High Throughput Computing

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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 …

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

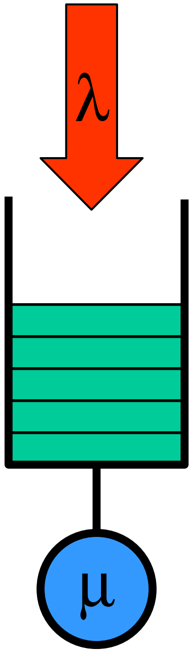
- Name spaces …
- Distributed ownership …
- Heterogeneity …
- Object addressing …
- Data caching …
- Object Identity …
- Trouble shooting …
- Circuit breakers …

24 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

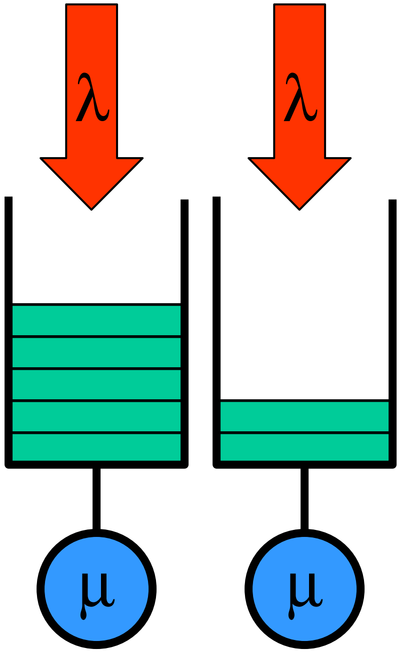
BASICS OF A M/M/1 SYSTEM



Expected # of customers is 1/(1-ρ), where (ρ = λ/μ) is the utilization

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

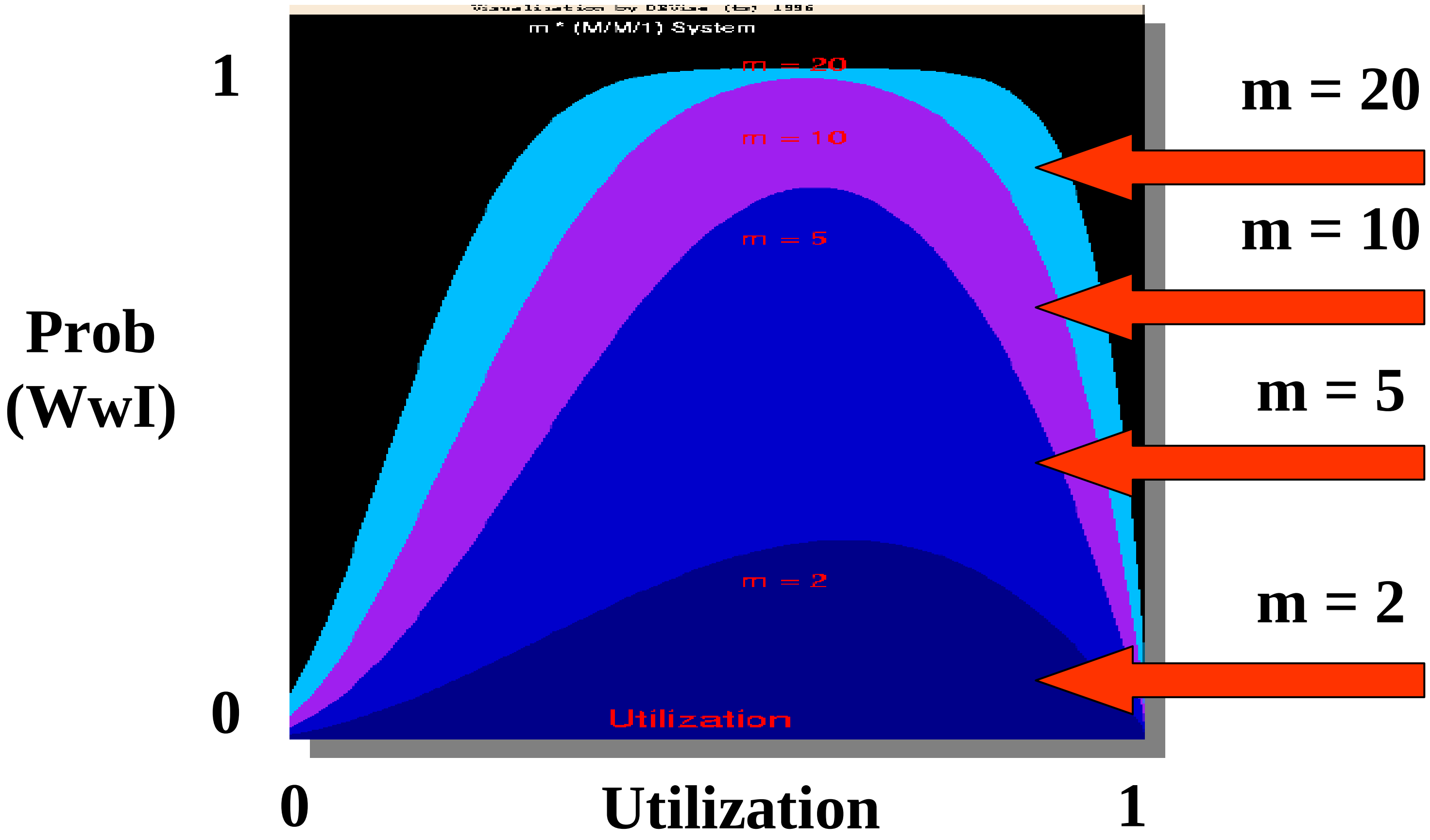
BASICS OF TWO M/M/1 SYSTEMS



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

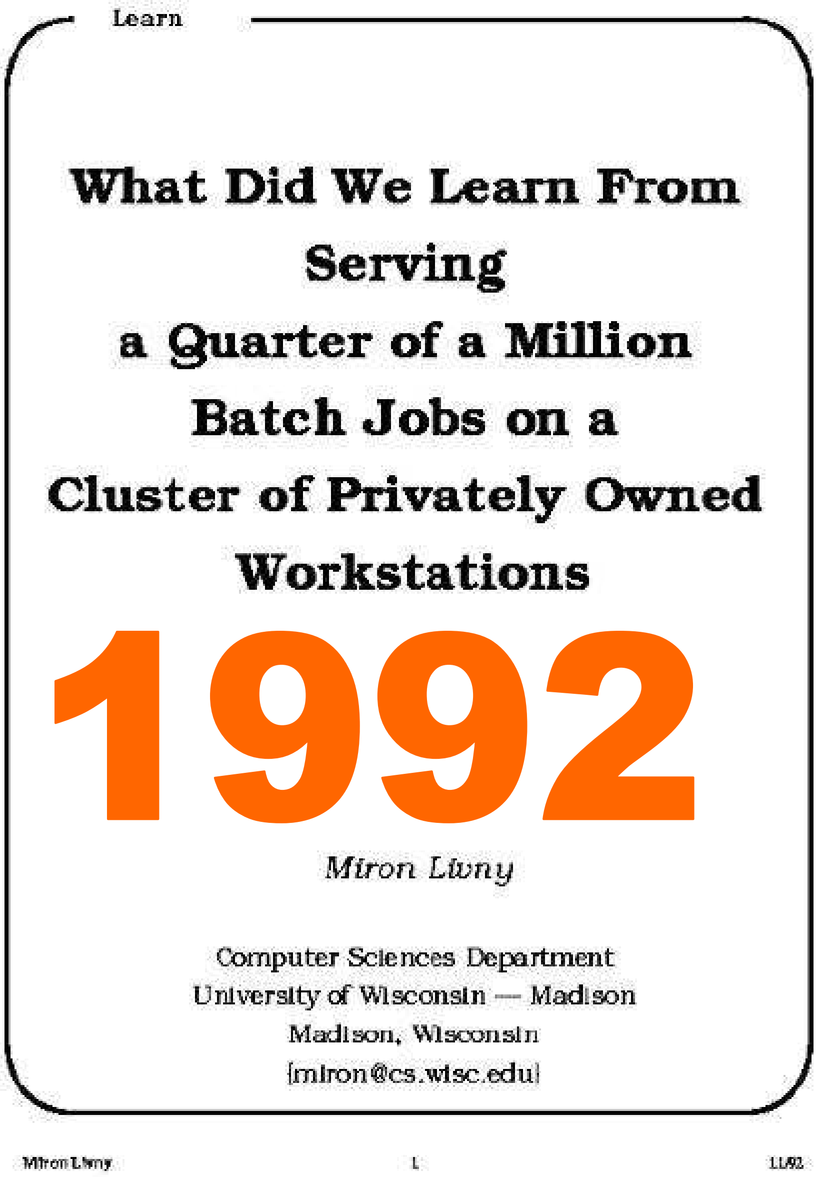


" … Since the early days of mankind the primary motivation for the establishment of *communities* has been the idea that by being part of an organized group the capabilities of an individual are improved. The great progress in the area of inter-computer communication led to the development of means by 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.

