Resource Scheduling, Authentication and Authorization in Large Institutional Grids

Abhijit Bose, Ph.D.

Associate Director, Michigan Grid Research and Infrastructure Development (MGRID)

and

Center for Advanced Computing (CAC)

The University of Michigan

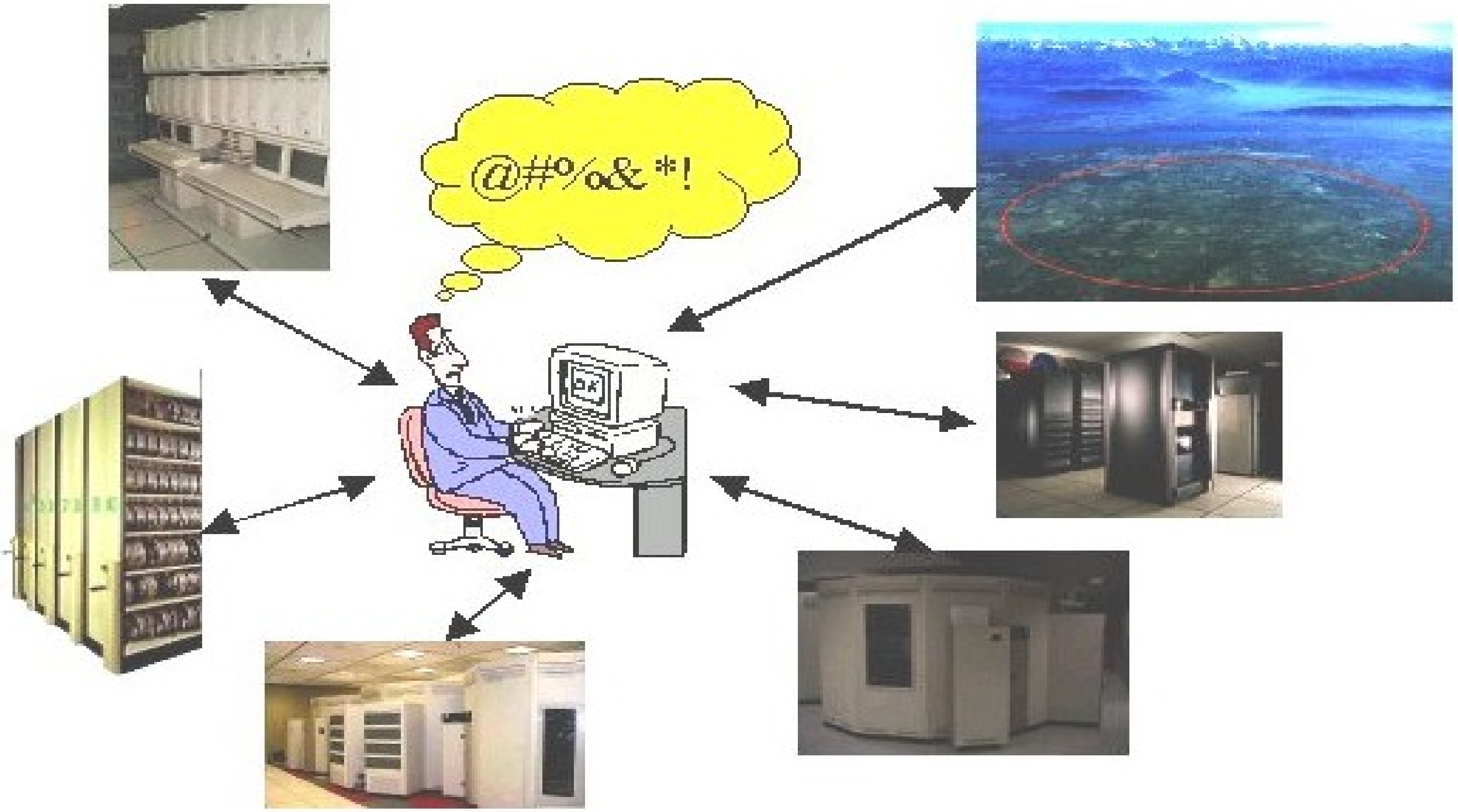
Ann Arbor, MI 48109

abose@eecs.umich.edu

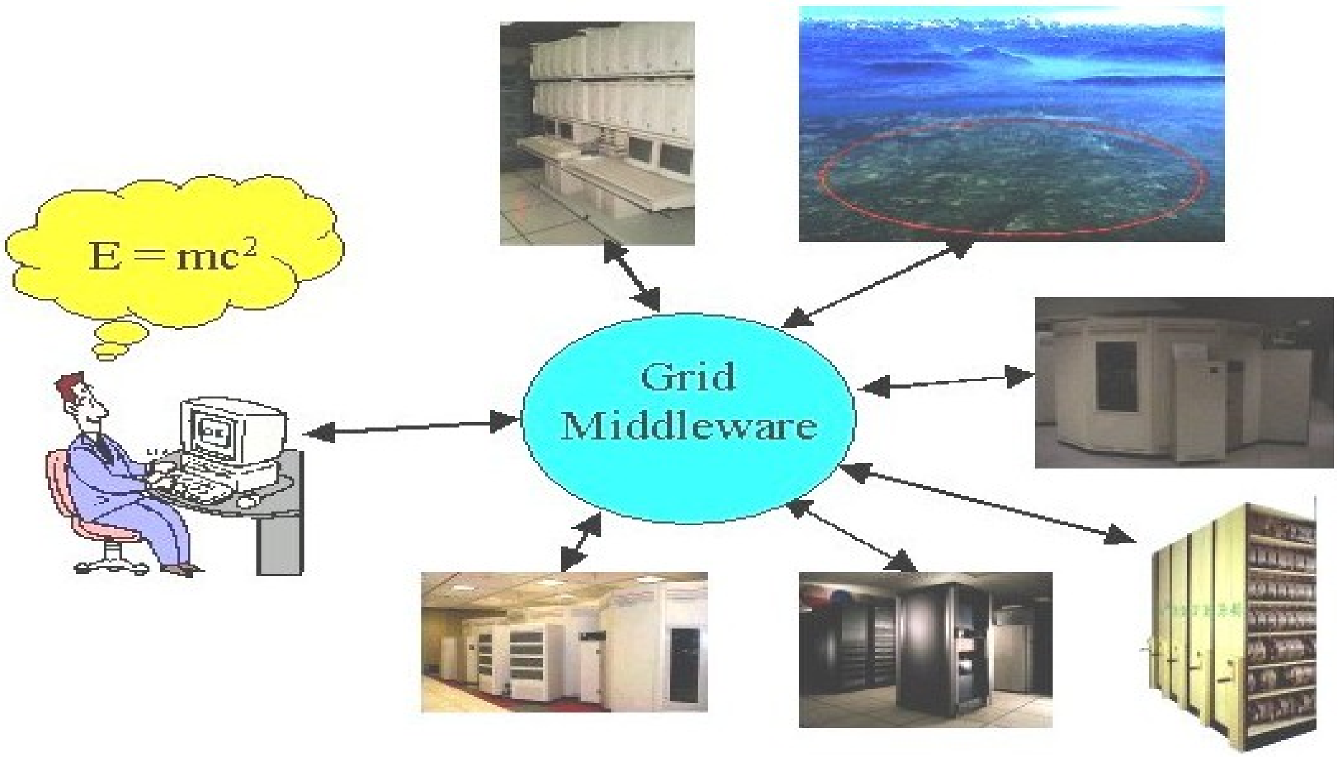
MGRID: Background

- Multiple Grid efforts at the U of M
  - Cluster Computing (ATLAS, CAC/NPACI, DZero)
  - Automated network configuration and testing, Network QoS reservation (CITI, ITCom)
  - Remote Instrument (SI – NEES Earthquake Grid)
  - Collaborative tools (SI – CHEF Collaboration portal)
  - Data base searches (Bioinformatics, MCBI)
- Current Grid technology is designed for small communities (100s of users)
  - Integration challenge for U-M (tens of thousands of users)

The Common Problem



The Promise of Grids



So far, small and incremental steps towards this goal .

Why MGRID?

- Grid software (Globus etc.) is difficult to run, complex to install and manage
  - Promote ease of use
  - More time to do science, instead of IT management
- How to prototype the Grid to fit into UM IT environment
  - Large (> 100,000) user base for Grid service
  - Produce a generalized Grid service

Why MGRID

- Middleware issues are difficult (AAAA)
  - Authorization, Authentication, Accounting, Auditing
- Leverage existing security and group services
- Add Fine grained policy driven access control
  - Let the owners of resources control their resource
    - Who, what, where, when, and how
    - But make it easy for them to do so

Why MGRID

- Campus wide meta scheduler for common resources
  - Computers, Collaboration Technology, Laboratory Instruments
- Enhance accounting capabilities
- Add auditing capabilities
- Use MGRID testbed to pursue distributed systems and applications research

MGRID Partnership

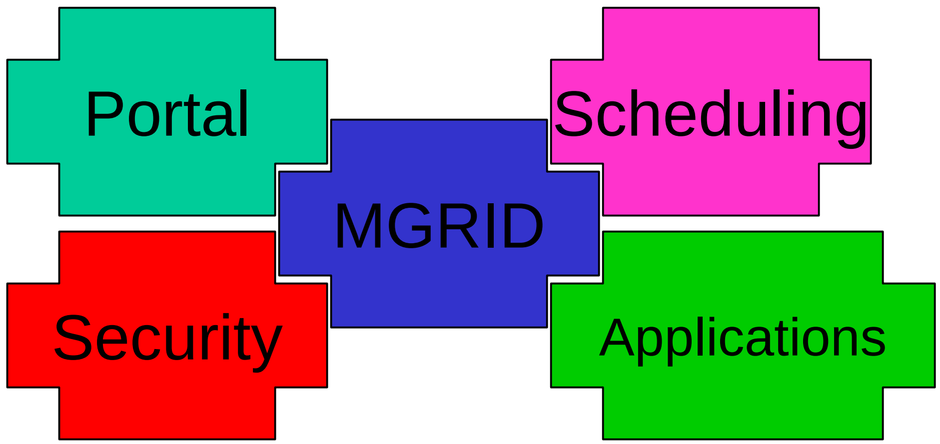
- Goal: build pilot institutional grid

Founding Partners

External Sponsors

NFS NMI/NSF NEES Mid-America Earthquake Center

MGRID Overview



MGRID PROJECTS

CORE INFRASTRUCTURE

Kerberos Leveraged PKI

kx509 Clients, KCT and mod_KCT Apache web server modules.
authenticates users against Globus Gatekeepers (password-less)

MARS

robust task scheduling and resource management
forecasting algorithm to predict resource-level scheduling parameters such as queue lengths, turn-around times, and resource utilization.
research fault-tolerant scheduling of tasks

GridNFS

integrates distributed file system (NFSv4) and flexible identity management to meet the needs of grid-based virtual organizations.

