Cluster Computing

Metacomputing: Harnessing Informal Supercomputers

- General Introduction
- The Evolution of Metacomputing
- Metacomputing Design Objectives and Issues
- Metacomputing Projects
- Emerging Metacomputing Environments
- Summary and Conclusions

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General Introduction

- From CASA project, one of several U.S. Gigabit testbeds around 1989
- Metacomputer
  - a dynamic environment that has some informal pool of nodes that can join or leave the environment whenever they desire
    - The nodes refer to independent machines
    - A parallel computer (IBM SP2) can be viewed as a "metacomputer in a box"
    - An SMP parallel computer (Tera MTA or SUN E10000) cannot as individual computational nodes in an SMP are not independent
  - By Catlett & Smarr
    - "the use of powerful computing resources transparently available to the user via a networked environment"
  - a networked virtual supercomputer
  - Steps to realize a metacomputer
    - the integration of individual SW & HW resources into a combined networked resources
    - the implementation of middleware to provide a transparent view of the resources available
    - the development & optimization of distributed applications to take advantage of the resources

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Why Do We Need Metacomputing?

- Our computational needs are infinite, whereas our financial resources are finite
  - users will always want more & more powerful computers
  - try & utilize the potentially hundreds of thousands of computers that are interconnected in some unified way
  - need seamless access to remote resources

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What is Metacomputer?

- Computational Grid
  - Equivalent to metacomputing environments
  - Describe a universal source of computing power
  - The means to provide pervasive access to advanced computational resources, databases, sensors, and people
  - Analogy to electricity grid
- Metacomputing encompasses
  - Seamless access to high performance resources
  - Parameter studies (embarrassingly parallel application)
  - The linkage of scientific instruments, analysis system, archival storage, and visualization (4-way metacomputing)
  - The general complex linkage of N distributed components

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Towards Grid Computing … .

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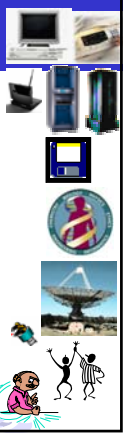
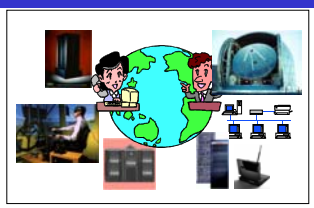
What is Grid ?



- An infrastructure that couples
  - Computers (PCs, workstations, clusters, traditional supercomputers, and even laptops, notebooks, mobile computers, PDA, and so on) …
  - Software (e.g., renting expensive special purpose applications on demand)
  - Databases (e.g., transparent access to human genome database)
  - Special Instruments (e.g., radio telescope--SETI@Home Searching for Life in galaxy, Austrophysics@Swinburne for pulsars)
  - People (may be even animals who knows ?)
- Across the Internet and presents them as an unified integrated (single) resource

7 http://www.csse.monash.edu.au/~rajkumar/ecogrid/

Conceptual view of the Grid



Leading to Portal (Super)Computing

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Grid Application-Drivers

- Old and new applications getting enabled due to coupling of computers, databases, instruments, people, etc.
  - (distributed) Supercomputing
  - Collaborative engineering
  - High-throughput computing
    - large scale simulation & parameter studies
  - Remote software access / Renting Software
  - Data-intensive computing
  - On-demand computing

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The Grid Impact

" The global computational grid is expected to drive the economy of the 21st century similar to the electric power grid that drove the economy of the 20th century"

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The Parts of a Metacomputer

- A metacomputer
  - A virtual computer architecture
  - Its constituent components are individually not important
  - The key concept is how these components work together as a unified resources
  - Components
    - Processors and Memory
      - An array of processors with some dynamic memory associated
    - Networks and Communications Software
      - Physical connections and some communications software
    - Virtual Environment
      - Configure, manage, and maintain the metacomputing environment like an OS
    - Remote Data Access and Retrieval
      - Interacting between supercomputers across national or international networks (a major challenge for metacomputing environment)

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The Evolution of Metacomputing

- Early examples
  - FAFNER
    - Running on any workstation with more than 4MB of memory
  - I-WAY
    - A means of unifying the resource of large supercomputing centers

