GRID / MetaComputing

Naming, RPC, PSEs

CS 594 Spring 2003

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Some Material from talks by Mark Baker, Henri Casanova and Keith Moore.

Contents - Naming Services

- Naming
  - What's in a name?
  - Naming, binding, and distribution.
  - Name consistency.
  - Scaling.
  - Capabilities.
  - Examples.

Naming Services - Emphasis

- Naming is intimately related to network (access and location) transparency and migration transparency.
- We need a separate name service in addition to the naming schemes used in the context of specific services.

Naming Services - Emphasis

- There are separate concerns to be addressed:
  - Designing the name space.
  - Meeting administrative requirements to partition the name space.
  - Creating an implementation that scales.

Naming Services - Emphasis

- A system such as the DNS that resolves names on a world-wide scale represents a considerable engineering achievement - as does the system of routing daemons that resolves IP addresses.
- Should understand the engineering problems and strong motivation for getting naming right.
- Caching and replication are key to naming service implementation.
  - Compare Internet2, IBP & RCDS

Things that are named...

- People.
- Files.
- Machines.
- Services.
- Programs.
- Variables.
- Datatypes.
- Mailing lists.

What Names Do

- Uniquely identify something.
- Can name a not-yet-created object.
- Specify membership in a group.
- Provide information about location, function.
- Convey knowledge of a secret.

Embedding Information in Names

- Names can be location-independent or location-dependent:
  - `http://www.cs.utk.edu/` is location-dependent.
  - `/user/me` is not.
  - Is PVM Tid 0x40001 ????
- At an extreme, a pure name conveys no information about the named object, except by convention:
  - **`/u/pvm/bin/foo`** is probably some sort of executable.

Embedding Information in Names

- Impure names imply a commitment not to change the embedded information:
  - `423 - 9745790` *must* stay in the `423` area code.
    - What happens when the area code changes to 865??
      - Do we change all the Names? If so WHO does it and makes sure its correct, how do we know everybody has changed including those outside our domain?
      - What about calls that use it now?
      - Are the updates synchronous?

Pure Names and Location

- How do we find an object with a pure name?
  - Example system that provide pure names;
    - Legion and Globe.
    - SNIPE provides location information relating to which RCDS server in which DNS domain to ask first….
- Use name servers.
  - Server remembers where objects are.
  - Three ways to use them:
    - Hash name to a name server; object tells server where it is… a matrix of names...
    - Name contains location of name server.
    - Hierarchical naming.

Pure Names and Location

- But how to find name servers?
  - Hacks…
    - ENV, hard coded..
- Alternative - broadcast name request to everybody...
- Cache location hints to avoid lookups.
  - (Maybe just ask portmap on port 111)
    - 111 is a hard coded value.

Hierarchical Naming

- Like UNIX files.
- Name is a sequence of components, separated by dividers.
  - Example:
    `fagg/cs/utk/u/server`
- Can implemented by a hierarchy of name servers.
  - Find each name server from its parent.
  - How to find parent?
    - Answer - hacks...

Relative versus Absolute Naming

- Absolute - every process sees the same namespace.
  - Like UNIX.
  - Advantage - same name means same thing to everybody.
- Relative - every process has its own root
  - Like World Wide Web.
  - Complex tangle of directories.
  - Advantages - easy to customize, no need for central root server.

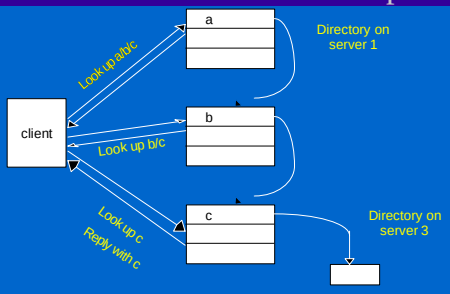
Errors and Inconsistencies

- What if the requested name didn't exist?
  - Maybe it was not created yet.
  - Maybe it was deleted.
  - Maybe a server was down.
  - Maybe name was misspelled.
- With caching, or replicated name servers, inconsistencies can arise.
- Deal with them by:
  - Not caching.
  - Ignoring the problem.
  - Using a real distributed database.

Scaling and Uniqueness Control

- In a large system, how to make sure names are unique?
- *Solution* - central registry.
  - Problem - Doesn't scale...
- *Solution* - local management of sub-trees of hierarchical name space.
  - Problem - This can result in inefficiencies.

