Grid/Meta-Computing Lecture 10

Dr Graham E Fagg

Specific GRID/MetaComputing Systems
aka Globus, Legion, Unicore, SNIPE & HARNESS

Overview

- Cover the most common Grid & Meta-Computer systems currently on offer and a few that are/were in the pipe.

GRID/Meta-Computing Projects

- Legion - University of Virginia
- Wide Area Metacomputer Manager (WAMM) – Pisa, Italy
- Wide Area Network Environment (WANE) - Florida State University
- WebFlow and MetaWeb - Syracuse University
- DISCWorld - University of Adelaide / University of Bangor
- Globus - Argonne National Lab., ISI, USC
- Toolset
- SNIPE - UTK
- HARNESS - UTK/ORNL/Emory
- UNICORE – multiple German Universities
- Globe - Vrije University in Amsterdam.
  - See http://www.cs.vu.nl/~steen/globe/

Legion

- Legion is an object-based, meta-systems software project designed to build a system of millions of hosts and trillions of objects, tied together with high-speed links.
- Users working on their home machines have the illusion of working on a single computer, with access to all kinds of data and physical resources, such as digital libraries, physical simulations, cameras, linear accelerators, and video streams.
- Users can construct shared virtual work spaces, to collaborate research and exchange information.
- Legion supports this abstraction with transparent scheduling, data management, fault tolerance, site autonomy, and a wide range of security options.

Legion

- Legion is an object-based, meta-systems software project at the University of Virginia. From the project's beginning in late 1993, the Legion Research Group’s goal has been a highly usable, efficient, and scalable system founded on solid principles. We have been guided by our own work in object-oriented parallel processing, distributed computing, and security, as well as by decades of research in distributed computing systems. Our system addresses key issues such as scalability, programming ease, fault tolerance, security, site autonomy, etc. Legion is designed to support large degrees of parallelism in application code and manage the complexities of the physical system for the user. The first public release was made at Supercomputing ’97, San Jose, California, on November 17, 1997.

Legion

- Legion is an open system, designed to encourage third party development of new or updated applications, runtime library implementations, and core components.
Legions Design

- Legion sits on top of the user's operating system, negotiating between the computer's resources and whichever resources or applications are required.
- Legion handles resources scheduling and security issues so that the user isn't bogged down with time-consuming negotiations with outside systems and system administrators.
- Legion offers a user-controlled naming system called context space, so that users can easily track and use objects in farflung systems.
- Users can also run applications written in multiple languages, since Legion supports interoperability between objects written in multiple languages.

Legion Design

- Philosophy
  - Legion users will require a wide range of services in many different dimensions, including security, performance, and functionality. No single policy or static set of policies will satisfy every user, so, whenever possible, users must be able to decide what trade-offs are necessary and desirable. Several characteristics of the Legion architecture reflect and support this philosophy.

  - Everything is an object: The Legion system will consist of a variety of hardware and software resources, each of which will be represented by a Legion object, which is an active process that responds to member function invocations from other objects in the system. Legion defines the message format and high-level protocol for object interaction, but not the programming language or the communications protocol.

  - Classes manage their instances: Every Legion object is defined and managed by its class object, which is itself an active Legion object. Class objects are given system-level responsibility; classes create new instances, schedule them for execution, activate and deactivate them, and provide information about their current location to client objects that wish to communicate with them. In this sense, classes are managers and policy makers, not just definers of instances. Classes whose instances are themselves classes are called metaclasses.

  - Users can provide their own classes: Legion allows users to define and build their own class objects; therefore, Legion programmers can determine and even change the system-level mechanisms that support their objects. Legion 1.4 (and future Legion systems) contains default implementations of several useful types of classes and metaclasses. Users will not be forced to use these implementations, however, particularly if they do not meet the users' performance, security, or functionality requirements.

Legion Design

- Core objects implement common services: Legion defines the interface and basic functionality of a set of core object types that support basic system services, such as naming and binding, and object creation, activation, deactivation, and deletion. Core Legion objects provide the mechanisms that classes use to implement policies appropriate for their instances.
  - Examples of core objects include hosts, vaults, contexts, binding agents, and implementations.

