Scheduling and Resource Management in Grids and Clouds

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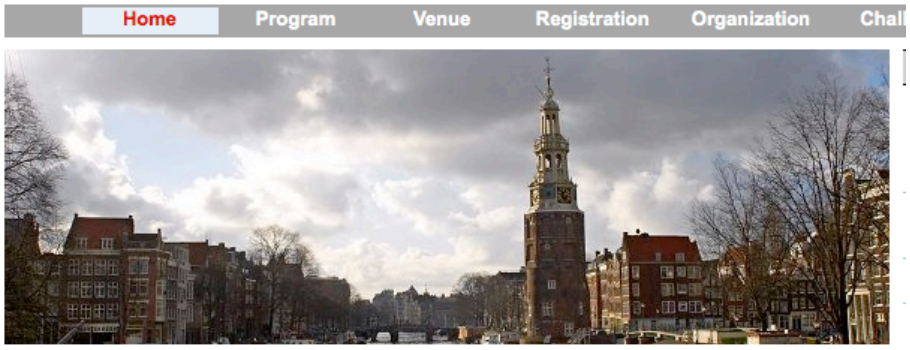

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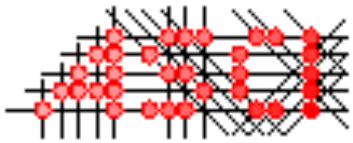

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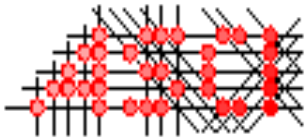
Outline

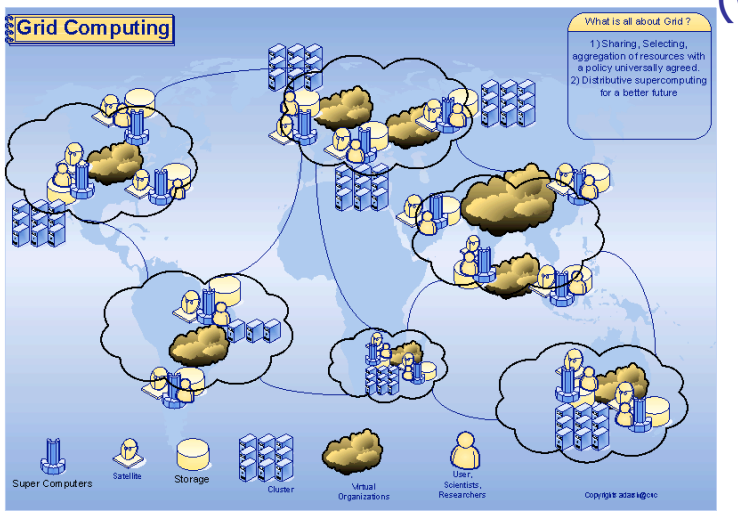
- Resource Management
  - Introduction
  - A framework for resource management
- Grid Scheduling
  - Problems in grid scheduling
  - Stages in grid scheduling
  - Service level agreements
  - Scheduling policies
- Examples of Grid Resource Management Systems
- Cloud Resource Management

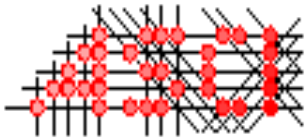


Resource Management (1)

- "***Resource management*** *refers to the operations used to control how capabilities provided by grid resources and services are made available to other entities, whether users, applications or services*"

(Czajkowski, Foster, Kesselman)





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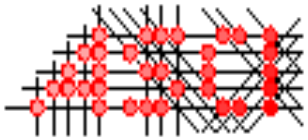
Resource Management (2)

- **Main goal**: establish a **mutual agreement** between resource providers and resource consumers

- **Grid Resource Consumers**
  - Execute jobs for solving problems of various size and complexity
  - Benefit by judicious selection and aggregation of resources

- **Grid Resource Providers**
  - Contribute ("idle") resources for executing consumer jobs
  - Benefit by maximizing resource utilization



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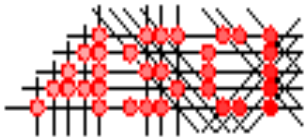
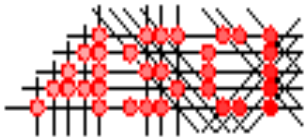
Resource Characteristics in Grids (1)

- A **resource** denotes any capability that may be shared and exploited in a networked environment
  - e.g., processor, data, disk space, bandwidth, telescope, etc.
- **Autonomous**
  - Each resource has its own management policy or scheduling mechanism
  - No central control/multi-organizational sets of resources
- **Heterogeneous**
  - Hardware (processor architectures, disks, network)
  - Basic software (OS, libraries)
  - Grid software (middleware)
  - Systems management (security set-up, runtime limits)
- **Compute power is a complex utility!!!**



Resource Characteristics in Grids (2)

- **Size (up to exascale computing!)**
  - Large numbers of nodes, providers, consumers
  - Large amounts of data
- **Varying Availability**
  - Resources can join or leave to the grid at any time due to maintenance, policy reasons, and failures
- **Geographic distribution and different time zones**
  - Resources may be dispersed across continents
- **Insecure and unreliable environment**
  - Prone to various types of attacks



