(my) Principals of Distributed Computing

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2,000 years ago we had the words of

Koheleth son of David king in Jerusalem

The words of Koheleth son of David, king in Jerusalem ….

Only that shall happen
Which has happened,
Only that occur
Which has occurred;
There is nothing new
Beneath the sun!

Ecclesiastes Chapter 1 verse 9

35 years ago we had

The ALOHA network

One of the early computer networking designs, the ALOHA network was created at the University of Hawaii in **1970** under the leadership of Norman Abramson. Like the ARPANET group, the ALOHA network was built with DARPA funding. Similar to the ARPANET group, the ALOHA network was built to allow people in different locations to access the main computer systems. But while the ARPANET used leased phone lines, the ALOHA network used packet radio.

ALOHA was important because it used a shared medium for transmission. This revealed the need for more modern contention management schemes such as CSMA/CD, used by Ethernet. Unlike the ARPANET where each node could only talk to a node on the other end, in ALOHA everyone was using the same frequency. This meant that some sort of system was needed to control who could talk at what time. ALOHA's situation was similar to issues faced by modern Ethernet (non-switched) and Wi-Fi networks.

This shared transmission medium system generated interest by others. ALOHA's scheme was very simple. Because data was sent via a teletype the data rate usually did not go beyond **80 characters per second**. When two stations tried to talk at the same time, both transmissions were garbled. Then data had to be manually resent. ALOHA did not solve this problem, but it sparked interest in others, most significantly Bob Metcalfe and other researchers working at Xerox PARC. This team went on to create the Ethernet protocol.

30 years ago we had

Distributed Processing Systems

Claims for "benefits" provided by Distributed Processing Systems

P.H. Enslow, *"What is a Distributed Data Processing System?"* Computer, January 1978

- High Availability and Reliability
- High System Performance
- Ease of Modular and Incremental Growth
- Automatic Load and Resource Sharing
- Good Response to Temporary Overloads
- Easy Expansion in Capacity and/or Function

Definitional Criteria for a Distributed Processing System

P.H. Enslow and T. G. Saponas ""*Distributed and Decentralized Control in Fully Distributed Processing Systems*" Technical Report, 1981

- Multiplicity of resources
- Component interconnection
- Unity of control
- System transparency
- Component autonomy

Multiplicity of resources

The system should provide a number of assignable resources for any type of service demand. The greater the degree of replication of resources, the better the ability of the system to maintain high reliability and performance

Component interconnection

A Distributed System should include a communication subnet which interconnects the elements of the system. The transfer of information via the subnet should be controlled by a two-party, cooperative protocol (loose coupling).

Unity of Control

All the component of the system should be unified in their desire to achieve a common goal. This goal will determine the rules according to which each of these elements will be controlled.

System transparency

From the users point of view the set of resources that constitutes the Distributed Processing System acts like a "single virtual machine". When requesting a service the user should not require to be aware of the physical location or the instantaneous load of the various resources

Component autonomy

The components of the system, both the logical and physical, should be autonomous and are thus afforded the ability to refuse a request of service made by another element. However, in order to achieve the system's goals they have to interact in a cooperative manner and thus adhere to a common set of policies. These policies should be carried out by the control schemes of each element.

Challenges

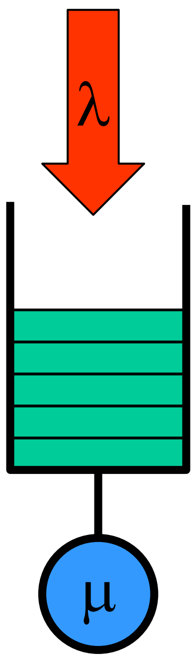
- Name spaces …
- Distributed ownership …
- Heterogeneity …
- Object addressing …
- Data caching …
- Object Identity …
- Trouble shooting …
- Circuit breakers …

23 years ago I wrote my Ph.D. thesis –

"Study of Load Balancing Algorithms for Decentralized Distributed Processing Systems"

http://www.cs.wisc.edu/condor/doc/livny-dissertation.pdf

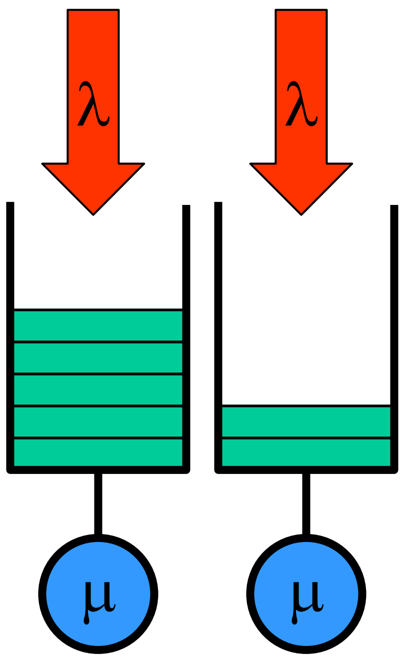
BASICS OF A M/M/1 SYSTEM



Expected # of customers is $1/(1-\rho)$, where ($\rho = \lambda/\mu$) is the utilization

When utilization is 80%, you wait on the average 4 units for every unit of service

