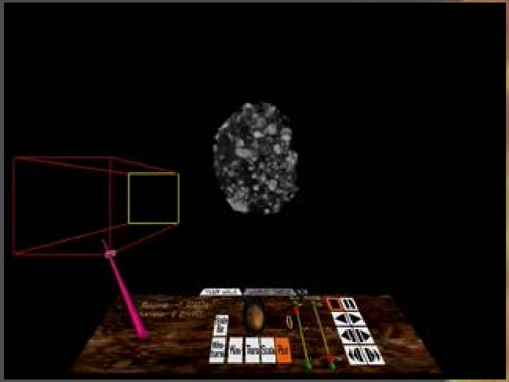
Introduzione al Grid Computing e al Globus Toolkit™

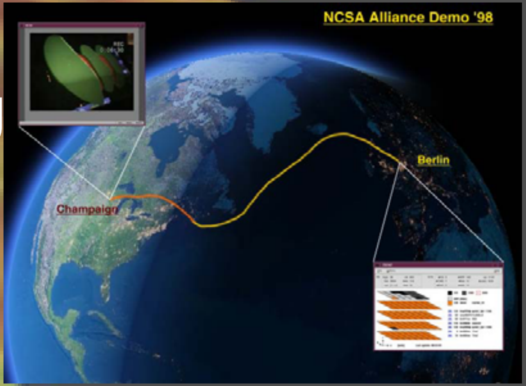
The Globus Project™

USC Information Sciences Institute

Argonne National Laboratory



http://www.globus.org



Sommario

- Introduzione al Grid Computing
- Alcune Definizioni
- La Filosofia della Architettura di Griglia
- Il Globus Toolkit (GT2)
  - Introduzione, Security, Resource Management, Information Services, Data Management
- Open Grid Services Architecture (GT3)

Il Problema della Griglia

- Condivisione flessible, sicura, coordinata condivisione di risorse tra gruppi dinamici di individui, instituzioni e sistemi.

  Da *"The Anatomy of the Grid: Enabling Scalable Virtual Organizations"*

- Permettere a comunità reali o virtuali ("virtual organizations") con obiettivi comuni di condividere risorse distribuite geograficamente - *assumendo l' assenza di*…
  - sito centrale,
  - controllo centrale,
  - completa conoscenza,
  - l'esistenza di relazioni affidabili.

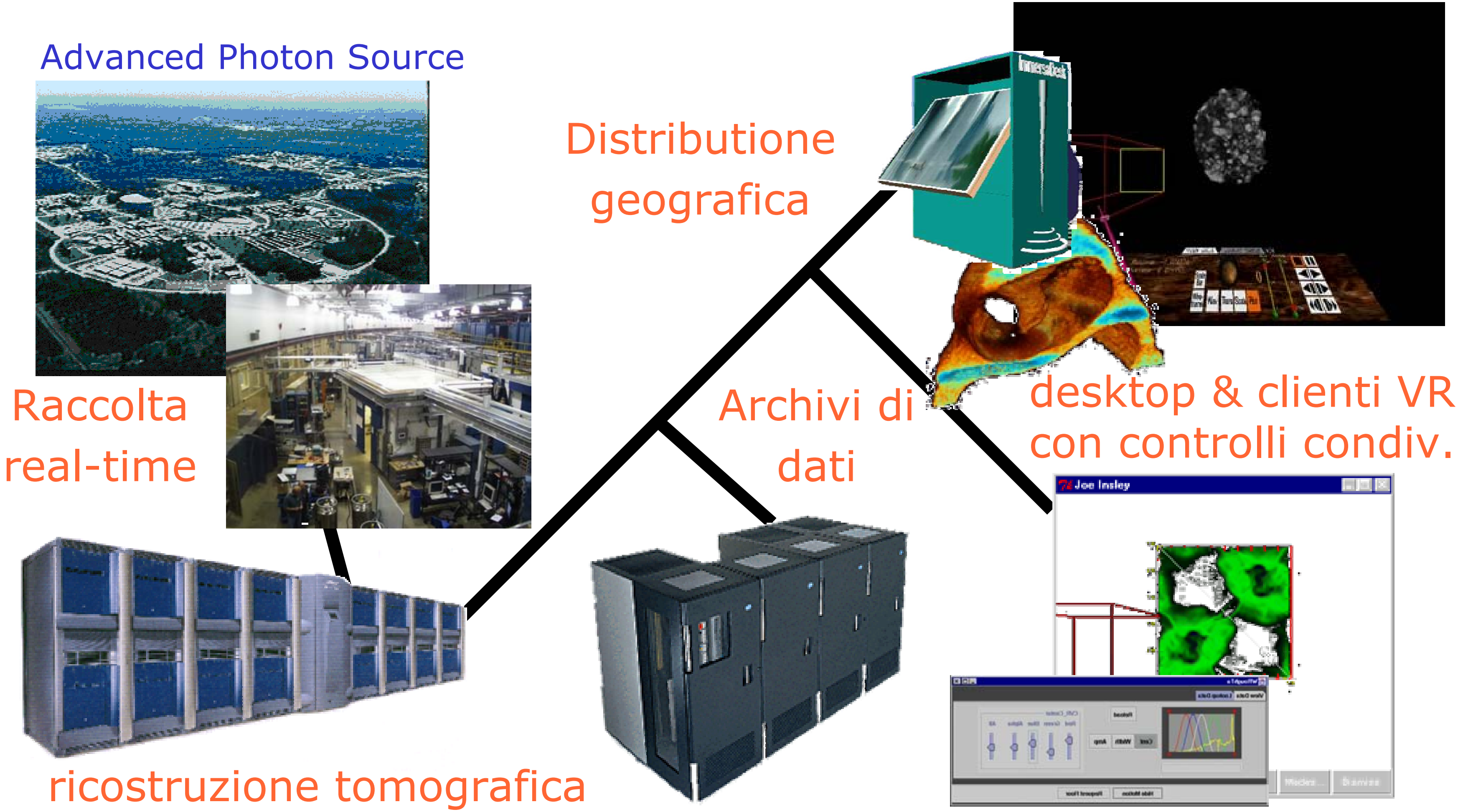
Elementi del Problema

- Condivisione di risorse
  - Computer, memorie, sensori, reti, …
  - Condivisione condizionale: problemi di fiducia, politiche, negoziazione, pagamento, …
- Coordinated problem solving
  - Oltre il client-server: analisi distribuita di dati, elaborazione distribuita, collaborazione, …
- Organizzazioni dinamiche, multi-istituzionali e virtuali
  - Comunità sovrapposte su strutture org. Classiche.
  - Grandi o piccole, statiche o dinamiche.

Perché usare le Griglie?

- Un biochimico usa 10.000 computer per analizzare 100.000 composti in un’ora.
- 1.000 fisici nel mondo usano in maniera integrata alcuni petabytes di dati.
- Ingegnerici civili collaborano per progettare, realizzare e analizzare esperimenti di terremoti.
- Scienziati del clima visualizzano, annotano, e analizzano terabyte di dati di simulazioni.
- Un team di gestione di emergenze integra dati real time, weather modelli di previsione e dati sulla popolazione.

Accesso Online a Strumenti Scientifici



DOE X-ray grand challenge: ANL, USC/ISI, NIST, U.Chicago

Data Grid per la Fisica delle Alte Energie

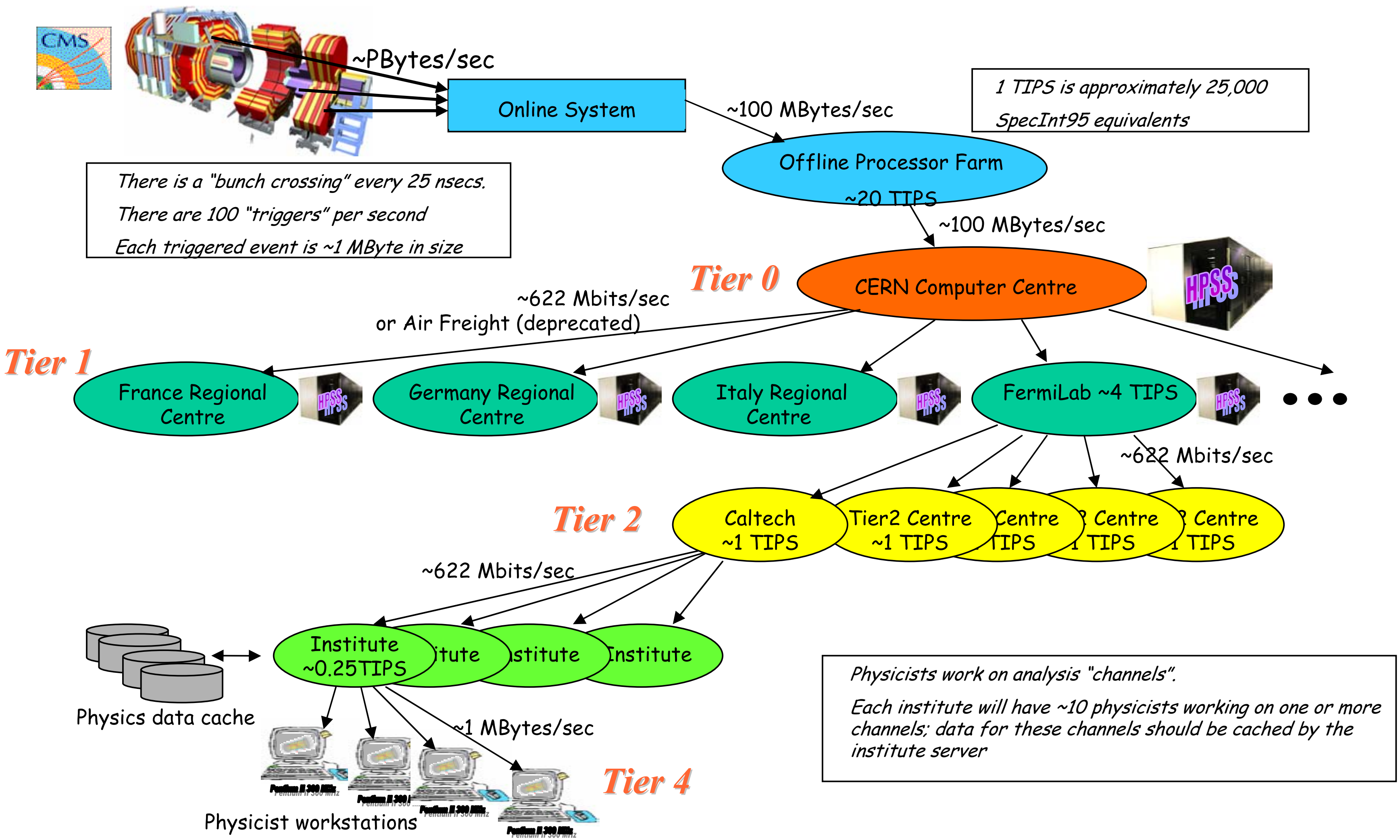
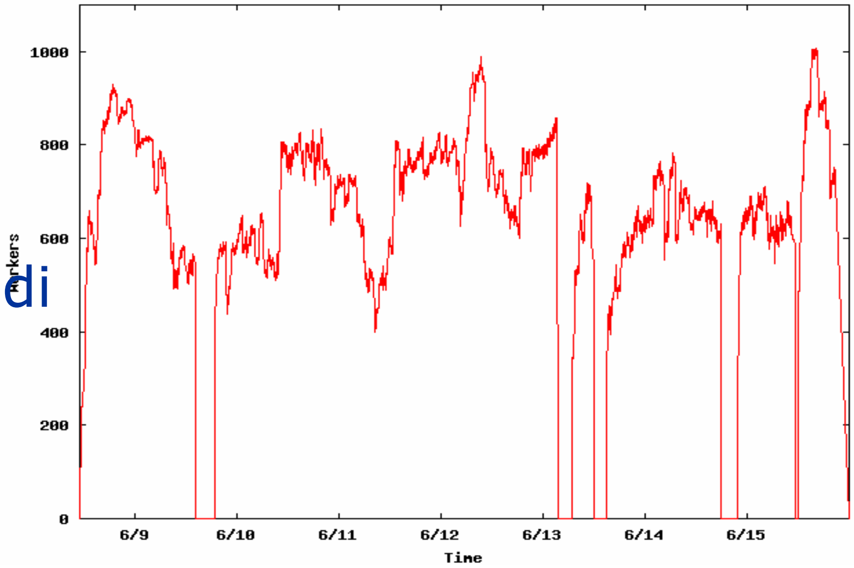


Image courtesy Harvey Newman, Caltech

Matematici Risolvono il NUG30

- Ricerca della soluzione del problema dell'assegnamento quadratico NUG30
- Una collaborazione informale di matematici e informatici
- Condor-G ha gestito 3.46E8 secondi di CPU in 7 gg. (peak 1009 processors) in U.S.A. e in Italia (8 sites)

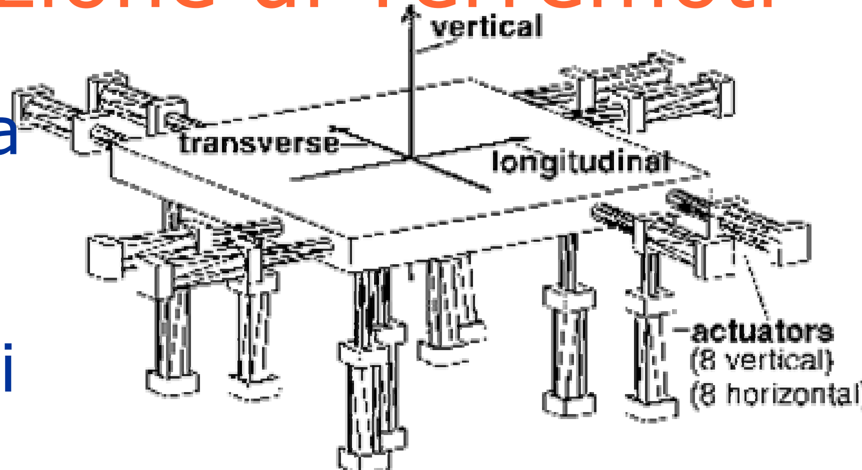


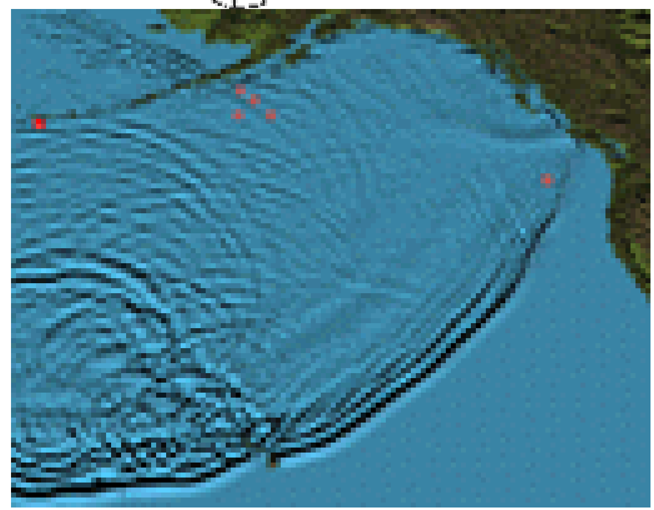
14,5,28,24,1,3,16,15,
10,9,21,2,4,29,25,22,
13,26,17,30,6,20,19,
8,18,7,27,12,11,23

MetaNEOS: Argonne, Iowa, Northwestern, Wisconsin

Rete per la Simulazione di Terremoti

- NEESgrid: infrastruttura nazionale per la collaborazione tra ingegneri civili e l'uso di dispositivi sperimentali, databases, computers, & altro
- Accesso on-demand ad esperimenti, dati, calcolo, archivi, e collaborazioni.





