Introduction to Grid Computing

The Globus Project™

Argonne National Laboratory

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http://www.globus.org/

Outline

- Introduction to Grid Computing
- Some Definitions
- Grid Architecture
- The Programming Problem
- The Globus Toolkit™
  - Introduction, Security, Resource Management, Information Services, Data Management
- Related work
- Futures and Conclusions

The Grid Problem

- Flexible, secure, coordinated resource sharing among dynamic collections of individuals, institutions, and resource

  From "The Anatomy of the Grid: Enabling Scalable Virtual Organizations"

- Enable communities ("virtual organizations") to share geographically distributed resources as they pursue common goals -- *assuming the absence* of…
  - central location,
  - central control,
  - omniscience,
  - existing trust relationships.

Elements of the Problem

- Resource sharing
  - Computers, storage, sensors, networks, …
  - Sharing always conditional: issues of trust, policy, negotiation, payment, …
- Coordinated problem solving
  - Beyond client-server: distributed data analysis, computation, collaboration, …
- Dynamic, multi-institutional virtual orgs
  - Community overlays on classic org structures
  - Large or small, static or dynamic

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The Globus Project™

Making Grid computing a reality

- Close collaboration with real Grid projects in science and industry
- Development and promotion of standard Grid protocols to enable interoperability and shared infrastructure
- Development and promotion of standard Grid software APIs and SDKs to enable portability and code sharing
- The Globus Toolkit™: Open source, reference software base for building grid infrastructure and applications
- Global Grid Forum: Development of standard protocols and APIs for Grid computing

Some Definitions

Some Important Definitions

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

Resource

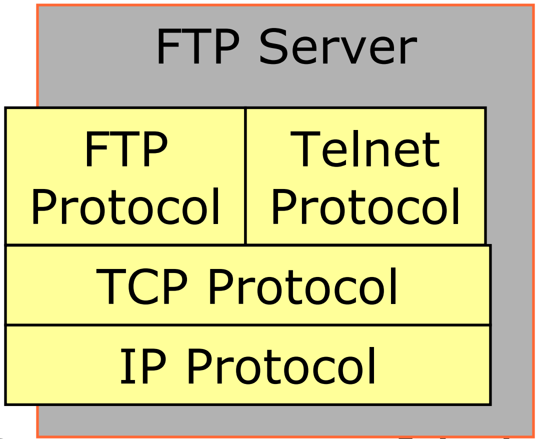
- An entity that is to be shared
  - E.g., computers, storage, data, software
- Does <u>not</u> have to be a physical entity
  - E.g., Condor pool, distributed file system, …
- Defined in terms of interfaces, not devices
  - E.g. scheduler such as LSF and PBS define a compute resource
  - Open/close/read/write define access to a distributed file system, e.g. NFS, AFS, DFS

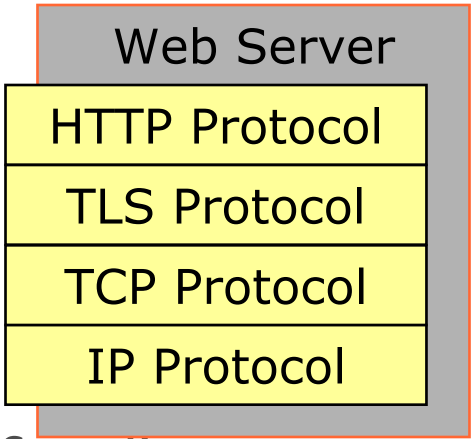
Network Protocol

- A formal description of message formats and a set of rules for message exchange
  - Rules may define sequence of message exchanges
  - Protocol may define state-change in endpoint, e.g., file system state change
- Good protocols designed to do one thing
  - Protocols can be layered
- Examples of protocols
  - IP, TCP, TLS (was SSL), HTTP, Kerberos

Network Enabled Services

- Implementation of a protocol that defines a set of capabilities
  - Protocol defines interaction with service
  - All services require protocols
  - Not all protocols are used to provide services (e.g. IP, TLS)
- Examples: FTP and Web servers