20 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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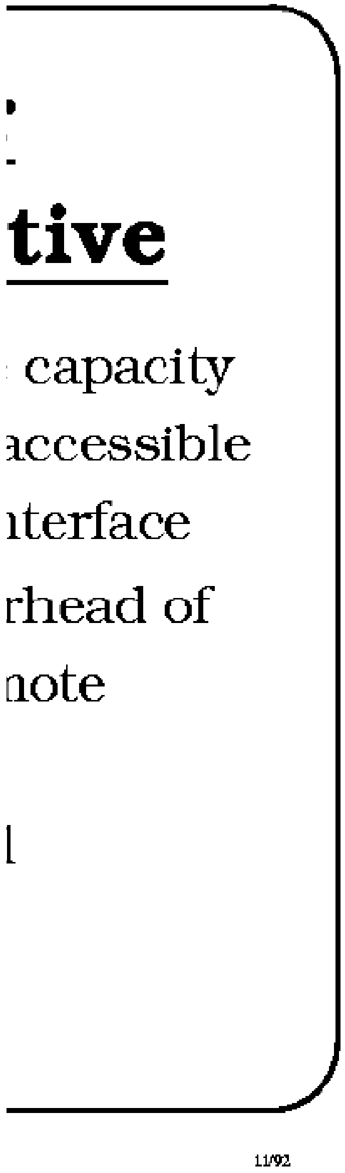

tive

capacity

accessible

iterface

rhead of

note

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

We are still very busy

1986-2006

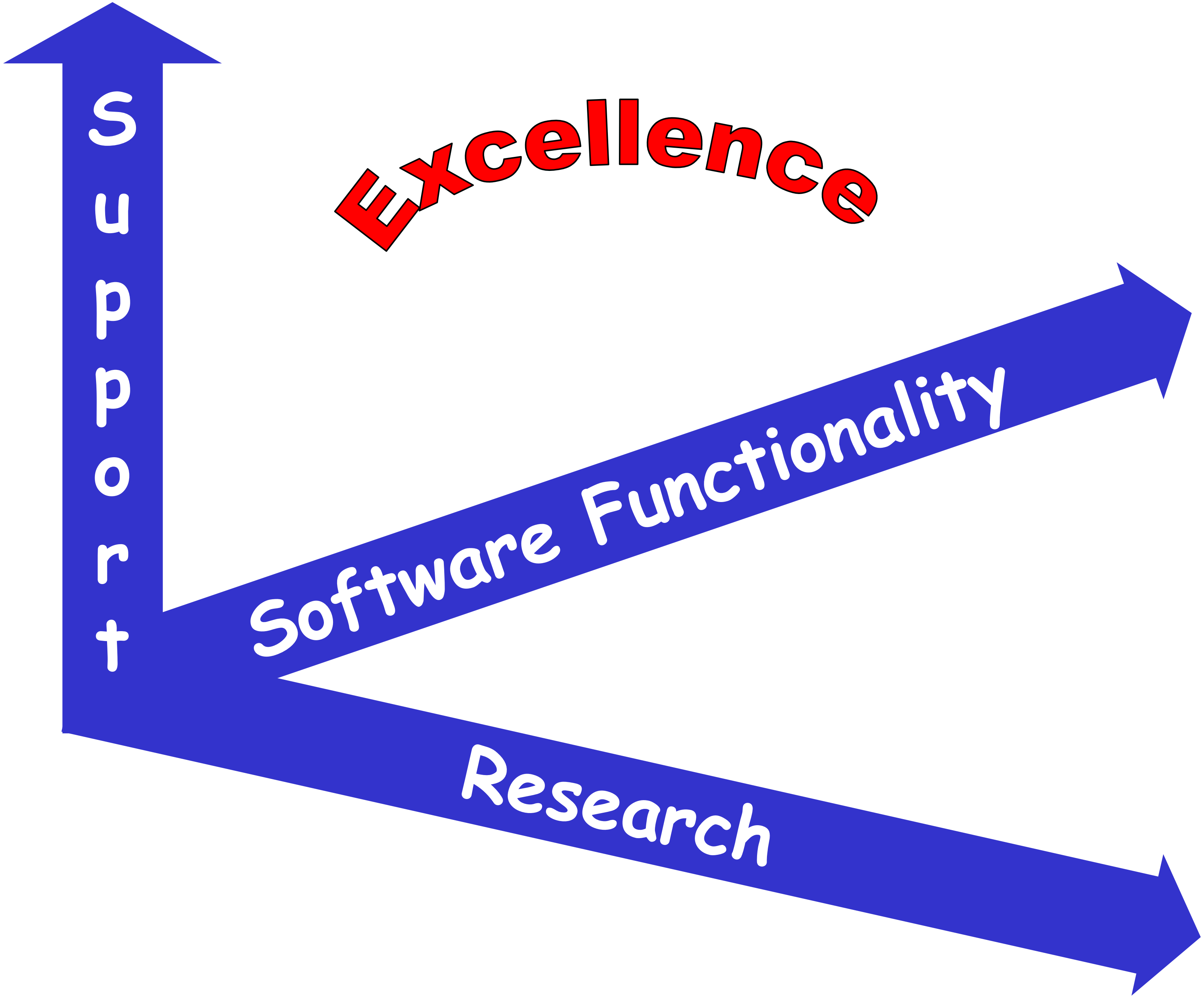
Celebrating
20 years since we
first installed Condor
in our department

The Condor Project (Established '85)

Distributed Computing **research** performed by a team of **~40** faculty, full time staff and students who

- face **software/middleware engineering** challenges in a UNIX/Linux/Windows/OS X environment,
- involved in national and international **collaborations**,
- interact with **users** in academia and industry,
- maintain and support a distributed **production** environment (more than 3800 CPUs at UW),
- and educate and train **students**.

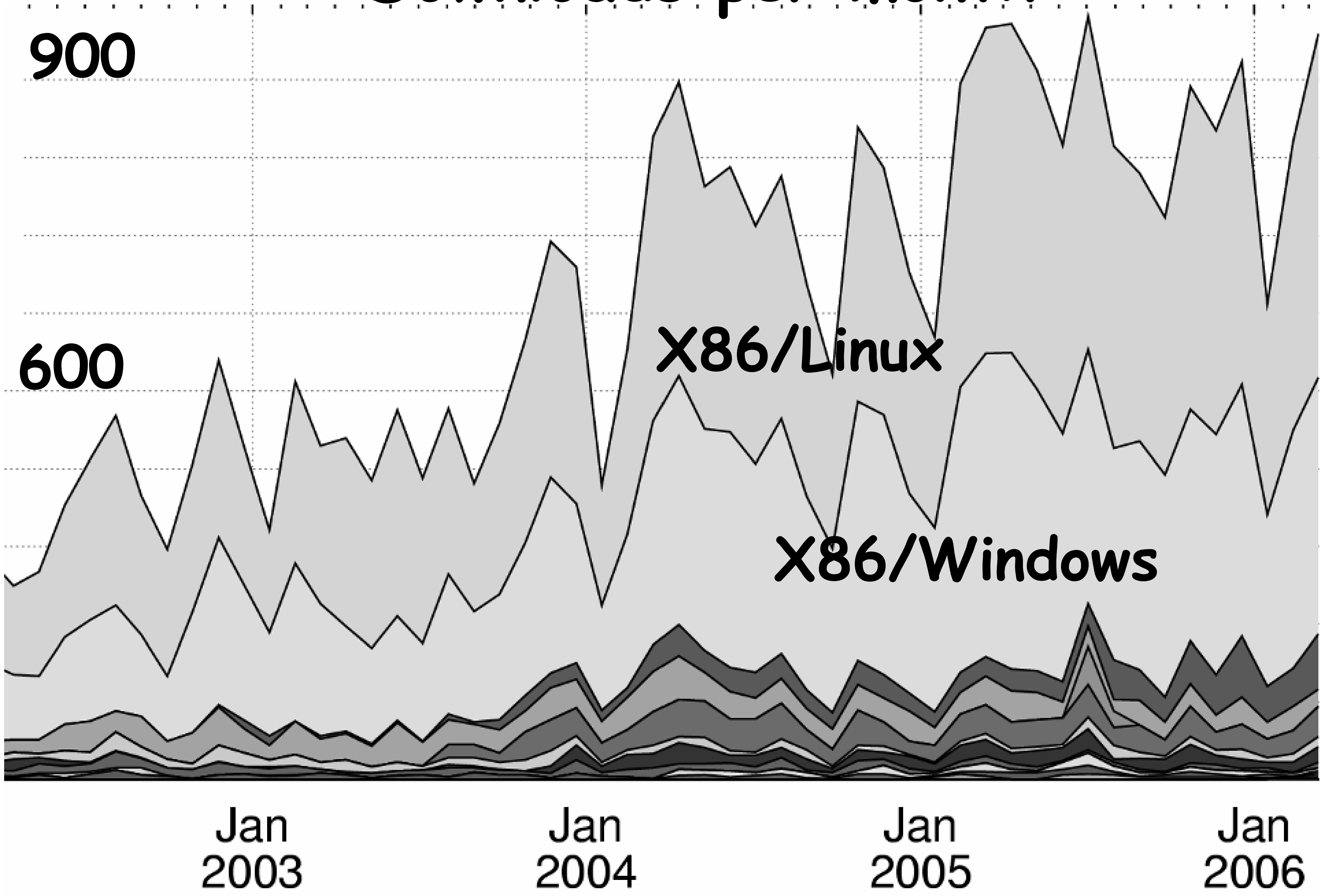
Funding – **DOE, NIH, NSF, INTEL, Micron, Microsoft and the UW Graduate School**