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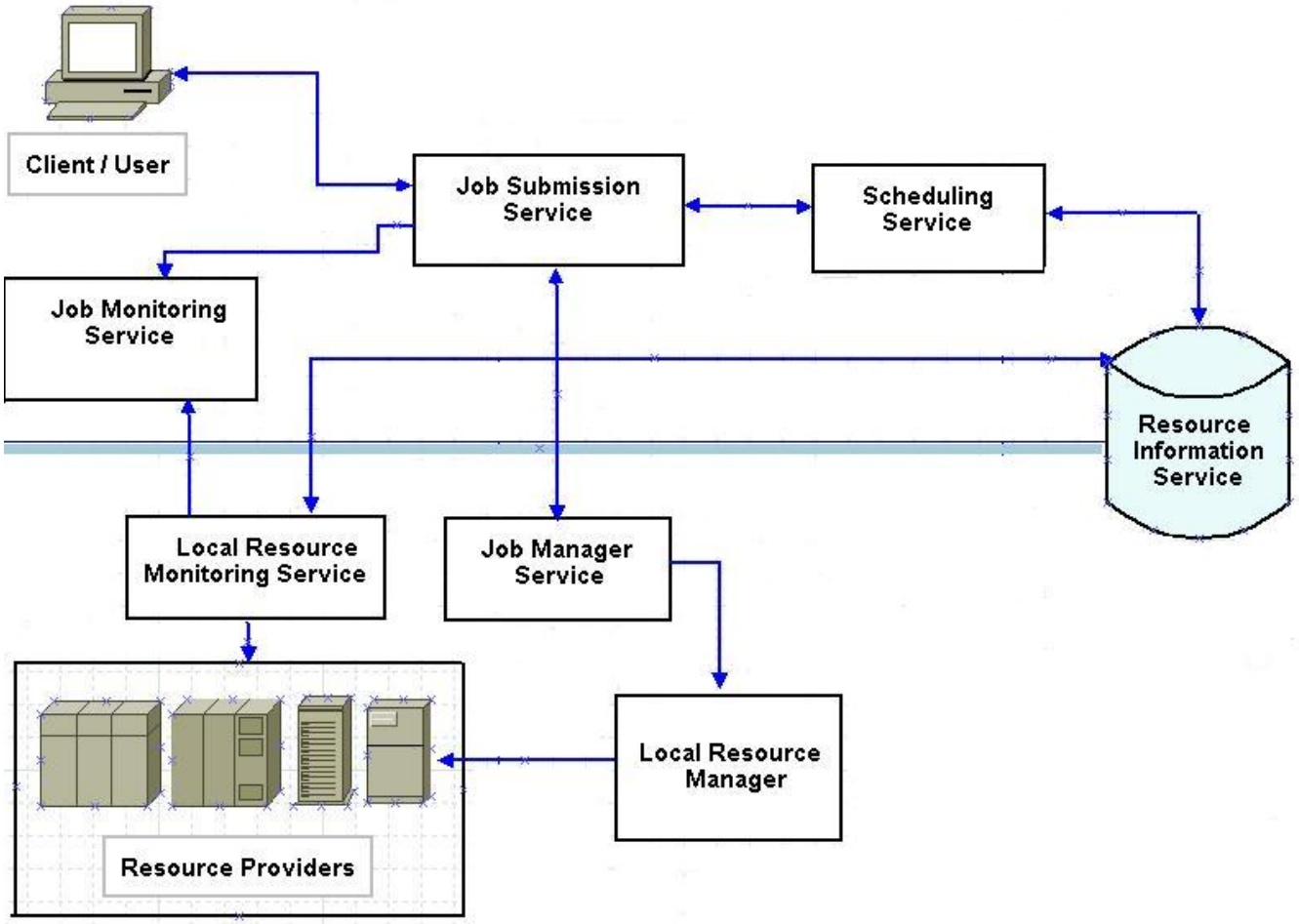
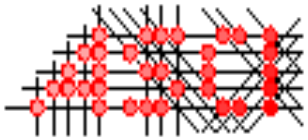
A General Resource Management Framework (1)





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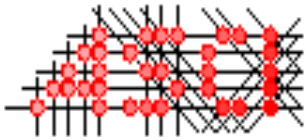
A General Resource Management Framework (2)

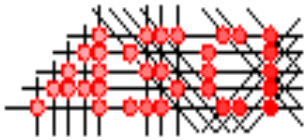
- **Local resource management system (Resource Level)**
  - Basic resource management unit
  - Provides low level resource allocation and scheduling
  - e.g., PBS, SGE, LSF

- **Global resource management system (Grid Level)**
  - Coordinates all local resource management systems within multiple or distributed sites
  - Provides high-level functionalities to efficiently use resources:
    - Job submission
    - Resource discovery and selection
    - Authentication, authorization, accounting
    - Scheduling (possibly including co-allocation)
    - Job monitoring
    - Fault tolerance



Co-Allocation (1)