Application Programming Interface

- A specification for a set of routines to facilitate application development
  - Refers to definition, not implementation
  - E.g., there are many implementations of MPI
- Spec often language-specific (or IDL)
  - Routine name, number, order and type of arguments; mapping to language constructs
  - Behavior or function of routine
- Examples
  - GSS API (security), MPI (message passing)

Software Development Kit

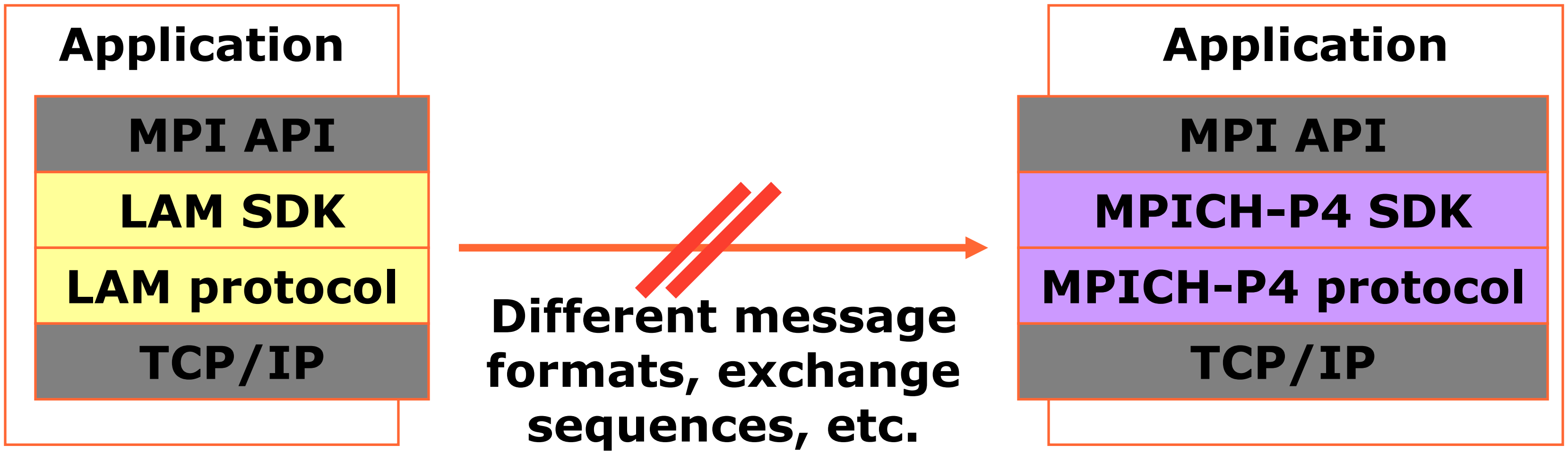
- A particular instantiation of an API
- SDK consists of libraries and tools
  - Provides implementation of API specification
- Can have multiple SDKs for an API
- Examples of SDKs
  - MPICH, Motif Widgets

A Protocol can have Multiple APIs

- TCP/IP APIs include BSD sockets, Winsock, System V streams, …
- The protocol provides interoperability: programs using different APIs can exchange information
- I don't need to know remote user's API

An API can have Multiple Protocols

- MPI provides portability: any correct program compiles & runs on a platform
- Does not provide interoperability: all processes must link against same SDK
  - E.g., MPICH and LAM versions of MPI



APIs and Protocols are Both Important

- Standard APIs/SDKs are important
  - They enable application *portability*
  - But w/o standard protocols, interoperability is hard (every SDK speaks every protocol?)
- Standard protocols are important
  - Enable cross-site *interoperability*
  - Enable shared infrastructure
  - But w/o standard APIs/SDKs, application portability is hard (different platforms access protocols in different ways)

Grid Architecture

Why Discuss Architecture?