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FAFNER

- The RSA algorithm - combining prime numbers
  - factoring is computationally very expensive
- By Bellcore Labs. ,Syracus University and Co-Operating Systems in 1995
- A project of factoring via the Web
- Use parallel factoring algorithm (RSA130) which require no communications after the initial setup
- Use a numerical technique NFS (Number Field Sieve) factoring method using computational Web servers
- The consortium produced a Web interface to NFS
- Server-side CGI scripts (in Perl) invoked by contributors support services for the sieving step of the factorization
- Won award in TeraFlop challenge at SC95

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FAFNER

- Factors for success
  - The NFS implementation allowed even single workstations with 4MB to perform useful work using small bounds and a small sieve
  - Support anonymous registration – users could contribute their hardware resources to the sieving effort without revealing their identity to anyone other than the local server administrator
  - A consortium of sites was recruited to run the CGI script package locally, forming a hierarchical network of RSA130 Web servers which reduced the potential administrator bottleneck and allowed sieving to proceed around the clock with minimal human intervention

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I-WAY

- Information Wide Area Year (I-WAY)
  - an experimental high performance network linking many high performance computers & advanced visualization environment
  - conceived in early 1995 with the idea not to build a network, but to integrate existing high-bandwidth networks with telephone systems
  - connect 17 different U.S. sites by 10 networks
    - based on ATM technology
- I-POP (Point-of-Presence)
  - gateways to I-WAY
  - UNIX workstation
    - accessible via the Internet, operated within its site's firewall
    - had an ATM interface
  - I-POP provide uniform authentication, resource reservation, process creation, and communication functions across I-WAY resource

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I-WAY

- I-Soft
  - a standard S/W environment of I-POP
  - help overcome issues such as heterogeneity, scalability, performance, and security
- Computational Resource Broker (CRB)
  - Resource scheduler
  - Consist user-to-CRB and CRB-to-local-scheduler protocols
  - A single central scheduler and multiple local scheduler daemons (one per I-POP)
    - Central scheduler maintain queues of jobs and tables representing the state of local machines, allocating jobs to machine and maintaining state information on the AFS file system
  - Authentication proxy, performing subsequent authentication to I-WAY resource on a user's behalf
    - Kerberos authentication and encryption

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I-WAY

- AFS
  - Provide a shared file repository for software and scheduler information
  - A version of remote copy (ircp) to move data between machines
- Nexus
  - Low-level communication library
  - Support automatic configuration mechanism to choose appropriate configuration depending on the technology used
- Application driven
  - Supercomputer – Supercomputing
  - Remote Resource – Virtual Reality
  - Virtual Reality- Virtual Reality
  - Multisupercomputer – Multivirtual Reality
  - Video, Web, GII-Windows

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Summary of FAFNER and I-WAY

- FAFNER
  - Forerunner of projects such as WebFlow
  - Work on any platform where a Web server could be run
  - Tailored to a particular factoring application that was in itself trivially parallel and was not dependent on a fast interconnect
  - Dependent on quite a lot of human intervention to distribute and collect sieving results
  - Lack of a number of features
    - Every client had to compile, link, and run a FAFNER daemon
    - Individual computational tasks were unable to communicate with one another
- I-WAY
  - I-soft was very influential on the approach used to design components employed in the Globus toolkit
  - Unify the resource at supercomputing sites
  - Cope with a range of diverse high performance applications that typically need a fast interconnect
  - Limited by the design of components that made up I-POP and I-Soft
  - A number of inappropriate features
    - I-POP is a single-points-of-failure

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Metacomputer Design Objectives and Issues

- General Principles
  - Not interfere with the existing site administration or autonomy
  - Not compromise existing security of users or remote sites
  - Not need to replace existing OS, network protocols, or services
  - Allow remote sites to join or leave the environment whenever they choose
  - Not mandate the programming paradigms, languages, tools, or libraries that a user wants
  - Provide a reliable and fault tolerance infrastructure with no single point of failure
  - Provide support for heterogeneous components
  - Use standards, and existing technologies, and is able to interact with legacy applications
  - Provide appropriate synchronization and component program linkage

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Metacomputer Design Objectives and Issues

- Underlying Hardware and Software Infrastructure
  - A metacomputing environment must be able to operate on top of the whole spectrum of current and emerging HW & SW technology
  - An ideal environment will provide access to the available resources in a seamless manner such that physical discontinuities such as difference between platforms, network protocols, and administrative boundaries become completely transparent

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Metacomputer Design Objectives and Issues