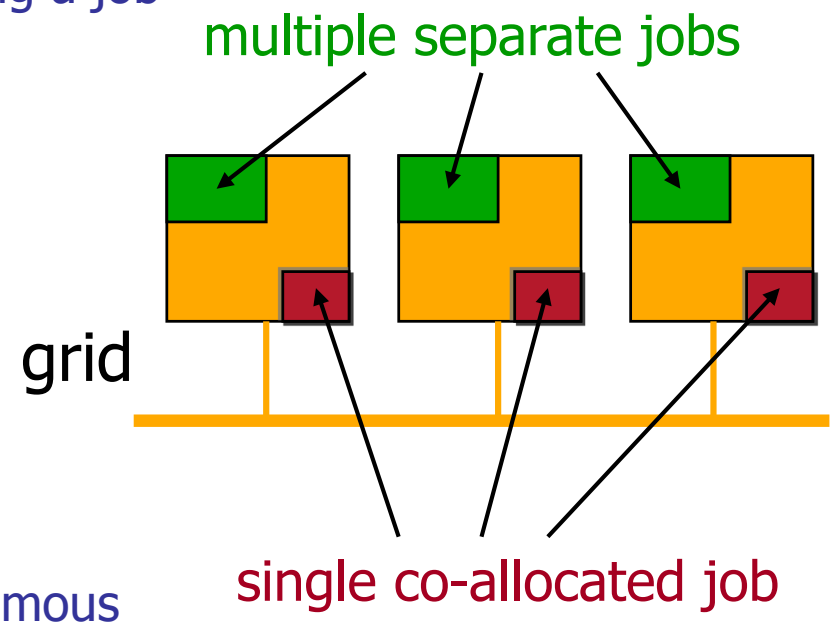
- In grids, jobs may use multiple types of resources in multiple sites: **co-allocation** or **multi-site operation**
- **Reasons:**
  - To use available resources (e.g., processors)
  - To access and/or process geographically spread data
  - Application characteristics (e.g., simulation in one location, visualization in another)
- Resource possession **in different sites** can be:
  - Simultaneous (e.g., parallel applications)
  - Coordinated (e.g., workflows)

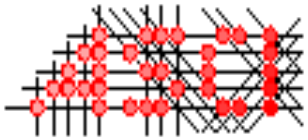


Co-Allocation (2)

- **Without co-allocation**, a grid is just a big load-sharing device with a **metascheduler** or **superscheduler**:
  - Find suitable candidate system for running a job
  - If the candidate is not suitable anymore, migrate

- **With co-allocation**:
  - Better utilization of resources
  - Better response times
  - More difficult resource-discovery process
  - Need to coordinate allocations by autonomous resource managers (**local schedulers**)





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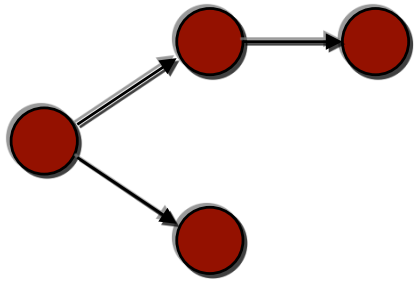
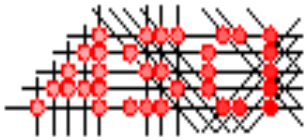
Job types in Grids

- **Sequential jobs/bags-of-tasks**
  - E.g., parameter sweep applications (PSAs)
  - These account for the vast majority of jobs of grids
  - Leads to **high-throughput** computing
- **Parallel jobs**
  - Extension of **high-performance** computing
  - In most grids, only a small fraction
- **Workflows**
  - Multi-stage data filtering, etc
  - Represented by directed (acyclic) graphs
- **Miscellaneous**
  - Interactive simulations
  - Data-intensive applications
  - …





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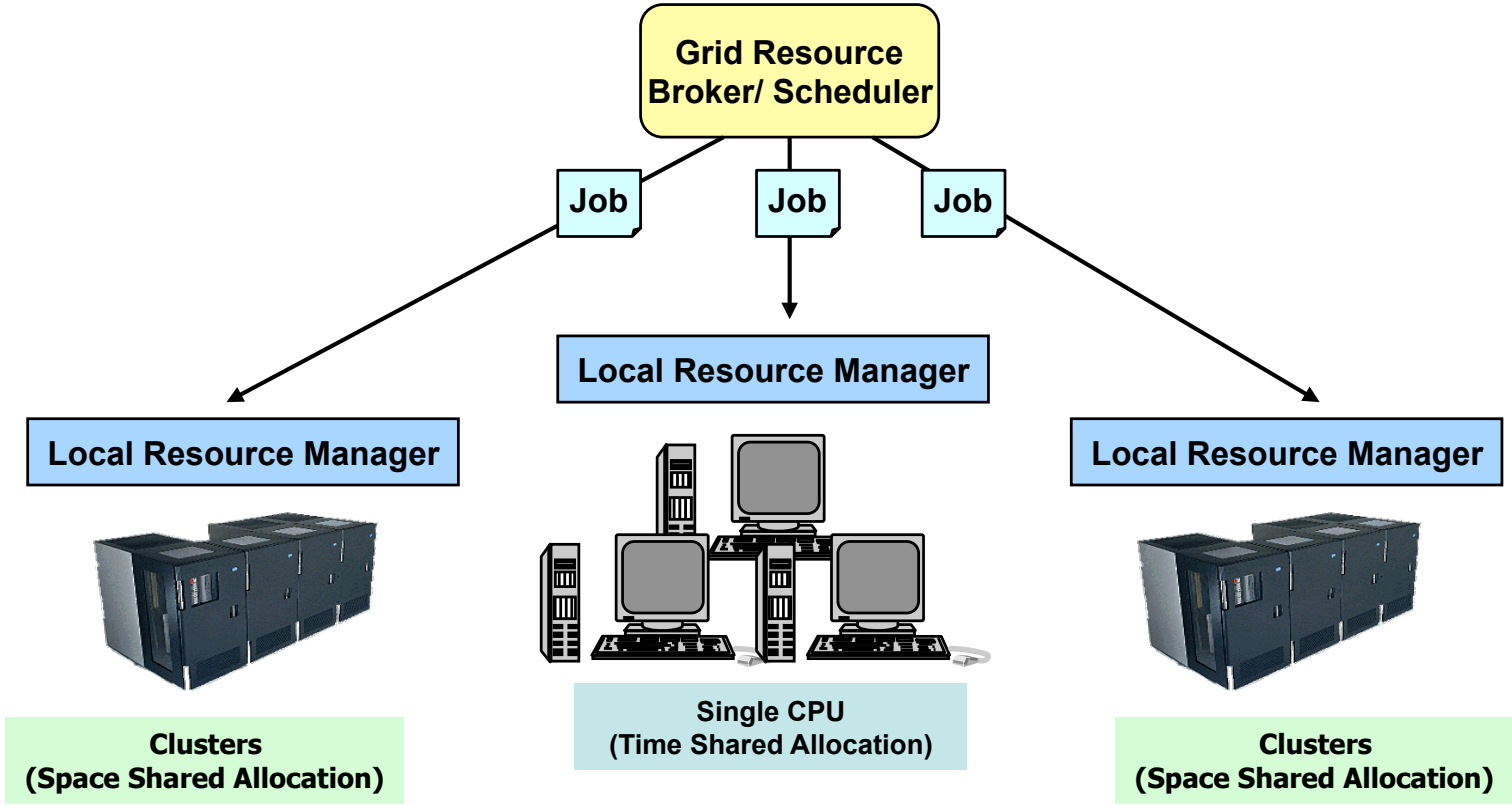
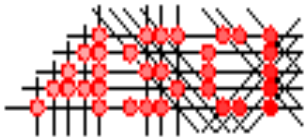
How to select resources in the grid?