NEESgrid: Argonne, Michigan, NCSA, UIUC, USC

Home Computers Per l'Analisi di Farmaci per l'AIDS

- Comunità=
  - migliaia di utenti di I
  - Philanthropic computing vendor (Entropia)
  - Gruppo di Ricerca (Scripps)
- Obiettivo Comune= avanzamento nella Ricerca e nello studio dell'AIDS

Contesto più Generale

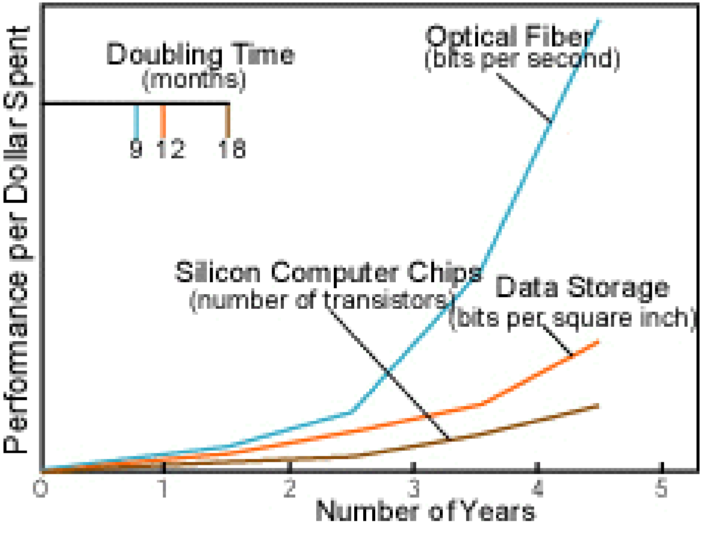
- Il “Grid Computing” ha molto in comune con i maggiori trend industriali
  - Business-to-business, Peer-to-peer, Application Service Providers, Storage Service Providers, Distributed Computing, Internet Computing…
- Problemi comuni non adeguatamente affrontati dalle tecnologie esistenti
  - Requisiti Complicati: “eseguire il programma X sul sito Y conforme alla politica di Comunità P, fornendo l'accesso ai dati in Z secondo la politica Q”
  - High performance: richieste particolari di sistemi avanzati con alte prestazioni.

Perchè Adesso?

- I miglioramenti di legge di Moore nei sistemi di elaborazione produce sistemi finali altamente funzionali.
- Internet e le diverse reti wired o wireless forniscono una connettività globale.
- I cambiamenti nel modo di lavorare in team e orientato alle soluzioni favoriscono questa soluzione.
- Le elevate prestazioni delle reti producono cambiamenti drammatici in termini geometrici e geografici.

Prestazioni Elevate delle Reti

- Prestazioni delle reti e dei calcolatori
  - La velocità dei calcolatori raddoppia ogni 18 mesi
  - La velocità delle reti raddoppia ogni 9 mesi
  - Differenza = un ordine di grandezza ogni 5 anni
- Dal 1986 al2000
  - Computers: x 500
  - Reti: x 340.000
- Dal 2001 al 2010
  - Computers: x 60
  - Reti: x 4000



Moore's Law vs. storage improvements vs. optical improvements. Graph from **Scientific American** (Jan-2001) by Cleo Vilett, source Vined Khoslan, Kleiner, Caufield and Perkins.

Il Globus Project™

- Stretta collaborazione con progetti “reali” di Griglia nella scienza e nell’industria
- Sviluppo e promozione dei protocolli standard e delle interfacce di griglia per permettere interoperabilità ed infrastruttura comune
- Il Globus Toolkit™: Open source, software di base di riferimento per la costruzione dell'infrastruttura e le applicazioni di griglia
  - GT2:
  - GT3: Nuova implementazione basata sui Grid Services (che estendono i Web Services)
- Global Grid Forum: Sviluppo di protocolli standard e API per Grid computing (www.ggf.org)

Principali Progetti di Grid

Nome	URL & Sponsors	Focus
DOE Science Grid	sciencegrid.org DOE Office of Science	Creare una Grid che fornisca l'accesso a risorse & applicazioni nei laboratori del DOE e di università partner.
Earth System Grid (ESG)	earthsystemgrid.org DOE Office of Science	Griglia per l'analisi di dati per modelli climatologici a larga scala
European Union (EU) DataGrid	eu-datagrid.org European Union	Creare e usare una Grid for nella fisica delle alte energie, le scienze ambientali e la bioinformatica

Principali Progetti di Grid

Nome	URL/Sponsor	Focus
Fusion Collaboratory	fusiongrid.org DOE Off. Science	Creare un ambiente collaborativo U.S.A. per ricerche sulla fusione
Globus Project™	globus.org DARPA, DOE, NSF, NASA, Msoft	Ricerca sulle Grid technologies; sviluppo e supporto del Globus Toolkit™; applicazioni e messa in uso (deployment)
Grid Research Integration Dev. & Support Center	grids-center.org NSF	Integrazione, deployment, supporto della NSF Middleware Infrastructure per ricerca e formazione.

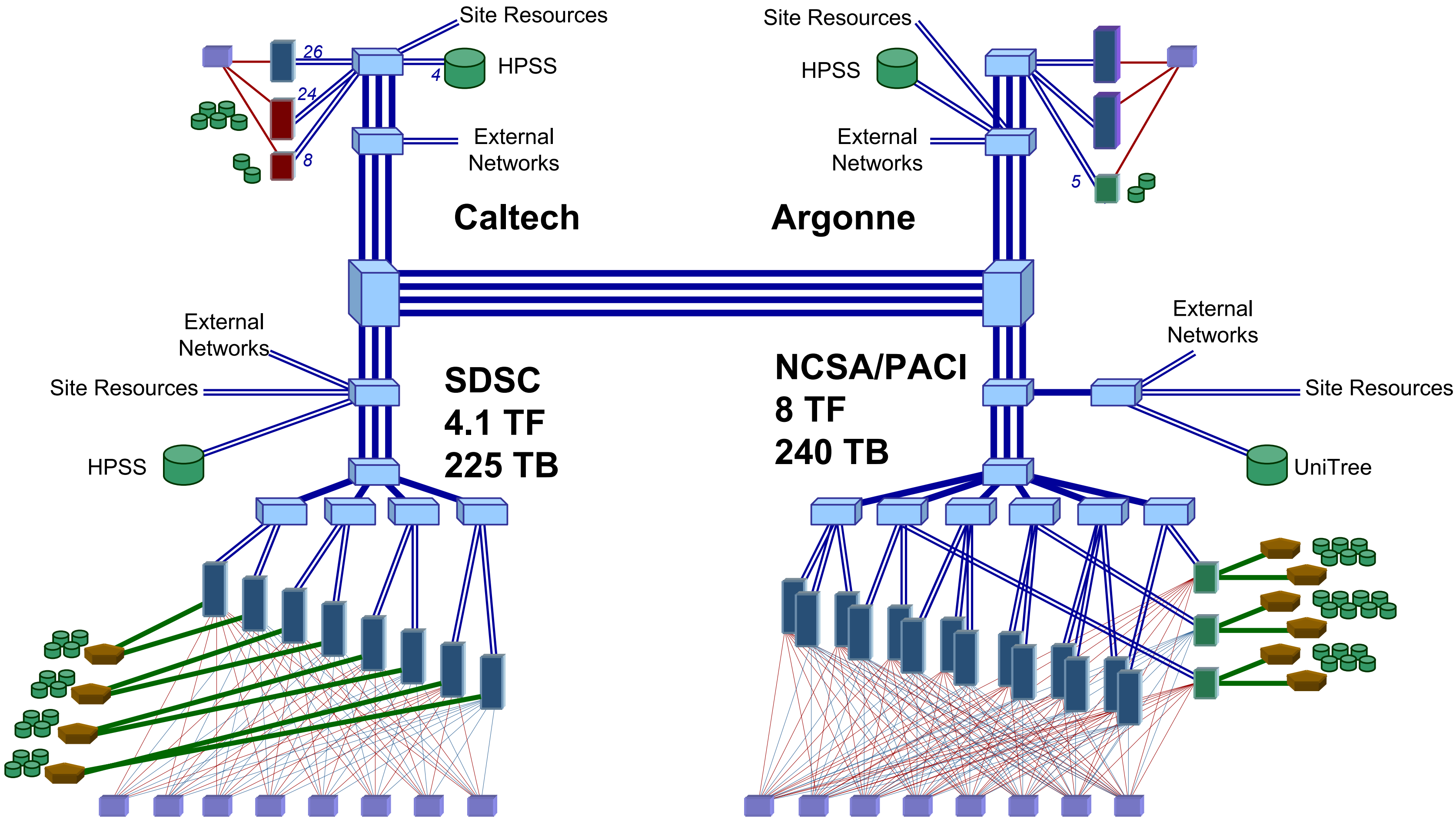
Principali Progetti di Grid

Nome	URL/Sponsor	Focus
Grid Physics Network	griphyn.org NSF	Tecnologia R&S per data analysis in esper. di fisica: ATLAS, CMS, LIGO, SDSS
Information Power Grid	ipg.nasa.gov NASA	Creare e usare una production Grid per aeroscienze e altre missioni NASA
International Virtual Data Grid Laboratory	ivdgl.org NSF	Creare una Data Grid intern. Per permettere esp. su larga scala di tecnologie & applicazioni Grid
Network for Earthquake Eng. Simulation Grid	neesgrid.org NSF	Creare e usare una production Grid per l'ingegneria dei terremoti
Particle Physics Data Grid	ppdg.net DOE Science	Creare e usare una production Grid per data analysis in esperim. di fisica nucleare e delle alte energie.

Principali Progetti di Grid

Nome	URL/Sponsor	Focus
TeraGrid	teragrid.org NSF	infrastruttura U.S.A. per la scienza che collega 4 siti a 40 Gb/s
UK Grid Support Center	grid-support.ac.uk U.K. eScience	Centro di supporto per progetti Grid nel Regno Unito

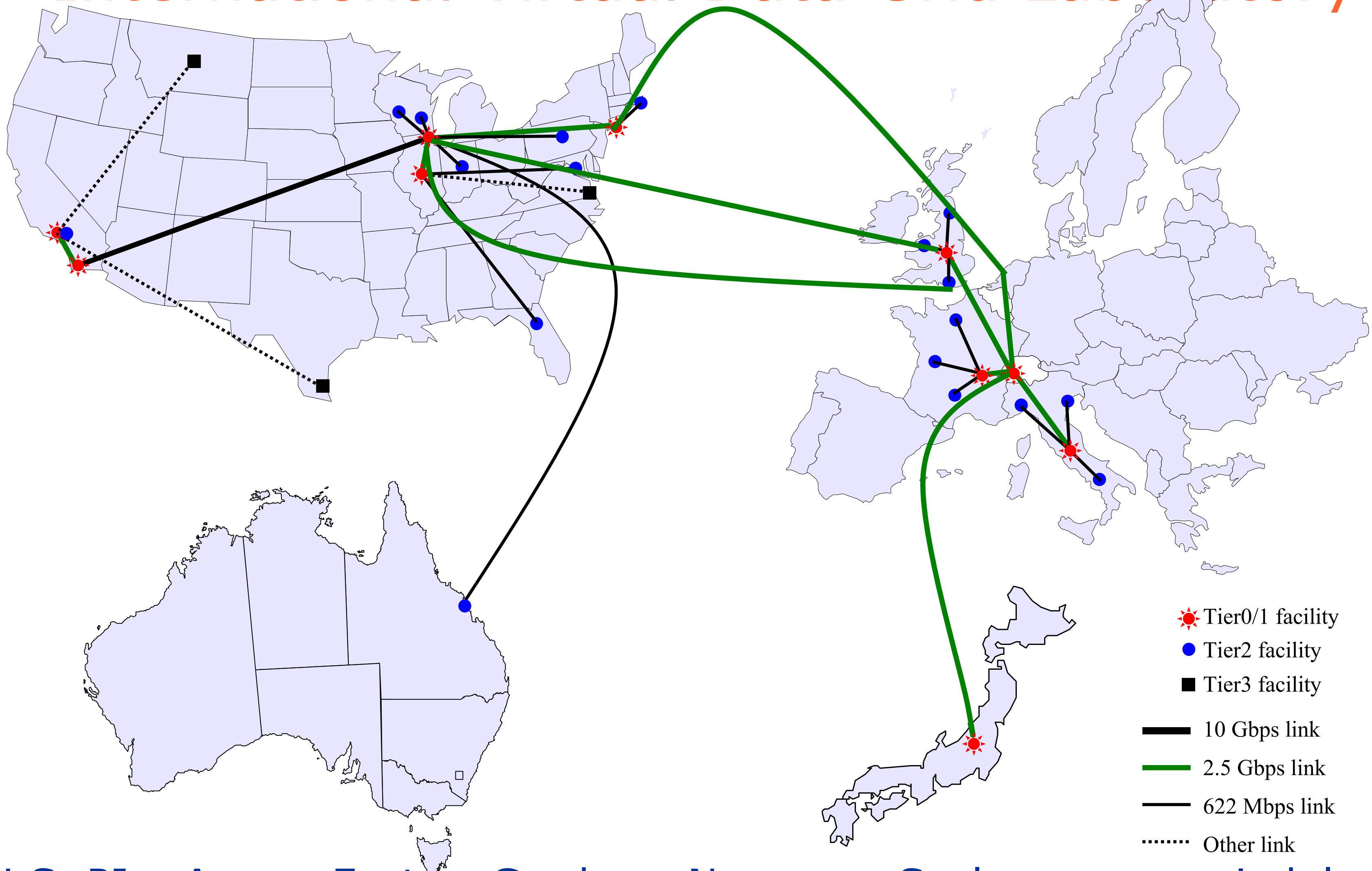
Il 13.6 TF TeraGrid: Elaborazione a 40 Gb/s



TeraGrid/DTF: NCSA, SDSC, Caltech, Argonne www.teragrid.org

the globus project
www.globus.org

iVDGL: International Virtual Data Grid Laboratory



U.S. PIs: Avery, Foster, Gardner, Newman, Szalay   www.ivdgl.org

Alcune Definizioni

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Alcune Importanti Definizioni

- Risorsa
- Network protocol
- Network enabled service
- Application Programmer Interface (API)
- Software Development Kit (SDK)
- Sintassi

- Non discusse, ma importanti: politiche

Risorsa

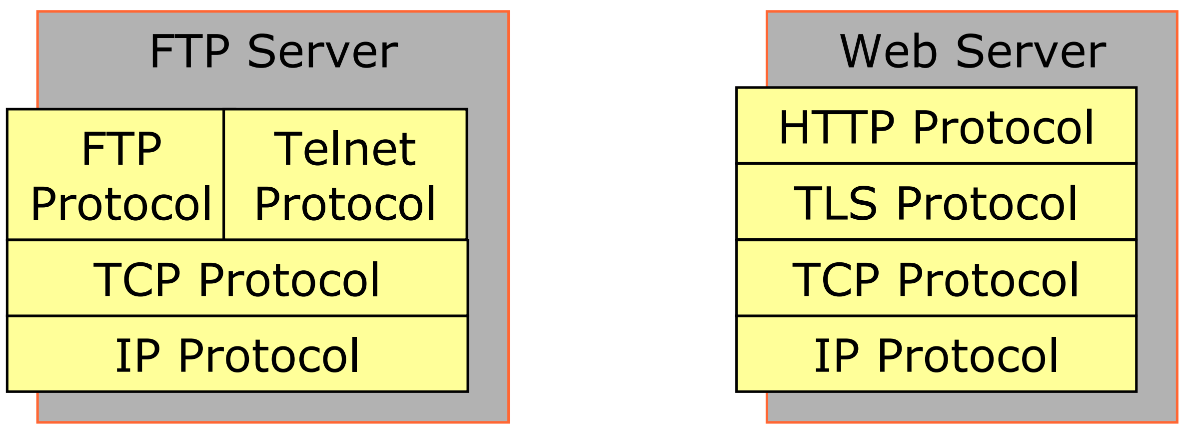
- Una entità da condividere
  - Es., computers, memorie, dati, software
  - Definita in termini di interfacce, non di dispositivi
  - Es. uno scheduler come LSF e PBS definisce una risorsa di calcolo come un cluster
  - Es., Open/close/read/write definiscono accessi ad un file system distribuito come NFS, AFS, DFS.