- Middleware – The Metacomputing Environment
  - Administrative hierarchy
    - the way that each metacomputing environment divides itself up to cope with a potentially global extent
  - Communication services
    - needs to support protocols that are used for bulk-data transport, streaming data, group communications, and those used by distributed objects
  - Directory/registration services
    - provide the mechanism for registering and obtaining information about the metacomputer structure, resources, services, and status
  - Processes, threads, and concurrency control
    - share data and maintain consistency when multiple processes or threads have concurrent access to it

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Metacomputer Design Objectives and Issues

- Middleware – The Metacomputing Environment
  - Time and clocks
    - time is an entity that we wish to measure accurately
    - algorithms have been developed that depends on clock synchronization
    - use for maintaining the consistency of distributed data or as a part of the Kerberos authentication protocol
  - Naming services
    - provide an uniform name space across the complex metacomputing environment
      - X.500, DNS naming schemes
  - Distributed file systems and caching
    - provide an uniform global namespace
    - support a range of file I/O protocols
    - require little or no program modification
    - provide means that enable performance optimization to be implemented

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Metacomputer Design Objectives and Issues

- Middleware – The Metacomputing Environment
  - Security and authorization
    - confidentiality: prevent disclosure of data
    - integrity: prevent tampering with data
    - authorization: verify identity
    - accountability: knowing whom to blame
  - System status and fault tolerance
  - Resource management and scheduling
    - efficiently and effectively schedule the applications that need to utilize the available resource in the metacomputing environment

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Metacomputer Design Objectives and Issues

- Middleware – The Metacomputing Environment
  - Programming tools and paradigms
    - include interface, APIs, and conversion tools so as to provide a rich development environment
    - support a range of programming paradigms
    - a suite of numerical and other commonly used libraries should be available
  - User and administrative GUI
    - intuitive and easy to use interface to the services and resources available
  - Availability
    - easily port on to a range of commonly used platforms, or use technologies that enable it to be platform neutral

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Metacomputing Projects

- Globus (from Argonne National Laboratory)
  - provides a toolkit on a set of existing components to build metacomputing environments
- Legion (from the University of Virginia)
  - provides a high-level unified object model out of new and existing components to build a metasystem
- Webflow (from Syracuse University)
  - provides a Web-based metacomputing environment

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Globus

- A computational grid
  - A hardware and software infrastructure to provide dependable, consistent, and pervasive access to high-end computational capabilities, despite the geographical distribution of both resources and users
- A layered architecture
  - high-level global services are built upon essential low-level core local services
- Globus Metacomputing Toolkit (GMT)
  - a central element of the Globus system
  - defines the basic services and capabilities required to construct a computational grid
  - consists of a set of components that implement basic services
  - provides a bag of services
  - only possible when the services are distinct and have well-defined interfaces (API)

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Globus

- The GMT consists of the followings
  - Resources allocation and process management (GRAM)
  - Unicast and multicast communications services (Nexus)
  - Authentication and related security services (GSI)
  - Distributed access to structure and state information (MDS)
  - Monitoring of health and status of system components (HBM)
  - Remote access to data via sequential and parallel interfaces (GASS)
  - Construction, caching, and location of executables (GEM)

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Globus

- Administrative hierarchy
  - no obvious administrative hierarchy
- Communication services
  - Nexus
    - Support for multimethod communication
    - Provide an application a single relatively low-level communication API to support a wide range of high-level communication protocol characteristics
- Directory/registration services
  - Globus Metacomputing Directory Service (MDS)
    - Provide static and dynamic information about the status of Globus system components
    - Use Lightweight Directory Access Protocol (LDAP) server to store metacomputing-specific objects
    - House information pertaining to the potential computing resource, their specifications, and their current availability

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Globus

- Processes, threads, and concurrency control
  - Work at process level
  - Nexus API can be used to construct communication primitive between threads
  - No concurrency control
- Time and clocks
  - No particular time service
- Naming services
  - Use of LDAP, DNS and X.500
- Security and authorization
  - Generic Security Service API (GSI) using an implementation of Secure Sockets Layer and X509 certificate as authentication system
  - Use RSA encryption algorithm and associated public and private keys