Excellence
Support
Software Functionality
Research

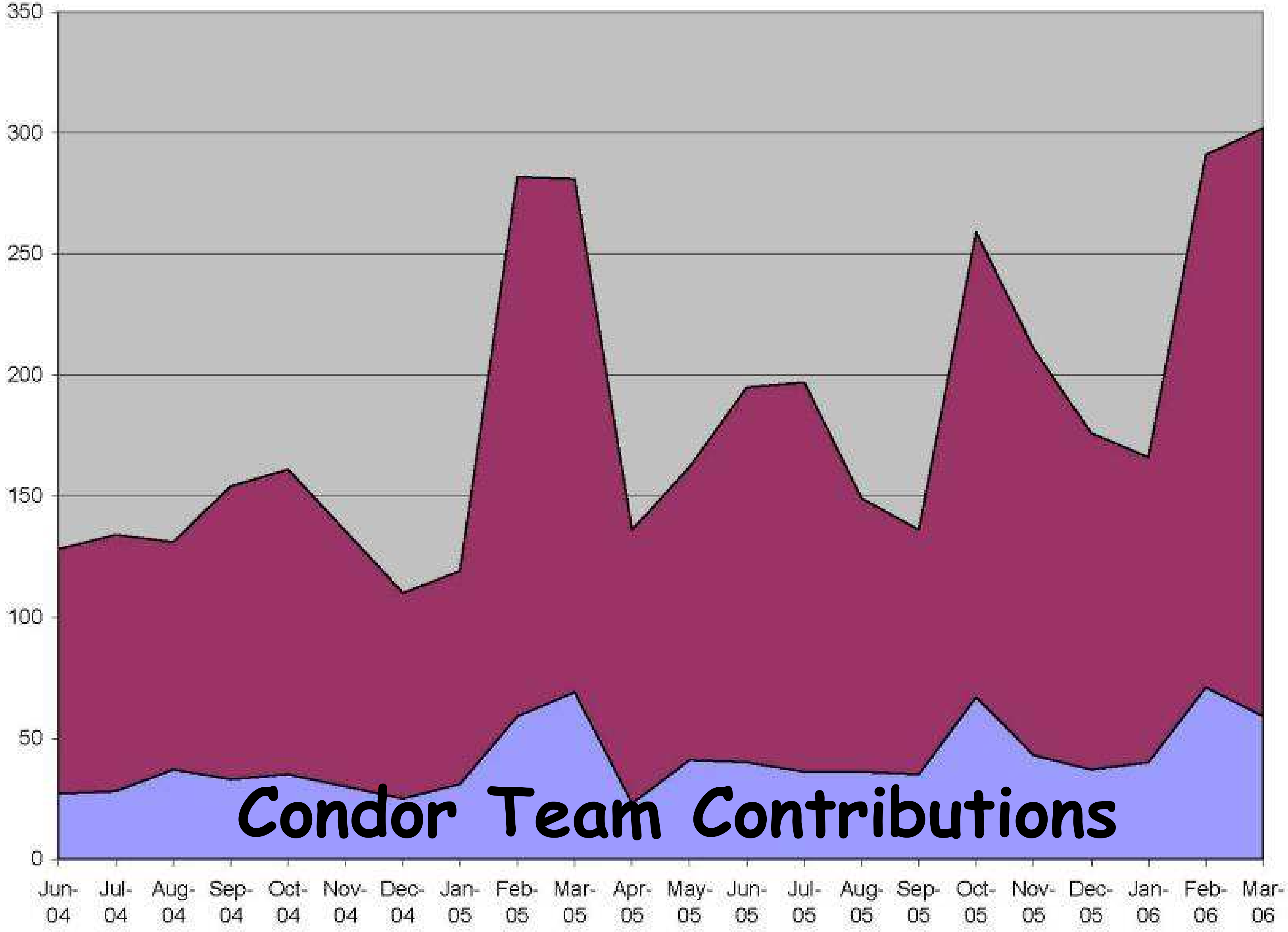
Main Threads of Activities

- Distributed Computing Research – develop and evaluate new concepts, frameworks and technologies
- The Open Science Grid (OSG) – build and operate a national distributed computing and storage infrastructure
- Keep Condor "flight worthy" and support our users
- The NSF Middleware Initiative (NMI) – develop, build and operate a national Build and Test facility
- The Grid Laboratory Of Wisconsin (GLOW) – build, maintain and operate a distributed computing and storage infrastructure on the UW campus

Downloads per month



Condor-Users –Messages per month



The past year:

- Two Ph.D students graduated:
  - Tevfik Kosar went to LSU
  - Sonny (Sechang) Son went to NetApp
- Three staff members left to start graduate studies
- Released Condor 6.6.9-.11
- Released Condor 6.7.6-.18
- Contributed to the formation of the Open Science Grid (OSG) consortium and the OSG Facility
- Interfaced Condor with BOINC
- Started the NSF funded CondorDB project
- Released Virtual Data Toolkit (VDT) 1.3.3-.10
- Distributed five instances of the NSF Middleware Initiative (NMI) Build and Test facility

ABOUT THE FILM
CHARACTERS
PHOTOS
Walt Disney THE WILD NOW IN THEATERS
VIDEO
GAMES
DOWNLOADS
01 02 03 04 05 06 07 08 09 10 11 12 13 14 15 16 17 18 19 20 21 22 23
WILD VISION
CLICK HERE TO GET THE WILD TOKENS
BACK

The search for SUSY

- Sanjay Padhi is a UW Chancellor Fellow who is working at the group of Prof. Sau Lan Wu at CERN
- Using Condor Technologies he established a "grid access point" in his office at CERN
- Through this access-point he managed to harness in 3 month (12/05-2/06) more that 500 CPU years from the LHC Computing Grid (LCG) the Open Science Grid (OSG) and UW Condor resources

GAMS

Optimization

www.gams.com

Support

Sales

Solvers

Documentation

Model Library

gamsworld.org

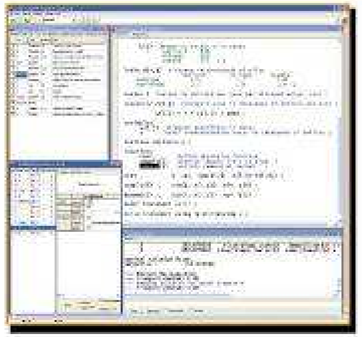
High-Level Modeling

The General Algebraic Modeling System (GAMS) is a **high-level modeling system** for mathematical programming problems. GAMS is tailored for complex, large-scale modeling applications, and allows you to build large maintainable models that can be adapted quickly to new situations. Models are **fully portable** from one computer platform to another.

Wide Range of Model Types

GAMS allows the formulation of models in **many different problem classes**, including

- Linear (LP) and Mixed Integer Linear (MIP)
- Quadratic Programming (QCP) and Mixed Integer QCP (MIQCP)
- Nonlinear (NLP) and Mixed Integer NLP (MINLP)
- Constrained Nonlinear Systems (CNS)
- Mixed Complementary (MCP)
- Programs with Equilibrium Constraints (MPEC)
- Conic Programming Problems
- Stochastic Linear Problems



GAMS Integrated Developer Environment for editing, debugging and solving models and viewing data.

State-of-the-Art Solvers

GAMS incorporates all major commercial and academic **state-of-the-art solution technologies** for a broad range of problem types, including global nonlinear optimization solvers.

Contact:

GAMS Development Corporation

1217 Potomac Street, N.W.
Washington, D.C. 20007, USA
Tel: +1-202-342-0180
Fax: +1-202-342-0181
sales@gams.com
http://www.gams.com

in Europe:

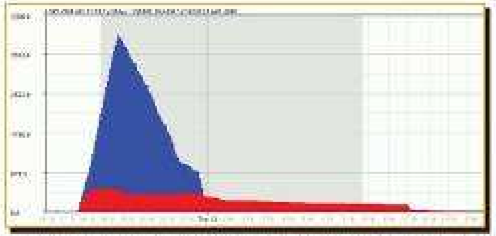
GAMS Software GmbH

Eupener Str. 135-137
50933 Cologne, Germany
Tel.: +49-221-949-9170
Fax: +49-221-949-9171
info@gams.de
http://www.gams.de

Cyberinfrastructure: GAMS, Condor and the Grid

Researchers at the University of Wisconsin in Madison, partially supported by NSF Cyberinfrastructure-OR funding, have used the GAMS Grid Computing language extensions in conjunction with the Condor Resource Manager to process long running mixed integer programming models.

In the case depicted in the figure, over 4000 MIP subproblems were solved on a collection of over 1000 workstations managed by the Condor system.



UW-Madison Condor Pool User Statistics showing running jobs (red) and idle jobs (blue).

Condor
High Throughput Computing

At times over 500 workstations were running multiple instances of the CPLEX and XPRESS solvers delivering more than 5000 CPU hours in a little over 20 hours wall clock time. Communication of cutoff values and incumbent solutions between models running asynchronously over the grid was handled automatically using recently added solver features.

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

$$FLOPY \neq (60*60*24*7*52)*FLOPS$$

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

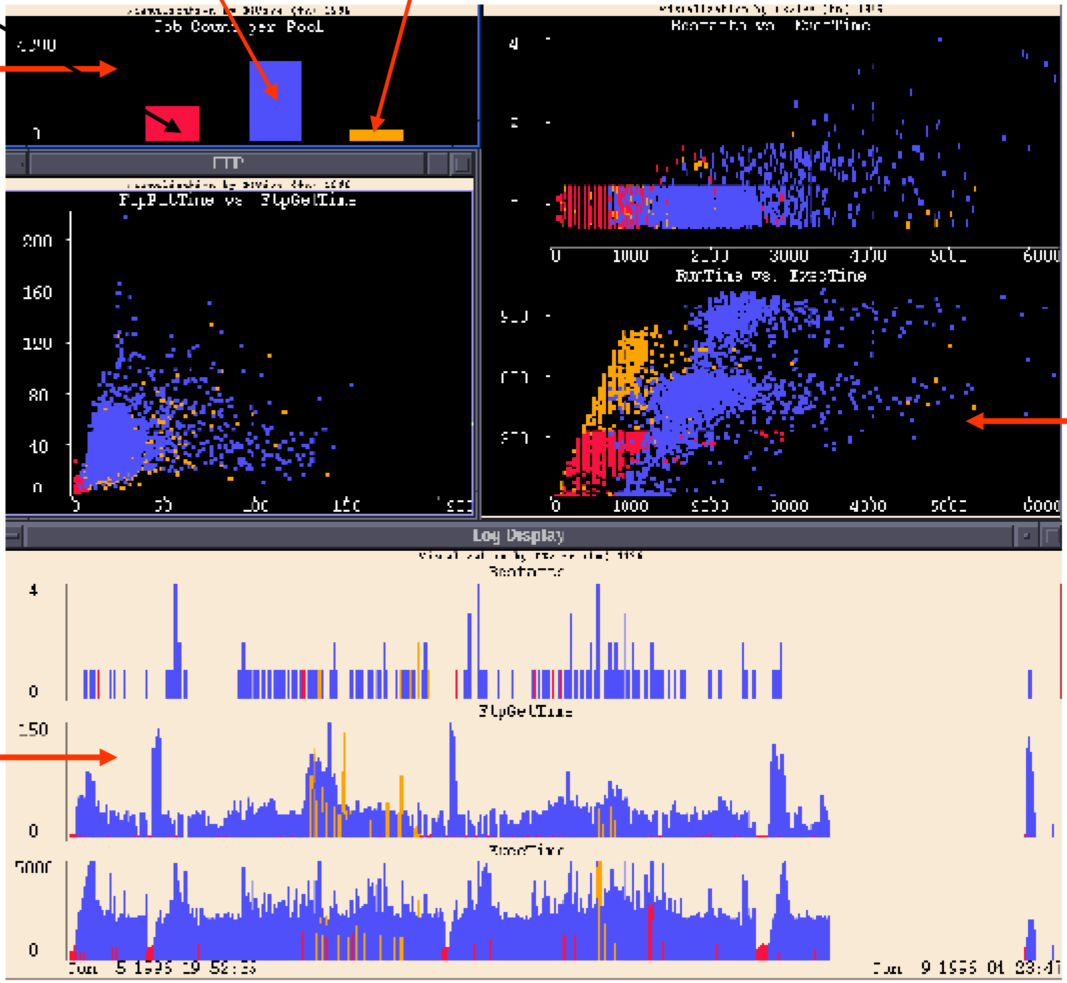
Executed on Condor pools at the University of Washington, University of Wisconsin and NASA. Controlled by DBC (Distributed Batch Controller). Execution log visualized by DEVise