MGRID PROJECTS

CORE INFRASTRUCTURE

WALDEN

eliminates the need to manage user identities on hosts that participate in a grid environment. This is accomplished by moving user authentication to the client, replacing the static mapping between X.509 identities (Distinguished Names) and local user names in the Globus grid-mapfile with a dynamic approach using secure LDAP.

Accounting

allows usage reports on disparate scheduler log formats, such as PBSPro and Condor. Usage logs are translated into a common, standard XML format (defined by GGF UR-WG).

MGRID PROJECTS

MGRID APPLICATIONS AT MICHIGAN

ATLAS
UltraLight
NEESGrid
BioPhysics (Gaussian, Protein Folding)
Chemistry
Agent-Based Simulations, Financial Modeling
NTAP
Secure Multipoint Video-Conferencing

PORTAL SOFTWARE

MGRID Portal (CHEF-based)
SAKAI/MGRID

Existing U of M Services

- Uniqname
  - Unique campus wide user name to UID
- Kerberos V5 (multiple cells)
- KX509
- Group Services
  - AFS PTS, LDAP
- Directory services
  - LDAP

MGRID Portal

- Proxy KX509 credentials, keep the Globus client off workstations
- Ease of use for U of M faculty, staff, and students
  - Kerberos + kx509 + browser = Grid access
- Single point for PKI management
  - CA self-signed keys
  - CA policy files
- Single entry point for Grid resources

MGRID Portal

- User workstation
  - KX509 to obtain user X509 credentials
  - KX509 Certificate available to browser
- Additions to OpenSSL (in 9.0.7), required on MGRID Portal
  - SSL handshake recorded
- MGRID Portal SSL configured to require user X509 credentials

MGRID Portal

SSL Handshake transcript

- Contains all packets exchanged
- Allows KCT (Kerberos Credential Translator) to repeat user certificate verification
- Handshake time stamp used

Apache module, mod_kct

- Sends ssl handshake transcript to KCT service
- Requests KCA Kerberos service ticket

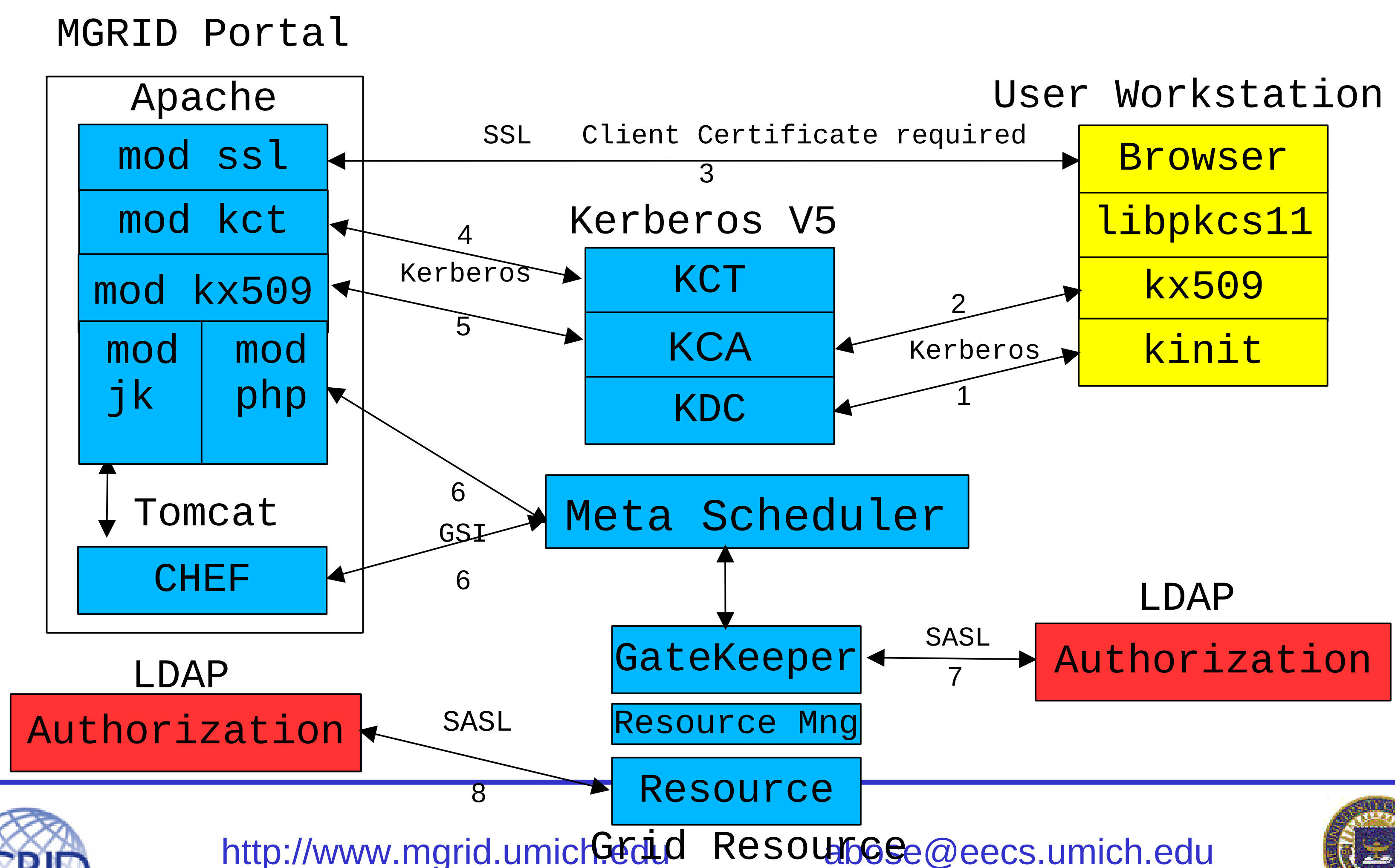
MGRID Portal

- Apache module, mod_kx509
  - Uses the KCA TGS
  - Obtains user proxy KX509 credentials
  - Places them in a ticket file
- Apache module, mod_php
  - Creates RSL, uses KX509 credentials
- CHEF runs in Tomcat
  - Communicates with Apache through mod_jk
  - Creates RSL, uses KX509 or MyProxy credentials

MGRID Portal

- Hides complexity from user
- Individual or Organizational presentation
  - CHEF
- Easily extensible
  - Add new Grid applications
  - With generic Grid resource, can run any back-end program
- Built on ***strong security***

MGRID Architecture



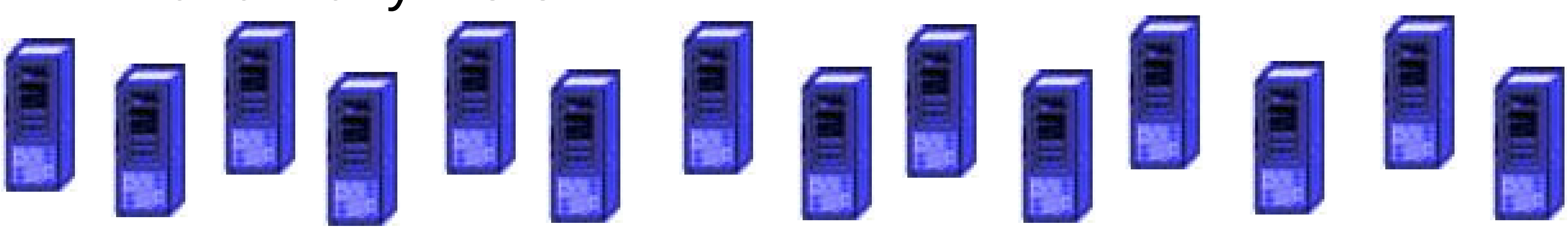
Walden: A Scalable Solution for Grid Account Management

abose@eecs.umich.edu

Problem Statement

Many disparate, decentralized clusters

- ATLAS (15 nodes, 39? CPUs)
- CAC Hypnos Cluster (128 nodes, 256 processors)
- CAC Morpheus Cluster (67 nodes, 134 processors)
- CAC Nyx Cluster (132 nodes, 264 processors)
- MCBI CTAlliance Cluster (59 nodes, 118 processors)
- CCS G5 Cluster (24 nodes, 48 processors)
- ... and many more ...



Problem Statement

How do we securely <u>authenticate</u>, <u>authorize</u> and provide user <u>access</u> to grids across disparate administrative and geographical domains?

Globus GSI uses public key cryptography and digital signatures for secure communications and single sign-on.

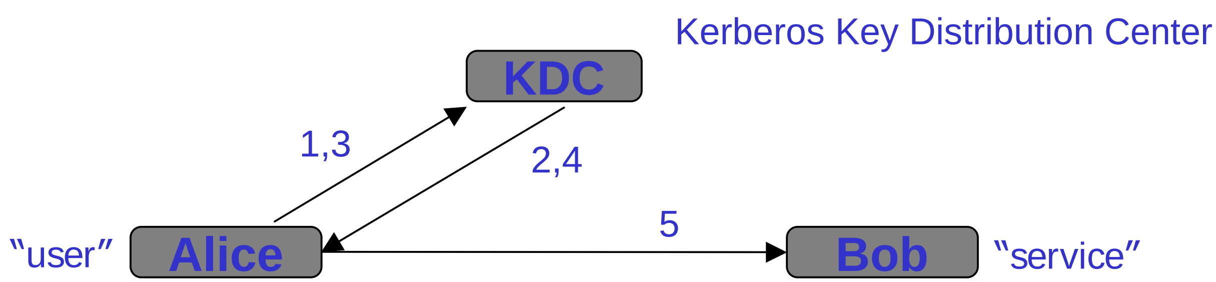
University of Michigan provides Kerberos authentication for users.