- **Grid scheduling** is the process of assigning jobs to grid resources





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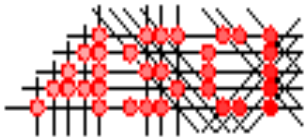
Different Levels of Scheduling

- **Resource level scheduler**
  - *a.k.a.* low-level scheduler, local scheduler, local resource manager
  - Scheduler controlling a supercomputer or a cluster
  - e.g.: Open PBS, PBS Pro, LSF, SGE
- **Enterprise level scheduler**
  - Scheduling across multiple local schedulers belonging to the same organization
  - e.g., PBS-Pro, LSF multi-cluster
- **Grid level scheduler**
  - *a.k.a.* super-scheduler, broker, community scheduler
  - Discovers resources that can meet a job's requirements
  - Schedules across lower level schedulers
- **System-level versus application-level scheduling**



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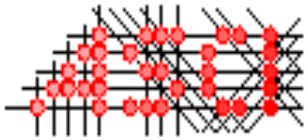
Grid Level Scheduler

- Discovers and selects the appropriate resources for a job
- No ownership or control over resources
- Jobs are submitted to local resource managers
- Local resource managers take care of actual execution of jobs

- **Architecture**
  - **Centralized**: all lower level schedulers are under the control of a single grid scheduler
    - not realistic in global grids
  - **Distributed**: lower level schedulers are under the control of several grid schedulers



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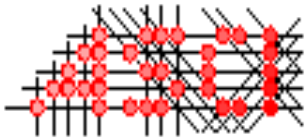
General Problems in Grid Scheduling

1. **Grid schedulers do not own resources themselves**
   - they have to negotiate with autonomous local schedulers
   - authentication/multi-organizational issues
2. **Grid schedulers have to interface to different local schedulers**
   - some may have support for reservations, others are queuing-based
   - some may support checkpointing, migration, etc
3. **Structure of applications**
   - many different structures (parallel, PSAs, workflows, etc.)
   - for co-allocation, optimized wide-area communications libraries are needed



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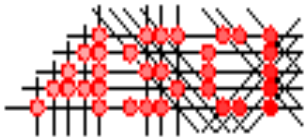
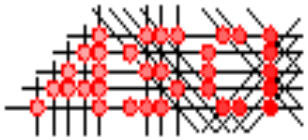
Problems (1): system

1. **Lack of a reservation mechanism**
   - but with such a mechanism we need good runtime estimates
2. **Heterogeneity**
   - hardware (processor architecture, disk space, network)
   - basic software (OS, libraries)
   - grid software (cluster scheduler)
   - systems management (security set-up, runtime limits)
3. **Failures**
   - monitor the progress of applications/sanity of systems
   - only thing we know to do upon failures: (move and) restart
   - we may interface to fault-tolerance mechanisms in applications



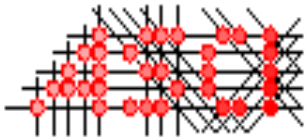
Problems (2): applications

4. **Communication in wide-area applications**
   - may need an additional initialization step to allow applications to communicate across multiple subsystems
5. **Structure of applications**
   - many different structures, can't deal with all of them
   - introduce application adaptation modules
   - allow application-level scheduling