U of Washington

U of Wisconsin

NASA

Jobs per Pool
(5000 total)



Exec time
vs.
Turn around

Time line
(6/5-6/9)

10 years ago we had

"The Grid"

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)

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)

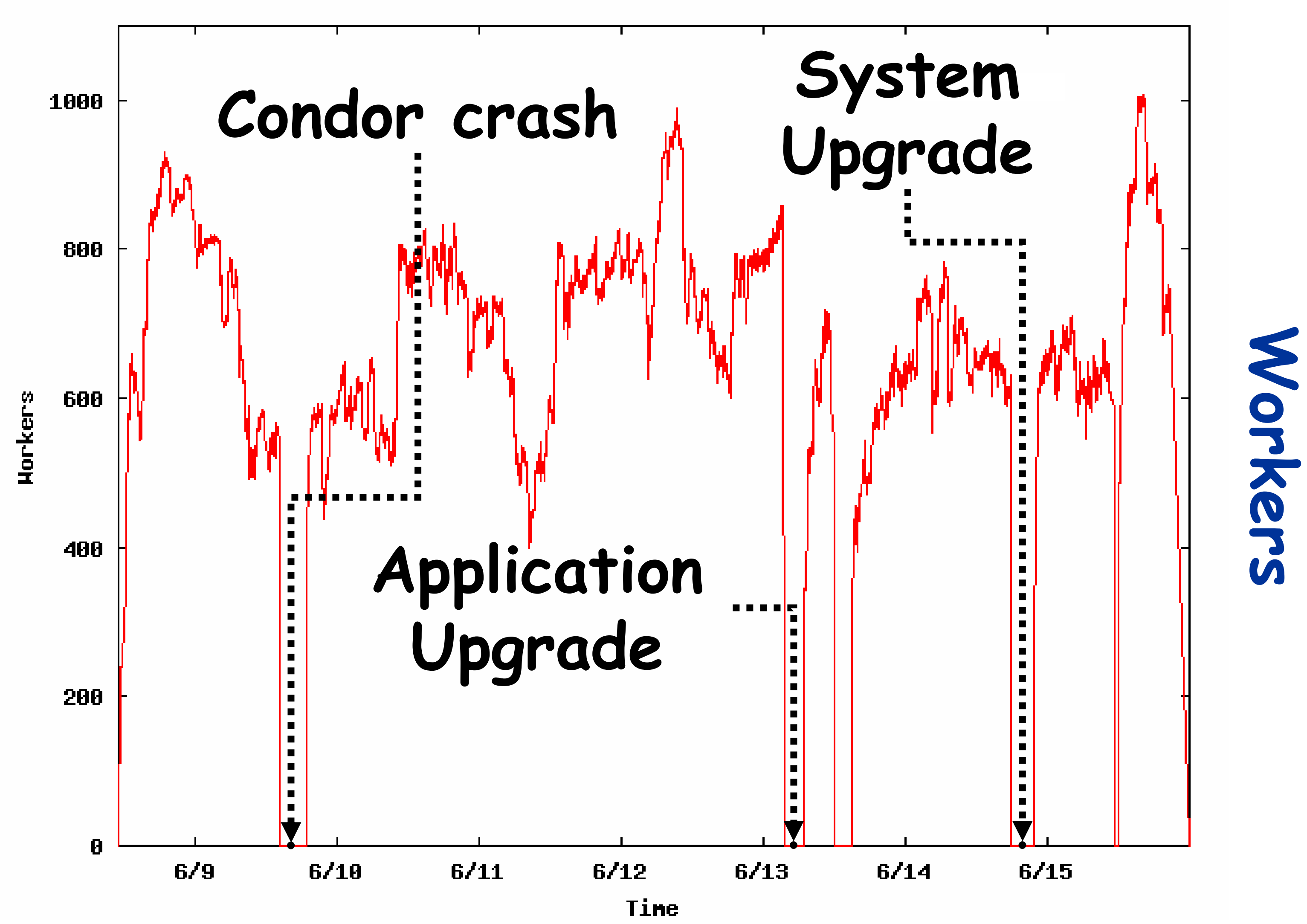
-- Origin 2000 (through LSF) at Argonne (96 processors)

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

Solution Characteristics.

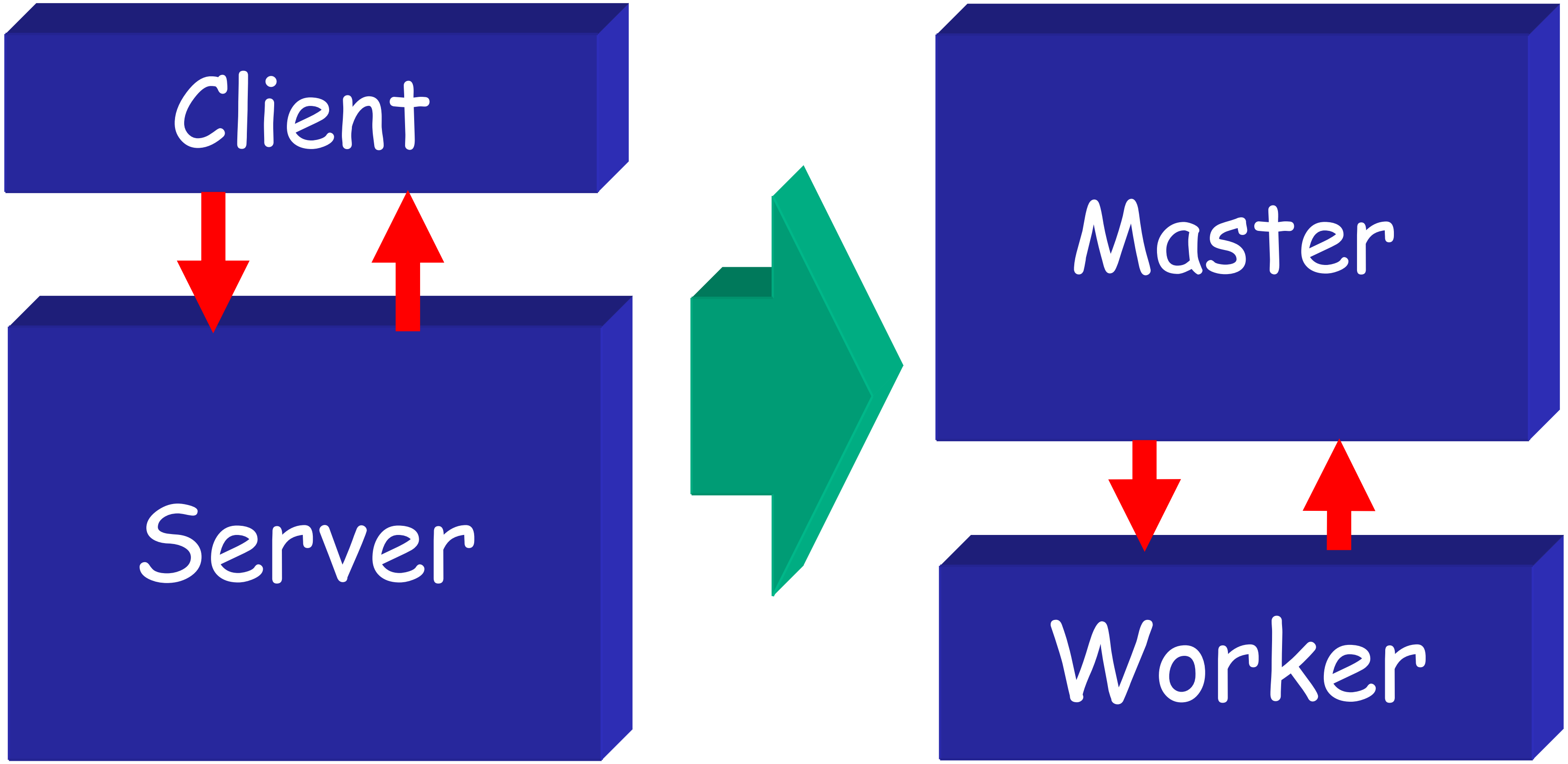
Scientists	**4**
Workstations	**1**
Wall Clock Time	6:22:04:31
Avg. # CPUs	653
Max. # CPUs	1007
Total CPU Time	Approx. 11 years
Nodes	11,892,208,412
LAPs	574,254,156,532
Parallel Efficiency	92%

The NUG30 Workforce



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.