- Descriptive
  - Provide a common vocabulary for use when describing Grid systems
- Guidance
  - Identify key areas in which services are required
- Prescriptive
  - Define standard “Intergrid” protocols and APIs to facilitate creation of interoperable Grid systems and portable applications

One View of Requirements

- Identity & authentication
- Authorization & policy
- Resource discovery
- Resource characterization
- Resource allocation
- (Co-)reservation, workflow
- Distributed algorithms
- Remote data access
- High-speed data transfer
- Performance guarantees
- Monitoring
- Adaptation
- Intrusion detection
- Resource management
- Accounting & payment
- Fault management
- System evolution
- Etc.
- Etc.
- …

Another View: "Three Obstacles to Making Grid Computing Routine"

1) New approaches to problem solving
   - Data Grids, distributed computing, peer-to-peer, collaboration grids, …
2) Structuring and writing programs
   - Abstractions, tools

Programming Problem

3) Enabling resource sharing across distinct institutions
   - Resource discovery, access, reservation, allocation; authentication, authorization, policy; communication; fault detection and notification; …

Systems Problem

Programming & Systems Problems

- The programming problem
  - Facilitate development of sophisticated apps
  - Facilitate code sharing
  - Requires <u>programming environments</u>
    - APIs, SDKs, tools
- The systems problem
  - Facilitate coordinated use of diverse resources
  - Facilitate infrastructure sharing
    - e.g., certificate authorities, information services
  - Requires <u>systems</u>
    - protocols, services

The Systems Problem: Resource Sharing Mechanisms That …

- Address security and policy concerns of resource owners and users
- Are flexible enough to deal with many resource types and sharing modalities
- Scale to large number of resources, many participants, many program components
- Operate efficiently when dealing with large amounts of data & computation

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Aspects of the Systems Problem

1) Need for interoperability when different groups want to share resources
   - Diverse components, policies, mechanisms
   - E.g., standard notions of identity, means of communication, resource descriptions
2) Need for shared infrastructure services to avoid repeated development, installation
   - E.g., one port/service/protocol for remote access to computing, not one per tool/appln
   - E.g., Certificate Authorities: expensive to run

- A common need for protocols & services

Hence, a Protocol-Oriented View of Grid Architecture, that Emphasizes …

- Development of Grid protocols & services
  - Protocol-mediated access to remote resources
  - New services: e.g., resource brokering
  - "On the Grid" = speak Intergrid protocols
  - Mostly (extensions to) existing protocols
- Development of Grid APIs & SDKs
  - Interfaces to Grid protocols & services
  - Facilitate application development by supplying higher-level abstractions
- The (hugely successful) model is the Internet

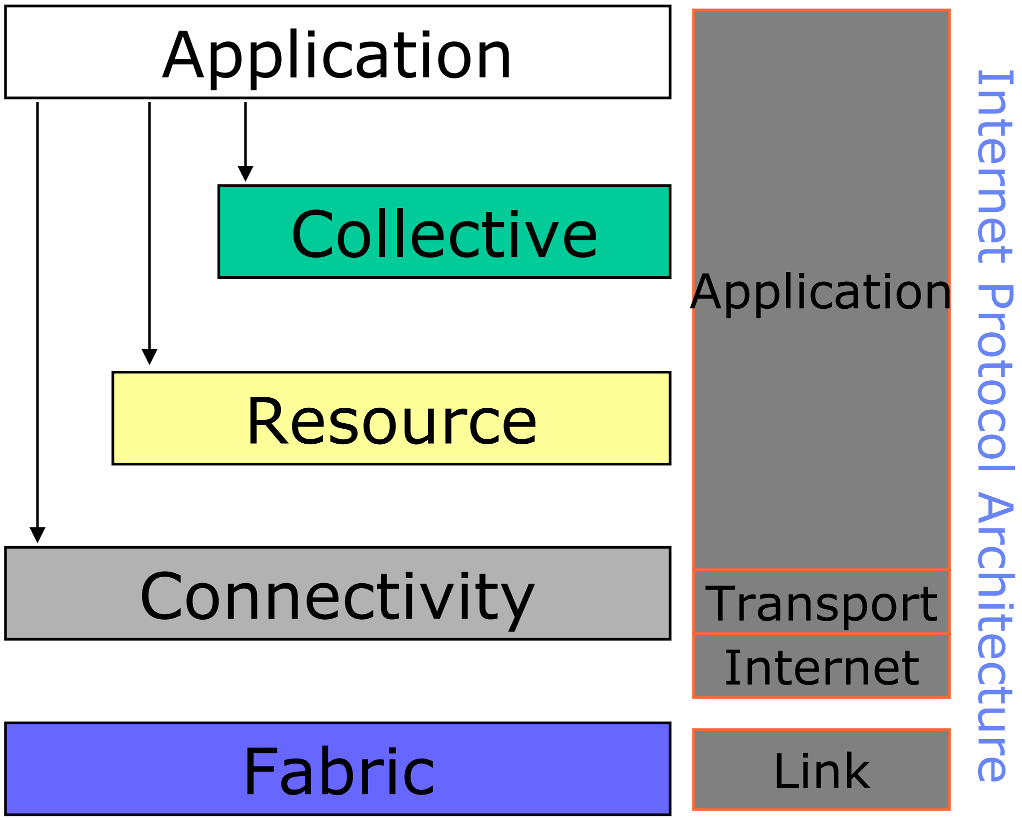
Layered Grid Architecture (By Analogy to Internet Architecture)