Current Work in Grid Authorization

Grid authorization options

- PERMIS uses of X.509 Attribute Certificates
- PRIMA uses X.509 Attribute Certificates
- Shibboleth no built-in authorization engine; limited scope (web browser)
- VOMS uses X.509 Attribute Certificates
- CAS Community Authorization Service
- XACML powerful policy engine; requires custom PEP (Policy Enforcement Point) & PDP (Policy Decision Point)

Kerberos Authentication



Login Phase: Once Per Session

1. Alice –> KDC "I am Alice"
2. KDC –> Alice $TGT=\{Alice,TGS,K_{A,TGS}\}_{KTGS},\{T\}_{KA},\{K_{A,,KCT}\}_{KA}$

Accessing Services: Every time a new/current kerberized service is requested

3. Alice –> TGS Alice, Bob, TGT, $\{T\}_{KA,TGS}$
4. KCT –> Alice $TKT = \{Alice, Bob, K_{A,B}\}_{KB}, \{T\}_{K\ A,TGS},\{K_{A,B}\}_{KA\ ,TGS}$
5. Alice –> Bob "I am Alice", TKT, $\{T\}_{KA,B}$

TGS: Ticket Granting Service (often same entity as KDC)
K_A: Shared key between Alice and KDC (derived from Alice's password upon login)
$K_{A,TGS}$: Session key for Alice and KDC K_{TGS}: Shared key between KDC and TGS
$K_{A,B}$: Session key for Alice and Bob
T: Timestamp to prevent replay attacks (requires synchronized clocks)

KX.509 Certificates

The story so far... User has a Kerberos ticket on the workstation she is logged into. But Globus uses X.509 certificates how does User use Globus-enabled services?

KX.509, developed at CITI, University of Michigan is a Kerberized client program (resides on local workstation) that generates an X.509 certificate and a private key based on the existing Kerberos ticket:

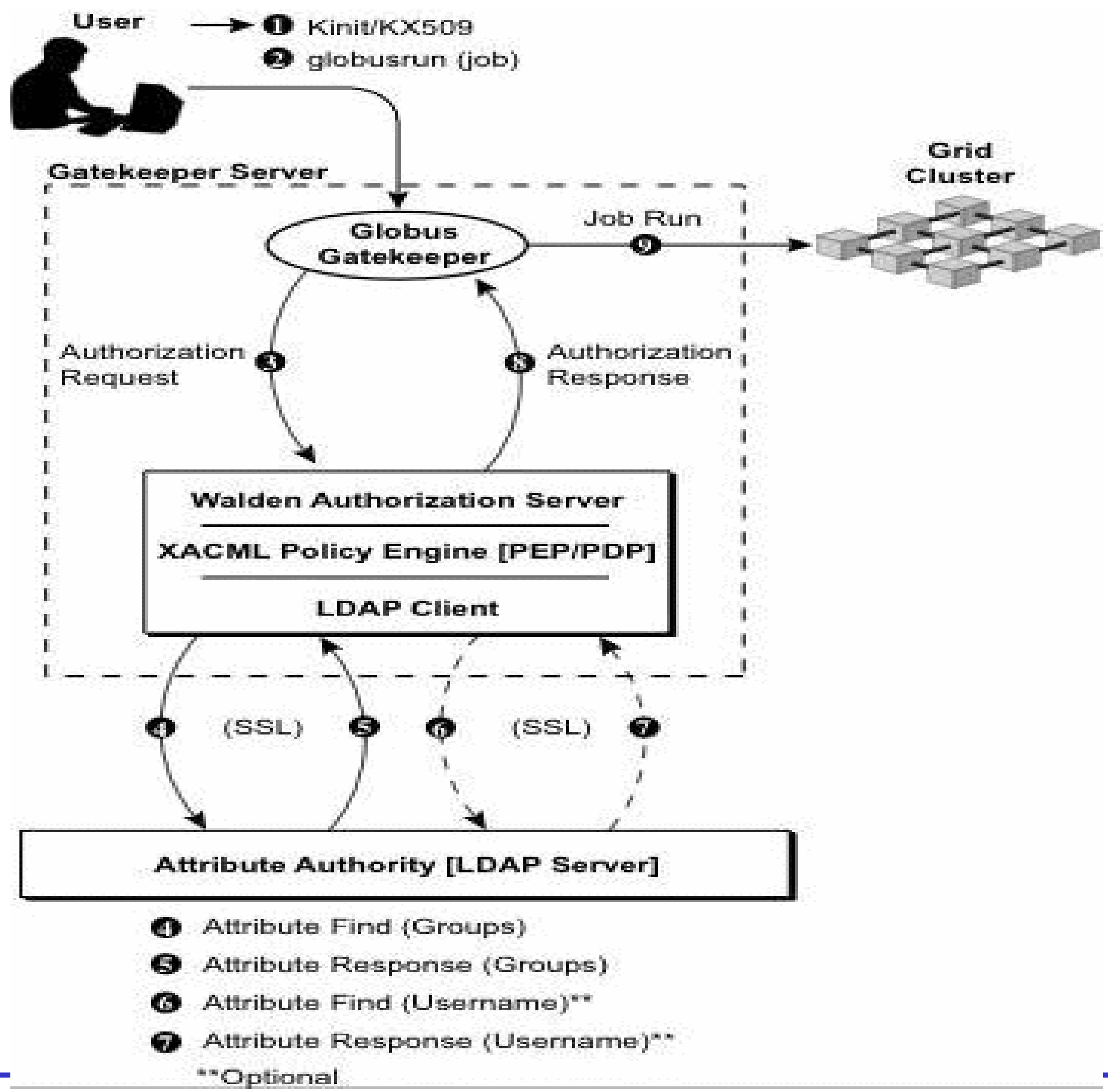
- **both are normally stored in the same Kerberos ticket cache**
- **the temporary <X.509 certificate, private key> are destroyed when Kerberos ticket expires**
- **Therefore, by adopting KX.509, an Kerberos-based organization can deploy and use Globus-enabled services without changing its security infrastructure. Kerberos is the most widely deployed network authentication system currently in use.**

Authorization Issues

- Globus provides a static grid-mapfile for coarse-grained authorization
- Each grid-mapfile is locally maintained on each resource, mapping a user's X.509 DN to a local account
- Users either share local accounts, providing little accountability, or are granted unique local accounts, creating administrative problems
- How to provide fine-grained authorization with one-to-one user-account mapping?

Walden Authorization

- **Fine-Grained authorization** module based on XACML standard (XACML-based policy engine)
- Cluster owners have complete <u>administrative control</u> over who uses their resources
- **Policy files** define rules based on group membership, time of day, resource load, etc.
- Local account management is *unnecessary*
- **Group membership** can be assigned from one or several secure LDAP servers


User
❶ Kinit/KX509
❷ globusrun (job)
Gatekeeper Server
Grid Cluster
Globus Gatekeeper
Job Run
Authorization Request
Authorization Response
Walden Authorization Server
XACML Policy Engine [PEP/PDP]
LDAP Client
(SSL)
(SSL)
Attribute Authority [LDAP Server]
❹ Attribute Find (Groups)
❺ Attribute Response (Groups)
❻ Attribute Find (Username)**
❼ Attribute Response (Username)**
**Optional

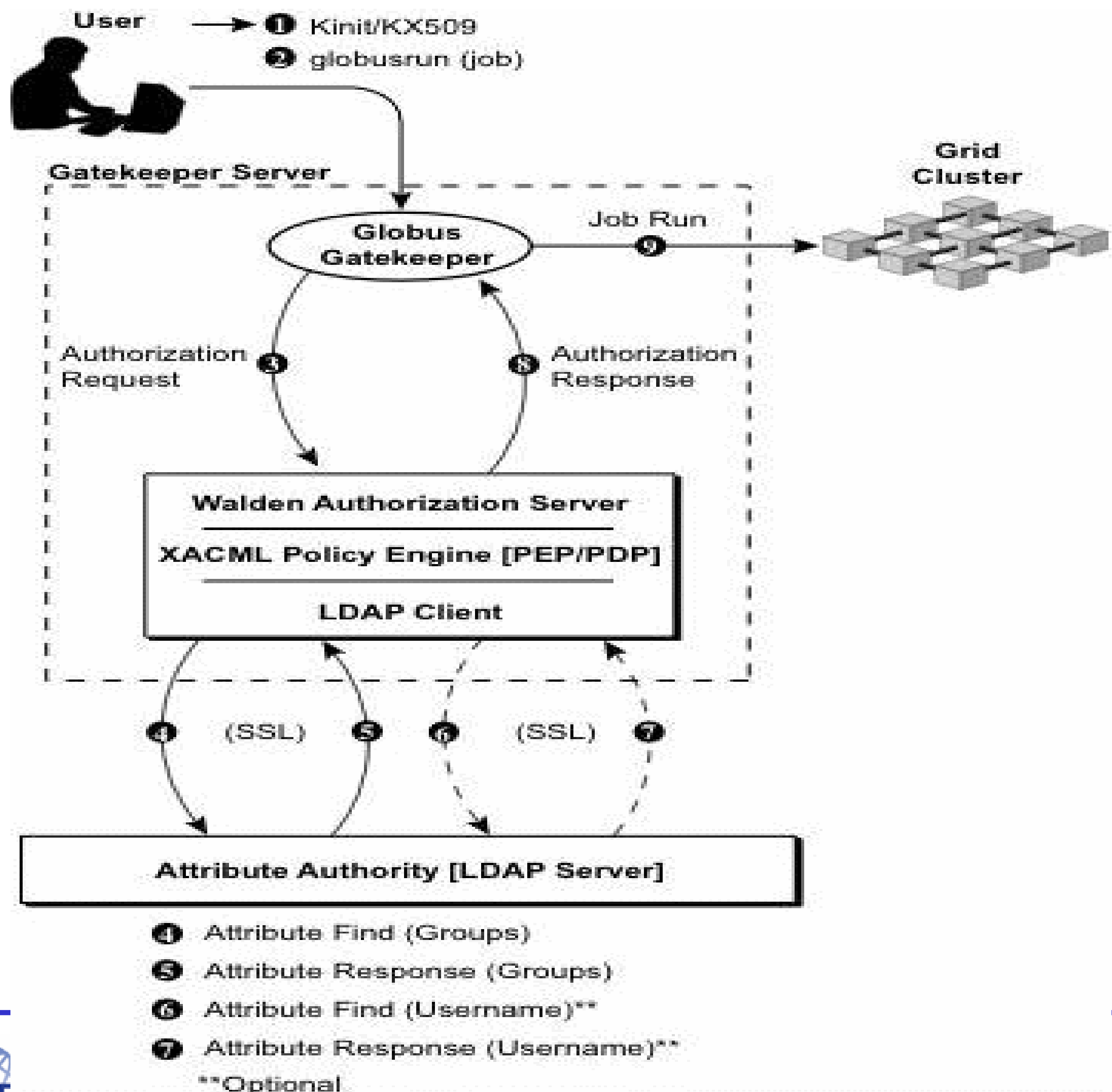
Walden Authorization

Step 1: Obtain a Kerberos V Ticket Granting Ticket (TGT), which is then used to obtain and cache a KX.509 certificate.