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

desktop

From

Condor

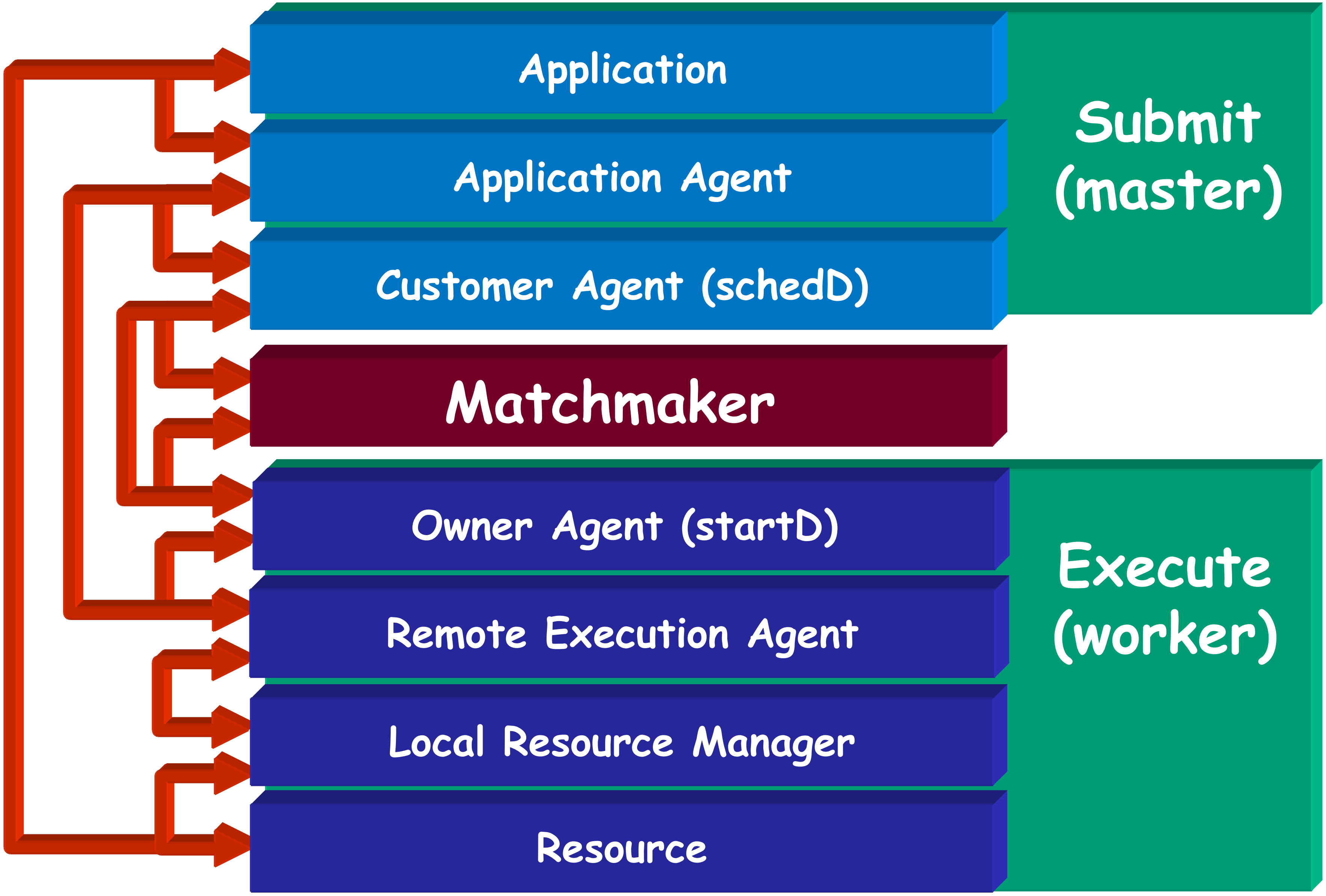
to

Condor-G

to

Condor-C

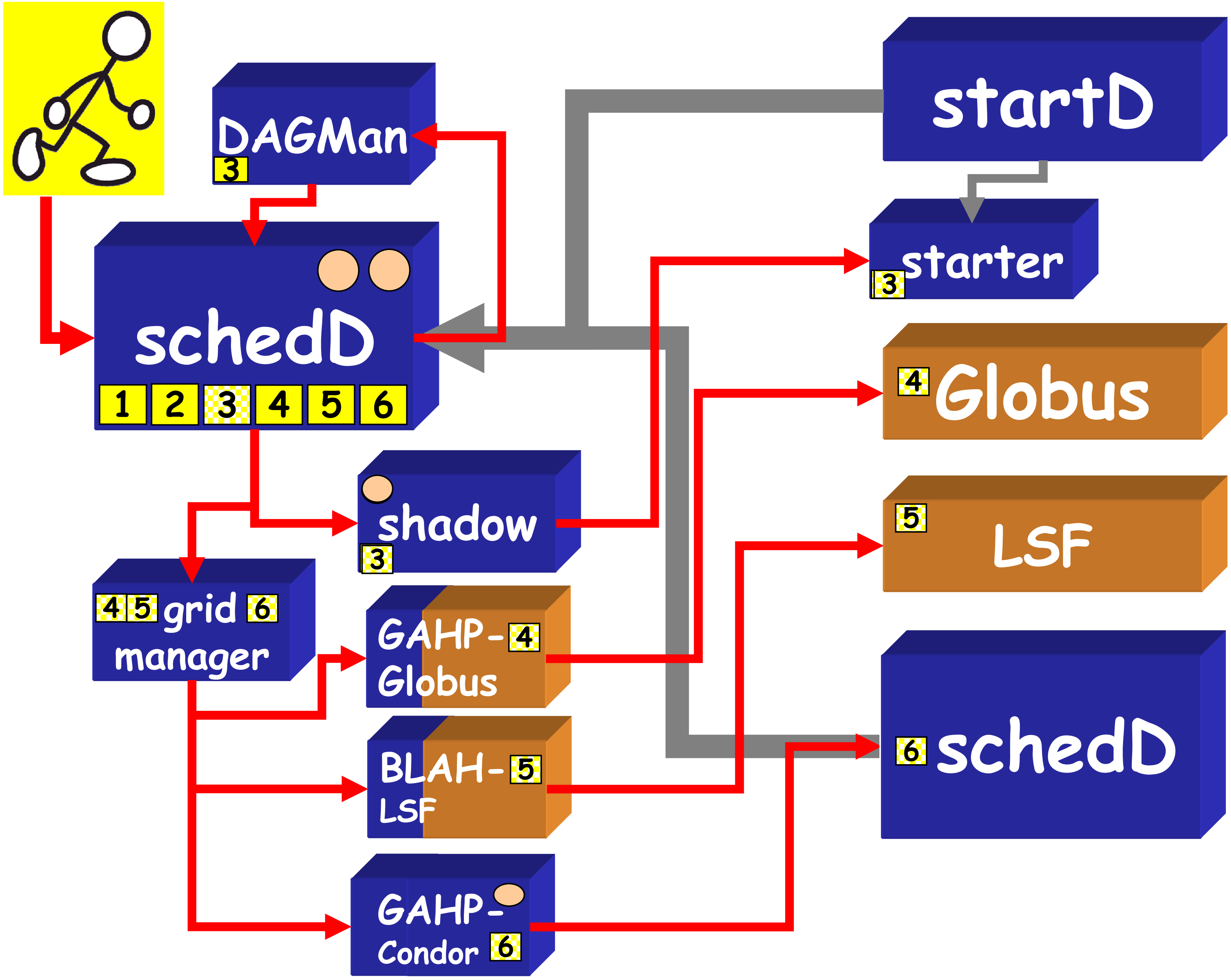
The Layers of Condor



Be matched, claim (+maintain), and then delegate

Job Submission Options

- leave_in_queue = <ClassAd Boolean Expression>
- on_exit_remove = <ClassAd Boolean Expression>
- on_exit_hold = <ClassAd Boolean Expression>
- periodic_remove = <ClassAd Boolean Expression>
- periodic_hold = <ClassAd Boolean Expression>
- periodic_release = <ClassAd Boolean Expression>
- noop_job = <ClassAd Boolean Expression>



DAGMan 3

schedD

1 2 3 4 5 6

shadow 3

4 5 grid 6 manager

GAHP- 4 Globus

BLAH- 5 LSF

GAHP- Condor 6

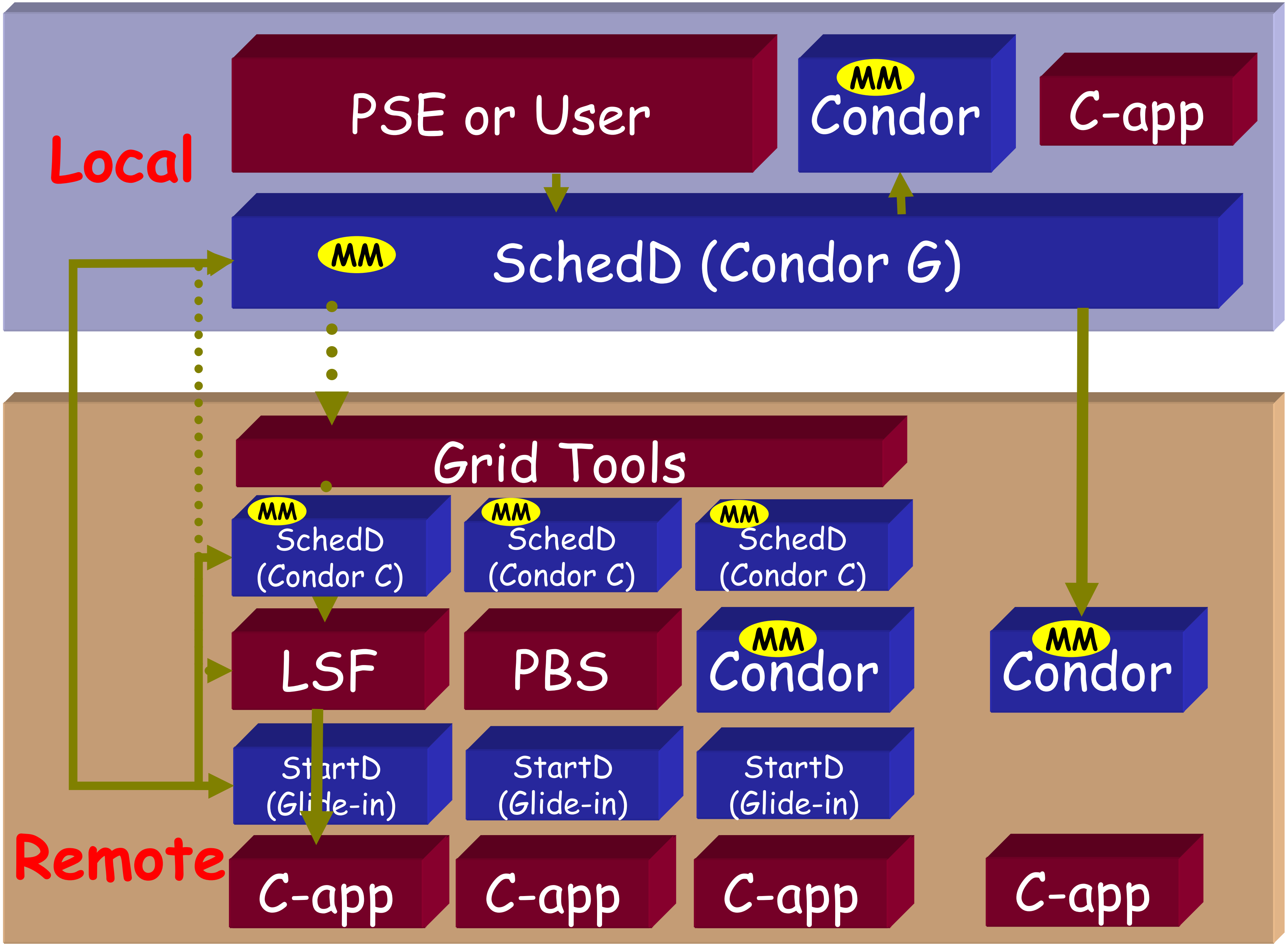
startD

starter 3

4 Globus

5 LSF

6 schedD


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

How can we accommodate an **unbounded** need for computing with an **unbounded** amount of resources?