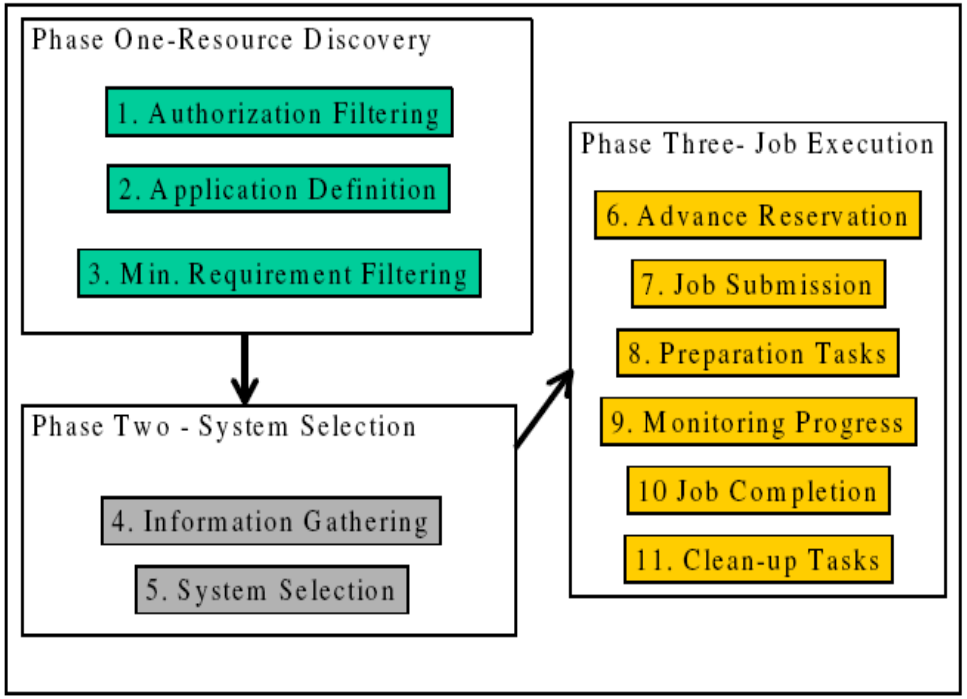
Problems (3): testing/performance

6. **Need for a suite of test applications**
   - for functionality and reliability testing
   - for performance evaluation
   - should run on "all grids"
7. **Reproducibility of performance experiments**
   - never the same circumstances
   - tools for mimicking same conditions

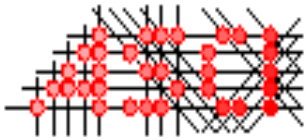


Stages of Grid Scheduling

1. **Resource Discovery**
2. **System Selection**
3. **Job Execution**



www.mcs.anl.gov/~jms/Pubs/sched.arch.2002.pdf



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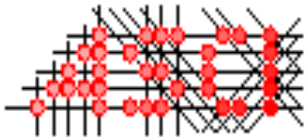
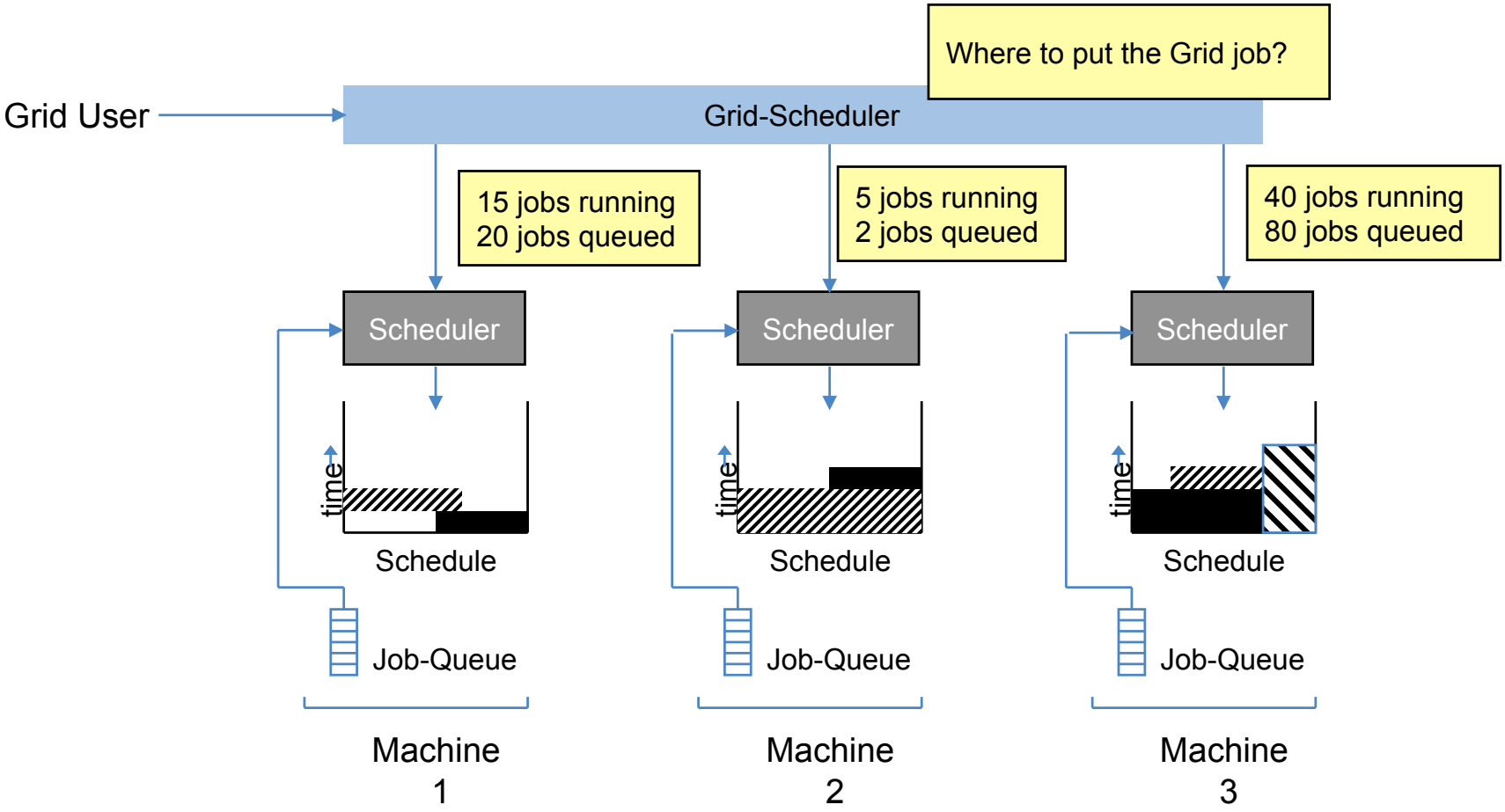
Resource Discovery