"Coordinating multiple resources": ubiquitous infrastructure services, app-specific distributed services

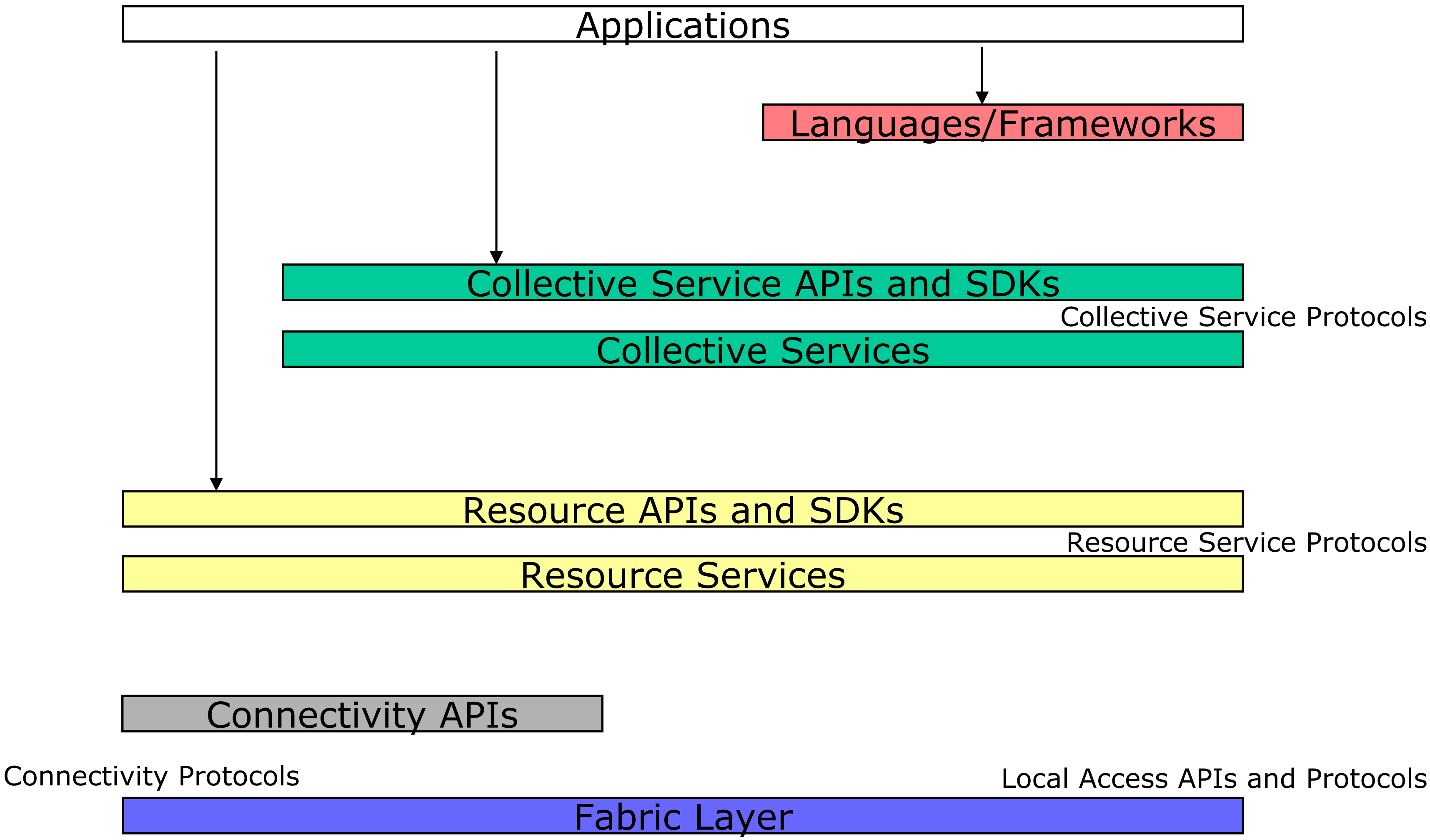
"Sharing single resources": negotiating access, controlling use