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

Close by storage is

small and **fast**

faraway storage is

big and slow

Many data challenges …

Managing data is a hard problem. Doing it in a distributed environment does not make it easier or simpler:

- Catalogs and metadata
- Access control
- Consistency and coherency
- Revocation and auditing
- Replication/cashing management
- Planning (optimization?)

Almost everything we do requires a

dependable

data placement mechanism

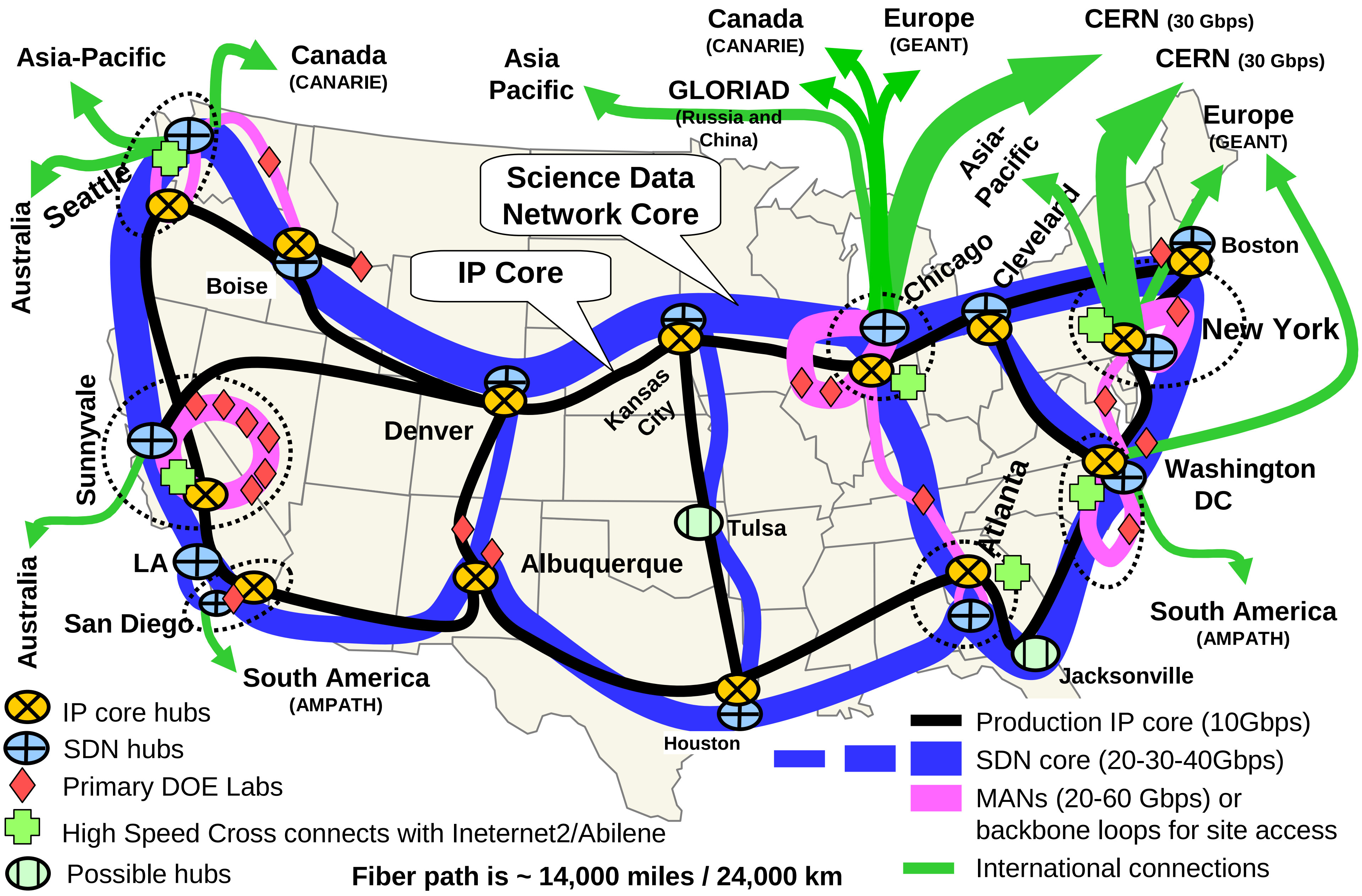
We are making progress …

- The Storage Resource Management (SRM) protocol – management of file copies and support for space reservations
- The Reliable File Transfer (RFT) service – management of large numbers of GridFTP requests
- The File Transfer Service (FTS) – manages file transfer requests and supports the concept of "channels"
- The Planning for Execution in Grids (Pegasus) planner – supports data placement steps in the workflow

High capacity networks are deployed all over the world and almost everyone is concerned about how to allocated their bandwidth. However, is bandwidth the real issue?

ESnet4 Target Configuration

Core networks: 40-50 Gbps in 2009, 160-400 Gbps in 2011-2012



Fiber path is ~ 14,000 miles / 24,000 km

Main trend

The ratio between the size of the organization and the volume (and complexity) of the data/information/knowledge the organization owns/manages/depends on will continue to dramatically increase

- Ownership cost of managed storage capacity goes down
- Data/information/knowledge generated and consumed goes up
- Network capacity goes up
- Distributed computing technology matures and is more widely adopted

Managed Object Placement

Management of storage space and bulk data transfers plays a key role in the end-to-end effectiveness of many scientific applications:

- Object Placement operations must be treated as "first class" tasks and explicitly expressed in the work flow
- Fabric must provide services to manage storage space
- Object Placement schedulers and matchmakers are needed
- Object Placement and computing must be coordinated
- Smooth transition of Compute/Placement interleaving across software layers and granularity of compute tasks and object size
- Error handling and garbage collection

Customer requests:

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

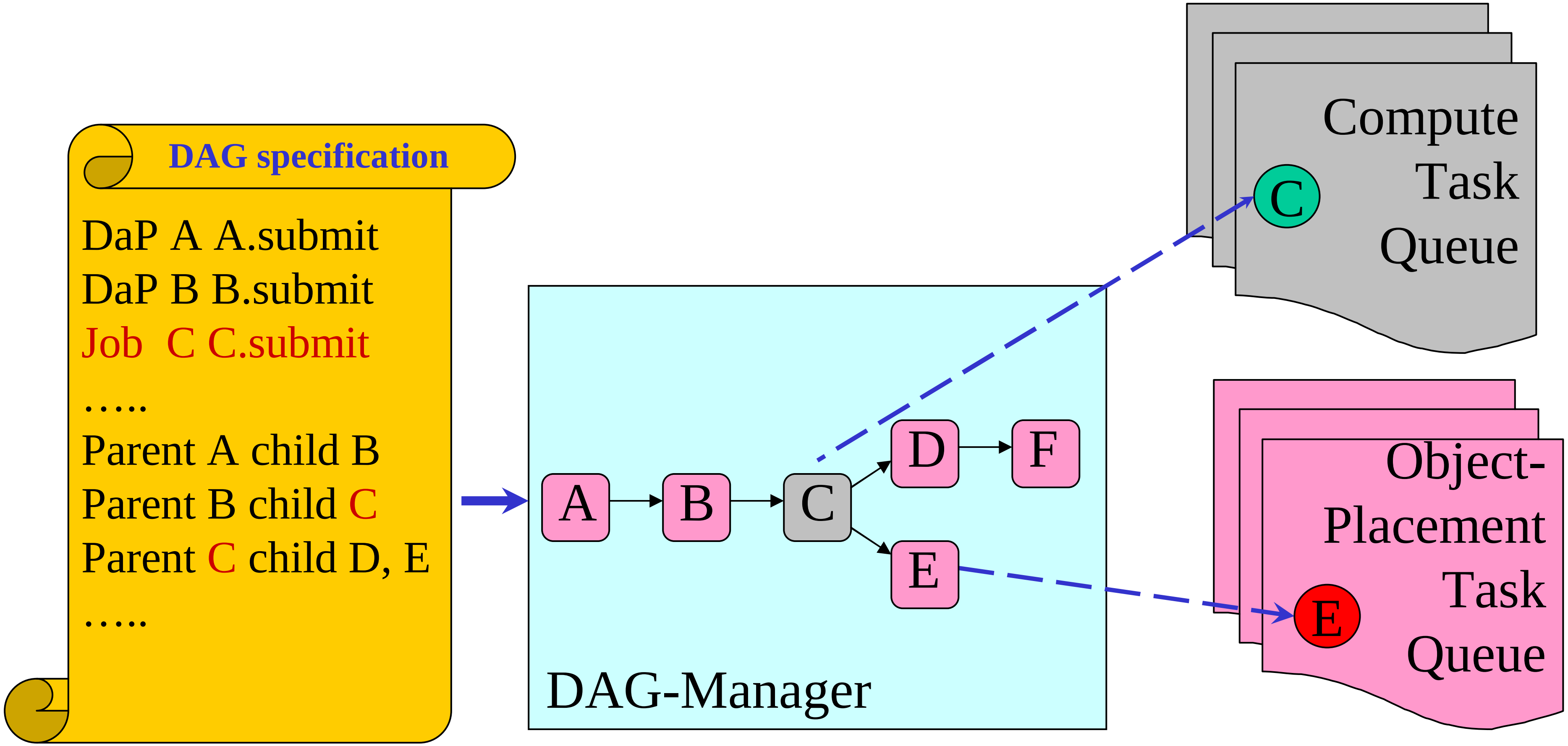
System delivers.