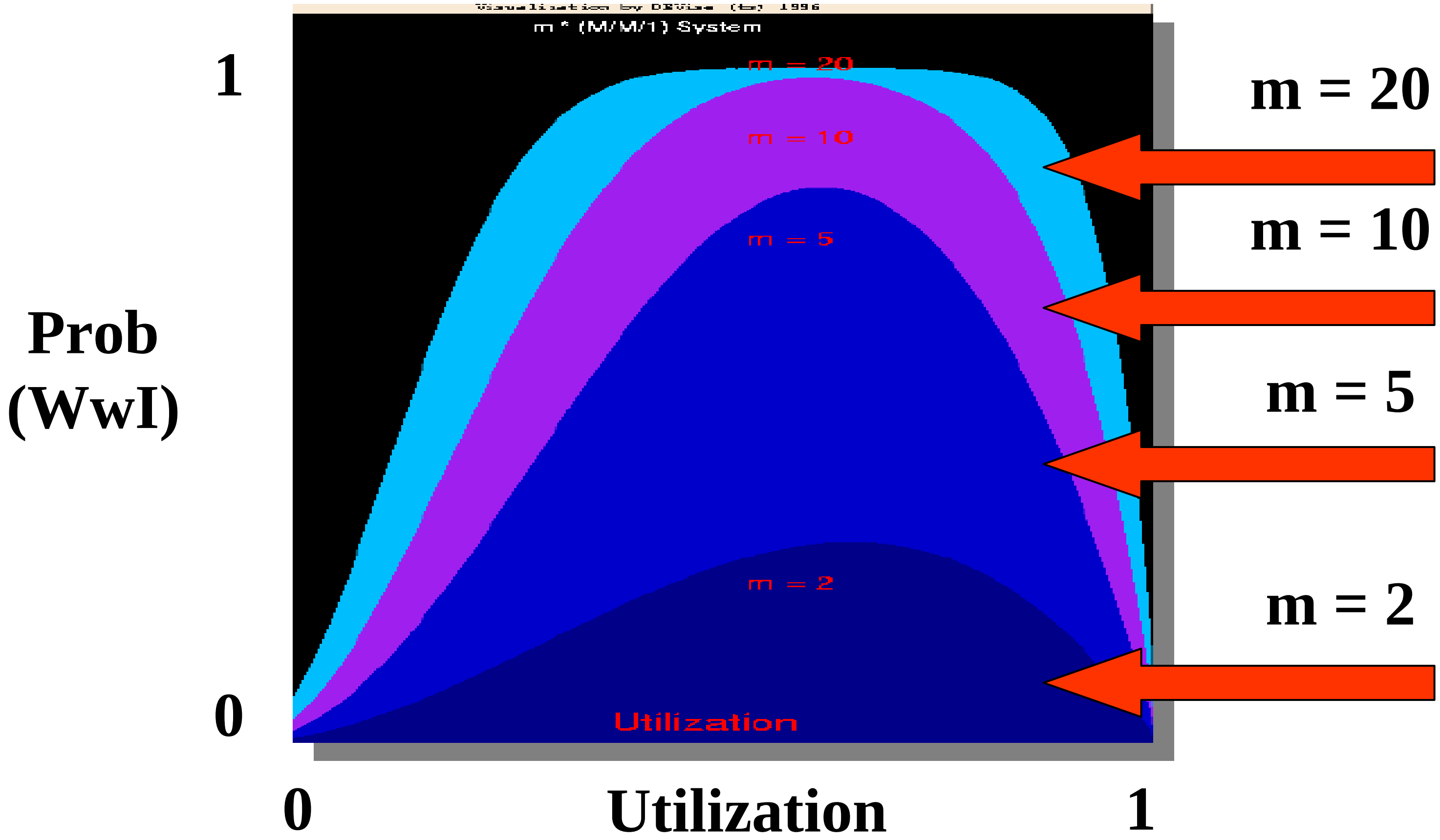
BASICS OF TWO M/M/1 SYSTEMS



When utilization is 80%, you wait on the average 4 units for every unit of service

When utilization is 80%, 25% of the time a customer is waiting for service while a server is idle

Wait while Idle (WwI) in m*M/M/1



" … Since the early days of mankind the primary motivation for the establishment of *communities* has been the idea that by being part of an organized group the capabilities of an individual are improved. The great progress in the area of inter-computer communication led to the development of means by which stand-alone processing sub-systems can be integrated into multi-computer '*communities*'. … "

Miron Livny, " *Study of Load Balancing Algorithms for Decentralized Distributed Processing Systems.*", Ph.D thesis, July 1983.

18 years ago we had

"Condor"

What Did We Learn From Serving a Quarter of a Million Batch Jobs on a Cluster of Privately Owned Workstations

1992

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capacity
accessible
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note

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Global Scientific Computing via a Flock of Condors

CERN 92

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MISSION

Give scientists effective and efficient access to large amounts of cheap (if possible free) CPU cycles and main memory storage

THE CHALLENGE

How to turn existing privetly owned clusters of *workstations*, *farms*, *multiprocessors*, and *supercomputers* into an efficient and effective Global Computing Environment?

In other words, how to minimize wait while idle?

APPROACH

Use wide-area networks to transfer batch jobs between Condor systems

- Boundaries of each Condor system will be determined by physical or administrative considerations

TWO EFFORTS

- ***UW CAMPUS***

  Condor systems at Engineering, Statistics, and Computer Sciences

- ***INTERNATIONAL***

  We have started a collaboration between CERN-SMC-NIKHEF-Univ. of Amsterdam, and University of Wisconsin-Madison

High Throughput Computing

We first introduced the distinction between High Performance Computing (HPC) and High Throughput Computing (HTC) in a seminar at the NASA Goddard Flight Center in July of **1996** and a month later at the European Laboratory for Particle Physics (CERN). In June of 1997 HPCWire published an interview on High Throughput Computing.

Why HTC?

For many experimental scientists, scientific progress and quality of research are strongly linked to computing throughput. In other words, they are less concerned about instantaneous computing power. Instead, what matters to them is the amount of computing they can harness over a month or a year --- they measure computing power in units of scenarios per day, wind patterns per week, instructions sets per month, or crystal configurations per year.