"Talking to things": communication (Internet protocols) & security

"Controlling things locally": Access to, & control of, resources



Protocols, Services, and APIs Occur at Each Level

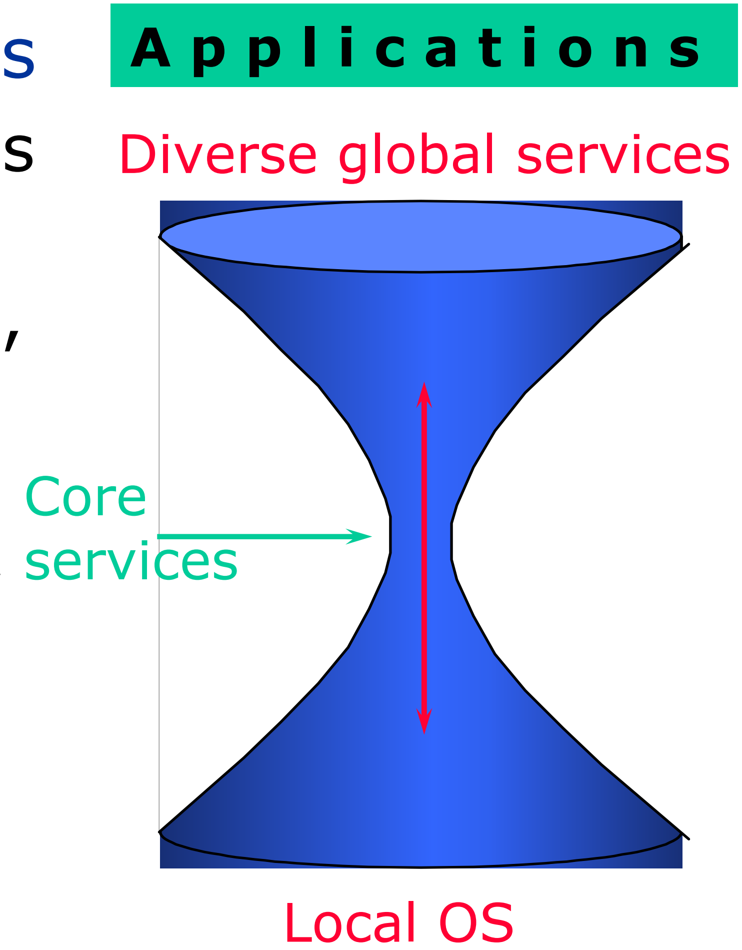


Important Points

- Built on Internet protocols & services
  - Communication, routing, name resolution, etc.
- "Layering" here is conceptual, does not imply constraints on who can call what
  - Protocols/services/APIs/SDKs will, ideally, be largely self-contained
  - Some things are fundamental: e.g., communication and security
  - But, advantageous for higher-level functions to use common lower-level functions