Network Protocol

- Una descrizione formale di formati di messaggi e un insieme di regole per lo scambio di messaggi.
  - Le regole possono definire sequenze di scambio di messaggi
  - Un protocollo può definire il cambio di stato nel punto finale, es., cambio di stato di un file system
  - I Protocolli possono prevedere più livelli.
- Esempi di protocolli
  - IP, TCP, TLS (era SSL), HTTP, Kerberos

Network Enabled Services

- Implementazione di un protocollo che definisce un insieme di capabilities
  - Il protocollo definisce l'interazione con il servizio
  - Tutti i servizi di rete richiedono protocolli
  - Non tutti i protocolli sono usati per fornire servizi (es. IP, TLS)
- Esempi: FTP e Web servers



Application Programming Interface

- Una specifica di un insieme di routine per facilitare lo sviluppo di applicazioni
  - Si riferiscono alla definizione, non all'implementazione
  - Es., vi sono implementazioni di MPI
- Specifiche spesso legate ad un linguaggio
  - Nome della routine, numero, ordine e tipo degli argomenti; mapping a costrutti del linguaggio
  - Comportamento o funzione della routine
- Esempi
  - GSS API (security), MPI (message passing)

Software Development Kit

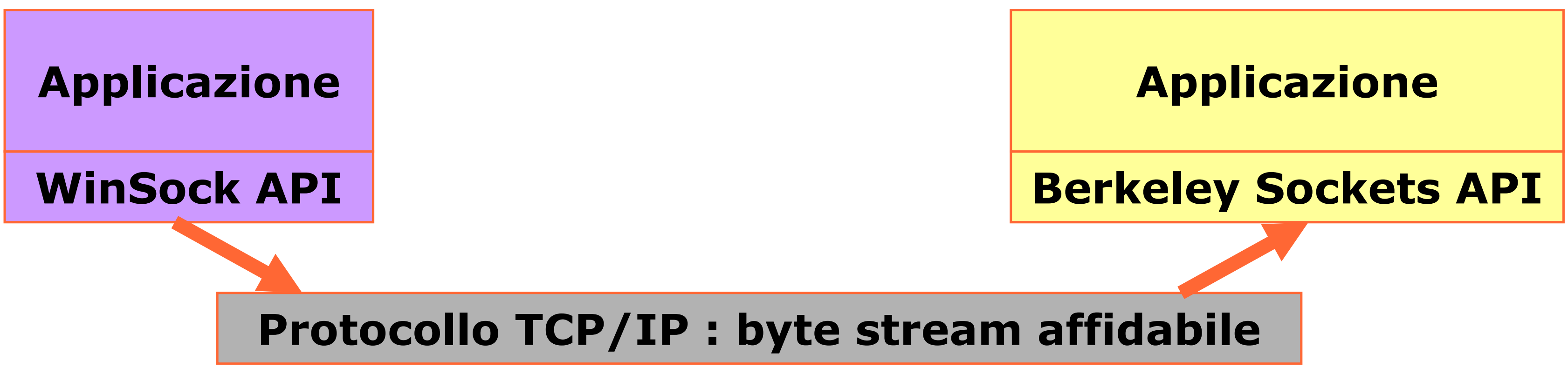
- Una particolare istanziazione di una API
- Un SDK consiste di librerie e strumenti
  - Fornisce una implementazione di una specifica di una API
- Possono esistere diversi SDK per una API
- Esempi di SDK
  - MPICH, Motif Widgets

Sintassi

- Regole per codificare l'informazione, es.
  - XML, Condor ClassAds, Globus RSL
  - X.509 certificate format (RFC 2459)
  - Cryptographic Message Syntax (RFC 2630)
- Distinta dai protocolli
  - Una sintassi puo' essere usata da molti protocolli (e.g., XML) e utile per molti scopi.
- Si possono avere sintassi a più livelli
  - Es., Condor ClassAds -> XML -> ASCII
  - Importante capire la stratificazione quando si paragonano e valutano più sintassi.

Un Protocollo può avere più API

- Le API TCP/IP includono i sockets BSD, Winsock, System V streams, …
- Il protocollo fornisce <u>interoperability</u>: programmi che fanno uso di API differenti possono scambiarsi informazioni.
- Io non ho bisogno di conoscere quali API sta usando un utente remoto.



Una API può avere più Protocolli

- MPI fornisce la portabilità: qualsiasi programma corretto compila e “gira” su una piattaforma.
- Non fornisce interoperabilità: tutti i processi devono comunicare tramite la stessa SDK
  - E.g., MPICH and LAM versions of MPI

API e Protocolli sono Entrambi Importanti

- API/SDK standard sono importanti
  - Permettono la *portabilità* delle applicazioni
  - Ma senza protocolli standard, interoperabilità è difficile (ogni SDK parla con ogni protocollo?)
- Protocolli standard sono importanti
  - Permettono *interoperabilità* tra siti diversi
  - Permettono una struttura condivisa
  - Ma senza API/SDK standard, la portabilità delle applicazioni è difficile (macchine differenti fanno uso di un protocollo in maniera differente)

Architettura di Grid

The Globus Project™

Argonne National Laboratory
USC Information Sciences Institute

http://www.globus.org

Oggi: Focus sul Problema dei Sistemi

- Il problema dei sistemi
  - Facilitare l’uso coordinato di risorse diverse
  - Facilitare condivisione dell’infrastruttura : es., autorità di certificazione, info services
  - Richiede sistemi: protocolli, servizi
  - Es., porte/servizi/protocolli per accedere informazioni e allocare risorse
- Il problema della programmazione
  - Facilitare lo sviluppo di applic. Sofisticate.
  - Facilitare il code sharing
  - Richiede ambienti di programmazione: APIs, SDKs, tools

Problema dei Sistemi : Meccanismi di Condivisione di Risorse che...

- Affrontino problemi di sicurezza e politiche dei proprietari e degli utenti.
- Siano abbastanza flessibili per gestire risorse di tipo diverso e modalità di cooperazione diverse.
- Gestiscano elevate risorse, programmi e utenti.
- Operino efficientemente nel gestire grandi moli di dati e di computazione.

Aspetti del Problema dei Sistemi

1) Necessità di interoperabilità quando differenti gruppi condividono risorse
   - Diverse componenti, politiche, meccanismi
   - Es., notioni standard di identità, mezzi di comunicazione, descrizione di risorse
2) Necessità servizi di infrastruttura condivisi per evitare sviluppi e configurazioni ripetute
   - Es., una porta/servizio/protocollo per accesso remoto all'elaborazione, non uno per tool/applicazione
   - Es., Autorità di Certificazione : costose

- Necessità comune per protocolli e servizi

Quindi, una Vista Protocol-Oriented dell’Architettura di Grid orientata a …

- Sviluppo di protocolli e servizi di Grid
  - Accesso “Protocol-mediated” a risorse remote
  - Nuovi servizi: es., brokering di risorse
  - “On the Grid” = uso di protocolli Intergrid
  - Essenzialmente (estensioni di) protocolli esistenti
- Sviluppo di Grid APIs & SDKs
  - Interfacce a protocolli e servizi di Grid
  - Facilitare lo sviluppo di applicazioni attraverso astrazioni di più alto livello
- Il modello (largamente vincente) è Internet.

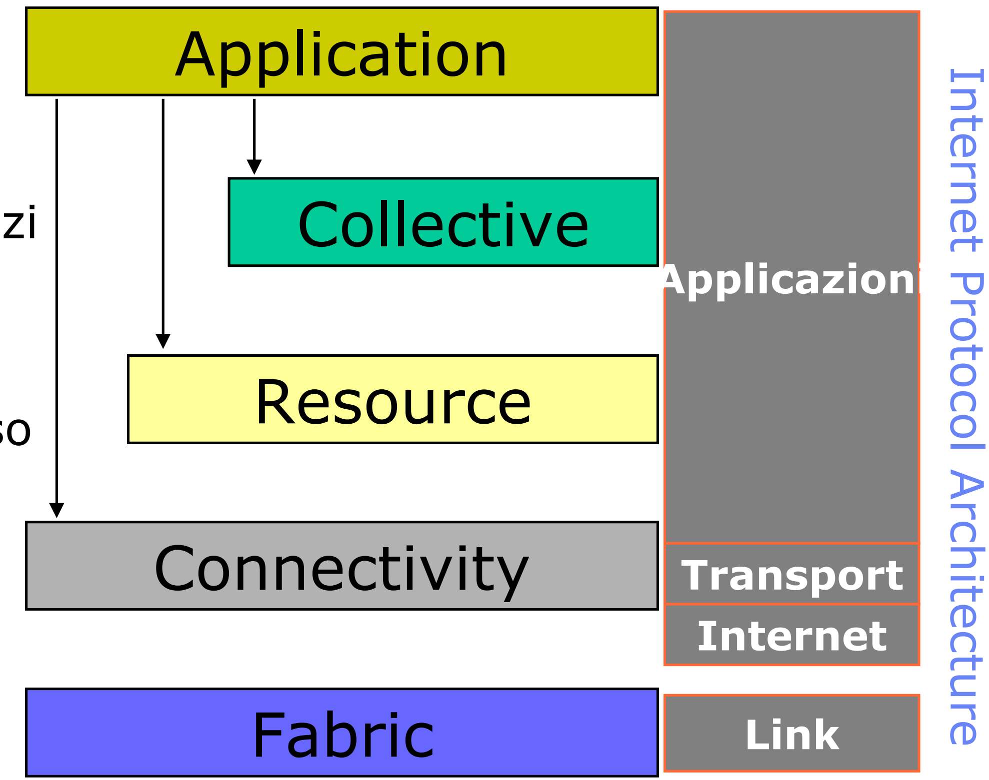
Architettura di Grid a Livelli (per analogia con l'Architettura di Internet)

"Coordinare risorse multiple": servizidi infrastruttura ubiqui, servizi distribuiti application-specific

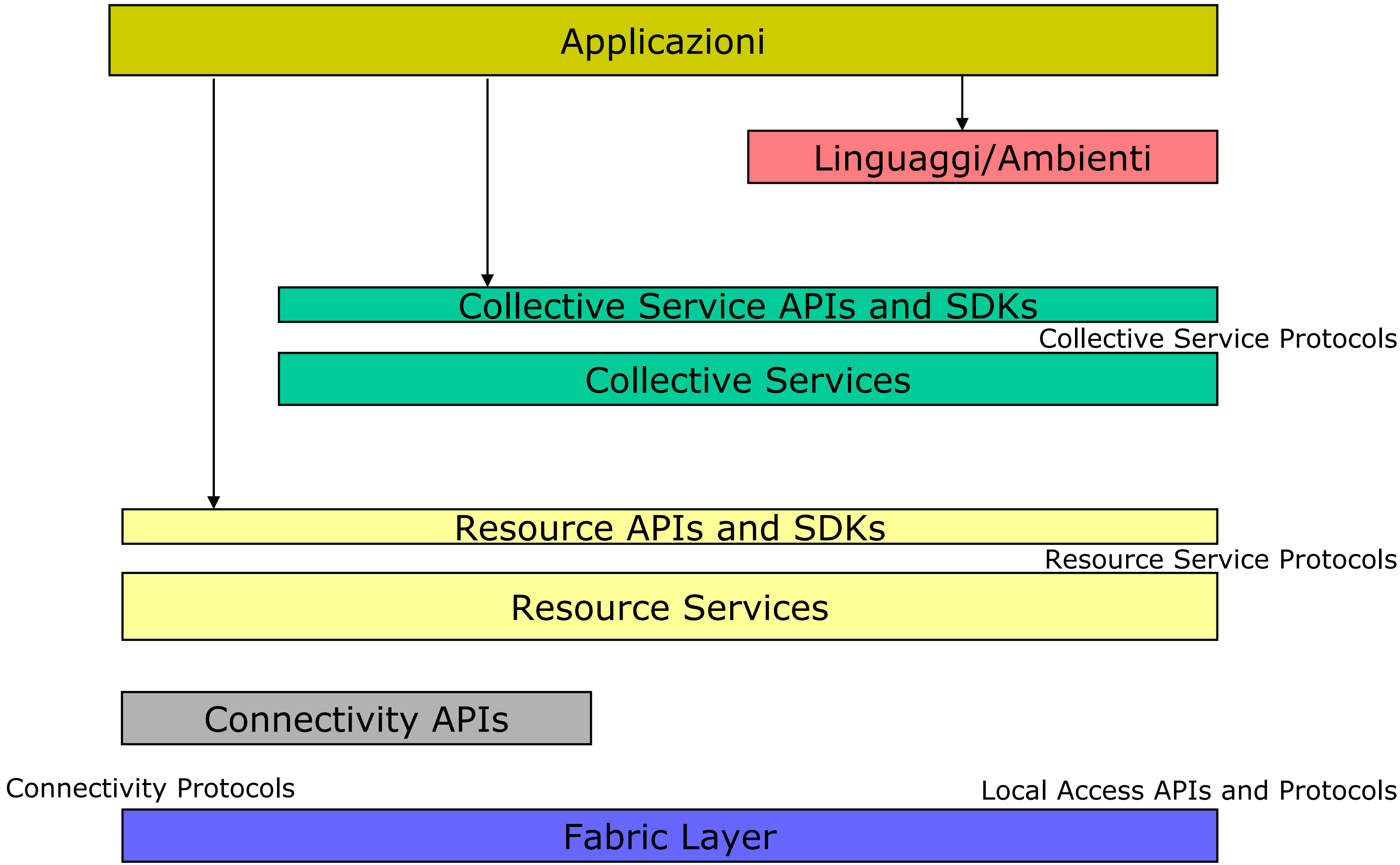
"Condividere risorse singole": negoziare l'accesso, controllare l'uso