High Throughput Computing
is a
24-7-365
activity

FLOPY ≠ *(60*60*24*7*52)*FLOPS*

Obstacles to HTC

› Ownership Distribution	(Sociology)
› Customer Awareness	(Education)
› Size and Uncertainties	(Robustness)
› Technology Evolution	(Portability)
› Physical Distribution	(Technology)

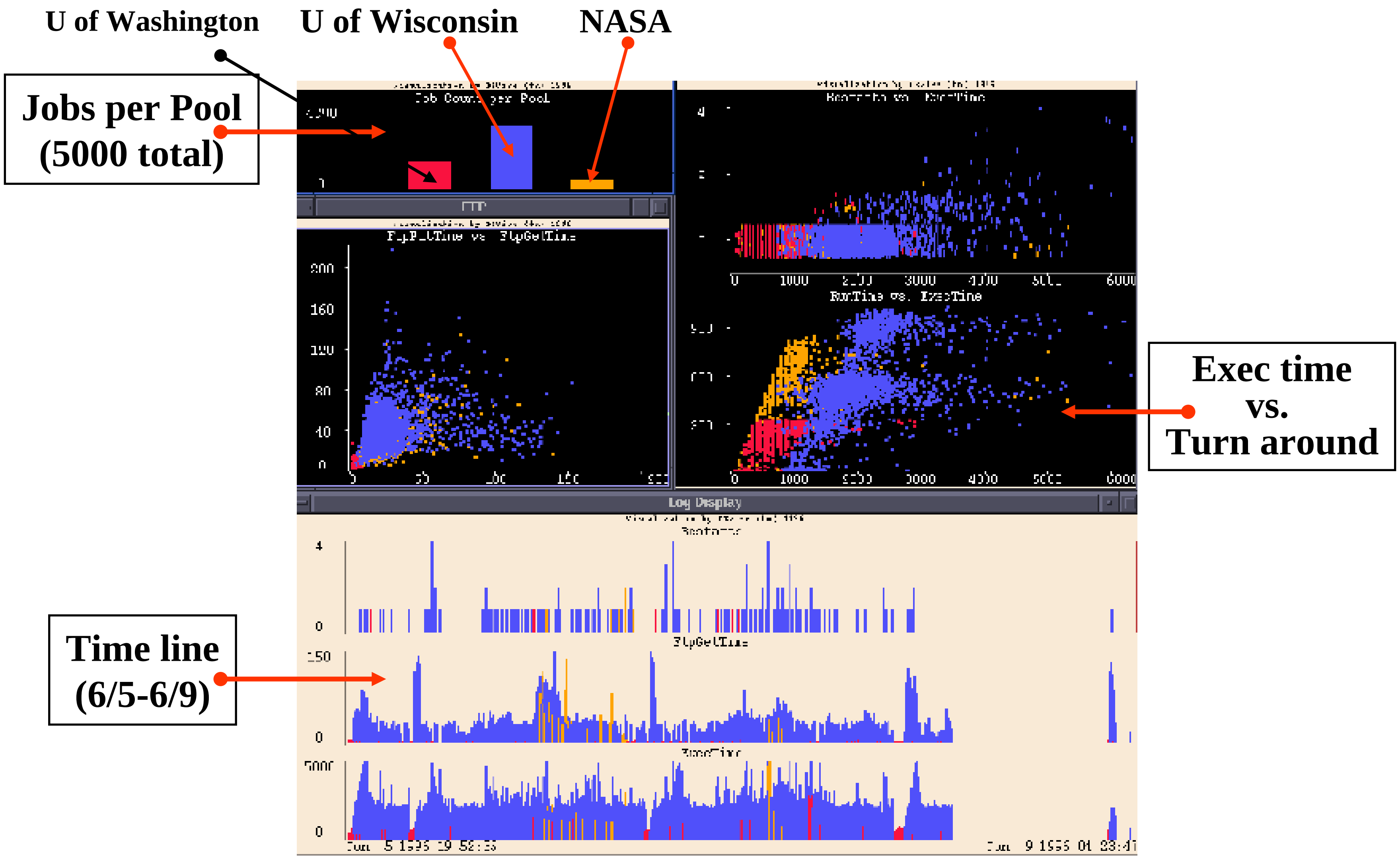
Focus on the problems that are **unique** to HTC not the latest/greatest **technology**

HTC on the Internet

Retrieval of atmospheric temperature and humidity profiles from 18 years of data from the TOVS sensor system.

- 200,000 images
- ~5 minutes per image

Executed on Condor pools at the University of Washington, University of Wisconsin and NASA. Controlled by DBC (Distributed Batch Controller). Execution log visualized by DEVise


U of Washington
U of Wisconsin
NASA
Jobs per Pool (5000 total)
Exec time vs. Turn around
Time line (6/5-6/9)
Log Display

10 years ago we had

"The Grid"

The Grid: Blueprint for a New Computing Infrastructure

Edited by Ian Foster and Carl Kesselman
July 1998, 701 pages.

The grid promises to fundamentally change the way we think about and use computing. This infrastructure will connect multiple regional and national computational grids, creating a universal source of **pervasive and dependable** computing power that supports dramatically new classes of applications. The Grid provides a clear vision of what computational **grids** are, why we need them, who will use them, and how they will be programmed.

" … We claim that these **mechanisms**, although originally developed in the context of a cluster of workstations, are also applicable to computational **grids**. In addition to the required flexibility of services in these grids, a very important concern is that the system be **robust** enough to run in "**production mode**" continuously even in the face of component failures. … "

Miron Livny & Rajesh Raman, *"High Throughput Resource Management"*, **in "*The Grid: Blueprint for a New Computing Infrastructure*".**

In the words of the CIO of Hartford Life

Resource: What do you expect to gain from grid computing? What are your main goals?