Step 2: Submit a job request to Globus gatekeeper

Step 3: Gatekeeper invokes gridmap callout function, forwarding authorization request to Walden module.

- Policy Enforcement Point (PEP) formats and sends request to Policy Decision Point (PDP).
- PDP retrieves XACML policy (if necessary) from central policy repository


User
❶ Kinit/KX509
❷ globusrun (job)
Gatekeeper Server
Globus Gatekeeper
Job Run
❾
Grid Cluster
Authorization Request ❸
❽ Authorization Response
Walden Authorization Server
XACML Policy Engine [PEP/PDP]
LDAP Client
❹ (SSL) ❺
❻ (SSL) ❼
Attribute Authority [LDAP Server]
❹ Attribute Find (Groups)
❺ Attribute Response (Groups)
❻ Attribute Find (Username)**
❼ Attribute Response (Username)**
**Optional

Walden Authorization

Step 4-5: **Policy Decision Point (PDP) retrieves a 'bag of attributes' corresponding to user from secure LDAP server, and extensible to many other sources.**

- **User attributes (e.g. Group Membership) is compared against authorization request**
- **PDP returns a response of Permit, Deny, or indeterminate, along with any obligations.**

Walden Authorization

Step 6-7: **Policy Enforcement Point (PEP) parses response and obligations.**

- **If no defined obligations, PEP binds user to (permanent) local account from secure LDAP query.**
- **If guest user obligation defined, PEP binds user to available guest account.**

Walden Authorization

Step 8: **If the user is authorized, the local account identity is returned to globus (otherwise, authorization is denied).**

Step 9: The globus gatekeeper submits the authorized job request to the grid cluster, using the defined permanent or guest user account.

MGRID Portal

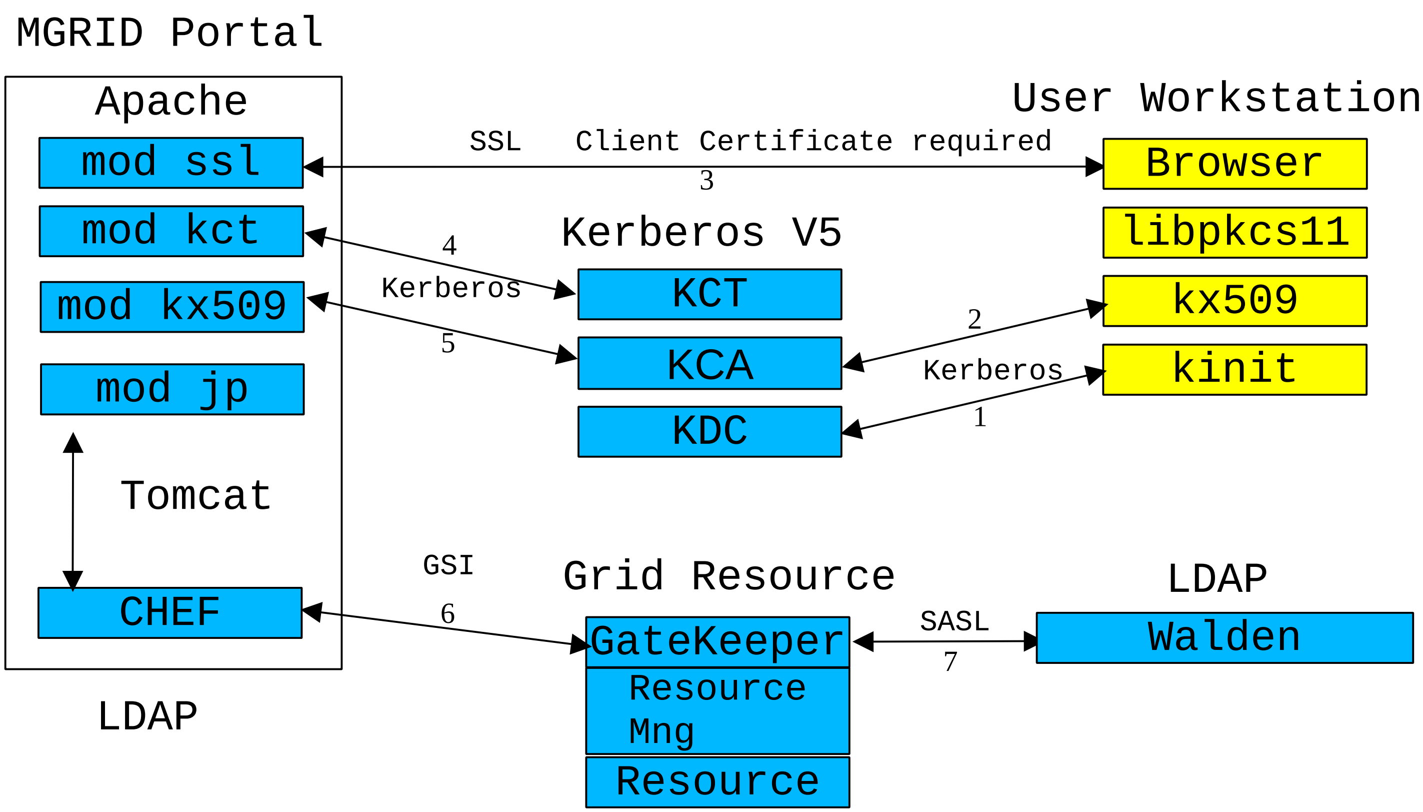
The story so far... Users are authenticated via Kerberos, a KX.509 credential is used by the authorization process, and globus is used to submit the job.

But what if the user doesn't want to install an entire globus client on their workstation?

But what if the user doesn't want to figure out the Globus Resource Specification Language (RSL) ?

Enter the MGRID portal...

MGRID Portal Architecture



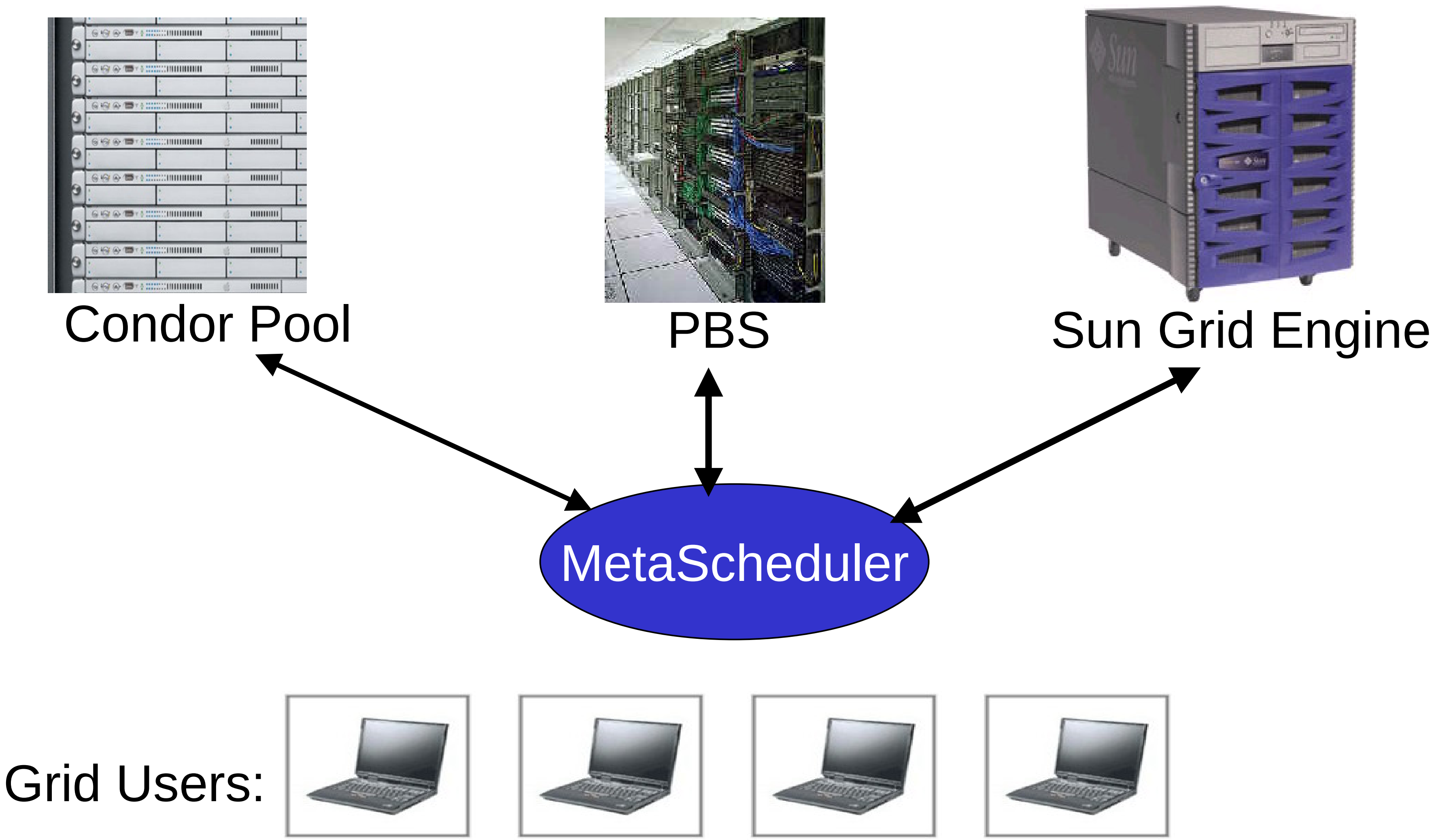
Walden provides...

- Scalable solution that integrates with existing University of Michigan authentication
- Secure authentication and authorization
- Extensible XACML policy engine
- Resource owners maintain administrative control over resources, optionally using existing Directory Services
- Guest/Template user account management
- Support for fluid Virtual Organizations

MARS: A Metascheduler for Distributed Resources in Campus Grids

abose@eecs.umich.edu

WHY METASCHEDULING ?