"Parlare alle cose": comunicazione (protocolli Internet) & security

"Controllare le cose localmente": Accesso a, e controllo di, risorse



Protocolli, Servizi, e API ad Ogni Livello

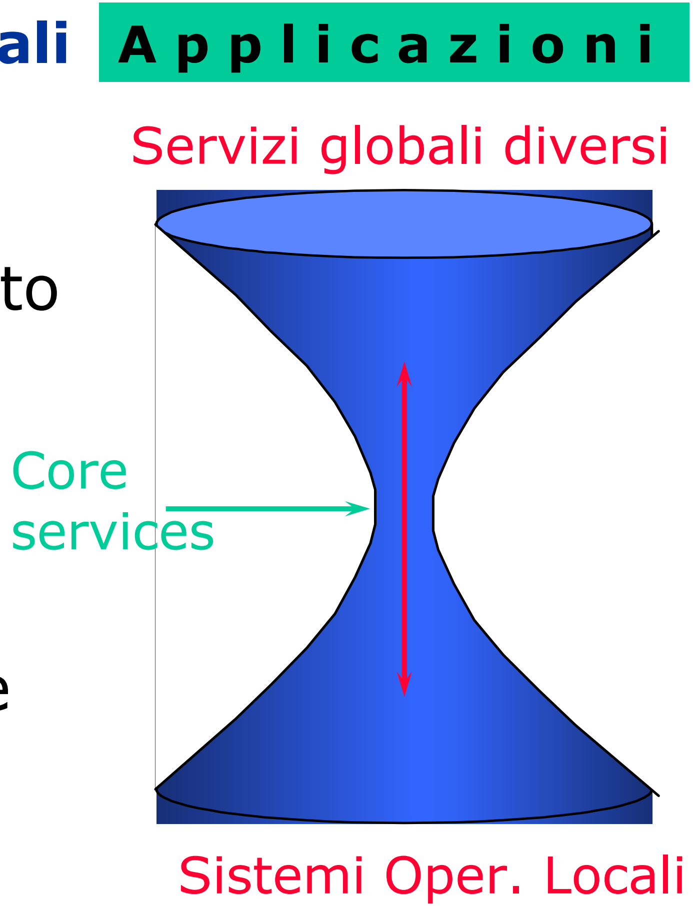


Aspetti Importanti

- Costruita sui protocolli e i servizi di Internet
  - Comunicazione, routing, risolutione dei nomi, ecc.
- “Stratificazione” qui è concettuale, non implica vincoli su chi può chiamare cosa
  - Protocolli/servizi/API/SDK sono, largamente auto-contenuti
  - Alcune cose sono fondamentali: es., comunicazione e sicurezza
  - E’ vantaggioso per funzioni di più alto livello usare funzioni comuni di più basso livello.

Il Modello a Clessidra

- **Focus sui problemi architetturali**
  - Un insieme di core services come infrastruttura di base
  - Costruzione di solutioni di alto livello, domain-specific
- **Principi di progettazione**
  - Mantenere basso il costo di participazione
  - Permettere il controllo locale
  - Supportare l'adattamento
  - Modello "clessidra IP"



Livello di Connettività Protocolli & Servizi

- Comunicazione
  - protocolli Internet : IP, DNS, routing, ecc.
- Sicurezza: Grid Security Infrastructure (GSI)
  - Autenticazione uniforme, autorizzazione, e meccanismi di protezione di messaggi in ambienti multi-istituzioni
  - Singola iscrizione, delega, mapping dell'identità
  - Tecnologia a Chiave Pubblica, SSL, X.509, GSS-API
  - Infrastruttura di Supporto : Certificate Authorities, gestione di certificati & chiavi, …

GSI: www.gridforum.org/security

Livello di Risorse Protocolli & Servizi

- Grid Resource Allocation Mgmt (GRAM)
  - Allocazione Remota, prenotazione, monitoraggio, controllo delle risorse di calcolo
- Protocollo GridFTP (estenzioni FTP)
  - Accesso a dati e trasporto ad alte prestazioni
- Grid Resource Information Service (GRIS)
  - Accesso a informazioni di struttura e di stato
- Network reservation, monitoring, controllo
- Tutto costruito sul livello di connettività: GSI & IP

GridFTP: www.gridforum.org
GRAM, GRIS: www.globus.org

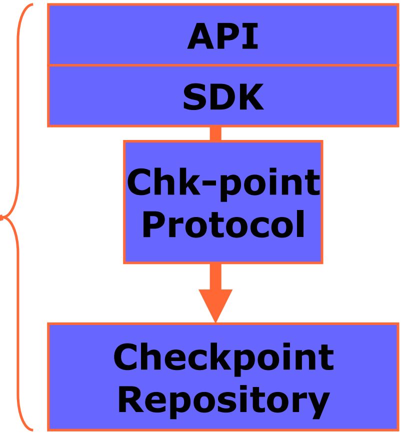
Livello Collective Protocolli & Servizi

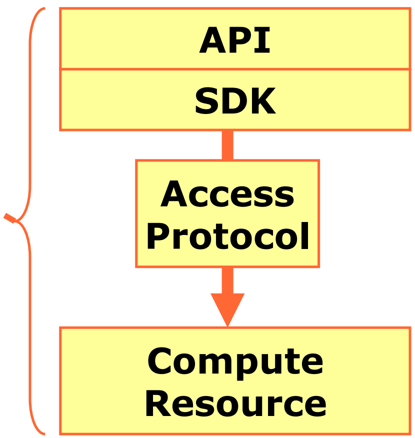
- Index server (es. Monitoring and Discovery Service)
  - Viste personalizzate su collezioni di risorse dinamiche assemblate da una comunità
- Resource brokers (e.g., Condor Matchmaker)
  - Scoperta e allocazione di risorse
- Servizi di Replica Location e Management
- Servizi di gestione di Metadati
- Servizi di Co-reservation and co-allocation
- Servizi di Gestione di Workflow
- Ecc.

Condor: www.cs.wisc.edu/condor

Esempio: High-Throughput Computing System

Appl	High Throughput Computing System
Collective (Appl)	checkpoint dinamico, job management, failover, staging
Collective (Generico)	Brokering, certificate authorities
Resource	Access to data, access to computers, access to network performance data
Connectivity	Comunicazione, service discovery (DNS), autenticazione, autorizzazione, delegation
Fabric	Sistemi di memorizzazione, schedulers





Esempio: Grid Services per Applicazioni Data-Intensive

Applicaz.	Applicazioni Data Grid Specifiche per Disciplina
Collective (Appl)	Controllo di Coerenza, replica selection, task management, virtual data catalog, virtual data code catalog, …
Collective (Generic)	Replica catalog, replica management, co-allocazione, certificate authorities, metadata catalogs,
Resource	Accesso ai dati, accesso ai computers, accesso a dati di performance di rete, …
Connect	Comunicazione, service discovery (DNS), autenticazione, autorizzazione, delegation
Fabric	Sistemi di memorizzazione, clusters, reti, cache di rete, .

The Globus Toolkit™ Version 2: Introduction

Globus Toolkit™ Version 2

- 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
  - Make available under liberal open source license

Four Main Components

- Security
- Information Management
- Resource Management
- Data Management

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, …
- Learn through deployment and applications

Four Key Protocols

- The Globus Toolkit™ Version 2 centers around four key protocols
  - Connectivity layer:
    - *Security*: Grid Security Infrastructure (GSI)
  - Resource layer:
    - *Resource Management*: Grid Resource Allocation Management (GRAM)
    - *Information Services*: Grid Resource Information Protocol (GRIP)
    - *Data Transfer*: Grid File Transfer Protocol (GridFTP)

The Globus Toolkit™ Version 2:
Security Services

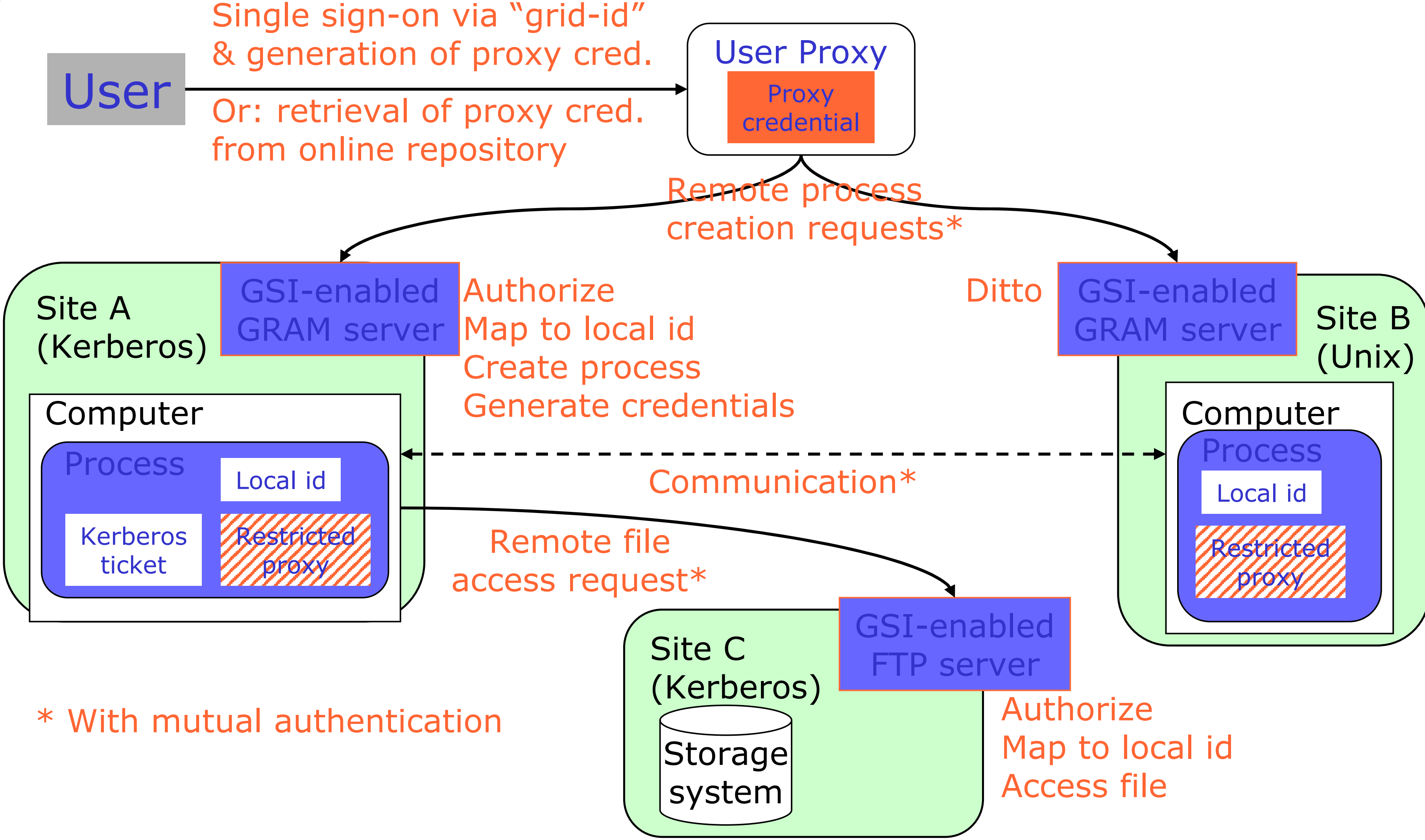
Security Terminology

- Authentication: Establishing identity
- Authorization: Establishing rights
- Message protection
  - Message integrity
  - Message confidentiality
- Non-repudiation
- Digital signature
- Accounting
- Certificate Authority (CA)

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

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



* With mutual authentication

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

API/SDK with authentication, flexible message protection, flexible communication, delegation, ...

- Direct calls to various security functions (e.g. GSS-API)
- Or security integrated into higher-level SDKs:
  - E.g. GlobusIO, Condor-G, MPICH-G2, HDF5, etc.

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 + SSO/delegation
  - Tools and services to interface to local security
  - Tools for credential management
    - Login, logout, etc.
    - Smartcards
    - MyProxy: Web portal login and delegation
    - K5cert: Automatic X.509 certificate creation

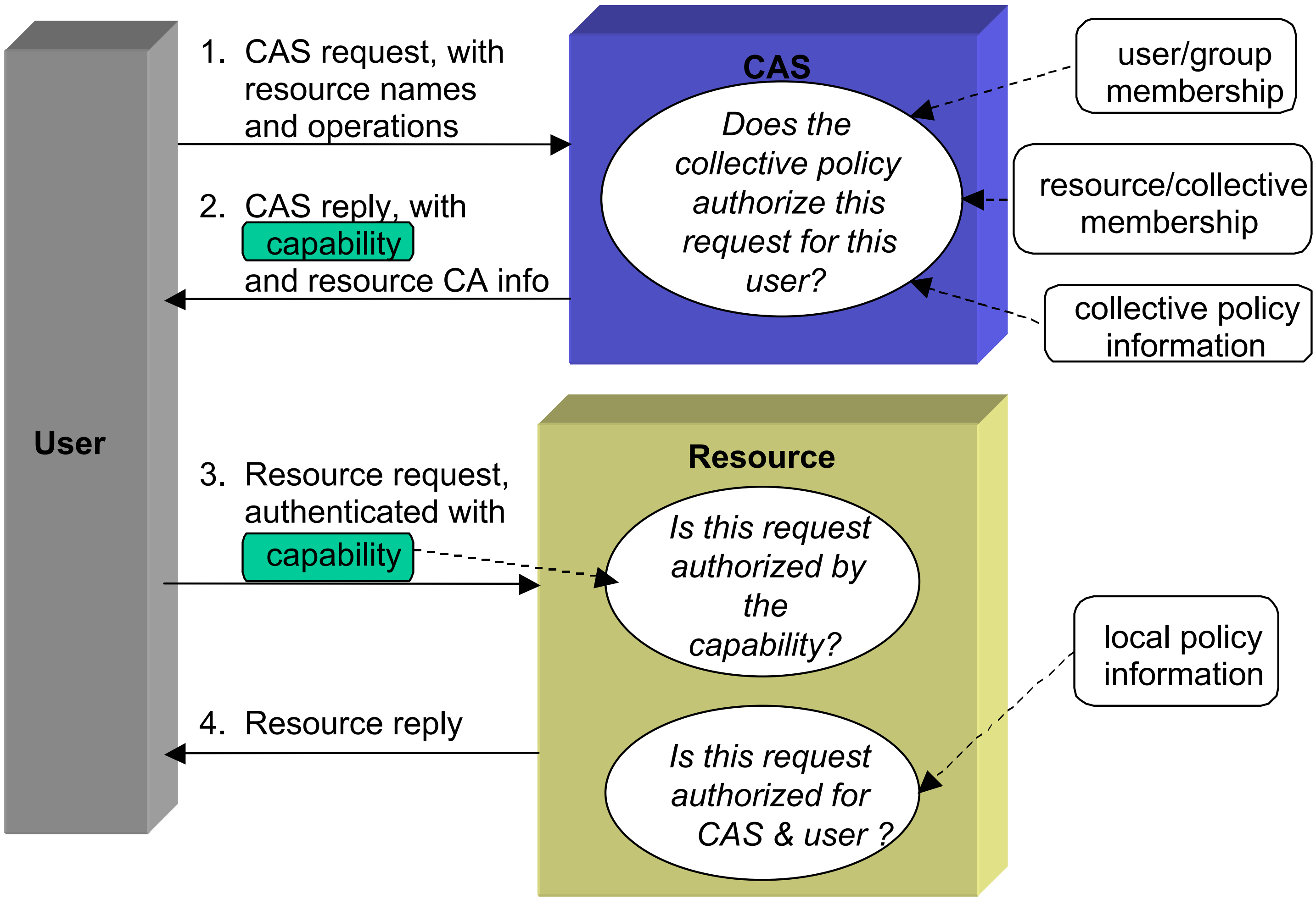
Other Globus Security Work

- Protection against compromised resources
  - Restricted delegation, smartcards
- Standardization
- Scalability in numbers of users & resources
  - Credential management
  - Online credential repositories (“MyProxy”)
  - Account management
- Authorization
  - Policy languages
  - Community authorization