Severino: Well number one was scalability. …

Second, we obviously wanted scalability with stability. As we brought more servers and desktops onto the grid we didn't make it any less stable by having a bigger environment.

The third goal was cost savings. One of the most …

Introduction

"The term "the Grid" was coined in the mid 1990s to denote a proposed distributed computing infrastructure for advanced science and engineering [27]. Considerable progress has since been made on the construction of such an infrastructure (e.g., [10, 14, 36, 47]) but the term "Grid" has also been conflated, at least in popular perception, to embrace everything from advanced networking to artificial intelligence. One might wonder if the term has any real substance and meaning. Is there really a distinct "Grid problem" and hence a need for new "Grid technologies"? If so, what is the nature of these technologies and what is their domain of applicability? While numerous groups have interest in Grid concepts and share, to a significant extent, a common vision of Grid architecture, we do not see consensus on the answers to these questions."

"The Anatomy of the Grid - Enabling Scalable Virtual Organizations" Ian Foster, Carl Kesselman and Steven Tuecke 2001.

Global Grid Forum (March 2001)

The Global Grid Forum (***Global GF***) is a community-initiated forum of individual researchers and practitioners working on distributed computing, or "grid" technologies. Global GF focuses on the promotion and development of Grid technologies and applications via the development and documentation of "best practices," implementation guidelines, and standards with an emphasis on rough consensus and running code.

Global GF efforts are also aimed at the development of a broadly based Integrated Grid Architecture that can serve to guide the research, development, and deployment activities of the emerging Grid communities. Defining such an architecture will advance the Grid agenda through the broad deployment and adoption of fundamental basic services and by sharing code among different applications with common requirements.

Wide-area distributed computing, or "grid" technologies, provide the foundation to a number of large scale efforts utilizing the global Internet to build distributed computing and communications infrastructures..

Summary

"We have provided in this article a concise statement of the "Grid problem," which we define as **controlled resource sharing and coordinated resource use in dynamic, scalable virtual organizations.** We have also presented both requirements and a framework for a Grid architecture, identifying the principal functions required to enable sharing within **VOs** and defining key relationships among these different functions."

"The Anatomy of the Grid - Enabling Scalable Virtual Organizations" Ian Foster, Carl Kesselman and Steven Tuecke 2001.

What makes an "O" a "VO"?

What is new beneath the sun?

- Distributed ownership – who defines the "system's common goal"? No more one system.
- Many administrative domains - authentication, authorization and trust.
- Demand is real – many have computing needs that can not be addressed by centralized locally owned systems
- Expectations are high – Regardless of the question, distributed technology is "the" answer.
- Distributed computing is once again "in".

Benefits to Science

- Democratization of Computing – "you do not have to be a SUPER person to do SUPER computing." (accessibility)
- Speculative Science – "Since the resources are there, lets run it and see what we get." (unbounded computing power)
- Function shipping – "Find the image that has a red car in this 3 TB collection." (computational mobility)

The NUG30 Quadratic Assignment Problem (QAP)

$$\min_{p \in \Pi} \sum_{i=1}^{30} \sum_{j=1}^{30} a_{ij} b_{p(i)p(j)}$$

Solved! (4 Scientists + 1 Linux Box)

www.cs.wisc.edu/condor

Condor

NUG30 Personal Grid …

Managed by **one** Linux box at Wisconsin

Flocking:
-- the main Condor pool at Wisconsin (500 processors)
-- the Condor pool at Georgia Tech (284 Linux boxes)
-- the Condor pool at UNM (40 processors)
-- the Condor pool at Columbia (16 processors)
-- the Condor pool at Northwestern (12 processors)
-- the Condor pool at NCSA (65 processors)
-- the Condor pool at INFN Italy (54 processors)