METASCHEDULING ADVANTAGES

Task Priorities : Allow On-Demand Scheduling

Examples: Satellite and radar data processing, Adaptive
Simulations, Disaster Management
(requires local resource preemption)

Optimize resource usage across many platforms

Campus-wide scheduling

Co-Scheduling of Resources

Computations, Data transfers, Network reservations, Sensors, Instruments

Integration of many local scheduling policies and frameworks

For the User: **Single Point of Job Submission!!**
(GRID Portal)

MARS Design Goals

Extensible Architecture

- Multiple standards for job description: JSDL, DRMAA, GRAAP
- Remote communications
- New scheduling algorithms can be easily incorporated

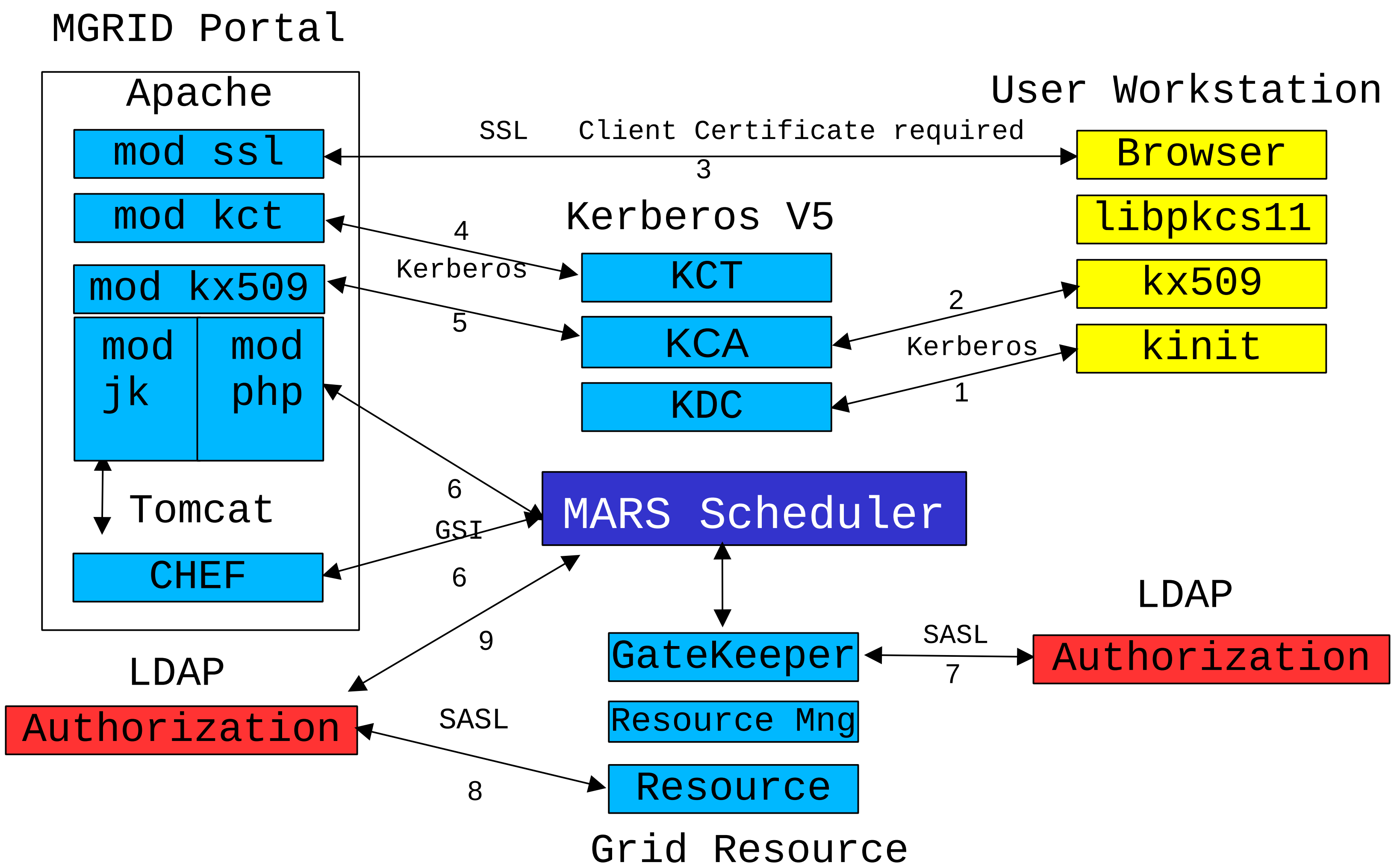
On-Demand Task Scheduling

- Resources on-demand (prioritized task queues and pre-emption of lower priority tasks

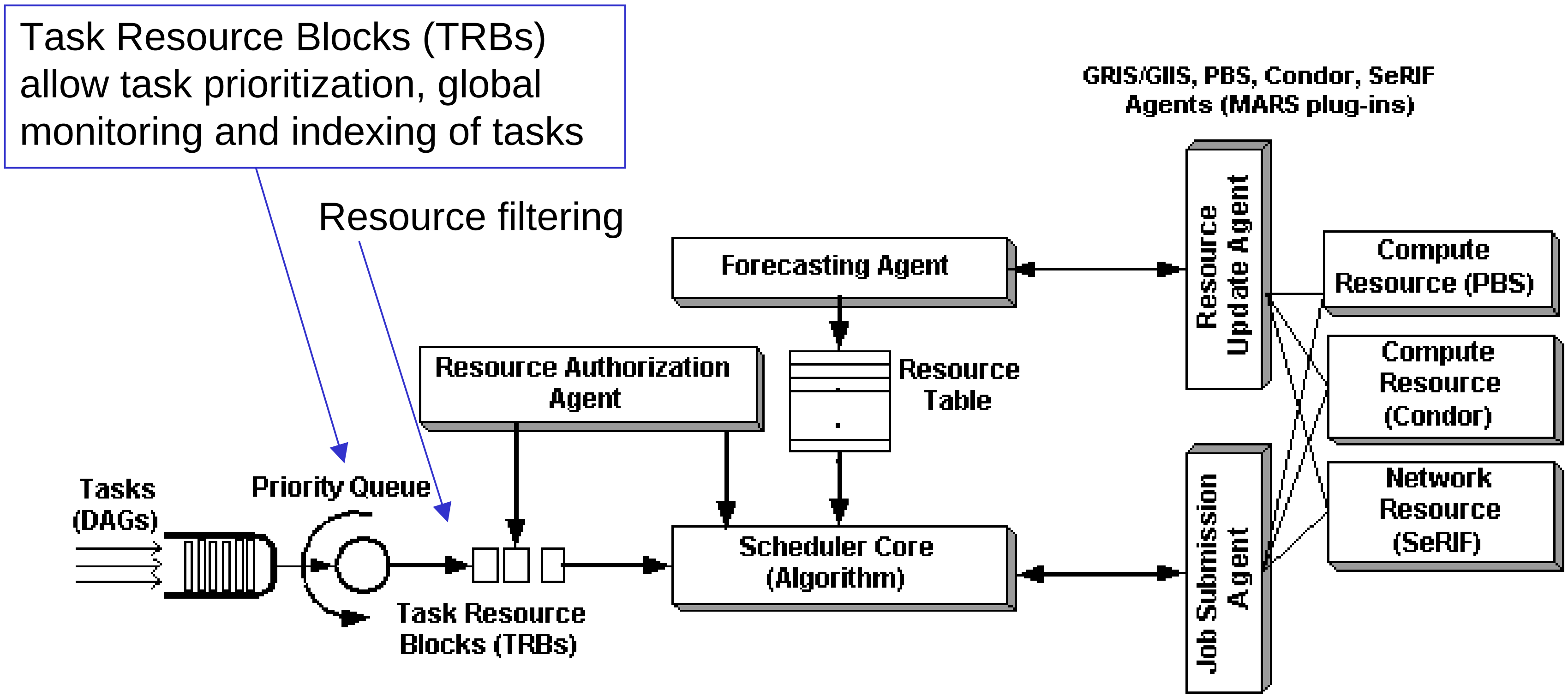
Resource Usage Forecasting

- Can lead to better scheduling decisions across multiple systems
- MARS currently uses low-pass filters (exponential smoothing)