The Hourglass Model

- Focus on architecture issues
  - Propose set of core services as basic infrastructure
  - Use to construct high-level, domain-specific solutions
- Design principles
  - Keep participation cost low
  - Enable local control
  - Support for adaptation
  - "IP hourglass" model



Fabric Layer Protocols & Services

- Just what you would expect: the diverse mix of resources that may be shared
  - Individual computers, Condor pools, file systems, archives, metadata catalogs, networks, sensors, etc., etc.
- Few constraints on low-level technology: connectivity and resource level protocols form the “neck in the hourglass”
- Defined by interfaces not physical characteristics

Connectivity Layer Protocols & Services

- Communication
  - Internet protocols: IP, DNS, routing, etc.
- Security: Grid Security Infrastructure (GSI)
  - Uniform authentication, authorization, and message protection mechanisms in multi-institutional setting
  - Single sign-on, delegation, identity mapping
  - Public key technology, SSL, X.509, GSS-API
  - Supporting infrastructure: Certificate Authorities, certificate & key management, …

GSI: www.gridforum.org/security/gsi

GT2 Resource Layer Protocols & Services

- Grid Resource Allocation Management (GRAM)
  - Remote allocation, reservation, monitoring, control of compute resources
- GridFTP protocol (FTP extensions)
  - High-performance data access & transport
- Grid Resource Information Service (GRIS)
  - Access to structure & state information
- Others emerging: Catalog access, code repository access, accounting, etc.
- All built on connectivity layer: GSI & IP

GRAM, GridFTP, GRIS: www.globus.org

GT2 Collective Layer Protocols & Services

- Index servers aka metadirectory services
  - Custom views on dynamic resource collections assembled by a community
- Resource brokers (e.g., Condor Matchmaker)
  - Resource discovery and allocation
- Replica catalogs
- Replication services
- Co-reservation and co-allocation services
- Workflow management services
- Etc.

Condor: www.cs.wisc.edu/condor

The Programming Problem

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Common Toolkit Underneath

- Each programming environment should not have to implement the protocols and services from scratch!
- Rather, want to share common code that…
  - Implements core functionality
    - SDKs that can be used to construct a large variety of services and clients
    - Standard services that can be easily deployed
  - Is robust, well-architected, self-consistent
  - Is open source, with broad input
- Which leads us to the Globus Toolkit™…

Introduction to 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
  - Make 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, …
- Learn through deployment and applications

Key Protocols

- The Globus Toolkit™ centers around four key protocols
  - Connectivity layer:
    - > *Security*: Grid Security Infrastructure (GSI)
  - Resource layer:
    - > *Resource Management*
    - > *Information Services*
    - > *Data Transfer*
- Also key collective layer protocols
  - Info Services, Replica Management, etc.

Grid Security Infrastructure (GSI)

- Globus Toolkit implements GSI protocols and APIs, to address Grid security needs
- GSI protocols extends standard public key protocols
  - Standards: X.509 & SSL/TLS
  - Extensions: X.509 Proxy Certificates & Delegation
- GSI extends standard GSS-API

Resource Management

- The Grid Resource Allocation Management (GRAM) protocol and client API allows programs to be started and managed 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, …

Information Services

- GT2 – MDS (GRIS/GIIS)
  - Based on LDAP protocol
- GT3 – Service Data Elements
  - From the OGSI spec

Data Access & Transfer

- GridFTP: extended version of popular FTP protocol for Grid data access and transfer
- Secure, efficient, reliable, flexible, extensible, parallel, concurrent, e.g.:
  - Third-party data transfers, partial file transfers
  - Parallelism, striping (e.g., on PVFS)
  - Reliable, recoverable data transfers
- Reference implementations
  - Existing clients and servers: wuftpd, globus-url-copy
  - Flexible, extensible libraries in Globus Toolkit

Summary

- The Grid problem: Resource sharing & coordinated problem solving in dynamic, multi-institutional virtual organizations
- Grid architecture emphasizes *systems problem*
  - Protocols & services, to facilitate interoperability and shared infrastructure services
- Globus Toolkit™: APIs, SDKs, and tools which implement Grid protocols & services
  - Provides basic software infrastructure for suite of tools addressing the *programming problem*