Simple plan for $y=F(x)\rightarrow L$

1. Allocate (size(x)+size(y)+size(F)) at SE_i
2. Place x from SE_j at SE_i
3. Place F on CE_k
4. Compute F(x) at CE_k
5. Move y from SE_i at L
6. Release allocated space at SE_i

Storage Element (SE); Compute Element (CE)

The Basic Approach*



DAG specification

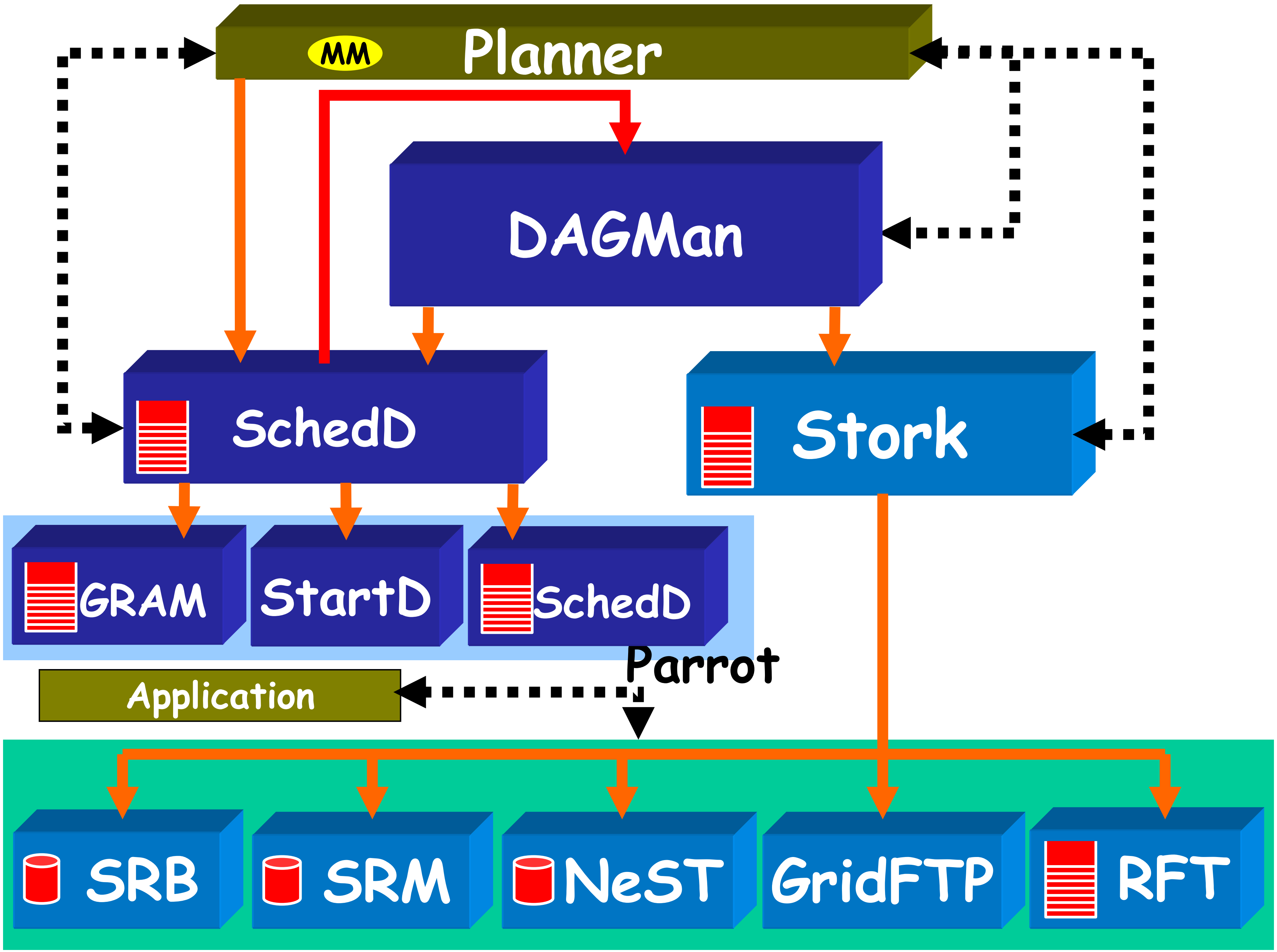
DaP A A.submit
DaP B B.submit
Job C C.submit
…..
Parent A child B
Parent B child C
Parent C child D, E
…..

*** DAG – Directed Acyclic Graph**

Stork-A possible solution

A portable, flexible and extensible Object Placement Scheduler.

- Uses ClassAds to capture jobs and policies (just like Condor)
- Supports matchmaking (just like Condor)
- Provides a suite of data transfer jobs that interface with a broad collection of storage systems and protocols and provide end-to-end reliability
- Supports storage allocate/release jobs


MM
Planner
DAGMan
SchedD
Stork
GRAM
StartD
SchedD
Parrot
Application
SRB
SRM
NeST
GridFTP
RFT

Customer requests:

Place y@S *at* L!

System delivers.

Basic step for y@S→L

1. Allocate size(y) at L,
2. Allocate resources (disk bandwidth, memory, CPU, outgoing network bandwidth) on S
3. Allocate resources (disk bandwidth, memory, CPU, incoming network bandwidth) on L
4. Match S and L

Or in other words,

it takes **two** (or more)

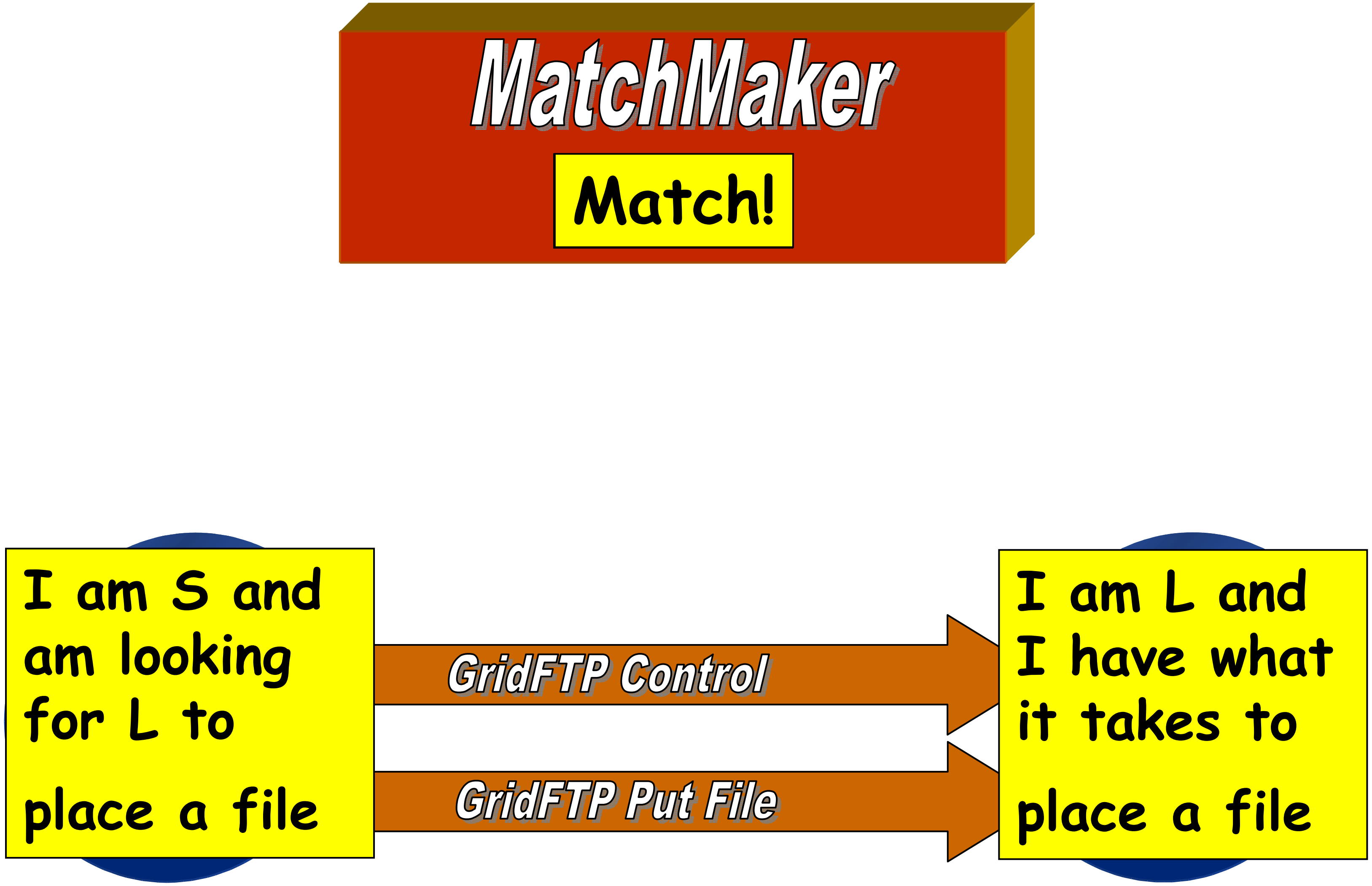
to Tango

(or to place an object)!

When the
"source" plays "nice"
it "asks"

in advance

for permission to
place an object at the
"destination"



MatchMaker

Match!