Legion Model

- Legion objects are independent, logically address-space-disjoint active objects that communicate with one another via non-blocking method calls that may be accepted in any order by the called object.
- Each method has a signature that describes the parameters and return value, if any, of the method. The complete set of method signatures for an object fully describes that object's interface, which is determined by its class.
- Legion class interfaces can be described in an interface description language (IDL), several of which will be supported by Legion.
Legion Design

Legion implements a three-level naming system.
- At the highest level, users refer to objects using human-readable strings, called context names. Context objects map context names to LOIDs (Legion object identifiers), which are location-independent identifiers that include an RSA public key. LOIDs are location independent, LOIDs by themselves are insufficient for communication.
- For communication, a LOID is mapped to an LOA (Legion object address) for communication. An LOA is a physical address (or set of addresses in the case of a replicated object) that contains sufficient information to allow other objects to communicate with the object (e.g., an <IP address, port number> pair).

Legion Design

Legion will contain too many objects to simultaneously represent all of them as active processes. Legion has a strategy for maintaining and managing the representations of these objects on persistent storage.
- Legion object can be in one of two different states, active or inert.
  - An inert object is represented by an OPR (object persistent representation), which is a set of associated bytes that exists in stable storage somewhere in the Legion system.
  - The OPR contains state information that enables the object to move to an active state.
- An active object runs as a process that is ready to accept member function invocations; an active object's state is typically maintained in the address space of the process (although this is not strictly necessary).

Legion Design

Several core object types implement the basic system-level mechanisms required by all Legion objects. Like classes and metaclasses, core objects are replaceable system components
- Host objects: Host objects represent processors in Legion. One or more host objects run on each computing resource that is included in Legion. Host objects create and manage processes for active Legion objects. Classes invoke the member functions on host objects in order to activate instances on the computing resources that the hosts represent. Representing computing resources with Legion objects abstracts the heterogeneity that results from different operating systems having different mechanisms for creating processes. Further, it provides resource owners with the ability to manage and control their resources as they see fit.

Legion Design

VAult objects: Just as a host object represents computing resources and maintains active Legion objects, a vault object represents persistent storage, but only for the purpose of maintaining the state, in OPRs, of the inert Legion objects that the vault object supports. Context objects: Context objects map context names to LOIDs, allowing users to name objects with arbitrary high-level string names, and enabling multiple disjoint name spaces to exist within Legion. All objects have a current context and a root context, which define parts of the name space in which context names are evaluated.
- Binding agents: Binding agents are Legion objects that map LOIDs to LOAs. A <LOID, LOA> pair is called a binding. Binding agents can cache bindings and organize themselves in hierarchies and software combining trees, in order to implement the binding mechanism in a scalable and efficient manner.

Legion Design

Implementation objects: Implementation objects allow other Legion objects to run as processes in the system. An implementation object typically contains machine code that is executed when a request to create or activate an object is made; more specifically, an implementation object is generally maintained as an executable file that a host object can execute when it receives a request to activate or create an object. An implementation object (or the name of an implementation object) is transferred from a class object to a host object to enable the host to create processes with the appropriate characteristics.
Legion

- Legion supports parallel processing in four ways:
  - Supporting popular parallel libraries, such as MPI
  - Supporting parallel languages, such as MPL
  - Offering wrap parallel components
  - Exporting the run-time library interface to library, toolkit, and compiler writers

Legion

- Scheduling under Legion:
  - Users can choose their own scheduler (class) or use the default method available

Legion Security

- All classes should provide a means of access control for their own resources.
- All accesses to an object can be controlled by the “MayI” class.

Legion Security

- Public-key cryptography based on RSAREF 2.0.
- Three message-layer security modes: private (encrypted communication), protected (fast digested communication with unforgeable secrets to ensure authentic replies to message calls), and no security.
- Caching secret keys for faster encryption of multiple messages between communicating parties.
- Auto-encrypted bearer credentials with free-form rights. Propagation of security modes and certificates through calling trees (e.g., if a caller demands encryption, all downstream calls will use it automatically).
- Drop-in addition of MayI functionality to existing objects.