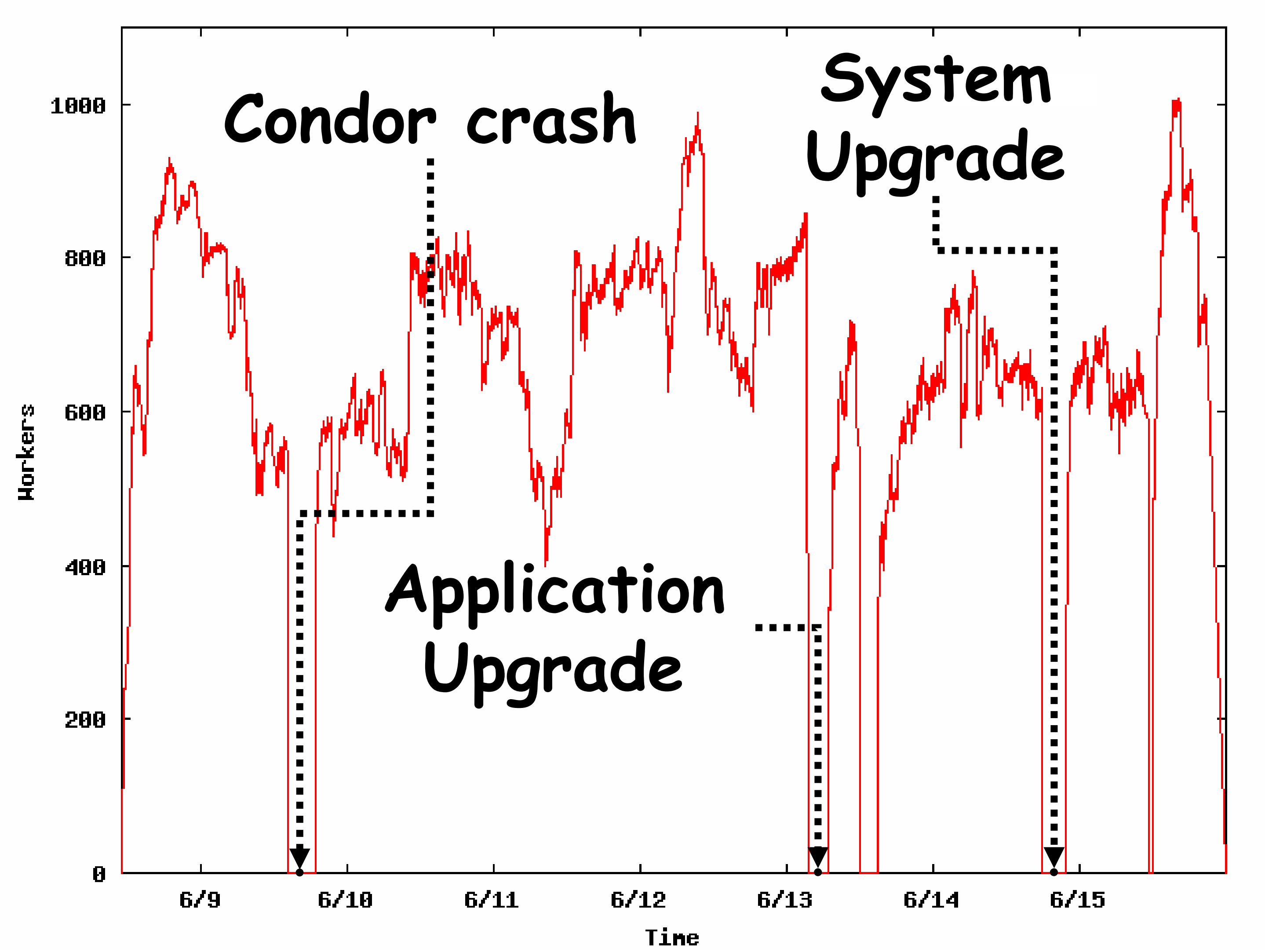
Glide-in:
-- Origin 2000 (through LSF) at NCSA. (512 processors)
-- Origin 2000 (through LSF) at Argonne (96 processors)

Hobble-in:
-- Chiba City Linux cluster (through PBS) at Argonne (414 processors).

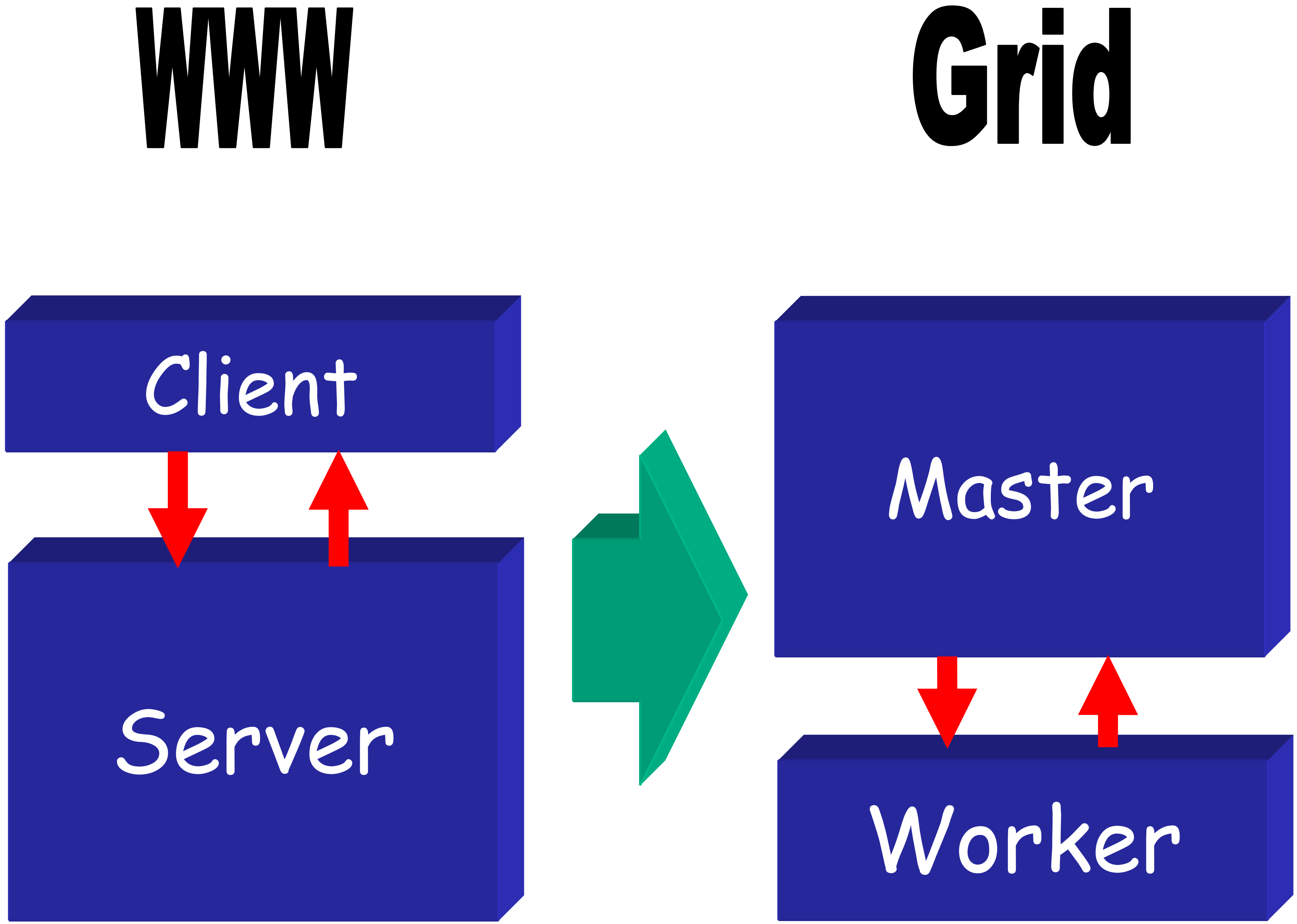
Solution Characteristics.