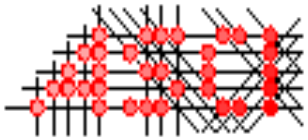
- **Describe jobs and resources:**
  - Job description files
  - Classads
- Determine which resources are available to the user:
  - **Authorization Filtering**
    - A list of machines or resources to which the user has access
  - **Application Requirement Definition**
    - Job requirements can be specified with job description languages (e.g., Condor ClassAd, GGF JSDL, Globus RSL)
  - **Minimal Requirement Filtering**
    - A reduced set of resources to investigate in more detail



System Selection (1)



From: Grid Resource Management and Scheduling, *Ramin Yahyapour*



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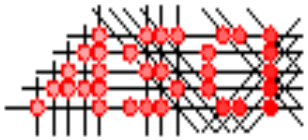
System Selection (2): Information Gathering

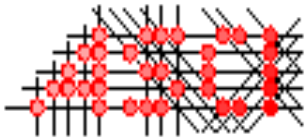
- **Grid Information Service (GIS)**
  - Gathers information from individual local resources
  - Access to static and dynamic information
  - Dynamic information include data about planned or forecasted future events
    - e.g., existing reservations, scheduled tasks, future availabilities
  - Create a database for the GIS



System Selection (3): Methods

- **Predictive state estimation**
  - Consider current and **historical** information
  - Heuristics
  - Pricing Models
  - Machine Learning

- **Non-predictive state estimation**
  - Consider only the **current** job and resource status information
  - No need to take into account the historical information
  - Heuristics



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System Selection (4): Objectives

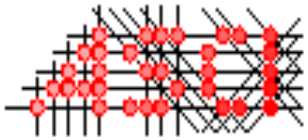
- **Application Oriented**
  - Optimizing metrics such as job response time, job wait time, etc.
  - e.g., average weighted response time

$$AWRT = \frac{\sum_{j \in Jobs} w_j \cdot (t_j - r_j)}{\sum_{j \in Jobs} w_j}$$

- r : submission time of a job
- t : completion time of a job
- w : weight/priority of a job

- **System Oriented**
  - Maximizing throughput, utilization (minimizing idle time)

- **Conflicting objectives!!**
  - The (main) scheduling criterion is usually static for an installation and implicitly given by the scheduling algorithm



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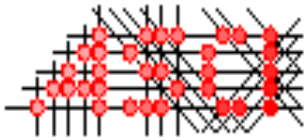
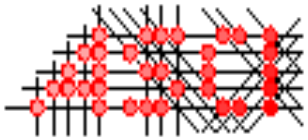
Job Execution (1)

- Advance Reservation
- Job Submission
- Preparation Tasks
- Monitoring Progress
- Job Completion
- Cleanup Tasks



Job Execution (2): Advance Reservations

- Co-allocated and other applications require a priori information about the precise resource availability
- Resource provider guarantees a specified resource allocation
  - two- or three-phase commit included for agreeing on the reservation
- **Implementations**
  - GARA/DUROC provide interfaces for Globus to create advanced reservation
  - Setup of a dedicated bandwidth between endpoints (e.g., DAS3/ StarPlane)



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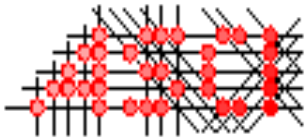
Job Execution (3): Job Submission

- It is the task of the resource management system to start a job on the allocated resources

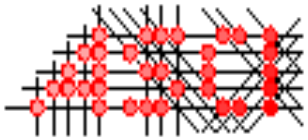
- The user 'submits' the job to the resource management system:
  - qsub jobscript.pbs
  - globus-submit-job job.rsl

- The user can control the job
  - *qsub*: submit
  - *qstat*: poll status information
  - *qdel*: cancel job



Job Execution (4): Other Phases

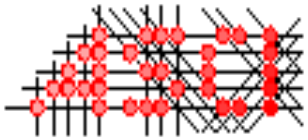
- **Preparation Tasks**
  - File staging, claiming a reservation
- **Monitoring Progress**
  - Resource conditions
  - Agreements
  - Schedules
  - Program execution
  - SLA conformance
- **Job Completion**
  - Notification
- **Cleanup Tasks**
  - File retrieval
  - Removing temporary settings



Service Level Agreements

- Old concept from the mainframe days

- The mapping of jobs to resources can be abstracted using the concept of Service Level Agreement (**SLAs**)
- **SLA**: Contract negotiated between
  - resource provider, e.g., local scheduler, and
  - resource consumer, e.g., grid scheduler, application
- **SLAs** provide a uniform approach for the client to
  - specify resource and QoS requirements, while
  - hiding from the client details about the resources,
  - such as queue names and current workload