Legion: how to

- We would run through the tutorials at legion.virginia.edu
  - But it is now no longer available

- Make sure you don’t get confused between what is in the Unix world and the Legion world.
Legion: how to

- Before running anything… login using
  - Legion_login /users/<USER_NAME>

- Running an MPI job
  - Build it as a Legion MPI executable
    - Native compile
  - Run legion_tty /home/<USER>/tty so that we can get output from Legion Space

- Compiling Legion MPI jobs
  - They are the same as normal (mpich) MPI jobs
    ```
    gcc -O -I/usr/local/Legion/include/MPI bwtest.c -c
    legion_link -mpi bwtest.c -o bwtest
    ```

- Before it can be used, it must be in Legion space as an object of the correct type.
  - Needs to be registered
    ```
    torc0.cs.utk.edu> legion_mpi_register
    usage: legion_mpi_register <class name>
    ```

- torc0.cs.utk.edu> ls -la bwtest
  ```
  -rwxr-xr-x   1 fagg     dongarra    14757 Apr 12 21:50 bwtest*
  ```

- torc0.cs.utk.edu> legion_mpi_register bwtest bwtest
  ```
  /home/fagg/mpi/programs does not exist - creating it
  /home/fagg/mpi/instances does not exist - creating it
  Task class /home/fagg/mpi/instances/bwtest does not exist - creating it
  Added 1 attributes(s) to object
  ```

- torc0.cs.utk.edu> legion_ls /home/fagg mpi tty
  ```
  /home/fagg/mpi/programs (context)
  ```

- torc0.cs.utk.edu> legion_ls -laL /home/fagg mpi/programs/bwtest
  ```
  /home/fagg/mpi/programs/bwtest
  ```

- torc0.cs.utk.edu> legion_tty /home/<USER>/tty
Legion: how to

• Running the MPI job

torc0.cs.utk.edu> legion_mpi_run -n 2 -v
/home/fagg/mpi/programs/bwtest
MPI run ID 128873583
emptying context /home/fagg/mpi/instances/bwtest
getting context /home/fagg/mpi/instances/bwtest
setting context /home/fagg/mpi/instances/bwtest
Looking up program name /home/fagg/mpi/programs/bwtest
Creating 2 objects:
Creating object 0...
Creating object 1...
Application is done -- all children are done.
torc0.cs.utk.edu>

Legion: how to

• And some time later (via the legion_tty object)

torc0.cs.utk.edu> Hello from node 0 of 2 hostname torc0.cs.utk.edu
0 2.045000 ms 0.000000 MB/Sec
8 2.262700 ms 0.003372 MB/Sec
80 2.186600 ms 0.034892 MB/Sec
800 2.384650 ms 0.319938 MB/Sec
8000 28.465600 ms 0.268022 MB/Sec
80000 18.631050 ms 4.094989 MB/Sec
800000 185.564750 ms 4.111446 MB/Sec
Hello from node 1 of 2 hostname torc2.cs.utk.edu

Legion: how to

• Controlling where you run the code:
  – Default scheduling policy will round robin execution
  – Or use a hostfile
    • Hostfile can be in legion space or on a unix file system
      – [-hf LegionHostsFile] [-HF LocalOSHostsFile]

Legion: how to

• The host file must list either the real legion contexts (that long string) or
• The short hand human readable form i.e. /hosts/<hostname> <default number of resources>

torc0.cs.utk.edu> cat h12 /hosts/torc1.cs.utk.edu 1 /hosts/torc0.cs.utk.edu 1

Legion: how to

Globus MetaComputing Toolkit

• is:
  – A set of applications and tools for running wide area computations on a heterogeneous collection of resources.
    • The collection of resources is now called the Computational Grid (or just Grid)
    • Was originally called Gusto
  – Uses current technology where ever possible.
Globus