Scientists	**4**
Workstations	**1**
Wall Clock Time	6:22:04:31
Avg. # CPUs	653
Max. # CPUs	1007
Total CPU Time	Approx. 11 years
Nodes	11,892,208,412
LAPs	574,254,156,532
Parallel Efficiency	92%

The NUG30 Workforce



Workers


WWW
Grid
Client
Server
Master
Worker

" … Grid computing is a partnership between clients and servers. Grid clients have more responsibilities than traditional clients, and must be equipped with powerful mechanisms for dealing with and recovering from failures, whether they occur in the context of remote execution, work management, or data output. When clients are powerful, servers must accommodate them by using careful protocols.… "

Douglas Thain & Miron Livny, *"Building Reliable Clients and Servers"*, *in "The Grid: Blueprint for a New Computing Infrastructure", 2nd edition*

Being a Master

Customer "delegates" task(s) to the master who is responsible for:

- Obtaining **allocation** of resources
- Deploying and managing workers on allocated resources
- **Delegating** work unites to deployed workers
- Receiving and processing results
- Delivering results to customer

Master must be …

- Persistent – work and results must be safely recorded on non-volatile media
- Resourceful – delegates "DAGs" of work to other masters
- Speculative – takes chances and knows how to recover from failure
- Self aware – knows its own capabilities and limitations
- Obedience – manages work according to plan
- Reliable – can mange "large" numbers of work items and resource providers
- Portable – can be deployed "on the fly" to act as a "sub master"

Master should not do …

- Predictions …
- Optimal scheduling …
- Data mining …
- Bidding …
- Forecasting …

The Ethernet Protocol

IEEE 802.3 CSMA/CD - A truly distributed (and very effective) access control protocol to a shared service.

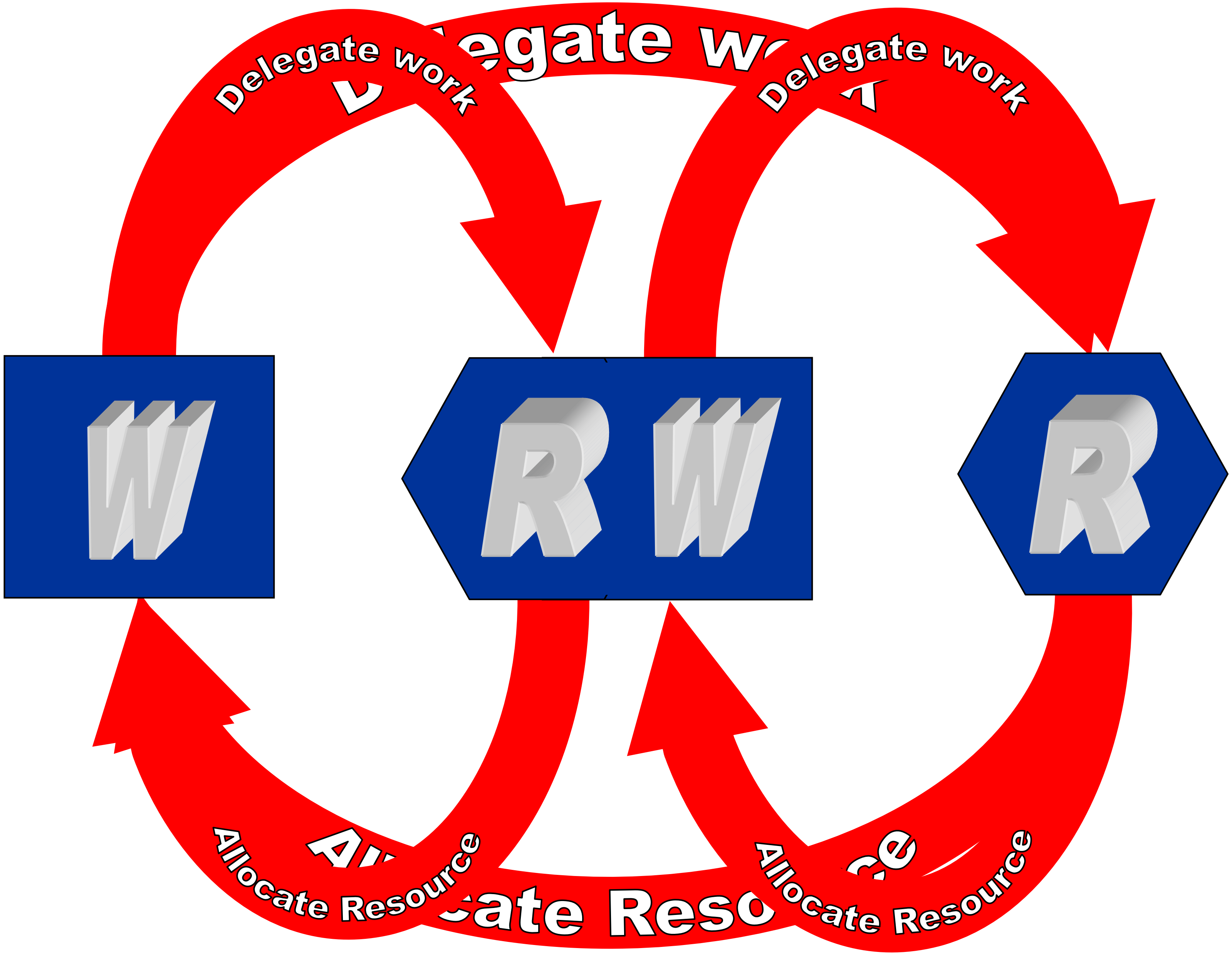
- Client responsible for access control
- Client responsible for error detection
- Client responsible for fairness

Never assume that *what you know* is still true and that *what you ordered* did actually happen.