MGRID ARCHITECTURE

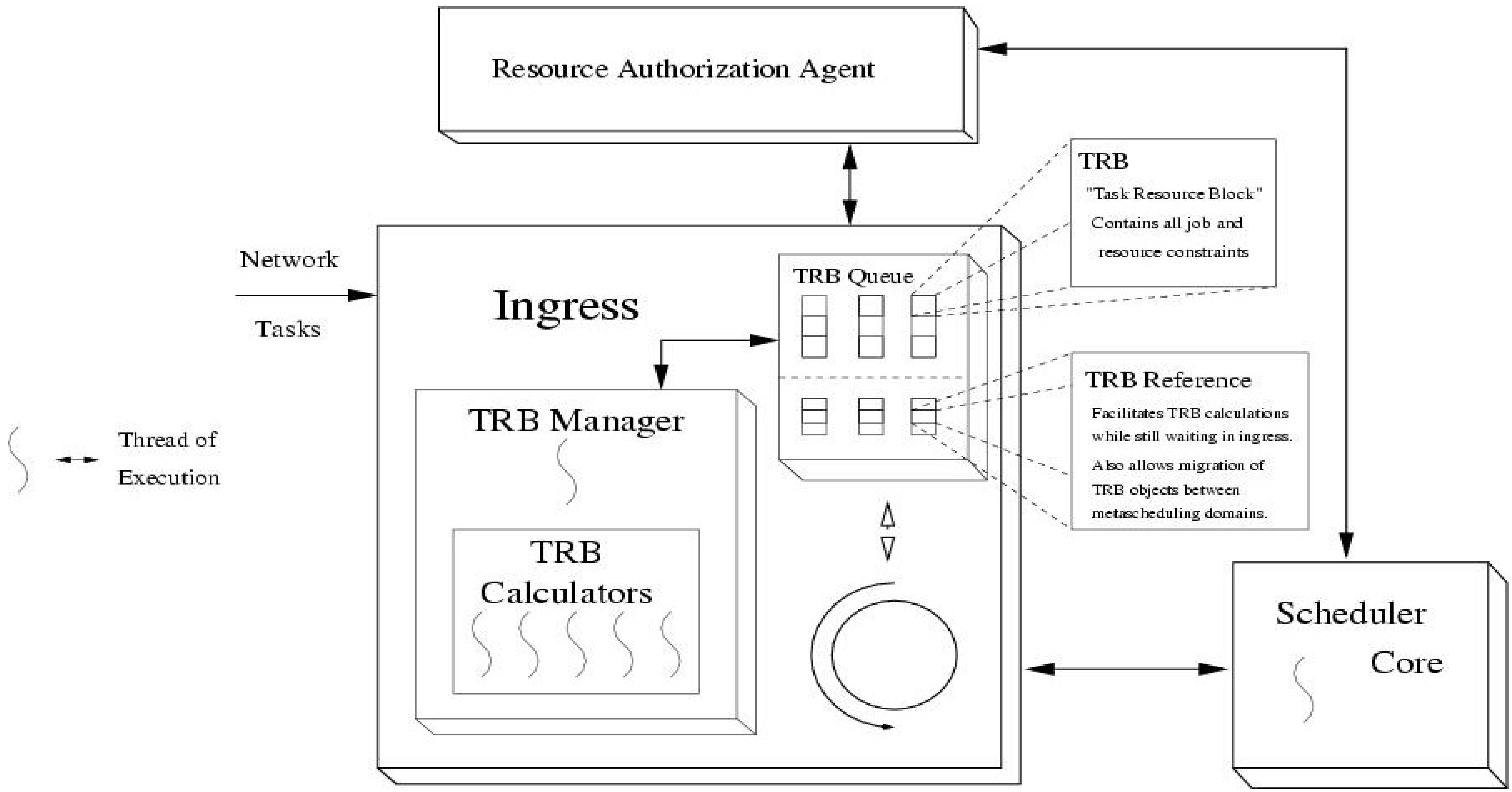


MARS COMPONENTS



- Each task gets a TRB that includes a MARS JobID
- Individual schedulers assign their own JobIDs
- TRBs encapsulate these IDs

SCHEDULER INGRESS



RESOURCE USAGE PREDICTION

Model transient behavior of local scheduler parameters from data collected by Resource Update Agents

Current parameters (compute resources only):

- CPU Utilization
- Maximum and average queue lengths of waiting tasks
- Maximum and average task turnaround times for queues

Use: Exponential Smoothing of time-series data of above parameters

$$\overline{Q(t+\nabla t)} = \alpha . Q(t) + (1-\alpha).\overline{Q(t)}$$

$\overline{Q(t)}, \overline{Q(t+\nabla t)}$: smoothed observations
Q(t): actual observation
α: smoothing parameter (evaluated from LS fit to time series data)

SCHEDULING ALGORITHMS

Minimum Completion Time (MCT)

e_{ij} = expected execution time for task t_i on resource r_j

s_{ij} = estimated start time (depends on number of tasks in queue)

c_{ij} = completion time

Find resource r_k for task t_i find the minimum of all c_{ij} s:

$$(t_i, r_k) = \min_{j=1,m} (c_{ij} = s_{ij} + e_{ij})$$

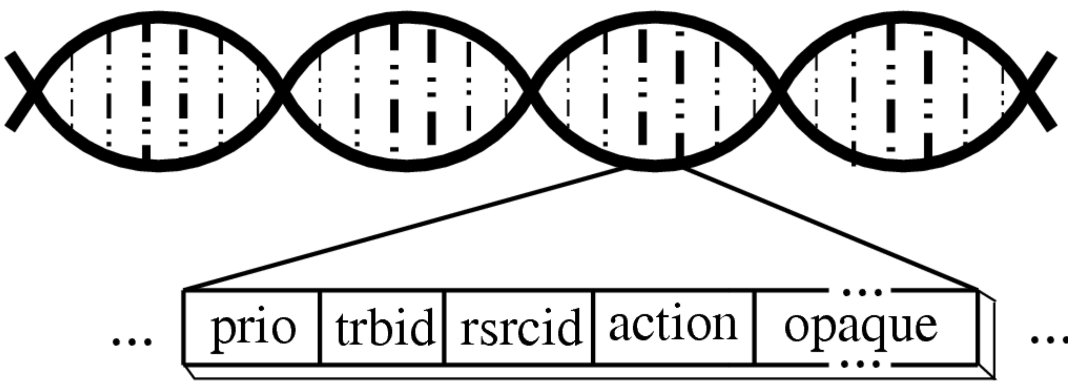
Easy to implement but not efficient as we will see later

Genetic Algorithm Scheduler

Allows metascheduler administrator to build schedules based upon complicated metrics

We modified a parallel GA solver (PGAPack) to implement

Easy to implement new algorithms in the framework

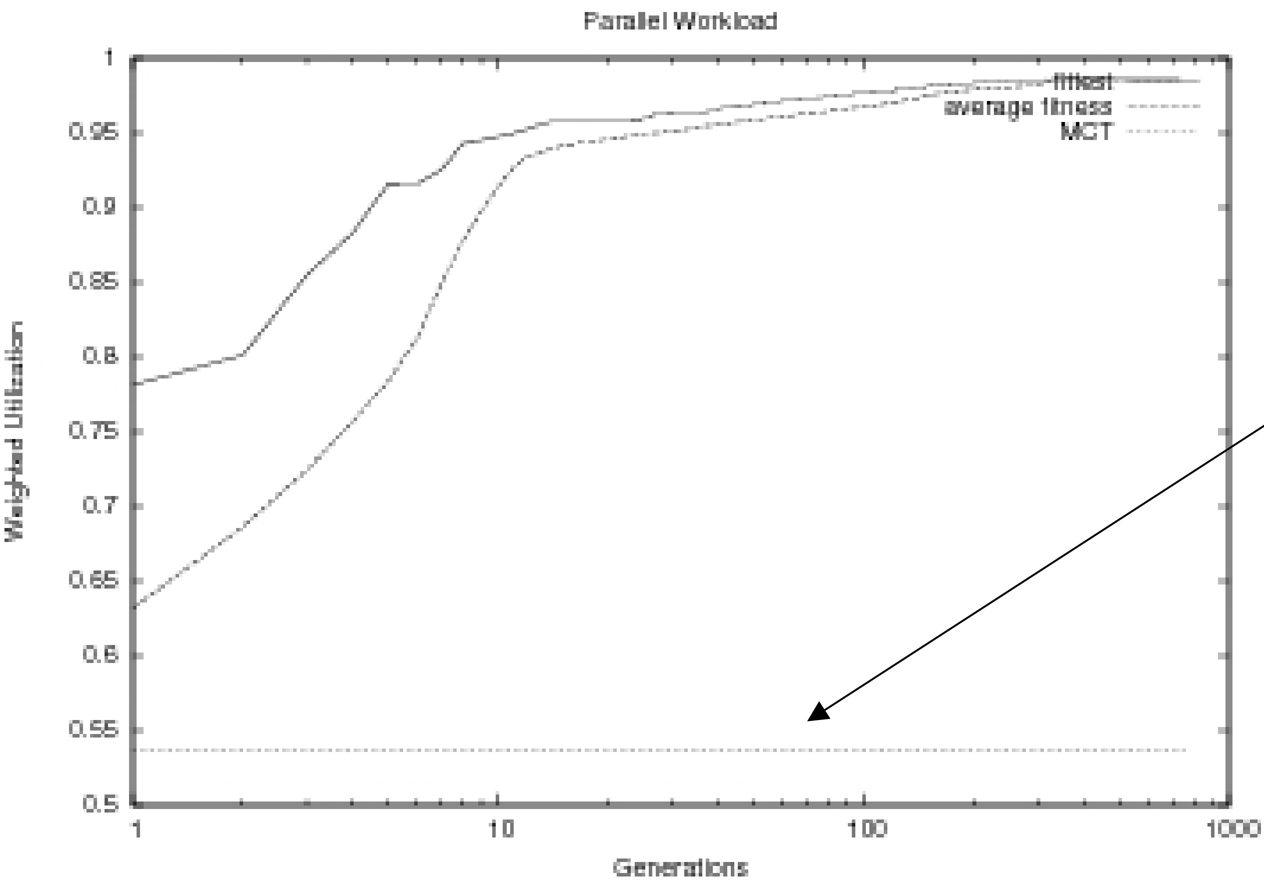


Opaque State as a parameter

- Introduce new parameters to optimize
  - Architectural considerations
  - Network topology considerations
- Administrator may supply custom fitness function that utilizes new parameters

OFFLINE WORKLOAD COMPARISONS

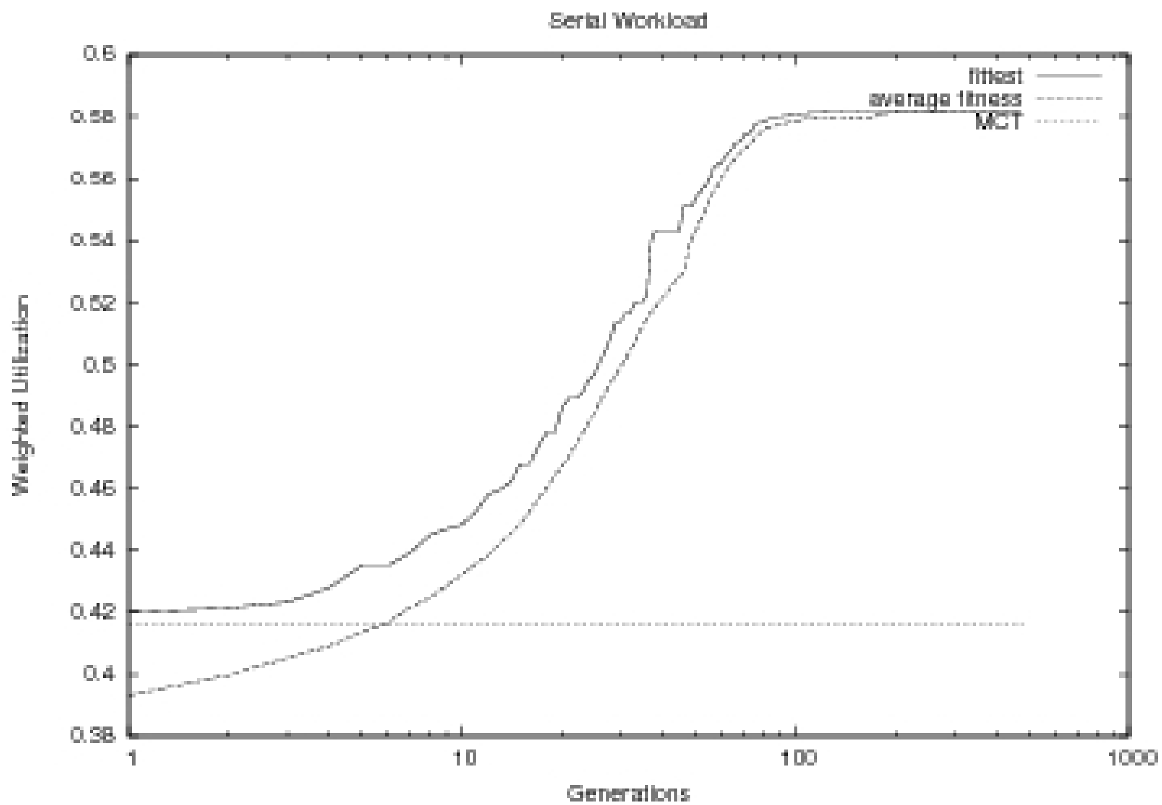
Parallel Workload on 700 CPUs



MCT is not desirable from resource owner s point of view!