- Mission statement:
  - The Globus project is developing the fundamental technology that is needed to build computational grids, execution environments that enable an application to integrate geographically-distributed instruments, displays, and computational and information resources. Such computations may link tens or hundreds of these resources.
  - Note: 10s to 100s… people have run PVM on a few hundred machines in '92! Also not aimed at workstation as computational resources but just as entry devices.
  - Real aim, MPPs… unlike Legion and Globe etc

Globus Components

- Globus is a modular system, so you can use some components without the need for others.
  - Communication
  - Resource Management
  - Remote Access
  - Security
  - Information Services

Globus Components

- Communications
  - Two systems are supported:
    - Native MPI (from Vendors or via MPICH)
    - NEXUS
      - Two version of NEXUS
        - Native, which is multithreaded
        - Lite, which is just socket based and single threaded
      - A special version of MPI using NEXUS as its ADI exists known as MPICH-g.
        - Newest version MPICH-G2 does not use NEXUS but only TCP!

Globus Components

- NEXUS
  - Nexus is a portable library providing the multithreaded communication facilities required to implement advanced languages, libraries, and applications in heterogeneous parallel and distributed computing environments. Its interface provides a global memory model via interprocessor references, asynchronous events, and is thread safe when used in conjunction with the Globus thread library. Its implementation supports multiple communication protocols and resource characterization mechanisms that allow automatic selection of optimal protocols.
  - Nexus is intended for use by compiler writers and library developers, rather than application programmers.

Globus Components

- Communications
  - NEXUS
    - Nexus supports five basic abstractions: the node, context, thread, communication endpoint, and remote service request.
      - Remote Service Request (RSR). A thread can request that an action be performed in a remote context by issuing a remote service request. This takes a handler identifier, a communication endpoint, and a message buffer as arguments and causes the specified handler to be executed on the node and within the context of the communication endpoint to which the startpoint is bound. The handler is passed the communication endpoint and the message buffer as arguments.
        - Note this is an async function.
        - Message passing would use this to say put the sent message into the receiver's memory!
      - The endpoints cannot move, but the startpoints can.
      - Communication between points is uni-directional!
The Globus Resource Allocation Manager (GRAM) processes the requests for resources for remote application execution, allocates the required resources, and manages the active jobs. It also returns updated information regarding the capabilities and availability of the computing resources to the Metacomputing Directory Service (MDS).

- MDS is now known as Grid Information Service (GIS)

GRAM provides an API for submitting and canceling a job request, as well as checking the status of a submitted job. The specifications are written by the user in the Resource Specification Language (RSL), and is processed by GRAM as part of the job request.

A job is submitted, the request is sent to the gatekeeper of the remote computer. The gatekeeper handles the request and creates a job manager for the job. The job manager starts and monitors the remote program, communicating state changes back to the user on the local machine. When the remote application terminates, normally or by failing, the job manager terminates as well.

This is much like the host objects under Legion.

The structure of the individual GRAMs are much like the GRM and Tasker combinations in PVM.

- Pending - resources have not yet been allocated for the job
- Active - the job has received resources, and the application is executing
- Failed - the job terminated before completion, as a result of an error, or a user or system cancel
- Done - the job completed successfully

Globus Executable Management (GEM) enables loading and executing a remote file through the GRAM resource manager.
### Globus Components

#### Remote Access

- **GSS**
  - A program that is to run on one or more remote MPPs can be modified to replace all open/close/fopen/fclose calls with gass_* versions. The program will then operate correctly on the remote computers. Furthermore, if multiple processes created on the remote computer read the same file, the file is copied only once.
  - GSS caches the data files in much the same way as AFS.

- **RIO: Remote I/O for Metasystems**
  - The RIO library provides basic mechanisms for tools and applications that require high-performance access to data located in remote, potentially parallel file systems. RIO implements the ADIO abstract I/O device interface specification, which defines basic I/O functionality that can be used to implement a variety of higher-level I/O libraries.
  - The RIO implementation comprises two components, as shown in the following figure. The RIO client defines a remote I/O device for ADIO. This component translates ADIO requests that name a remote file (by using a URL-like syntax) into appropriate communications to a remote I/O server. The server provides an interface to a particular file system, and serves requests from remote RIO clients that need to access that file system. The RIO server component itself calls ADIO routines to access different file systems.