Resource Allocation
(resource -> job)

vs.

Work Delegation
(job -> resource)


Delegate work
Delegate work
W
R
W
R
Allocate Resource
Allocate Resource

Resource Allocation

A limited assignment of the "ownership" of a resource

- Owner is charged for allocation regardless of actual consumption
- Owner can allocate resource to others
- Owner has the right and means to revoke an allocation
- Allocation is governed by an "agreement" between the client and the owner
- Allocation is a "lease"
- Tree of allocations

"We present some principles that we believe should apply in any compute resource management system. The first, P1, speaks to the need to avoid "resource leaks" of all kinds, as might result, for example, from a monitoring system that consumes a nontrivial number of resources.

P1 - It must be possible to monitor and control *all* resources consumed by a CE—whether for "computation" or "management."

Our second principle is a corollary of P1:

P2 - A system should incorporate circuit breakers to protect both the compute resource and clients. For example, negotiating with a CE consumes resources. How do we prevent an eager client from turning into a denial of service attack? "

Ian Foster & Miron Livny, *"Virtualization and Management of Compute Resources: Principles and Architecture ", A working document (February 2005)*

Garbage collection
is the
cornerstone
of
resource allocation

Work Delegation

A limited assignment of the responsibility to perform the work

- Delegation involved a definition of these "responsibilities"
- Responsibilities my be further delegated
- Delegation consumes resources
- Delegation is a "lease"
- Tree of delegations

Every Community can benefit from the services of

Matchmakers!

eBay is a matchmaker

Why? Because ...

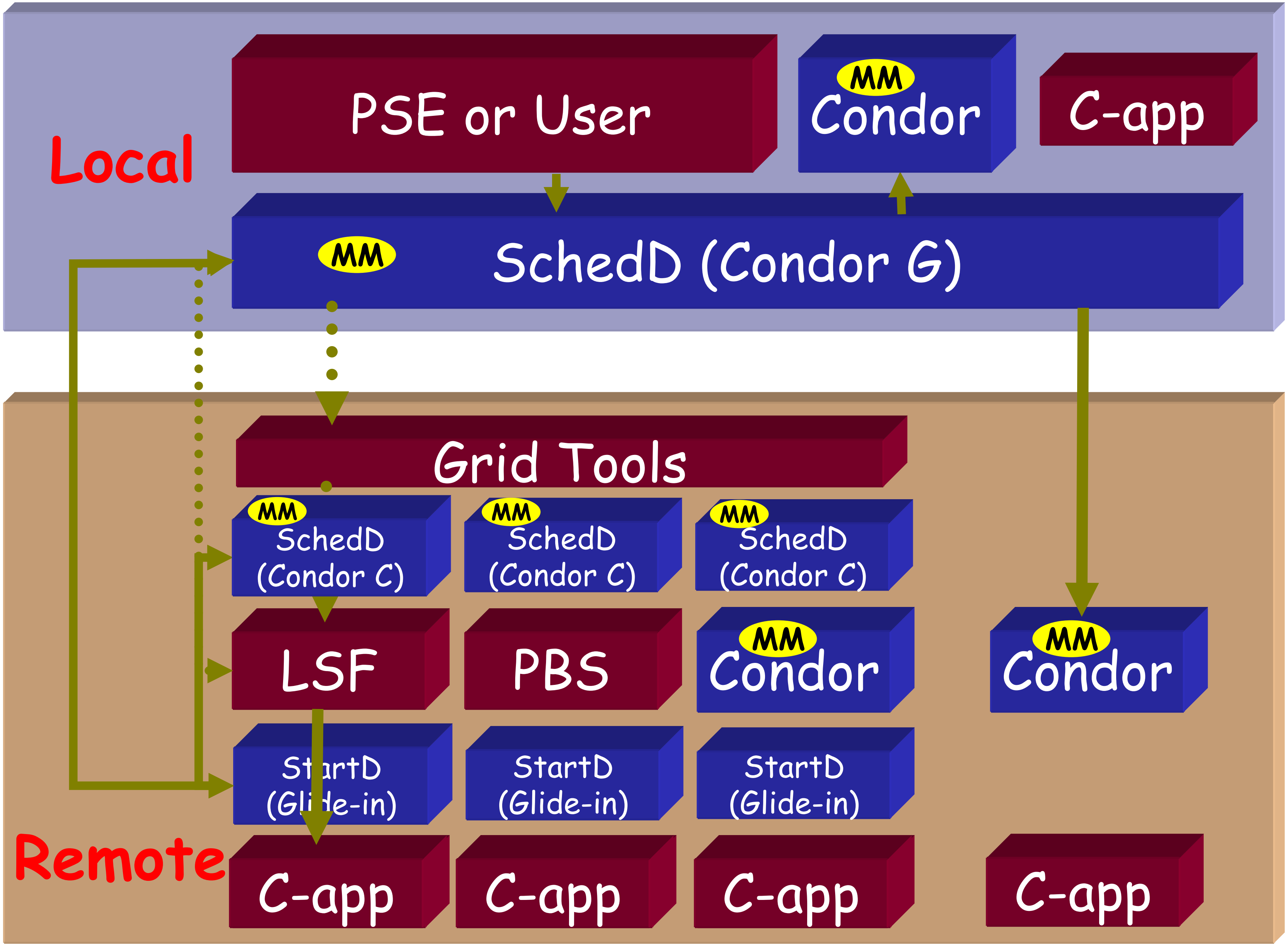
.. someone has to bring together community members who have requests for goods and services with members who offer them.