Community Authorization Service

- Question: How does a large community grant its users access to a large set of resources?
  - Should minimize burden on both the users and resource providers
- Community Authorization Service (CAS)
  - Community negotiates access to resources
  - Resource outsources some authorization to CAS
  - CAS handles user registration, group membership…
  - User who wants access to resource asks CAS for a capability credential
  - Resources can also do local access control

Community Authorization



Security Summary

- GSI successfully addresses wide variety of Grid security issues
- Broad acceptance, deployment, integration with tools
- Standardization on-going in IETF & GGF
- Community Authorization Service to address community-based allocation of resources
  - Continuing development

The Globus Toolkit™: Resource Management Services

The Globus Project™

Argonne National Laboratory
USC Information Sciences Institute

http://www.globus.org

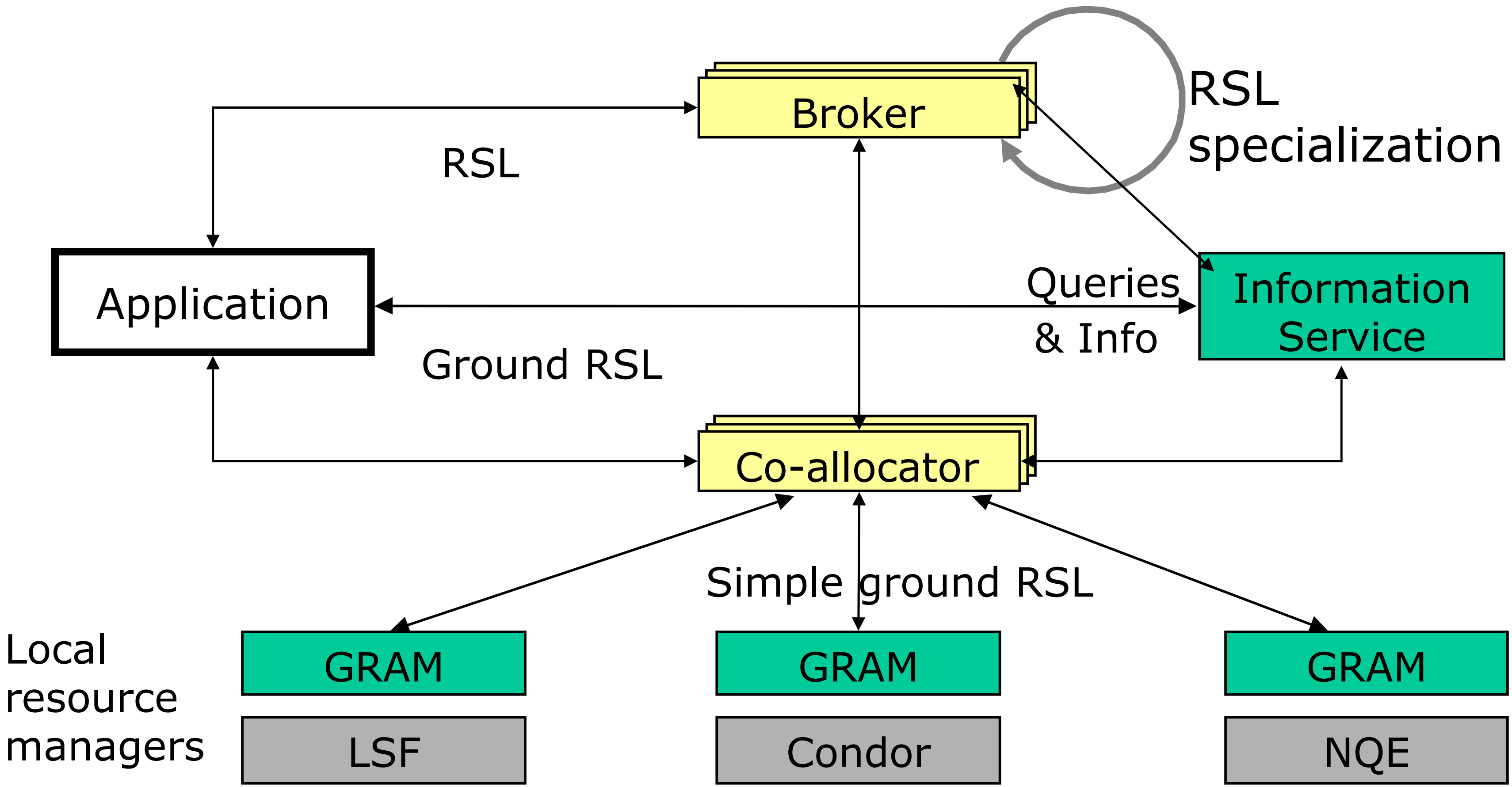
The Challenge

- Enabling secure, controlled remote access to heterogeneous computational resources and management of remote computation
  - Authentication and authorization
  - Resource discovery & characterization
  - Reservation and allocation
  - Computation monitoring and control
- Addressed by new protocols & services
  - GRAM protocol as a basic building block
  - Resource brokering & co-allocation services
  - GSI for security, MDS for discovery

Resource Management

- The Grid Resource Allocation Management (GRAM) protocol and client API allows programs to be started on remote resources, despite local heterogeneity
- Resource Specification Language (RSL) is used to communicate requirements
- A layered architecture allows application-specific resource brokers and co-allocators to be defined in terms of GRAM services
  - Integrated with Condor, PBS, MPICH-G2, …

Resource Management Architecture



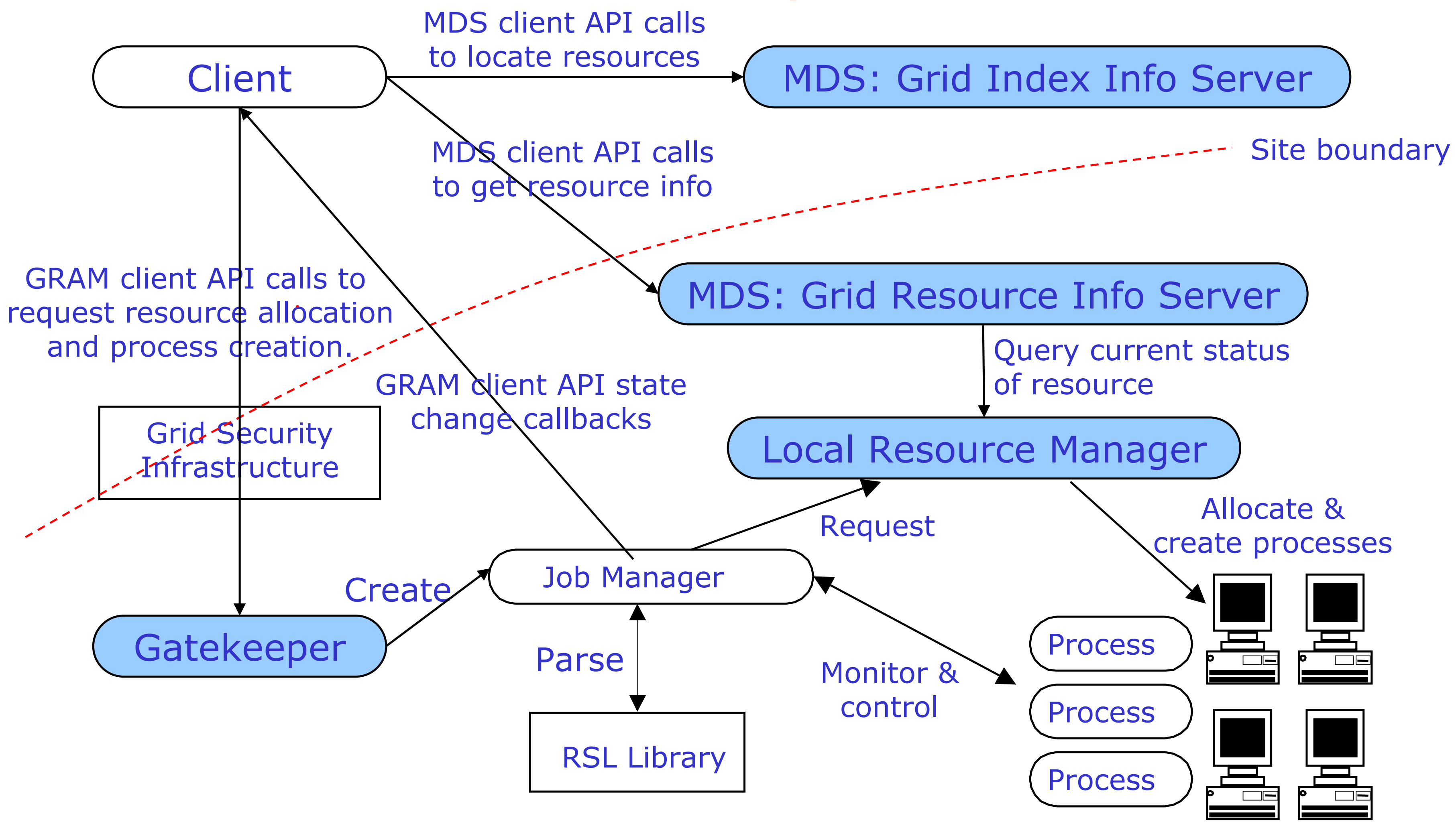
Resource Specification Language

- Common notation for exchange of information between components
  - Syntax similar to MDS/LDAP filters
- RSL provides two types of information:
  - Resource requirements: Machine type, number of nodes, memory, etc.
  - Job configuration: Directory, executable, args, environment
- Globus Toolkit provides an API/SDK for manipulating RSL

Globus Toolkit Version 2 Implementation

- Gatekeeper
  - Single point of entry
  - Authenticates user, maps to local security environment, runs service
  - In essence, a "secure inetd"
- Job manager
  - A gatekeeper service
  - Layers on top of local resource management system (e.g., PBS, LSF, etc.)
  - Handles remote interaction with the job

GRAM Components



Co-allocation

- 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 (already in prototype)
- Globus APIs/SDKs support the co-allocation of specific multi-requests
  - Uses a Globus component called the Dynamically Updated Request Online Co-allocator (DUROC)

The Globus Toolkit™: Information Services

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Grid Information Services

- System information is critical to operation of the grid and construction of applications
  - What resources are available?
    - > Resource discovery
  - What is the "state" of the grid?
    - > Resource selection
  - How to optimize resource use
    - > Application configuration and adaptation?
- We need a general information infrastructure to answer these questions

Examples of Useful Information

- Characteristics of a compute resource
  - IP address, software available, system administrator, networks connected to, OS version, load
- Characteristics of a network
  - Bandwidth and latency, protocols, logical topology
- Characteristics of the Globus infrastructure
  - Hosts, resource managers

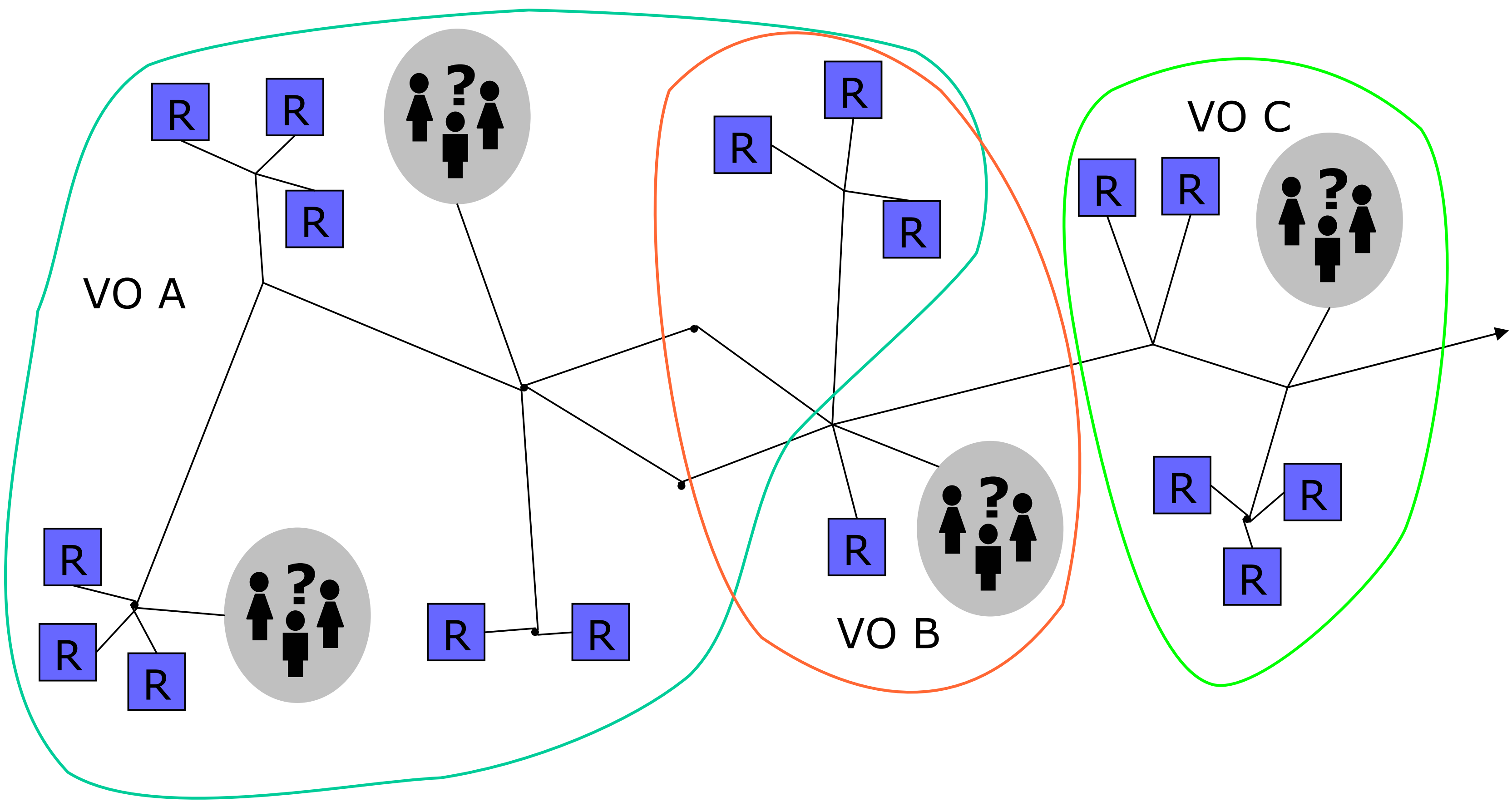
Grid Information: Facts of Life

- Information is always old
  - Time of flight, changing system state
  - Need to provide quality metrics
- Distributed state hard to obtain
  - Complexity of global snapshot
- Component will fail
- Scalability and overhead
- Many different usage scenarios
  - Heterogeneous policy, different information organizations, etc.