I am S and am looking for L to place a file

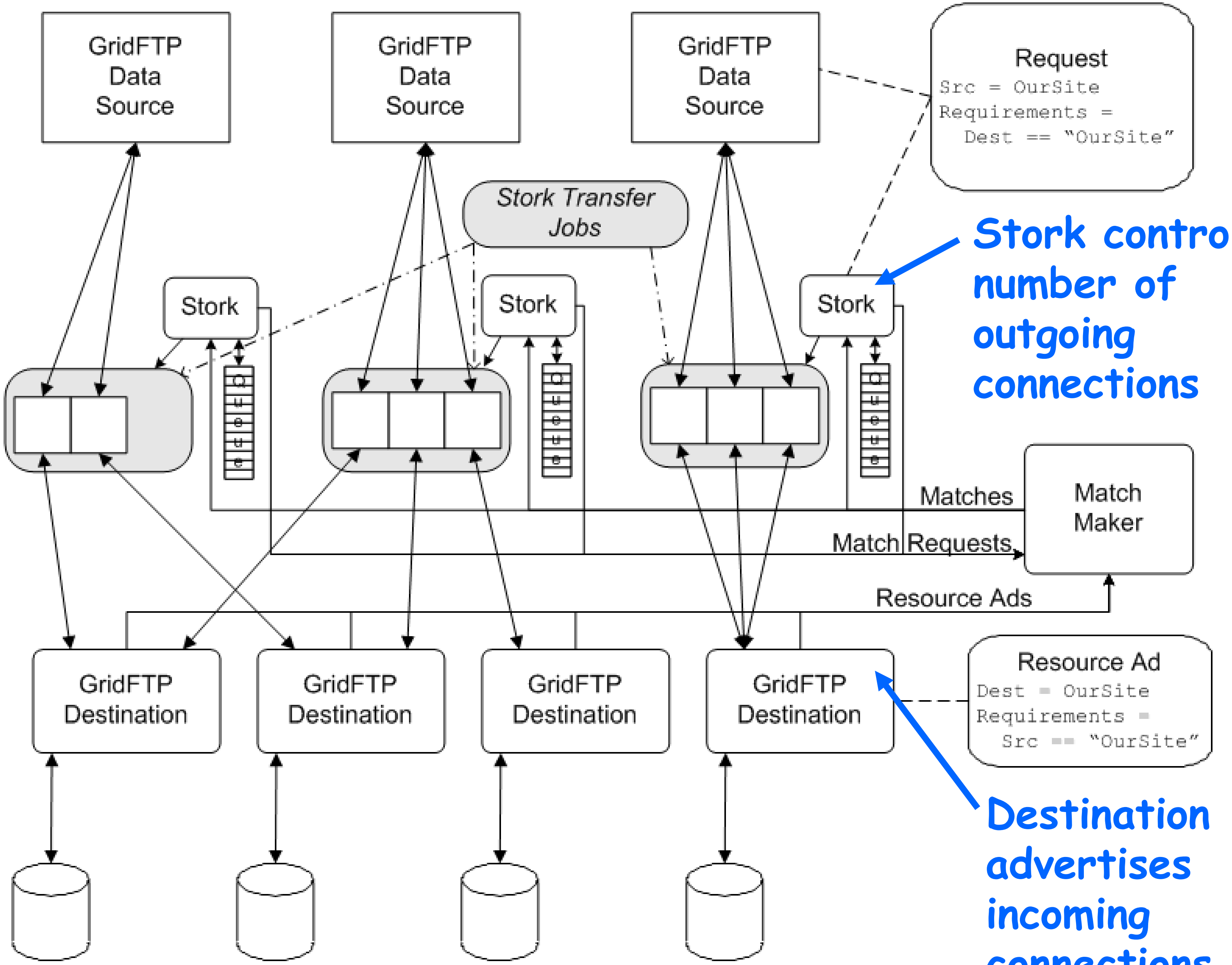
GridFTP Control

GridFTP Put File

I am L and I have what it takes to place a file

The SC'05 effort

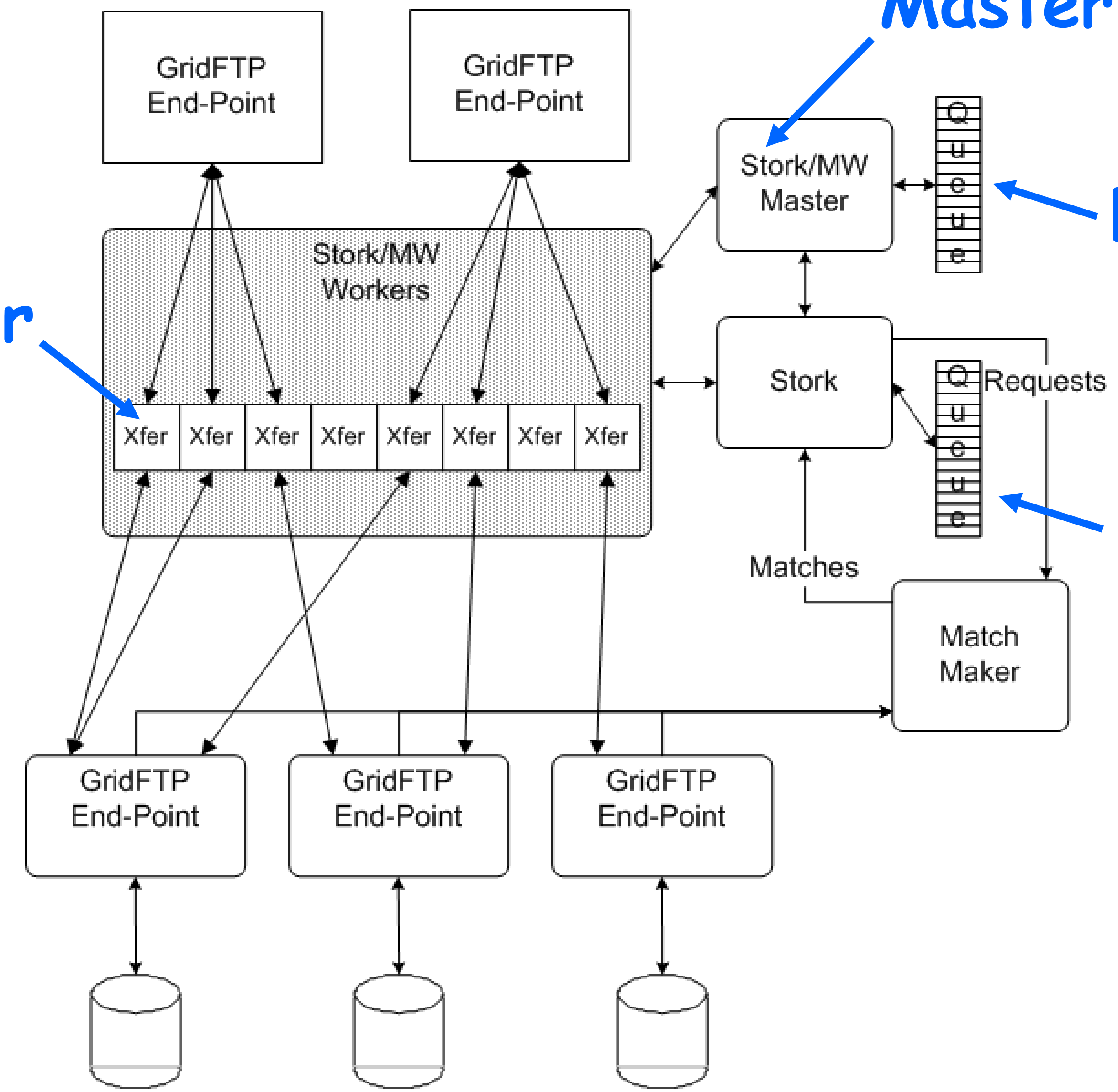
Joint with the Globus GridFTP team



Stork controls number of outgoing connections

Destination advertises incoming connections

A Master Worker view of the same effort



Master

Files

Worker

For Workers

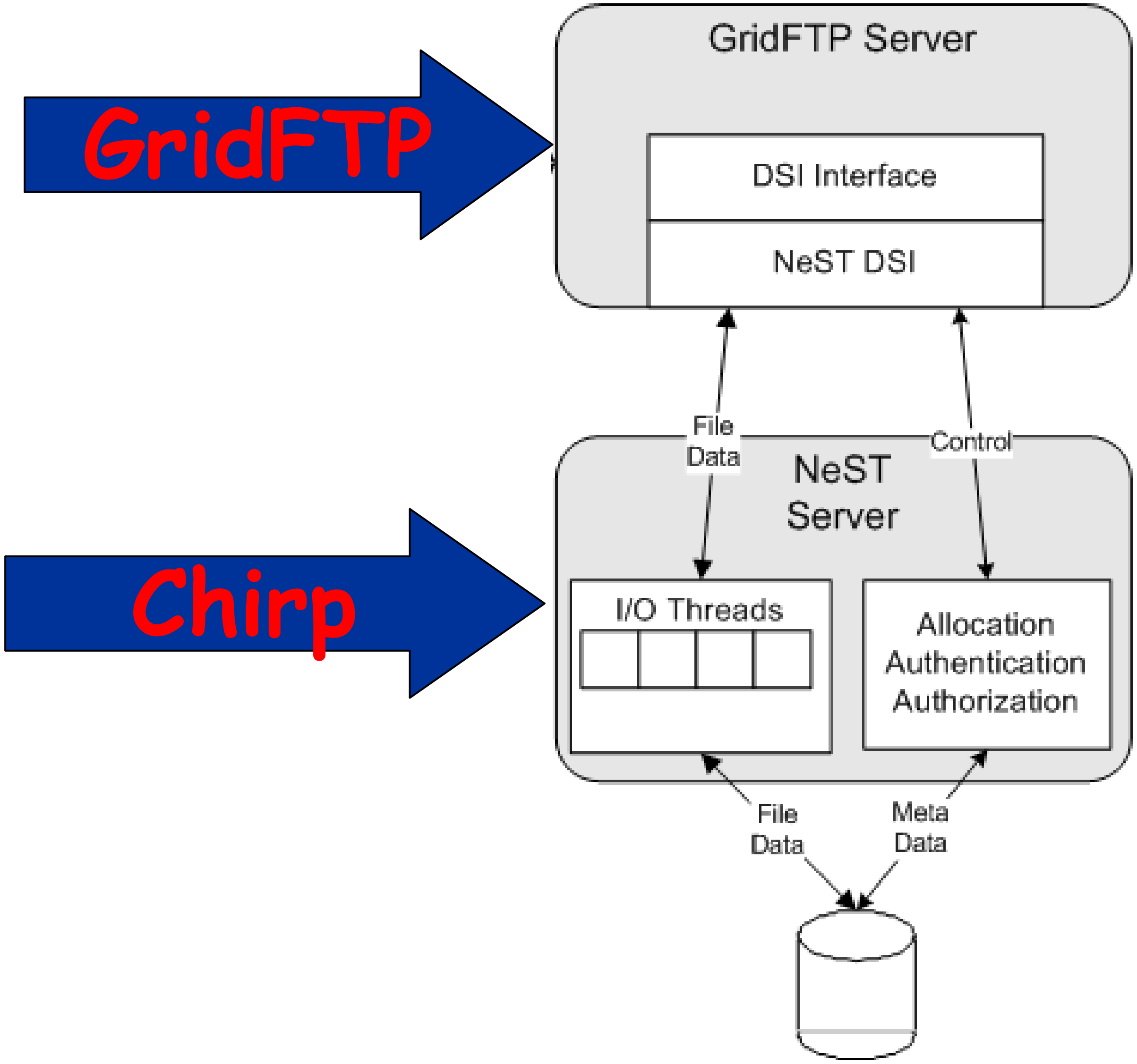
When the
“source” does not
play “nice”,
destination must

protect itself

NeST

Manages storage space and connections for a GridFTP server with commands like:

- ADD_NEST_USER
- ADD_USER_TO_LOT
- ATTACH_LOT_TO_FILE
- TERMINATE_LOT



GridFTP

Chirp

GridFTP Server

DSI Interface

NeST DSI

File Data

Control

NeST Server

I/O Threads

Allocation
Authentication
Authorization

File Data

Meta Data

How can we accommodate an **unbounded** amount of data with an **unbounded** amount of storage and network bandwidth?