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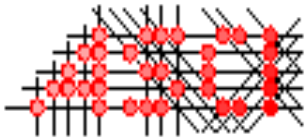
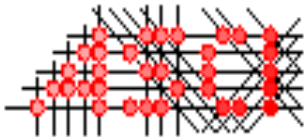
Scheduling and Replication Algorithms (1)

- **Random**
  - A randomly selected site
  - Each site has an equal or a different probability of getting selected
- **LeastLoaded**
  - The site that currently has the least load
  - A possible load definition: smallest number of waiting jobs
- **RandLeastLoaded**
  - A site randomly selected from a number of the least-loaded sites
- **DataPresent**
  - A site that already has the required data
- **Local**
  - The site where the job originated



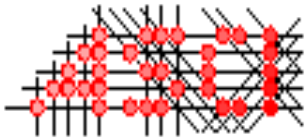
Scheduling and Replication Algorithms (2)

- **DataCaching**
  - Datasets are pre-assigned to different sites
  - No dynamic replication is in place
- **DataRandom**
  - Sites keep track of the popularity of the datasets they contain
  - When a site's load exceeds a threshold, "popular datasets" are replicated to a random site on the grid
- **DataLeastLoaded**
  - Sites keep track of dataset popularity and choose the least loaded site as a new host for a popular dataset
- **DataRandLeastLoaded**
  - A random site is picked from a number of the least loaded sites



Scheduling and Replication Algorithms (3)

- Scheduling in grids resembles **scheduling in distributed systems** (1980s and 1990s)
- **Differences with grids:**
  - In distributed systems, usually, a **centralized approach** was assumed
  - In distributed systems, the system was usually assumed to be **homogeneous**
- **Important research issues** in scheduling in distributed systems:
  - Amount of state information used (global FCFS, global SJF, …)
  - Staleness of state information used
- **Main lessons from distributed systems:**
  - Use simple policies
  - Use policies that don't use much state information



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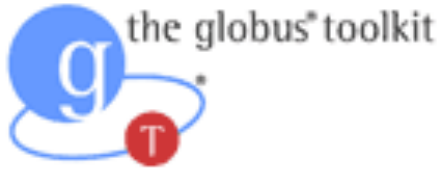
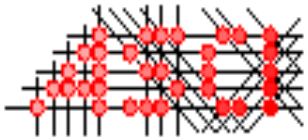
Example 1: The Globus Toolkit



- **Widely used grid middleware**
  - Negotiate and control access to resources
  - GRAM component for control of local execution

- **Globus toolkit includes software services and libraries for:**
  - resource monitoring
  - resource discovery and management
  - security
  - file management

- GT2
- GT3 – Web/GridService-based
- GT4 – WSRF-based



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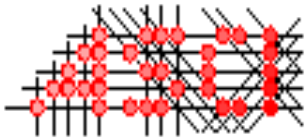
Example 2: Condor (1)

- Specialized **high-throughput** scheduling system
- Started around 1986 as one of many **batch queuing systems** for clusters (of desktop machines)
- Provides a queuing mechanism, scheduling policies, priority scheme, resource monitoring
- **Cycle scavenging**: can be set to use idle time on machines
- Condor introduced the notion of **classads**
- Cross-platform: UNIX/Linux, MacOS X, Windows
- **Condor-G(lide-in):**
  - used for submitting, queuing and monitoring jobs on Globus-managed resources
  - makes a Globus-managed resource appear as part of a Condor pool



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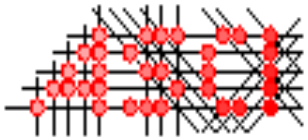
Example 2: Condor (2)

- **Basic operation of Condor:**
  - **jobs** send a **classad** to the **matchmaker**
  - **machines** send a **classad** to the **matchmaker**
  - the matchmaker **matches** jobs and machines,
  - and notifies the **submission machine**,
  - which contacts the **execution machine**
  - on the submission machine, a **shadow** process is started, which represents the remote job on the execution machine
  - on the execution machine, the actual **remote user job** is started