#### Other Components

- **Security**
  - Is based on SSLEAY and uses SSL and X509 to identify both users and resource (providers)
  - Globus Security Infrastructure (GSI)

- **Fault tolerance**
  - Uses the Heart Beat Monitor (HBM)

---

### Globus: how to

- Set the env variables and then
- Login!

```bash
tor0.cs.utk.edu> grid-proxy-init
Enter PEM pass phrase:
...+++++
...+++++
tor0.cs.utk.edu> grid-proxy-info -all
subject : /C=US/O=Globus/O=University of Tennessee at Knoxville/OU=Innovative Computing Laboratory/CN=Graham E Fagg/CN=proxy
issuer : /C=US/O=Globus/O=University of Tennessee at Knoxville/OU=Innovative Computing Laboratory/CN=Graham E Fagg
type : full
strength : 512 bits
timeleft : 11:59:46
tor0.cs.utk.edu>
```
Globus : how to

• GLOBUS still needs a machines as did MPICH

• Difference is it needs it in the current directory

```
cat ./machines
```

```
Torc2:2119/jobmanager 1
Torc3:2119/jobmanager 1
Torc6:2119/jobmanager 1
Torc7:2119/jobmanager 1
```

Used by MPICH to make a RSL file which is then passed to globus-run

Globus : how to

• BUT /usr/local/gt-mpich/bin/mpirun does not work! (MDS problem... grr)
  – Well it hangs... it does get their in the end (sometimes)

```
torc0.cs.utk.edu> /usr/local/gt-mpich/bin/mpirun -t -v -np 3 infompi
running /ptfe/homes/fagg/globus/infompi on 3 LINUX globus processors
```

Globus : how to

• This means we have to do what it does
  – It builds an RSL file and then globusruns it

• So we have to build a RSL file by hand!
  – Yes I am serious
    • But we can get MPIRUN to do most of it for us

```
torc0.cs.utk.edu> /usr/local/gt-mpich/bin/mpirun -np 1 -globusargs dumprsl infompi > c.rsl
torc0.cs.utk.edu> cat c.rsl
```

```
+ (resourceManagerContact="torc3.cs.utk.edu:2119/jobmanager")
+ (count=1)
+ (label="sub-job 0")
+ (environment=(GLOBUS_DUROC_SUBJOB_INDEX 0))
+ (directory=/ptfe/homes/fagg/globus)
+ (executable=/ptfe/homes/fagg/globus/infompi)
```

```
torc0.cs.utk.edu> /usr/local/gt-mpich/bin/mpirun -globusrsl c.rsl
```

```
[torc3:24098]  MPI version dependant startup information
[torc3:24098]  Argc = 1 and first argv is /ptfe/homes/fagg/globus/infompi
[torc3:24098]  0 /ptfe/homes/fagg/globus/infompi
[torc3:24098]  MPI independant information
[torc3:24098]  Host [torc3] Size of 1, my rank in that size 0
```
Globus: how to

torc0.cs.utk.edu> cat single.rsl
+
( & (resourceManagerContact="torc2.cs.utk.edu:2119/jobmanager")
  (count=2)
  (label="subjob 0")
  (environment=(GLOBUS_DUROC_SUBJOB_INDEX 0))
  (arguments=" ")
  (directory="/ptfe/homes/fagg/globus")
  (executable="/ptfe/homes/fagg/globus/infompi")
) torc0.cs.utk.edu>

torc0.cs.utk.edu> cat twin.rsl
+
( & (resourceManagerContact="torc2.cs.utk.edu:2119/jobmanager")
  (count=1)
  (label="subjob 0")
  (environment=(GLOBUS_DUROC_SUBJOB_INDEX 0))
  (arguments=" ")
  (directory="/ptfe/homes/fagg/globus")
  (executable="/ptfe/homes/fagg/globus/infompi")
)
( & (resourceManagerContact="torc3.cs.utk.edu:2119/jobmanager")
  (count=1)
  (label="subjob 1")
  (environment=(GLOBUS_DUROC_SUBJOB_INDEX 1))
  (arguments=" ")
  (directory="/ptfe/homes/fagg/globus")
  (executable="/ptfe/homes/fagg/globus/infompi")
)
torc0.cs.utk.edu>