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Globus

- Distributed file systems and caching
  - Global Access to Secondary Storage (GASS)
    - Define a global name space via URLs
    - Provide basic access to remote files via standard I/O interface
    - File cache is used to address bandwidth management issues associated with repeated access to remote files
    - A simple locking protocol for local concurrency control, not implement a wide-area cache coherency mechanism
  - Remote I/O (RIO)
    - A distributed implementation of MPI-IO, parallel I/O API
  - Globus Executable Management (GEM)
    - Enable loading and executing a remote file through GRAM using GASS caching calls

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Globus

- System status and fault tolerance
  - Detection of a fault is a necessary prerequisite to fault recovery and fault tolerance
  - Heartbeat monitor (HBM) as fault detection service
  - Nexus communication library support for fault detection
- Resource management and scheduling
  - Globus Resource Allocation Manager (GRAM)
    - Allow jobs to run remotely and provide an API for submitting, monitoring, and terminating jobs
    - Provide local component for resource management
    - GRAM is responsible for
      - Parsing and processing the Resource Specific Language (RSL) specifications that outline job requests
      - Enabling remote monitoring and managing of jobs already created
      - Updating MDS with information regarding the availability of the resource it manages

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Globus

- Programming tools and paradigms
  - Support MPI, Java, Compositional C++, Simple RPC, Perl
- User and administrative GUI
  - Use Web and command line interface
- Availability
  - Available on most version of UNIX

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Legion

- An object-based metasystem
- Organized by classes and metaclasses
  - Every thing is an object
  - Classes manage their instances
  - Users can define their own classes
  - Core objects
- Core objects
  - Classes and Metaclasses, Host objects, Vault objects, Binding Agents
  - Implementation Objects and Caches, Context objects and Context spaces

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Legion

- Interface Definition Language (IDL)
  - The set of methods of an object describes its interface
- Two state of Legion object
  - active: run as a process that is accept function invocations.
  - inert: the object which resides on some stable storage (OPR)
- Three-tiered naming system
  - Users refer to objects using human-readable strings, called context names
  - Context objects map context names to LOIDs which are location-independent identifier that include an RSA public key
  - A LOID is mapped to an LOA

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WebFlow

- A computational extension of the Web model
  - can act as a framework for the wide-area distributed computing and metacomputing
- The main goal
  - build a seamless framework for publishing and reusing computational modules on the Web
- Three-tier Java-based architecture
- The high performance backend tier is implemented using the Globus toolkit .
  - MDS, GRAM, GASS
- A high level, visual user interface and job broker for Globus

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WebFlow

- The Management Infrastructure - by three servelets
  - Session Manager
  - Module Manager
  - Connection Manager
- use URL addresses
- offer dynamic information about their services and current state
- communicate with each other via sockets

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Metacomputing Functionality Matrix

Design Objective	Globus	Legion	Webflow
Admin. Hierarchy	Peer	Peer	Peer
Comm. Service	Nexus – Low-Level	MMPS – Socket-based	Hierarchical – Sockets+MPI
Dir/Reg. Services	MDS - LDAP	via Binding agents	MDS - LDAP
Process	Process-based	Object/process-based	Process-based
Clock	Not specified	Not specified	Not specified
Naming Services	LDAP +DNS/x.500	Context Manger+DNS	LDAP +DNS
Filesystems & Caching	GASS+ROMIO	Custom Legion filesystem	GASS
Security	GSI (RSA+X.509 certs)	Object-based with RSA	SSL
Fault Tolerance	Heart-beat monitor	Not available yet	None
Resource Management	GRAM+RSL+Local	Host object+Local	GRAM-based
Prog. Paradigms	Many and varied	MPL, BFS+wrappers	MPI
User Interface	GUI+command-line	GUI+command-line	Applet-based GUI
Availability	Most UNIX	Most UNIX	Most UNIX and NT

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Emerging Metacomputing Environments

- Java and the Web
  - as the communications infrastructure
  - Java has revolutionized the shape and characteristics of the software environments for heterogeneous distributed systems
  - So the developers no longer have to focus on aspects such as portability and heterogeneity

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Metacomputing Trends

- Java
- CORBA
- From a relatively slow start, the development of metacomputers is accelerating fast with the advent of these new and emerging technologies
- The framework of a metacomputing environment must be adaptable, malleable, and extensible, whatever technology and fashions become influential

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The Impact of Metacomputing

- Metacomputing is an infrastructure that can bond and unify globally remote and diverse resources
- At some stage in the future, our computing needs will be satisfied in same pervasive and ubiquitous manner that we use the electricity power grid

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