OFFLINE WORKLOAD COMPARISONS

Serial Workload on 700 CPUs



Note difference in resource utilization between two workloads

OFFLINE WORKLOAD COMPARISONS

Comparison of maximum wait-times for any task

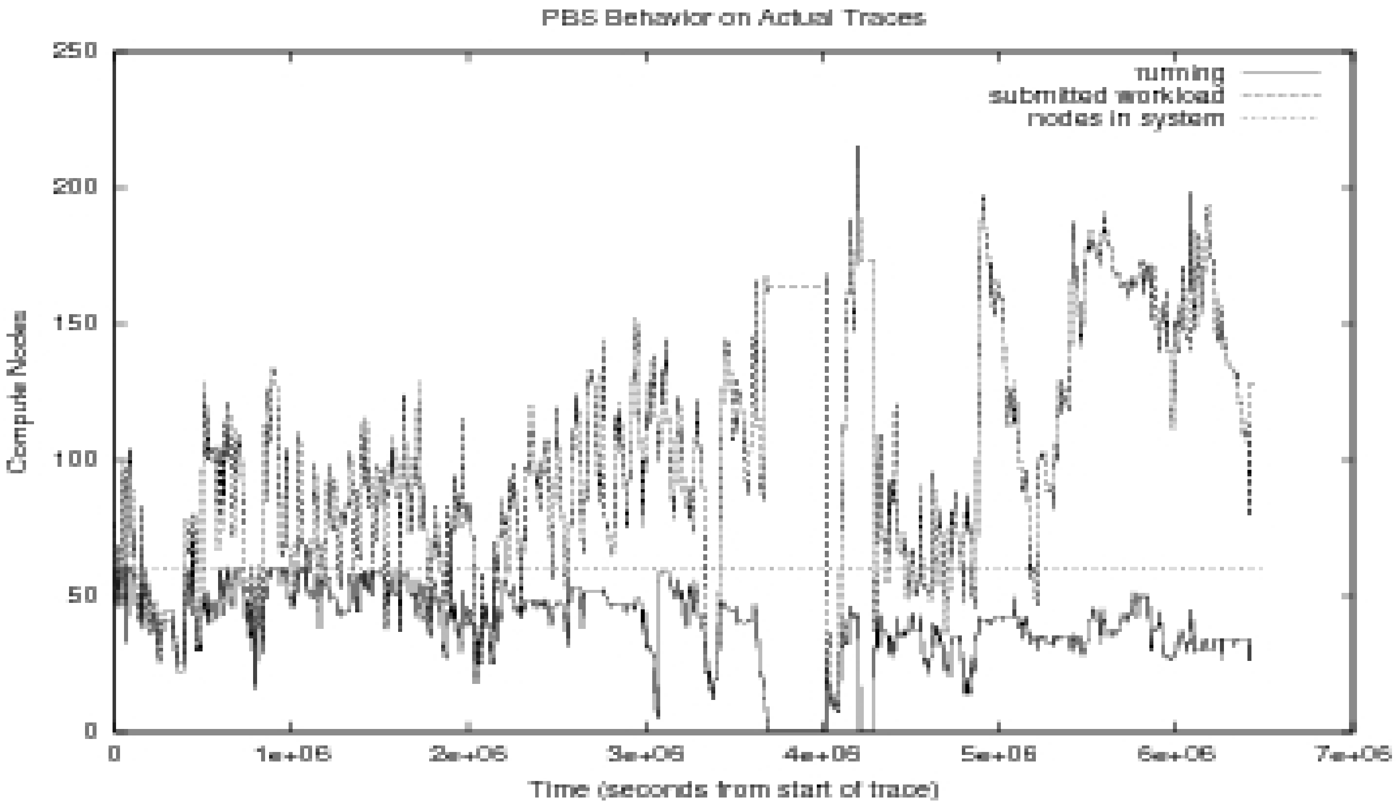
Workload	Algorithm	Max Wait-time (seconds)
Serial	MCT GA	615828 (613800*,986400)
Parallel	MCT GA	1839621 (1468800*,2458800)
Benchmark	MCT GA	879445 (739800*,1150200)

* Minimum wait-time

GA: maximize resource utilization, MCT: minimize completion time

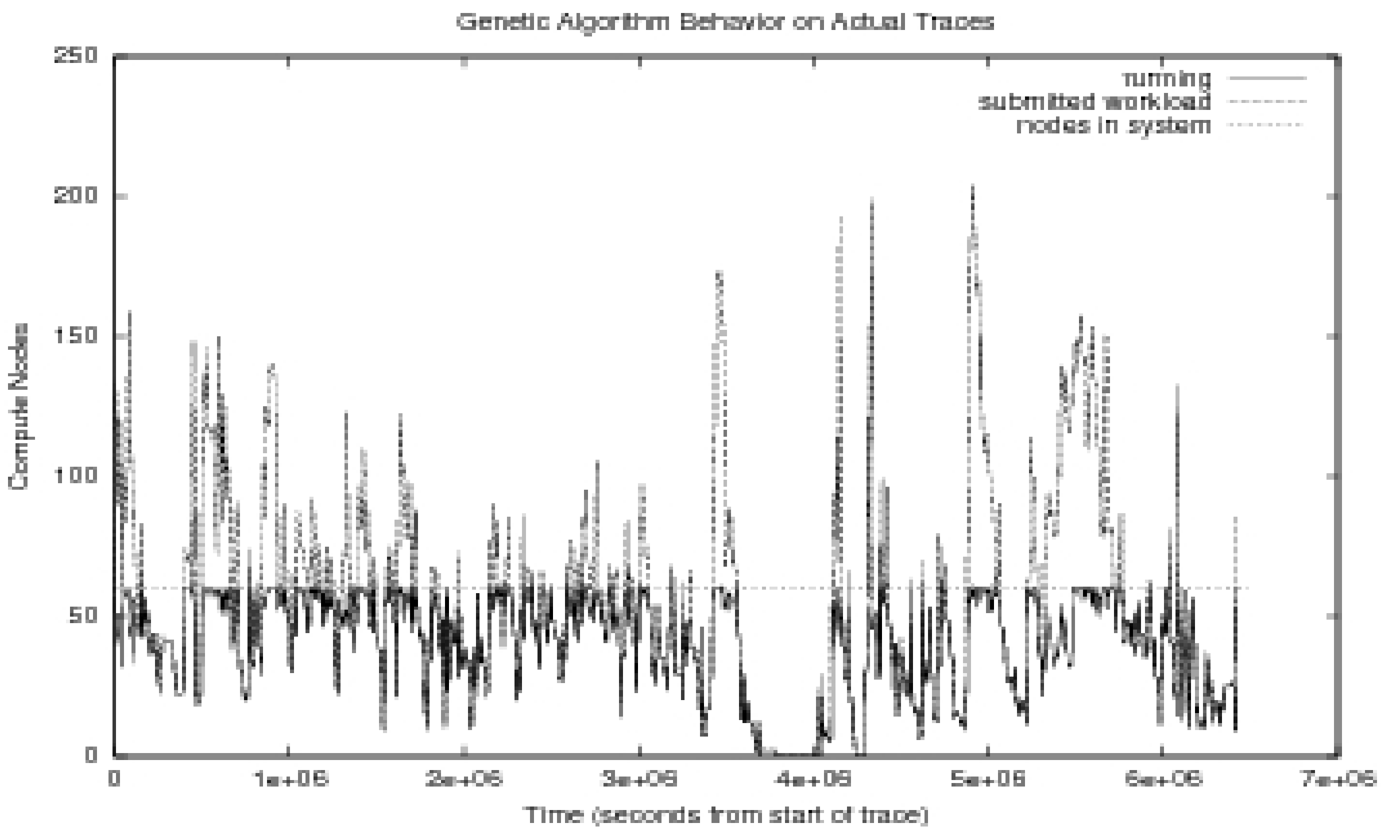
ONLINE WORKLOAD COMPARISONS BETWEEN MARS AND PBS

Three months of submitted workload traces
for a 120-CPU AMD Athlon cluster at NPACI/CAC
(mixed workload)



ONLINE WORKLOAD COMPARISONS BETWEEN MARS AND PBS

Three months of submitted workload traces for a 120-CPU AMD Athlon cluster at NPACI/CAC (mixed workload)



MARS: Ongoing Work

Integration of Walden authorization callout and MARS plug-ins for LRMs

Redesign of Ingress and Egress modules to accommodate general resources such as compute , storage and network resources

Ongoing study of characterization of archived workloads at various NPACI and Teragrid sites

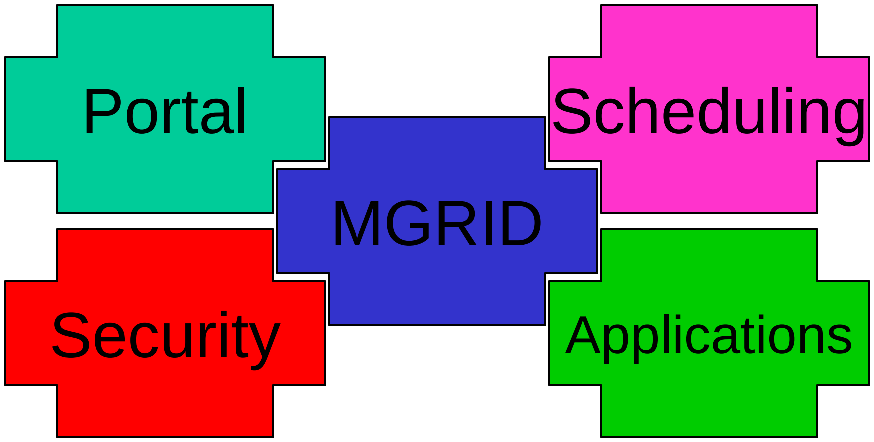
Time-series modeling techniques such as ARMA processes for LRM resource state predictions

Inter-domain scheduling by managing TRB queues on distributed MARS agents

Received NSF Award in October, 2004 for fault-tolerant scheduling, online workload characterization and resource-level prediction

Example Application:

CITI Network Testing And Performance (NTAP)



MGRID NTAP Project

NTAP: Network Testing and Performance

Purpose: Provide a secure and extensible network test and performance tool invocation service at U-M (Can we drop code on routers ?)