Grid Information Service

- Provide access to static and dynamic information regarding system components
- A basis for configuration and adaptation in heterogeneous, dynamic environments
- Requirements and characteristics
  - Uniform, flexible access to information
  - Scalable, efficient access to dynamic data
  - Access to multiple information sources
  - Decentralized maintenance

The GIS Problem: Many Information Sources, Many Views



What is a Virtual Organization?

- Facilitates the workflow of a group of users across multiple domains who share (some of) their resources to solve particular classes of problems
- Collates and presents information about these resources in a uniform view

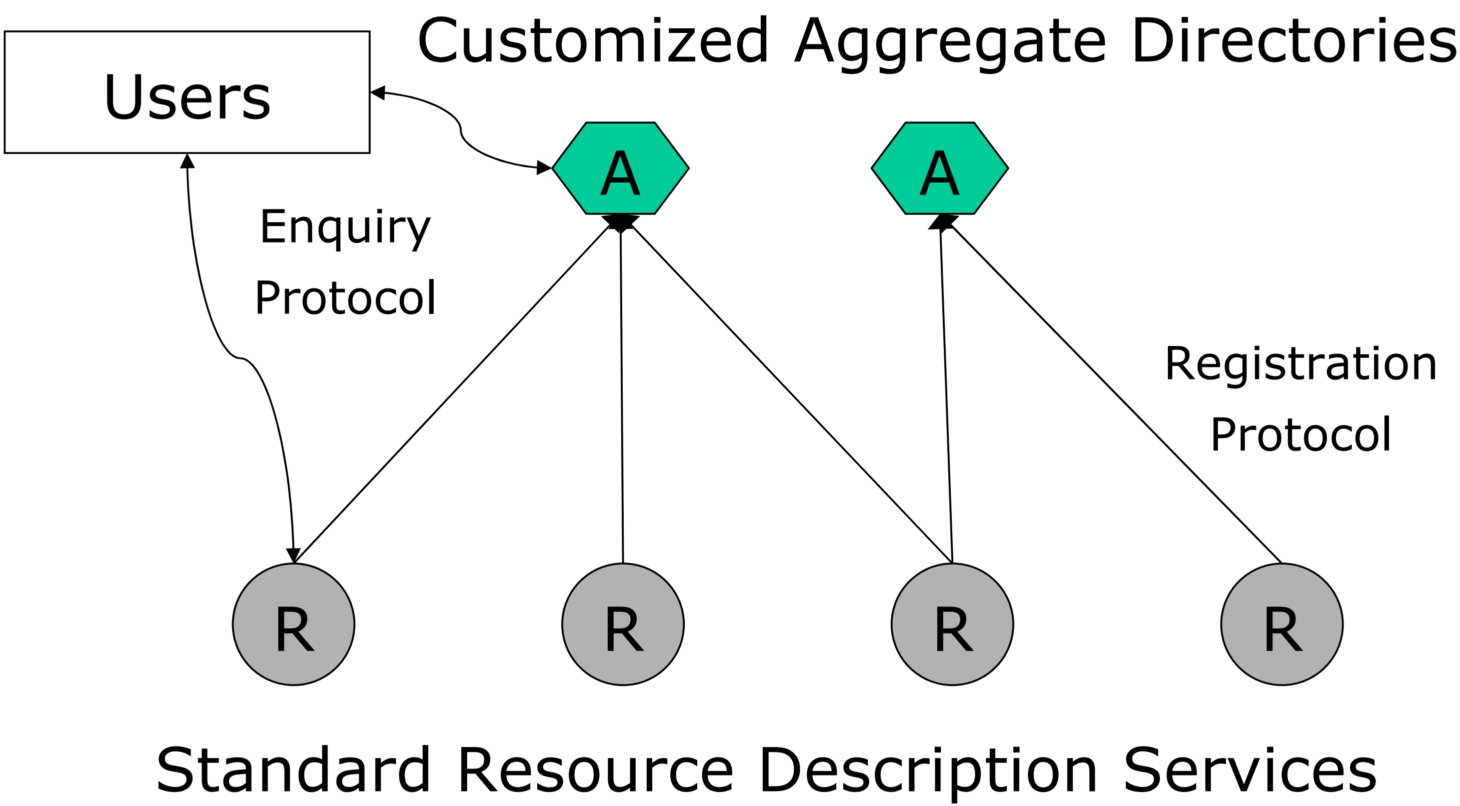
Two Classes Of Information Servers

- Resource Description Services
  - Supplies information about a specific resource (e.g. Globus 1.1.3 GRIS).
- Aggregate Directory Services
  - Supplies collection of information which was gathered from multiple GRIS servers (e.g. Globus 1.1.3 GIIS).
  - Customized naming and indexing

Information Protocols

- Grid Resource Registration Protocol
  - Support information/resource discovery
  - Designed to support machine/network failure
- Grid Resource Inquiry Protocol
  - Query resource description server for information
  - Query aggregate server for information
  - LDAP V3.0 in Globus 1.1.3

GIS Architecture



Monitoring and Discovery Service (MDS)

- Use LDAP as Inquiry
- Access information in a distributed directory
  - Directory represented by collection of LDAP servers
  - Each server optimized for particular function
- Directory can be updated by:
  - Information providers and tools
  - Applications (i.e., users)
  - Backend tools which generate info on demand
- Information dynamically available to tools and applications

Two Classes Of MDS Servers

- Grid Resource Information Service (GRIS)
  - Supplies information about a specific resource
  - Configurable to support multiple information providers
  - LDAP as inquiry protocol

- Grid Index Information Service (GIIS)
  - Supplies collection of information which was gathered from multiple GRIS servers
  - Supports efficient queries against information which is spread across multiple GRIS server
  - LDAP as inquiry protocol

Grid Resource Information Service

- Server which runs on each resource
  - Given the resource DNS name, you can find the GRIS server (well known port = 2135)
- Provides resource specific information
  - Much of this information may be dynamic
    - Load, process information, storage information, etc.
    - GRIS gathers this information on demand
- "White pages" lookup of resource information
  - Ex: How much memory does machine have?
- "Yellow pages" lookup of resource options
  - Ex: Which queues on machine allows large jobs?

Grid Index Information Service

- GIIS describes a class of servers
  - Gathers information from multiple GRIS servers
  - Each GIIS is optimized for particular queries
    - Ex1: Which Alliance machines are >16 process SGIs?
    - Ex2: Which Alliance storage servers have >100Mbps bandwidth to host X?
  - Akin to web search engines
- Organization GIIS
  - The Globus Toolkit ships with one GIIS
  - Caches GRIS info with long update frequency
    - Useful for queries across an organization that rely on relatively static information (Ex1 above)
- Can be merged into GRIS

The Globus Toolkit™:
Data Management Services

Data Management Problem

- "Enable a geographically distributed community [of thousands] to pool their resources in order to perform sophisticated, computationally intensive analyses on Petabytes of data"
- Note that this problem:
  - Is common to many areas of science
  - Overlaps strongly with other Grid problems
  - Sometimes term "data grid" is used, but this is a general grid problem

Requirements for Grid Data Management

- Terabytes or petabytes of data
  - Often read-only data, "published" by experiments
  - Other systems need to maintain data consistency
- Large data storage and computational resources shared by researchers around the world
  - Distinct administrative domains
  - Respect local and global policies governing how resources may be used
- Access raw experimental data
- Run simulations and analysis to create "derived" data products

Requirements for Grid Data Management (Cont.)

- Locate data
  - Record and query for existence of data
- Data access based on metadata
  - High-level attributes of data
- Support high-speed, reliable data movement
  - E.g., for efficient movement of large experimental data sets
- Support flexible data access
  - E.g., databases, hierarchical data formats (HDF), aggregation of small objects
- Data Filtering
  - Process data at storage system before transferring

Requirements for Grid Data Management (Cont.)

- Planning, scheduling and monitoring execution of data requests and computations
- Management of data replication
  - Register and query for replicas
  - Select the best replica for a data transfer
- Security
  - Protect data on storage systems
  - Support secure data transfers
  - Protect knowledge about existence of data
- Virtual data
  - Desired data may be stored on a storage system ("materialized") or created on demand

Grids for High Energy Physics

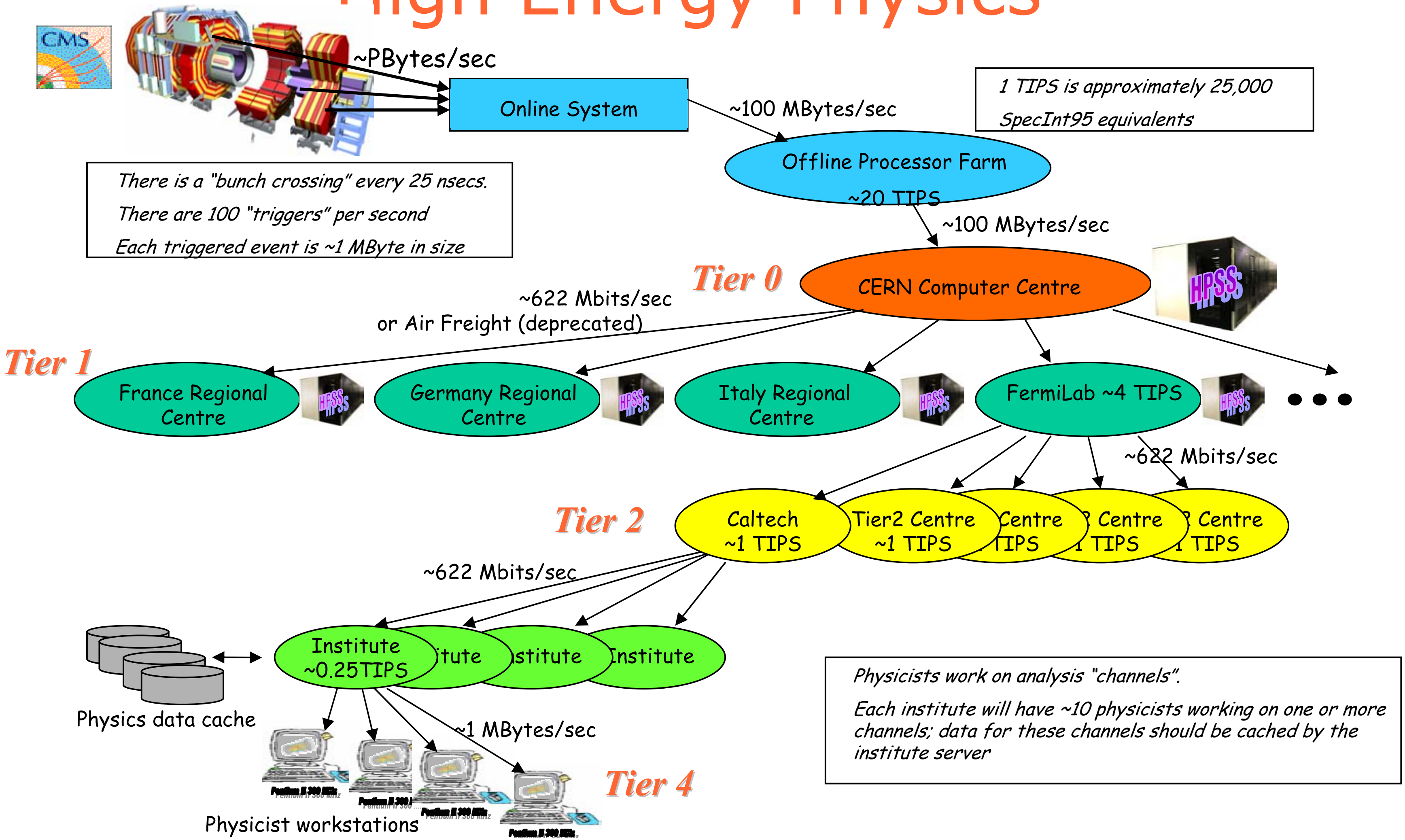


Image courtesy Harvey Newman, Caltech

Globus Toolkit Data Components

- GridFTP Data Transport Protocol
- Replica Location Service
- Metadata Catalog Service

GridFTP

- Data-intensive grid applications need to transfer and replciate large data sets (terabytes, petabytes)
- GridFTP Features:
  - Third party (client mediated) transfer
  - Parallel transfers
  - Striped transfers
  - TCP buffer optimizations
  - Grid security

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GridFTP: Basic Approach

- FTP protocol is defined by several IETF RFCs
- Start with most commonly used subset
  - Standard FTP: get/put etc., 3rd-party transfer
- Implement standard but often unused features
  - GSS binding, extended directory listing, simple restart
- Extend in various ways, while preserving interoperability with existing servers
  - Striped/parallel data channels, partial file, automatic & manual TCP buffer setting, progress monitoring, extended restart

GridFTP Implementation

- The GT2 GridFTP is based on the wuftpd server and client
- Important feature is separation of control and data channels
- GridFTP is a Command Response Protocol
  - Issue a command
  - Get only responses to that command until it is completed
  - Then can issue another command

Replica Management in Grids

- Data intensive applications
  - Produce Terabytes or Petabytes of data
- Replicate data at multiple locations
  - Fault tolerance
  - Performance: avoid wide area data transfer latencies, achieve load balancing
- Issues:
  - Locating replicas of desired files
  - Creating new replicas
  - Scalability
  - Reliability

A Replica Location Service

- **A Replica Location Service (RLS)** is a distributed registry service that records the locations of data copies and allows discovery of replicas
- Maintains mappings between *logical* identifiers and *target names*
  – Physical targets: Map to exact locations of replicated data
  – Logical targets: Map to another layer of logical names, allowing storage systems to move data without informing the RLS
- RLS was designed and implemented in a collaboration between the Globus project and the DataGrid project

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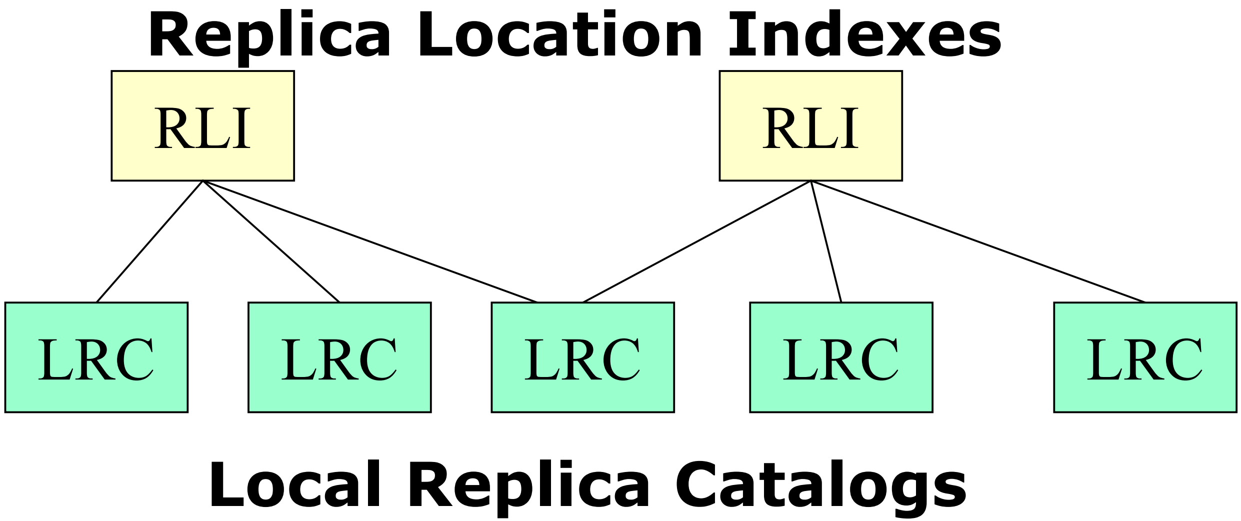