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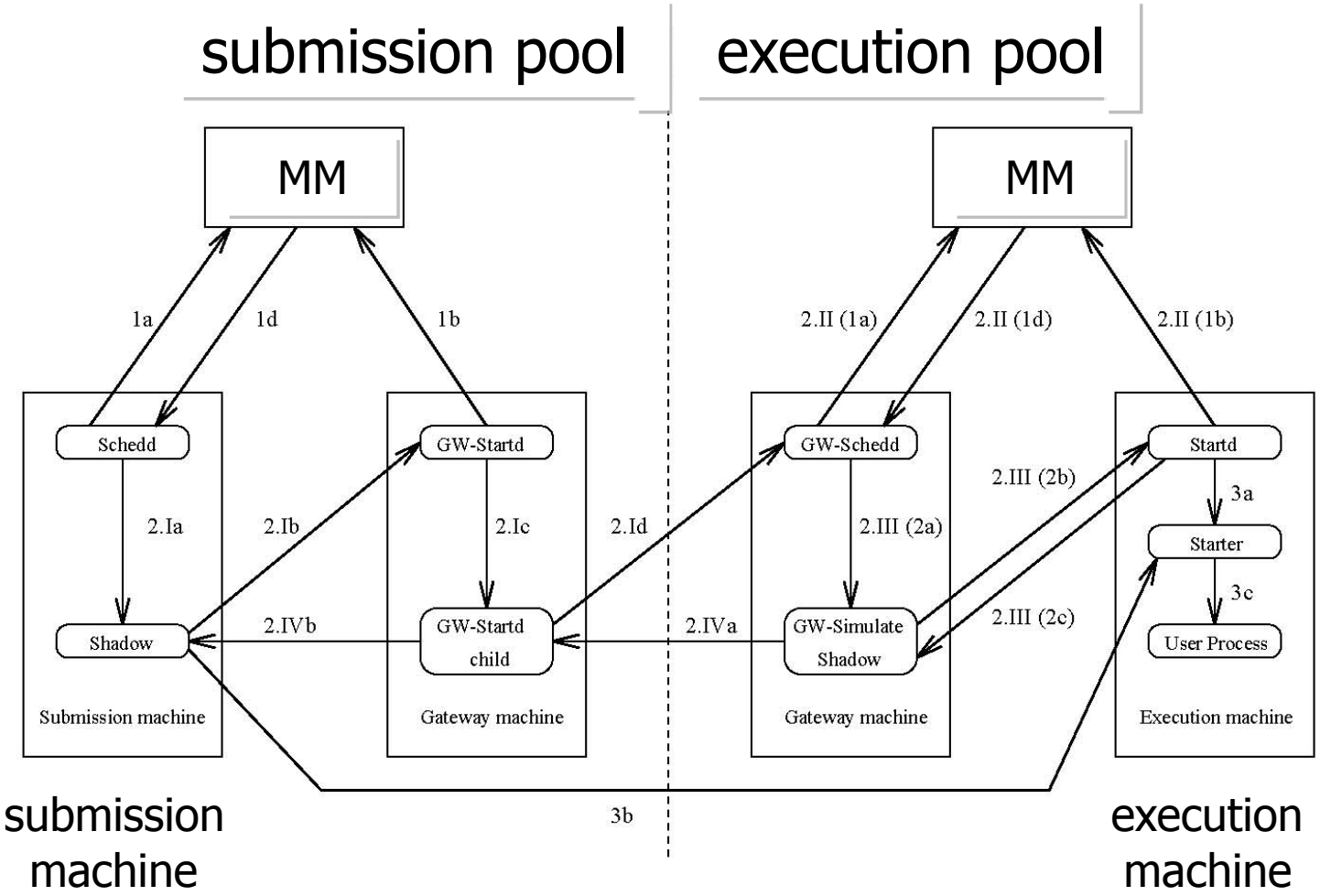
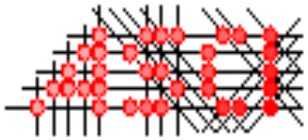
Example 2: Condor Flocking



Clouds (1): properties

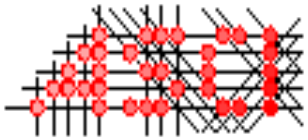
- **(Large-scale) data centers**
  - Offer compute, storage, and network resources
- **Pay per use**
  - No advance commitment, utility prices
- **Elastic capacity**
  - Scale up/down on demand (time granularity 1 hour)
- **Self-service interface**
  - Access through web services
- **Resources are abstracted/virtualized**
  - Virtualization technology
  - Provides for protection between users and for easy resource management



Clouds (2): types

- **By access:**
  - Public/private clouds

- **By level:**
  1. **Infrastructure As A Service** (IAAS):
     - basic computing infrastructure (processors, storage, network, etc)
     - resources are machine images
     - example: Amazon Elastic Compute Cloud (EC2)
  2. **Platform As A Service** (PAAS):
     - programming environment
     - execution environment
     - example: Google App Engine
  3. **Software As A Service** (SAAS):
     - application (service)s
     - example: Google Docs



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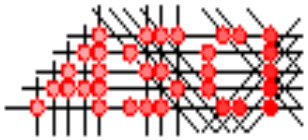
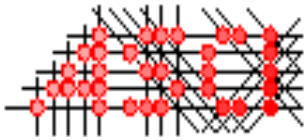
Clouds (3): Amazon EC2 features

- **SLA with 99.95% uptime**
- **Availability zones**
- **Types of "instances"**
  - **On-demand** instances (hourly basis)
  - **Reserved** instances (1—3 years)
  - **Spot** instances (specify maximum hourly price)
- **Elastic load balancing**
  - Distributes incoming application traffic across multiple EC2 instances and availability zones
- **EC2 for HPC:**
  - Cluster Compute instances (up to 128)
  - Guaranteed low-latency 10 Gbps interconnections
  - Single instance type (quad core, 23 GB MM, 1.7 TB storage)
  - Cluster GPU instances with NVIDIA Tesla GPU



Clouds (4): IAAS systems

- **Eucalyptus**
  - Open source
  - EC2 compatible
  - Spin-off at UCSB (Rich Wolski)
- **Open Nebula**
  - Open source
  - Cloudbursting (overflow to cloud from local compute infrastructure/outsource virtual machines to a public cloud)
  - Cloud federation



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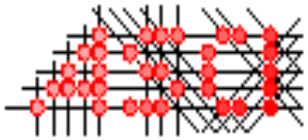

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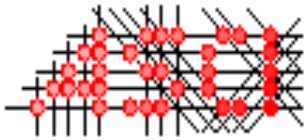
- Globus: www.globus.org
- Condor: www.cs.wisc.edu/condor
- Open Grid Forum: www.ogf.org
- See the CCGrid, Grid, and HPDC conferences for current research



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