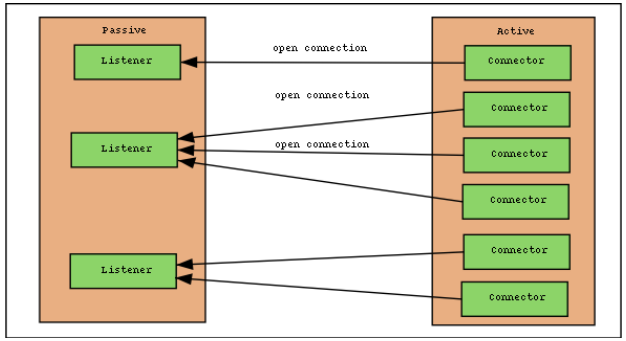


GridFTP Add-ons

- **Parallel Transfer**: multiple data pathway

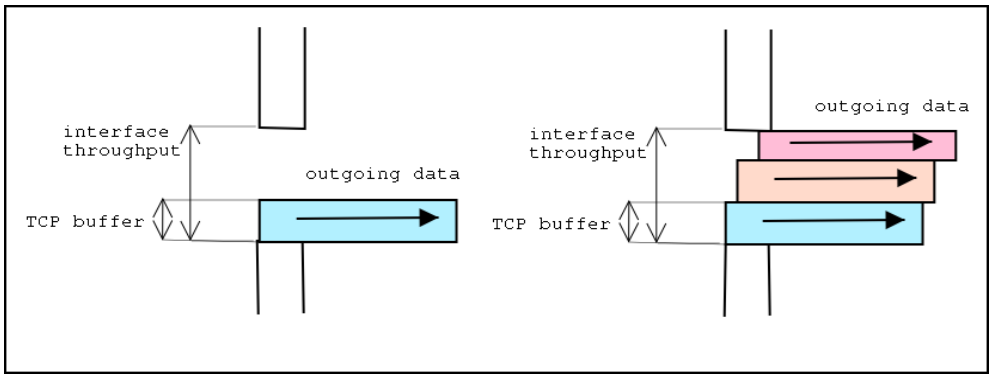


- **Striped Transfer**: distributed and parallel data transfer

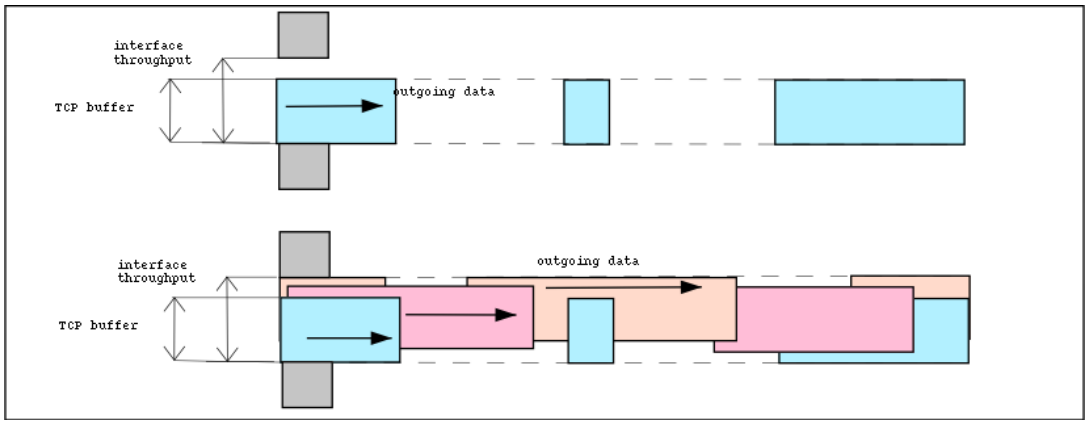


Why?