Service based on Globus

Runs on dedicated nodes attached to routers in a VLAN environment

MGRID NTAP Project

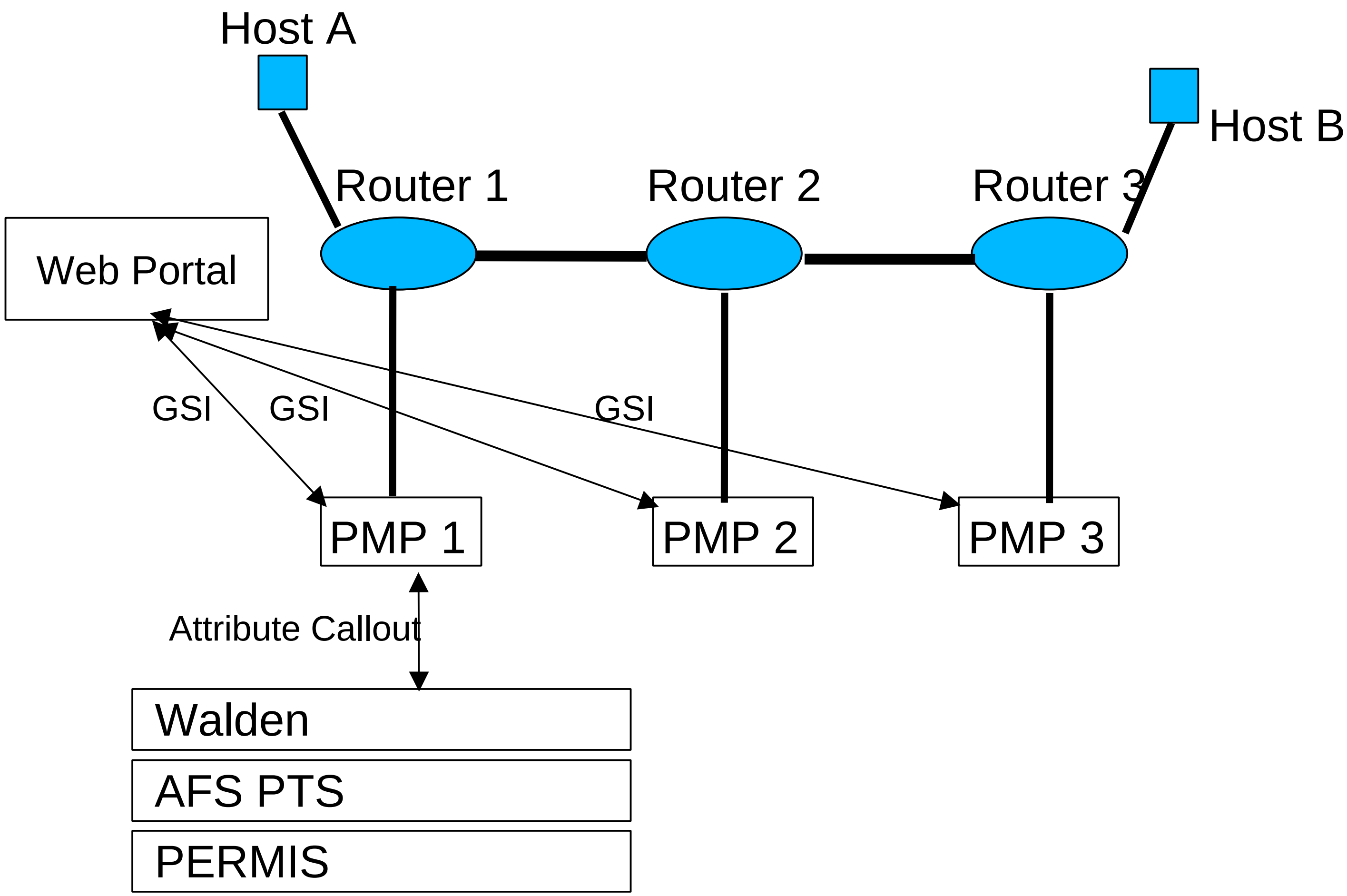
Initial work implemented a bandwidth reservation tool:

- Securely modifies network switch configurations
- Implements role-based authorization
- Includes scheduler for future reservations
- Based on GARA
  - General-purpose Architecture for Reservation and Allocation
- Layered on Globus

MGRID NTAP Project

- Added modular fine grained authorization
  - Keynote policy engine/AFS PTS group service
  - PERMIS policy engine/LDAP group service
  - Integrated with Walden Authorization Framework
- Added signed group membership RSL payload
- Generalized from bandwidth reservation to the ability to run arbitrary programs at a Grid service endpoint
  - Designed to easily add functionality
  - Network testing tools being run
    - Iperf, traceroute, ping, owamp, etc

MGRID NTAP Architecture



MGRID NTAP Project

- Multihomed PMP support (policy among peers)
  - One routing table per VLAN
  - Routing policy selects routing table based on source address of outgoing packet
  - Emulates a default route per virtual interface
- Path discovery
  - Use traceroute to obtain routing information
  - Use network topology databases to map network segments to PMP pairs

MGRID NTAP Project

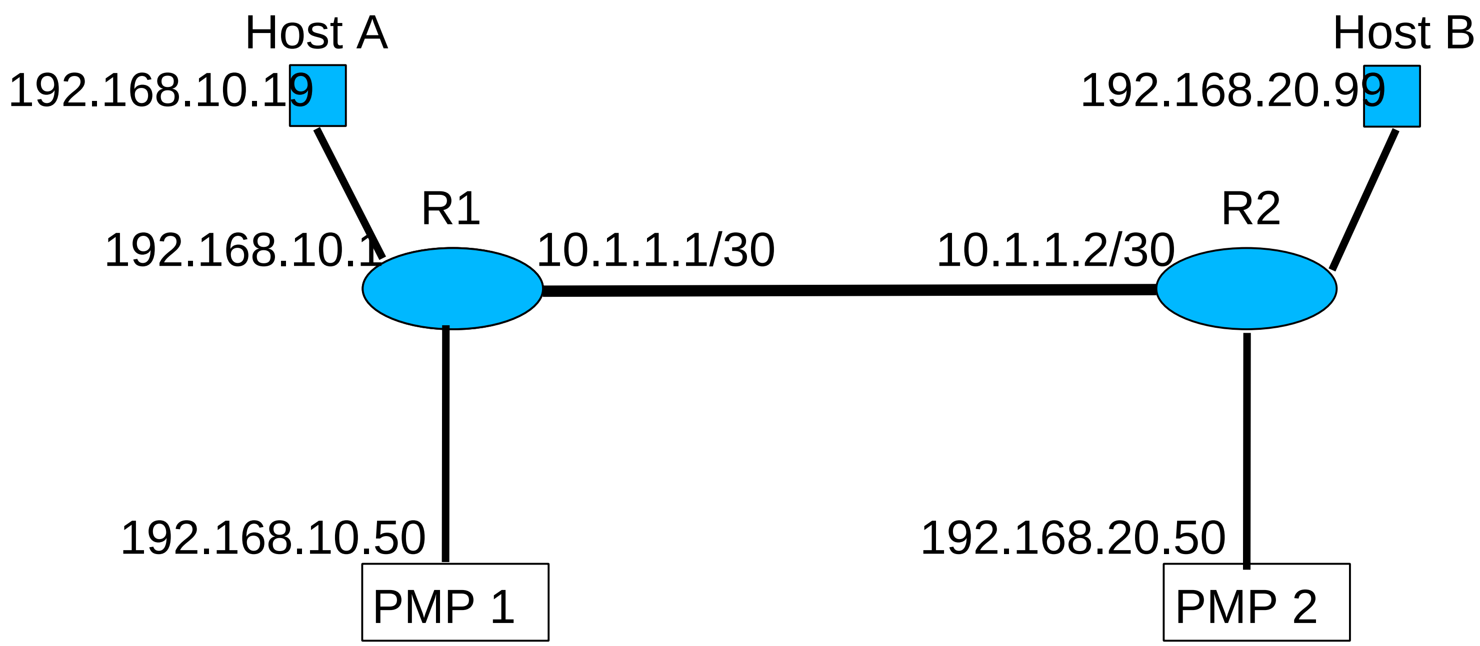
- PERMIS authorization
  - User, Target, Action
  - Attribute, policy certificates
  - Policy engine
- Production hardening
  - Error handling/recovery
  - Cleanup/restart
  - Log file management
  - Deployment packaging

MGRID NTAP Project

- Performance measurement
  - Deployment to ITCom lab
- Output Database
  - Permanent, secure storage of results
  - Searches and aggregations
  - Throughput/latency matrix
- Host Endpoint Testing
  - The last mile segment
  - Secure download of signed binaries

MGRID NTAP Project

Campus Prototype:



MGRID: Ongoing and Planned Work

Campus-wide grid prototype based on MGRID software

- Goal is to have 1000 CPUs by Summer, 2005

Continue focus on applications (Biomedicine, Computational Chemistry, Parallel Monte Carlo/Computational Finance, Agent Simulations, Distributed Visualization)

New Projects in 2005:

Fault-tolerant Grid Infrastructure

- develop fault models (resources, grid protocols, data handling, AAA etc.)
- fault-injection modules in MGRID components (MARS, Walden)
- scheduling in presence of application- and resource-level faults
- transparent VO-level checkpointing

Cross-Institutional (cross-domain) resource sharing and collaboration