- LRCs contain consistent information about logical-to-target mappings on a site
- RLIs nodes aggregate information about LRCs
- Soft state updates from LRCs to RLIs: relaxed consistency of index information, used to rebuild index after failures
- Arbitrary levels of RLI hierarchy

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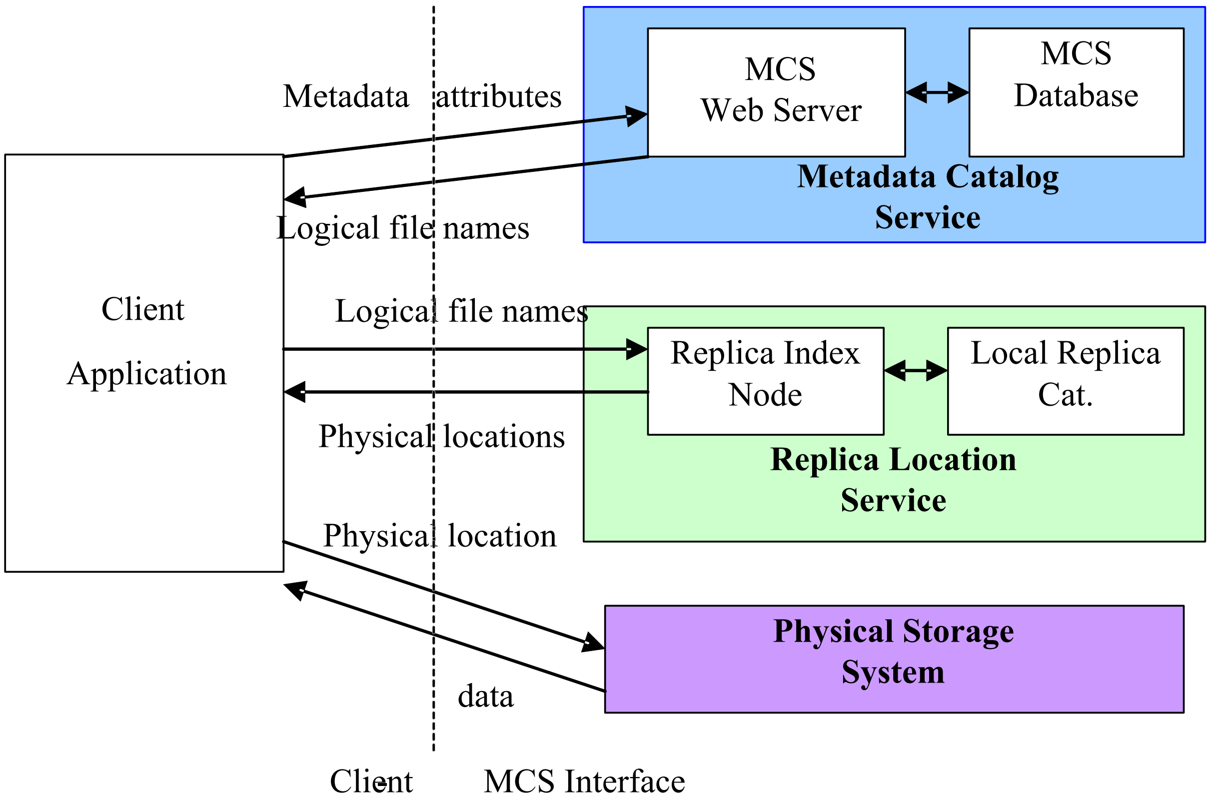
Metadata Services for Cataloguing and Discovery

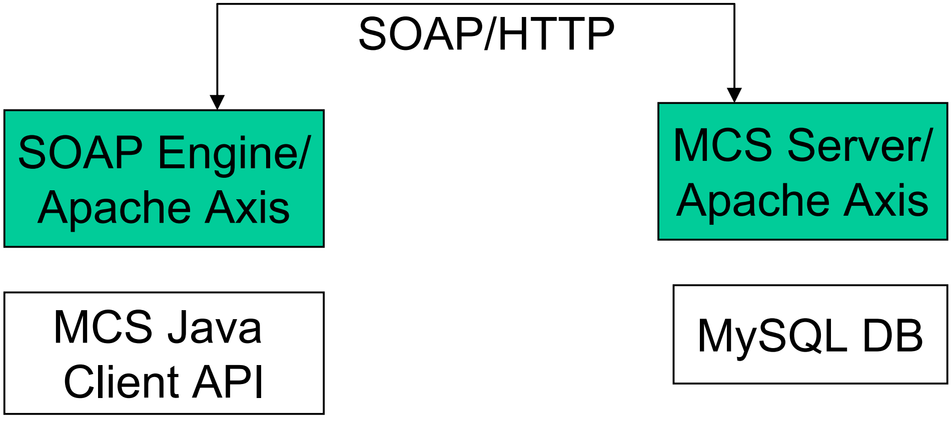
- Metadata is information that describes data sets
- Metadata Services
  - Store metadata attributes according to a specified schema
  - Answer queries for discovery of data with desired attributes
- Two types of metadata services
  - Distinguish between *logical* metadata and *physical* metadata
- Metadata Catalog Service
  - Stores logical metadata that describes contents of files and collections
  - Logical metadata is independent of a particular physical instance, applies to all replicas
  - Variables, annotations, some provenance information

Typical Use of Data Services in Grids

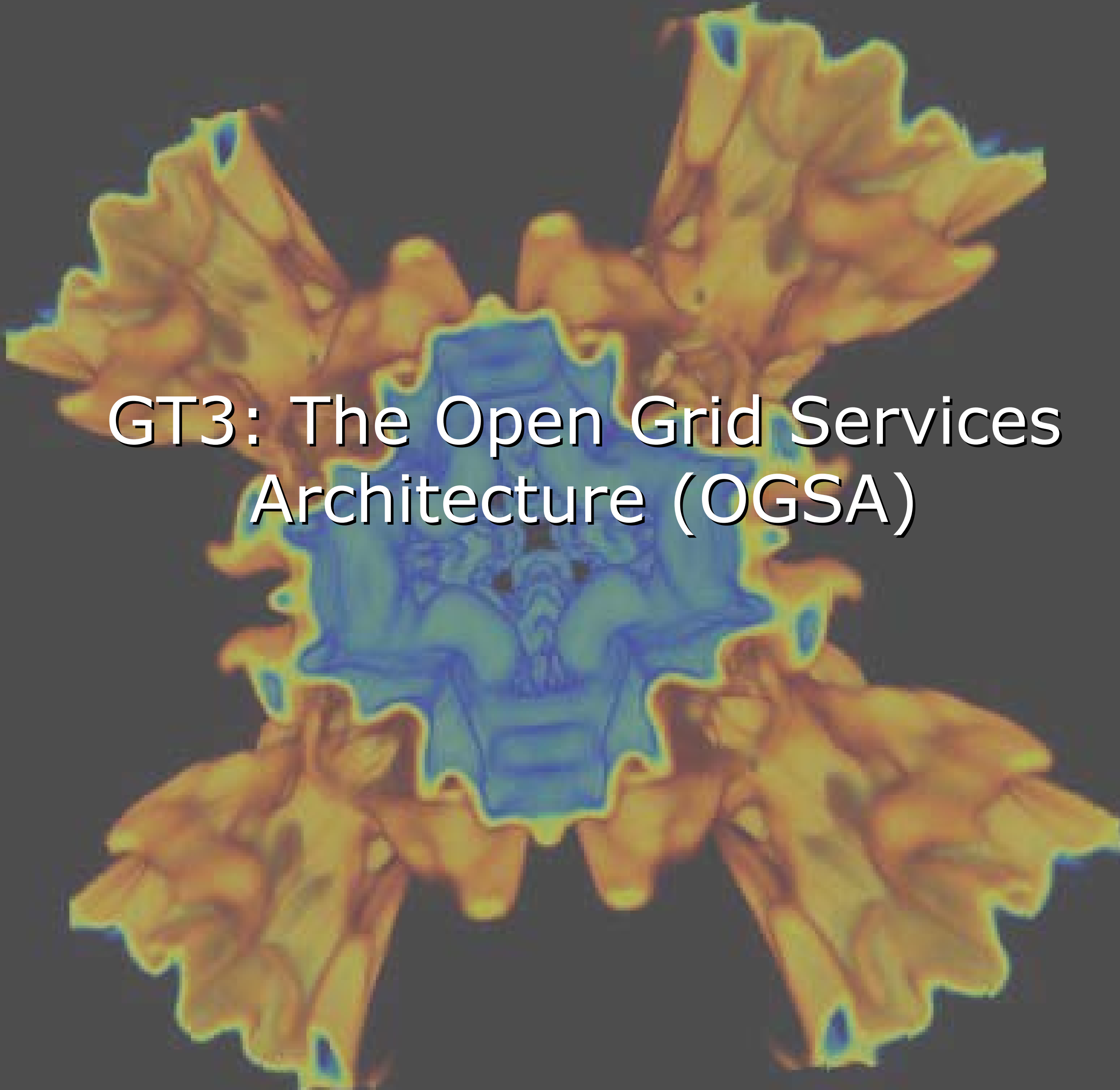


MCS Data Model and Implementation

- Logical files, logical collections and logical views
- May associate pre-defined or user-defined attributes with files, collections or views
- Prototype is a centralized service based on open source web service and database technology



GT3: The Open Grid Services Architecture (OGSA)



Globus Toolkit: Evaluation (+)

- Good technical solutions for key problems, e.g.
  - Authentication and authorization
  - Resource discovery and monitoring
  - Reliable remote service invocation
  - High-performance remote data access
- This & good engineering is enabling progress
  - Good quality reference implementation, multi-language support, interfaces to many systems, large user base, industrial support
  - Growing community code base built on tools

Globus Toolkit: Evaluation (-)

- Protocol deficiencies, e.g.
  - Heterogeneous basis: HTTP, LDAP, FTP
  - No standard means of invocation, notification, error propagation, authorization, termination, …
- Significant missing functionality, e.g.
  - Databases, sensors, instruments, workflow, …
  - Virtualization of end systems (hosting envs.)
- Little work on total system properties, e.g.
  - Dependability, end-to-end QoS, …
  - Reasoning about system properties

“Web Services”

- Increasingly popular standards-based framework for accessing network applications
  - W3C standardization; Microsoft, IBM, Sun, others
- WSDL: Web Services Description Language
  - Interface Definition Language for Web services
- SOAP: Simple Object Access Protocol
  - XML-based RPC protocol; common WSDL target
- WS-Inspection
  - Conventions for locating service descriptions
- UDDI: Universal Desc., Discovery, & Integration
  - Directory for Web services

Transient Service Instances

- "Web services" address discovery & invocation of persistent services
  - Interface to persistent state of entire enterprise
- In Grids, must also support transient service instances, created/destroyed dynamically
  - Interfaces to the states of distributed activities
  - E.g. workflow, video conf., dist. data analysis
- Significant implications for how services are managed, named, discovered, and used
  - In fact, much of our work is concerned with the management of service instances

OGSA Design Principles

- Service orientation to virtualize resources
  - Everything is a service
- From Web services
  - Standard interface definition mechanisms: multiple protocol bindings, local/remote transparency
- From Grids
  - Service semantics, reliability and security models
  - Lifecycle management, discovery, other services
- Multiple "hosting environments"
  - C, J2EE, .NET, …

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OGSA Service Model

- System comprises (a typically few) persistent services & (potentially many) transient services
  - Everything is a service
- OGSA defines basic behaviors of services: fundamental semantics, life-cycle, etc.
- Key issues:
  - Globally unique Grid Service Handle
  - Dynamic service creation (factories)
  - Lifetime management
  - Service discovery
  - Service data elements: associate state with service during its lifetime
  - Query service data elements
  - Subscription/notification

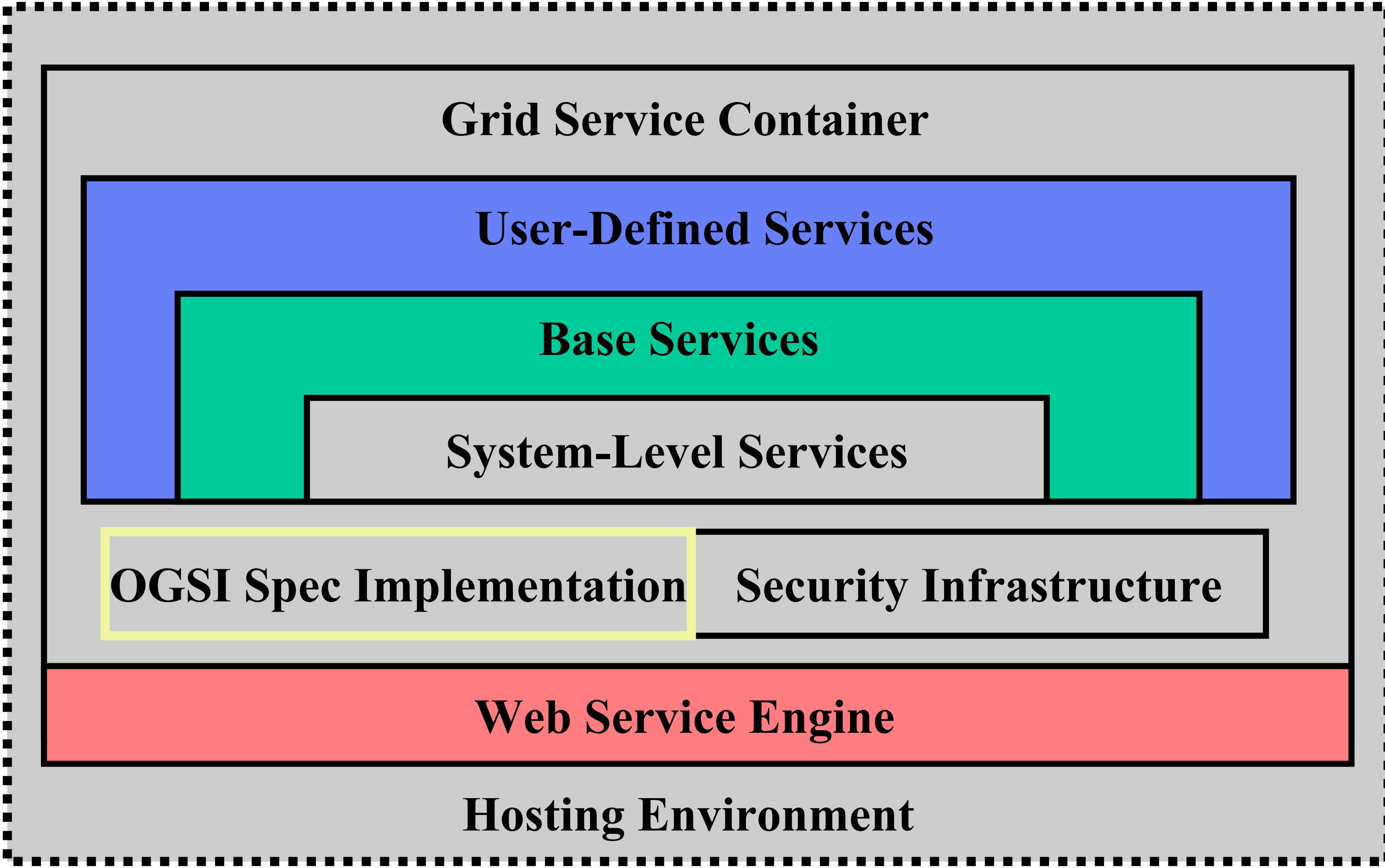
OGSA Development

- Standardization via the Global Grid Forum
  - Focus on RF licensing
- Wide industry interest
  - IBM, Sun, HP, SGI, Microsoft, Veritas, Oracle, …
- Open source reference implementation via Globus project
  - GT3.0 Alpha released in January
- Will be commercial products