- Both sides are looking for each other
- Both sides have constraints
- Both sides have preferences

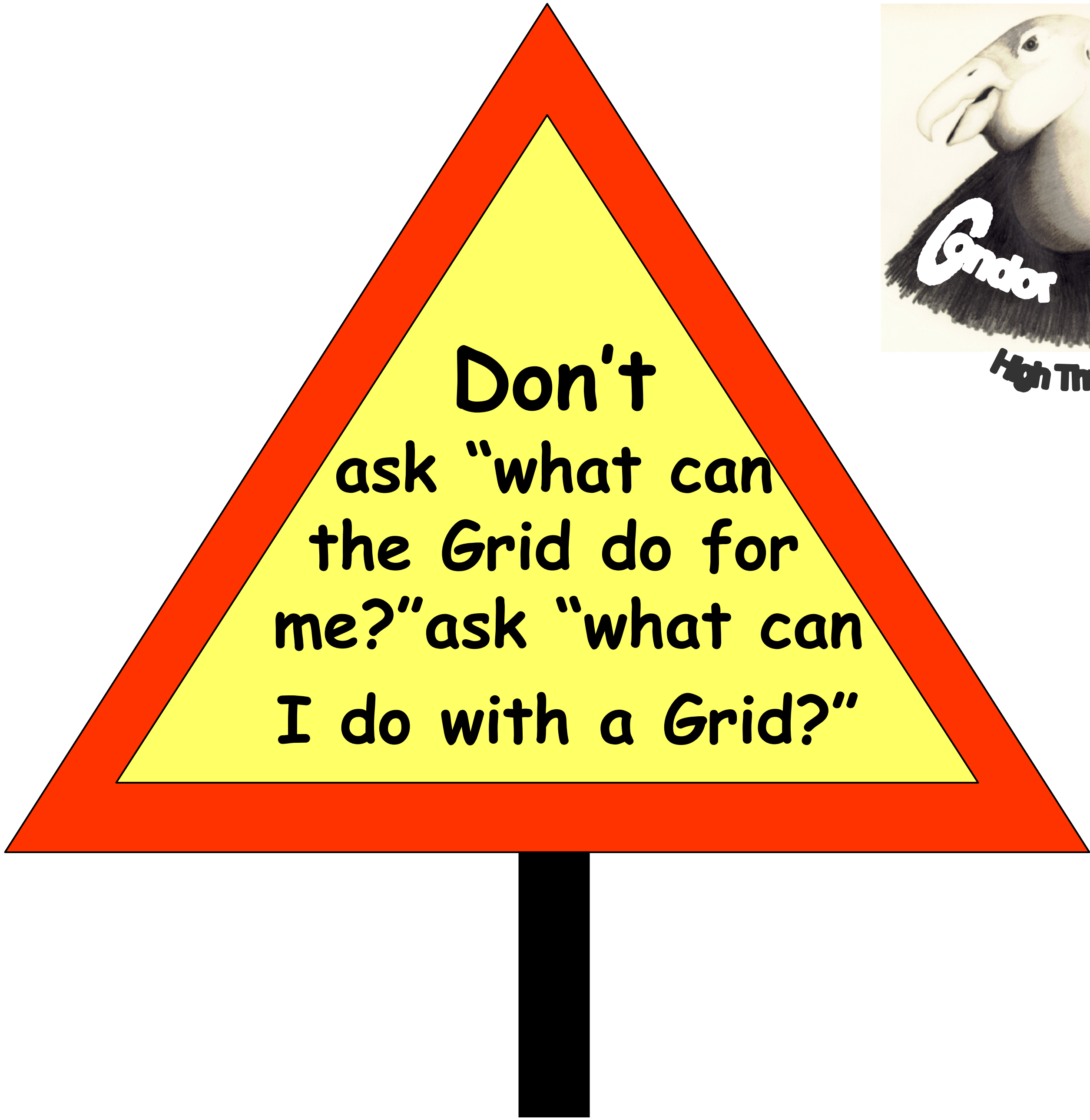
Being a Matchmaker

- Symmetric treatment of all parties
- Schema "neutral"
- Matching policies defined by parties
- "Just in time" decisions
- Acts as an "advisor" not "enforcer"
- Can be used for "resource allocation" and "job delegation"

Bringing it all Together



Local
PSE or User
MM
Condor
C-app
MM
SchedD (Condor G)
Grid Tools
MM
SchedD
(Condor C)
MM
SchedD
(Condor C)
MM
SchedD
(Condor C)
LSF
PBS
MM
Condor
MM
Condor
StartD
(Glide-in)
StartD
(Glide-in)
StartD
(Glide-in)
Remote
C-app
C-app
C-app
C-app


Don't
ask "what can
the Grid do for
me?"ask "what can
I do with a Grid?"

Customer requests:

Place $y = F(x)$ at L!

Master delivers.

Data Placement

Management of storage space and bulk data transfers play a key role in the end-to-end performance of an application.

- Data Placement (DaP) operations must be treated as "first class" jobs and explicitly expressed in the job flow
- Fabric must provide services to manage storage space
- Data Placement schedulers are needed.
- Data Placement and computing must be coordinated
- Smooth transition of CPU-I/O interleaving across software layers
- Error handling and garbage collection

A simple DAG for $y=F(x) \rightarrow L$

1. Allocate (size(x)+size(y)+size(F)) at SE(i)
2. Move x from SE(j) to SE(i)
3. Place F on CE(k)
4. Compute F(x) at CE(k)
5. Move y to L
6. Release allocated space

Storage Element (SE); Compute Element (CE)