• Now to run from an RSL file
  – Two methods...
    • Pass it to mpirun
      torc0.cs.utk.edu> /usr/local/gt-mpich/bin/mpirun -globusrsl b.rsl
    • Pass it to globusrun

What is SNIPE?

• Platform for large-scale distributed systems
• Reliable and fault-tolerant
• Supports continuous operation
• Very heterogeneous (PDAs to supercomputers)
• Adaptable to changing conditions (link or host failures)
• Secure (provides authentication and privacy)

SNIPE Design Principles

• Reliability
  “Better living through redundancy”
• Scalability
  “Minimize the amount of shared state”
• Simplicity and Flexibility
  “Keep the core small”
• Efficiency
  “Optimize the common cases”

Globus: how to

torc0.cs.utk.edu> cat twin.rsl
+
( & (resourceManagerContact="torc2.cs.utk.edu:2119/jobmanager")
  (count=1)
  (label="subjob 0")
  (environment=(GLOBUS_DUROC_SUBJOB_INDEX 0))
  (arguments=" ")
  (directory="/ptfe/homes/fagg/globus")
  (executable="/ptfe/homes/fagg/globus/infompi")
)
( & (resourceManagerContact="torc3.cs.utk.edu:2119/jobmanager")
  (count=1)
  (label="subjob 1")
  (environment=(GLOBUS_DUROC_SUBJOB_INDEX 1))
  (arguments=" ")
  (directory="/ptfe/homes/fagg/globus")
  (executable="/ptfe/homes/fagg/globus/infompi")
)
torc0.cs.utk.edu>

SNIPE
Scalable Networked Information Processing Environment
### SNIPE Components

<table>
<thead>
<tr>
<th>Component</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>RCDS metadata servers</td>
<td>Provides stable storage for metadata attributes of hosts, tasks, services, etc.</td>
</tr>
<tr>
<td>Host daemons</td>
<td>Mediates the use of resources on a host, authenticate requests for local processing, enforce access restrictions on local resources, manage local tasks (startup, monitoring, cleanup), deliver asynchronous messages to local tasks, inform interested parties of local state changes (e.g. local task dies or is moved elsewhere), monitor local resource usage (cpu, disk, mem)</td>
</tr>
<tr>
<td>Client library</td>
<td>Provides programming interface to clients, communication (routing, message passing, fragmentation, data conversion, authentication, encryption, use of different communications media), task management (initiate, monitor tasks), resource location (obtain information about named resources), access to data stores</td>
</tr>
<tr>
<td>Resource managers</td>
<td>Manage a group of named resources (hosts, processes, file servers), implement/enforce locally-specified policy, behave as a &quot;virtual host&quot; (you make requests of it as if it were a host, which it delegates to other hosts), may manage resources on several hosts, may be a replicated service, may migrate tasks from one host to another</td>
</tr>
<tr>
<td>File servers</td>
<td>Provide access to data sets by SNIPE processes, replicate data sets as needed to provide redundancy, maintain file metadata (including locations) in RCDS, implemented as a simple SNIPE process which functions as a source or sink</td>
</tr>
</tbody>
</table>

### RCDS (Resource Cataloging and Distribution System)

- Provides stable storage for metadata attributes of hosts, tasks, services, etc.
- Allows dynamic update on a per-attribute basis
- Replicates data for redundancy peer servers immediately/automatically updated
- Scalable queries or updates can go to any peer
- Supports end-to-end security authenticated updates; signed metadata