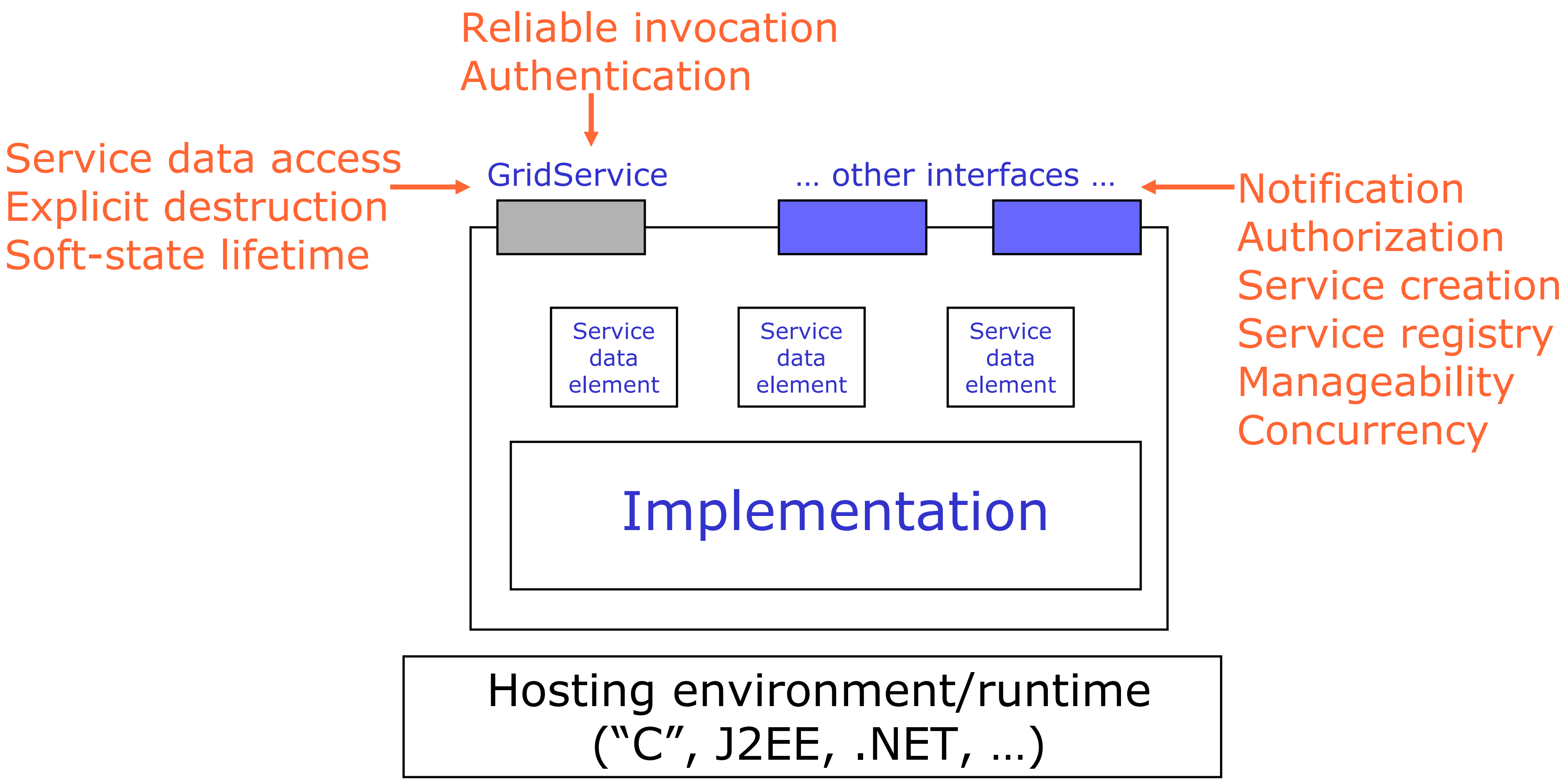
GT3 Architecture and Functionality

- Core
  - OGSI Implementation
  - Security Services
  - System-Level Services
  - Container
  - Hosting Environment
- Base Services
  - Resource Management
  - Information Services
  - Data Management
- User-Defined Services
  - Grid Service Development Framework
- Future Directions

GT-OGSA Grid Service Infrastructure



GT3 Core: The Grid Service = Interfaces + Service Data



GT3 Core: Notification and Subscription

- Our NotificationSourceProvider implementation allows any Grid Service to become a sender of notification messages
- A subscribe request on a NotificationSource triggers the creation of a NotificationSubscription service
- A NotificationSink can receive notification msgs from NotificationSources. Sinks are not required to implement the GridService portType
- Notifications can be set on SDEs

GT3 Core:
OGSI Specification (cont.)

Factory portType

- Factories create services
- Factories are typically persistent services
- Factory is an optional OGSI interface

(Grid Services can also be instantiated by other mechanisms)

GT3 Core: OGSI Specification (cont.)

Service group portTypes

- A ServiceGroup is a grid service that maintains information about a group of other grid services
- The classic registry model can be implemented with the ServiceGroup portTypes
- A grid service can belong to more than one ServiceGroup
- Members of a ServiceGroup can be heterogenous or homogenous
- Service group portTypes are optional OGSI interfaces

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GT3 Core: OGSI Specification (cont.)

Grid Service Handles (GSHs)

Globally unique

HandleResolver portType

- Defines a means for resolving a GSH (Grid Service Handle) to a GSR (Grid Service Reference)
  - A GSH points to a Grid Service
    (GT3 uses a hostname-based GSH scheme)
  - A GSR specifies how to communicate with the Grid Service
    (GT3 currently supports SOAP over HTTP, so GSRs are in WSDL format)

GT3 Core: Security Infrastructure

- Transport Layer Security/Secure Socket Layer (TLS/SSL)
  - To be deprecated
- SOAP Layer Security
  - Based on WS-Security, XML Encryption, XML Signature
- GT3 uses X.509 identity certificates for authentication
- It also uses X.509 Proxy certificates to support delegation and single sign-on, updated to conform to latest IETF/GGF draft

GT3 Core: Grid Service Container

Includes the OGSI Implementation, security infrastructure and system-level services, plus:

- Service activation, deactivation, construction, destruction, etc.
- Service data element placeholders that allow you to dynamically fetch service data values at query time
- Evaluator framework (supporting ByXPath and ByName notifications and queries)
- Interceptor/callback framework (allows one to intercept certain service lifecycle events)

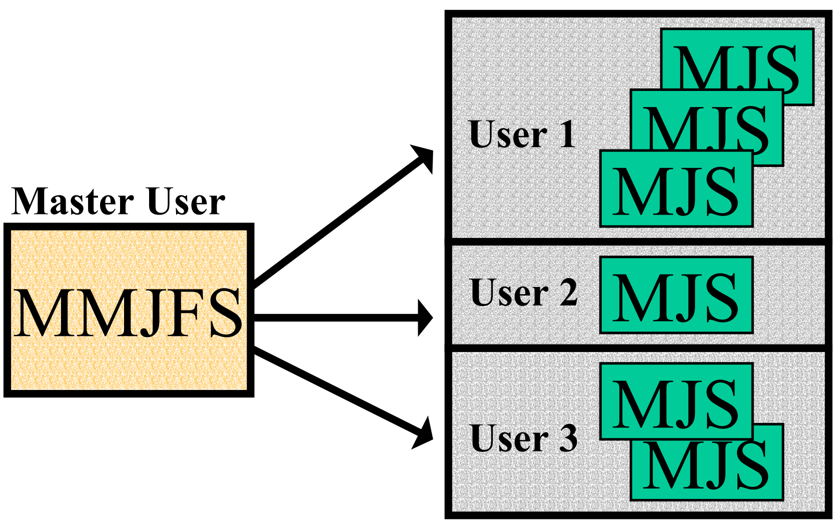
GT3 Core: Hosting Environment

GT3 currently offers support for four Java Hosting Environments:

- Embedded
- Standalone
- Servlet
- EJB

GT3 Base: Resource Management

- GRAM Architecture rendered in OGSA
- The MMJFS runs as an unprivileged user, with a small highly-constrained setuid executable behind it
- Individual user environments are created using Virtual Hosting

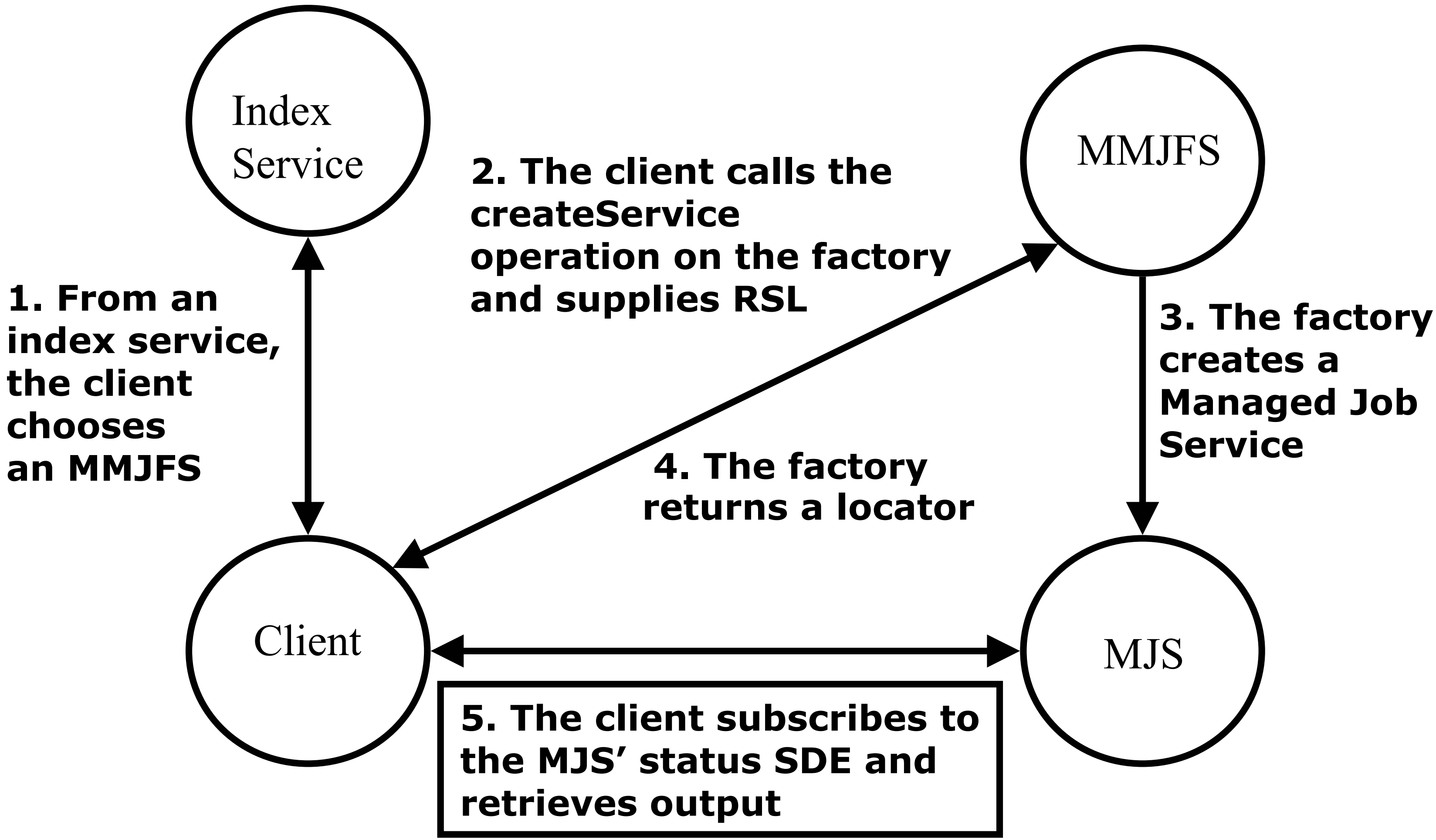


MMJFS: Master Managed Job Factory Service

MJS: Managed Job Service

User Hosting Env

GRAM Job Submission Scenario

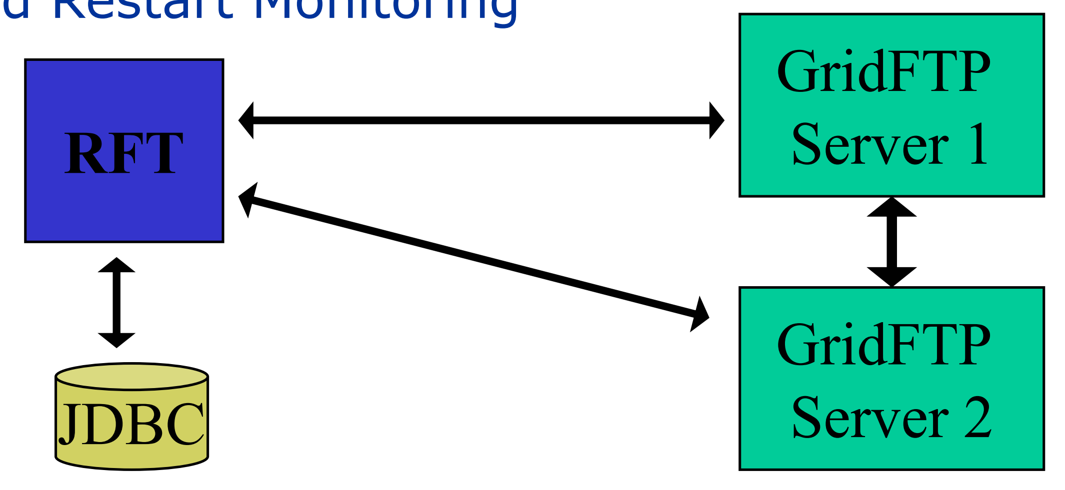


GT3 Base: Information Services

- Index Service as Caching Aggregator
  - Caches service data from other grid services
- Index Service as Provider Framework
  - Serves as a host for service data providers that live outside of a grid service to publish data

GT3 Base: Reliable File Transfer

- Reliably performs a third party transfer between two GridFTP servers
- OGSI-compliant service exposing GridFTP control channel functionality
- Recoverable Grid Service
  - Automatically restarts interrupted transfers from the last checkpoint
- Progress and Restart Monitoring



Summary

- The Grid problem: Resource sharing & coordinated problem solving in dynamic, multi-institutional virtual organizations
- Grid architecture: Emphasize protocol and service definition to enable interoperability and resource sharing
- Globus Toolkit™ Version 2: a source of protocol and API definitions, reference implementations
- GT3: Open Grid Services Architecture