- Network throughput maximization (TCP window)



- Network losses minimization (glitch)

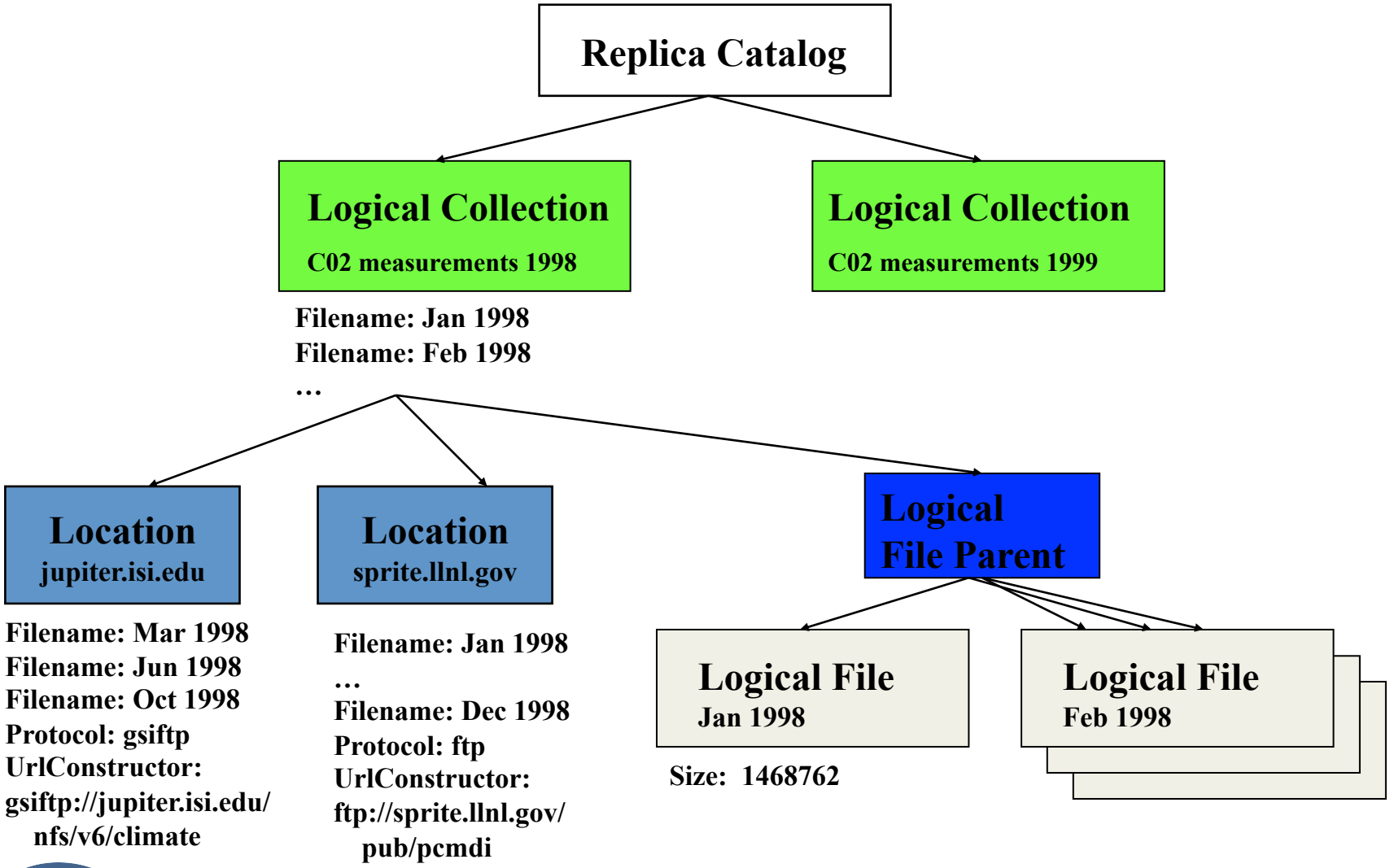


Data management

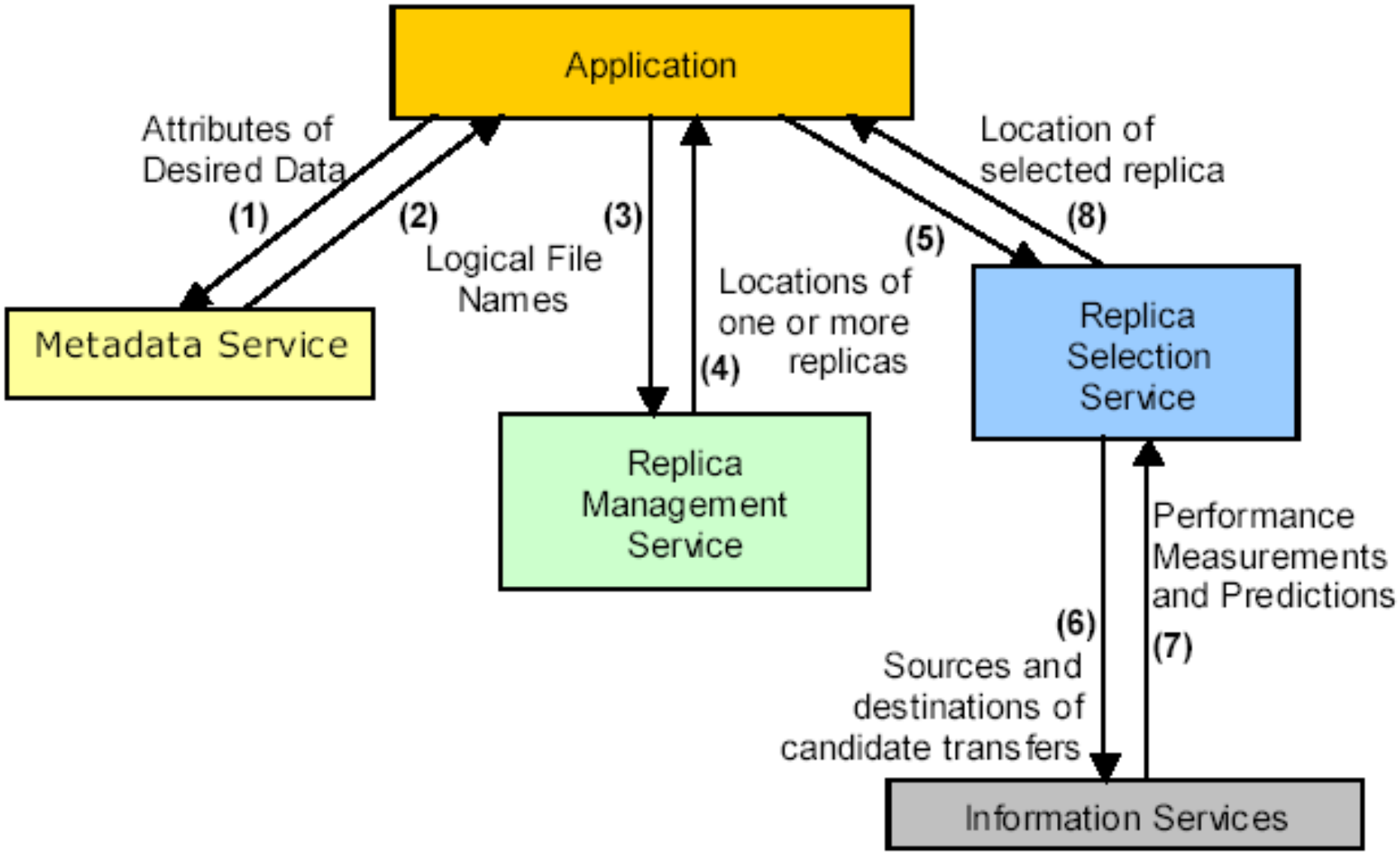
- Data can be **present** in different sites
- Data can be **replicated** in different locations
- How to **manage** the copies of data on the Grid?
- How to **leverage** the copies of data?

- Low level: Replica Catalog
  - A **catalog** represents files, collections and locations
  - A collection is represented by a **logical file**
  - A replica (partial or complete) of a collection is represented by a **physical file**
  - Given a *logical filename*, how to obtain the relevant *physical filename*?
    - Physical File Name (PFN): host + full path & file name
    - Logical File Name (LFN): logical name unique in the Grid
    - LFN : PFN = 1 : n

Replica Catalog



Replica Management Services



DataGrid: complete architecture