### Core Components

- RCDS
- Host Daemons
- Client Library
- Resource Managers
- File Servers

### Host Daemons

- Mediates the use of resources on a host
- Authenticates requests for local processing
- Enforces access restrictions on local resources
- Manages local tasks (startup, monitoring, cleanup)
- Delivers asynchronous messages to local tasks
- Informs interested parties of local state changes (e.g. local task dies or is moved elsewhere)
- Monitors local resource usage (cpu, disk, mem)

### Client Library

- Provides programming interface to clients
- Communication (routing, message passing, fragmentation, data conversion, authentication, encryption, use of different communications media)
- Task management (initiate, monitor tasks)
- Resource location (obtain information about named resources)
- Access to data stores
### Playgrounds

- Facilitates secure execution of mobile code
- Can be native machine code (modulo OS support), or interpreted (Java, Limbo, Python)
- Downloads code from a file server
- Verifies authenticity and access rights
- Enforces usage and access restrictions
- Logs violations
- Provides run-time environment

### SNIPE use of RCDS

- Host metadata: architecture, OS, network interfaces, resource manager, public keys
- Process metadata: current state and location, public keys
- Service metadata: locations of replicated services and data sets
- Multicast Group metadata: locations of multicast group servers

### Host Metadata

- Indexed by host URL
  - x-snipe://cetus1a.cs.utk.edu/
- Contains:
  - host architecture, OS name, and OS version
  - characteristics of host network interfaces (network, address, netmask, port, speed)
  - URLs of resource managers for this host
  - public keys for this host

### Process Metadata

- Indexed by Process URL
- Contains:
  - current host, pid, uid, gid, etc.
  - current SAPs for process communications (network, address, netmask, port, bandwidth)
  - SAP of current host daemon (for asynchronous messages)
  - “worry list” of processes that want to know if this process dies, migrates, cannot be reached, etc.

### File and Service Metadata

- Description (file content-type, creation date, etc.)
- Signatures (for static files - optional)
- Current Locations

### Multicast Group Metadata

- Multicast groups are named by URLs
- Host daemons elect themselves as servers for one or more multicast groups, depending on the presence or absence of other nearby servers for that group
- RCDS keeps track of locations of servers for any particular multicast group
- Multicast servers relay messages to other multicast servers, and to local clients
- Processes join a group by using RCDS to find servers for that group, then contacting a server that’s nearby
API Characteristics

- All identifiers are globally scoped:
  - URLs (hosts, processes, services, data stores)
  - Email addresses (security principals)
- Most identifiers are location-independent
- Integer resource-ids used within a process (similar to UNIX file descriptors)

Client Library Layers

- Simple communications core:
  - `snipe_connect()`, `snipe_listen()`, `snipe_read()`, `snipe_write()`, `snipe_sndmsg()`, `snipe_getmsg()`, `snipe_putattr()`, `snipe_getattr()`
- Core uses TCP, UDP, DNS, RCDS, SONAR
- Resource management, multicast, process migration, external file I/O layered above
- Planned: MPI, RPC, PVM layers above that
  - What we have is FT_MPI and Hcore

Client Library

<table>
<thead>
<tr>
<th>User Program</th>
<th>File I/O</th>
<th>Message Passing</th>
<th>Process Management</th>
<th>Resource Registration</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Message Routing</td>
<td>SONAR</td>
<td>DNS</td>
<td>RCDS</td>
</tr>
</tbody>
</table>

Connection Maintenance During Process Migration

1. Process B informs RCDS when it migrates to a new location. B also notifies its peers.
2. A gets connection migration notification from B. OR B fails to acknowledge message from A.
3. A asks RCDS for B’s current SAPs.
4. A contacts B at its new address, establishes new connection.
5. Communication resumes.

Other Features of SNIPE

- Can handle more than one connection media and protocol at a time, and then switch between them depending on message type, priority etc
  - NEXUS claims to be the only system that can do this.
  - NEXUS does not do it automatically but via a series of callbacks.

SNIPE

- Scalable Networked Information Processing Environment
- LAPTOP
- MPP
- RCDS
- Input Data Set
- Replicated Data Sets
- Node lose
- Com link lose
SNIPE Applications

- MPI_Connect()
- FT_MPI
- Fixing IBM’s implementation of MPI on the SMP SP2 nodes.
  - As used by LLNL for 2nd place in the 1999 Fall Top500 list with 2.144 TerraFlops
    - Was #1 for a month…

HARNESS

- Heterogeneous Adaptable Reconfigurable NEtworked SystemS
- Also described as a
  - “distributed, reconfigurable and heterogeneous computing environment that supports dynamically adaptable parallel applications”

Why HARNESS

- Basics:
  - Built on the Distributed Virtual Machine (DVM) concept
  - Allows different applications (new and legacy) to interact and alter their environment
    - Change their view of the world / multiple different views
- Why heterogeneous?
  - In terms of architecture, OS and high level programming paradigm.
    - I.e. a message passing code on a dedicated MPP should be able to communicate with a VSM application on a workstation cluster

HARNESS

- Adaptable and Reconfigurable - in terms of both the DVM itself and the application
- Application level:
  - An application can be reconfigured and steered by external processes (via tool modules)
  - An application can ask to change its view of the world by requesting that the DVM view changes its actions/functionality or capabilities.
    - I.e. I need a FFT solver, (the DVM finds one, loads it, makes its interface available and this discards it)

HARNESS

- Merge/split with other VMs
- Computer based Daemon
- Operation within VM uses Distributed Control
- Customization and extension by dynamically adding plug-ins
Plug-ins

Programming Models

- Different parts of an application can use different programming models/API
- 4 to be included
  - plug-in interface (HARNESS itself)
  - FT-MPI
  - PVM
  - IceT (from Emory)
    - Java based message passing system that allows code segments to be uploaded and executed on the fly.

Application Level plug-ins

HARNESS

- EMORY University
  - Has made a complete HARNESS system
  - JAVA based so no problems with Plug-ins not working
    - Its all BYTECODE
  - They also have a PVM plug-in
    - Works at the TD and SD protocol level
    - OK the level the messages work at in between the PVM Daemons and the PVM tasks... i.e. no need to recompile for PVM to work on their system.

- ORNL was building the control algorithms and C-based plug-ins
  - No single point (or set of points) of failure for Harness. It survives as long as one member still lives.
  - All members know the state of the virtual machine, and their knowledge is kept consistent w.r.t. the order of changes of state. (Important parallel programming requirement!)
  - No member is more important than any other (at any instant) i.e. here isn’t a pass-around “control token”

HARNESS

- EMORY DVM system
  - Consists of many parts
  - DVMs
    - Each has a master kernel that keeps track of the others in the DVM (HDVM server)
  - Single point of contact name service so you can find your own DVM
    - Had fault tolerance problems
    - We fixed this by making a ring of name servers
HARNESS

- **Scalable Design**
  \[ 1 \leq S \leq P \]

- **Supports fast host adding**
- **Parallel recovery from multiple host failures**

**ORNL**
- Symmetric Control Algorithm and C based HCORE

- Not built yet. Although they do have a control algorithm prototype in Java.

**UTK had to build a FT-MPI implementation**

- **What ICL-UTK needed for FT-MPI**
  - A kernel to plug into
  - Naming service
  - MetaData store to hold our plug-in state information

  - **ALL IN ‘C’**

**G_Hcore**

- **API**
  - Find cores to run on
  - Load package
  - Unload
  - Get ref to functions within a package
  - Execute a function
    - Local invocation (function call)
    - New thread
    - Fork
    - Call by socket
      - Protocol handler

- **Speedy**
  - Emory DVM invocation times (mSec)
    - RMI Local: 0.172 Remote: 1.406
    - Socket Local: 10.4 Remote: 8.6
  - G_hcore
    - Direct (new thread): 0.187
    - TCP Local: 0.58 Remote: 1.08
    - UDP Local: n/a Remote: 0.30
  - All tests done on the Torc cluster over 100MB ethernet
Next

• Break
• Future
  – Avaki
  – Unicore / Unicore plus
  – Globus 2.0b & 2.2
  – XMLing and SOAPing
  – Globus 3 (OGSA)
• Globus/Harness demo if possible
• Homework