Distributed Name Lookup



Naming and Security

- Naming and security are closely related.
- Names are "trusted" to refer to certain things.
- The name server(s) must be trusted.
- Capabilities combine naming and security.

Capabilities

- A capability is a secret name for an object, complete with access permissions.
- Anybody who knows the secret name can operate on the object as specified by those permissions.
  - An object might have many capabilities, each conferring different rights.

Capabilities

- Common implementation - capability is a digitally-signed statement from some authority that says *"The bearer has permission to perform operations X, Y, and Z on object O"*.
  - Often uses public-key cryptography.

Naming Methods

- Many fancy mechanisms have been proposed or implemented.
  - Symbolic links - indirection through names.
  - Filter links - a "view" of a directory that hides or renames some of the contents.
  - Union directories - a single directory that appears to contain all files in two or more other directories.
  - Computed directories - not a directory at all, but the output of some program.
    - CGI scripts or SQL query lookup results

Case Study - DNS

- The Domain Name System (DNS) is a name service whose principal naming database is used across the Internet.
- It replaced the original naming scheme in which all host names and addresses were held in a single central file and downloaded by FTP to all the computers that required them.

DNS

Shortcomings of the original scheme:

- It did not scale to large numbers of computers.
- Local organizations wished to administer their own naming schemes.
- General name service was needed, not just one that served to lookup computer addresses.

DNS

- The objects named by DNS are primarily computers - mainly IP numbers are stored as attributes.
- In principal any type of object named - its architecture gives rise to a variety of implementations.
- It also allows organizations or departments to manage their own naming data.

DNS

- DNS holds hundreds of thousands of names around the world.
- Any name can be resolved by any client.
- This is achieved by hierarchical partitioning of the database, by replication of naming data and caching.

DNS - Domain Names

- DNS names are called domain names:
  - `osiris.sis.port.ac.uk` (Computer)
  - `sis.port.ac.uk` (Department)
  - `port.ac.uk` (Organisation)
- The name space has a tree structure - a domain name consists of one or more strings called labels separated by the period "`.`" delimiter.

DNS - Domain Names

- Domains are collections of domain names; syntactically, a domain's name is the common suffix of the domain names within it, but otherwise it cannot be distinguished from, for example, a computer name.
- For example, cs.utk.edu is a domain which contains `kenner.cs.utk.edu`.

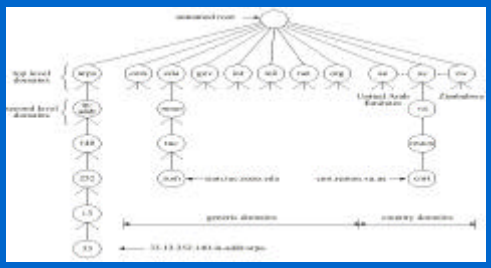
DNS - Domain Names

- DNS is designed for use in multiple implementations, each of which may have its own name space.
- In practice, only one is in widespread use - that is the one used for naming across the *Internet*.
- The Internet DNS name space is partitioned both organizationally and geographically.

DNS - Domain Names

- The names are written with the highest-level domain on the right.
- Top-level organizational domains may be: `com`, `edu`, `gov`, `mil`, `net`, `org`, `int`.
- Top-level geographical domains may be: `us`, `uk`, `fr`...
- In practice, the organizational domains mentioned above cover US organizations alone - reflecting the origins of DNS.

DNS Name Space



DNS - Domain Names

- Domain names are completely independent of their locations.
- For examples, a `.uk` domain could have objects located in France (company office).
- DNS servers do not recognize relative names - all names are referred to the to the global root.

DNS - Queries

- Host name resolution - generally applications use DNS to resolve host names into IP addresses.
- Mail host location - electronic mail software uses the DNS to resolve domain names into the IP addresses of mail hosts - computers that will accept mail for those domains
- Reverse Resolution (RARP) - some software applications requires a domain name to be returned given an IP address… why ?

DNS - Queries

- Host Information - the DNS can store the machine architecture type and operating system against the domain names of the hosts.
- Well know services - a list of the services run by a computer (`ftp`/`telnet`) and the protocol used to obtain them (UDP/TCP) can be returned, given the computer's domain name.

DNS - Name Servers

- The problems of scale are treated by the combination of partitioning the naming database and by replicating and caching parts of it close to the points of need.
- The DNS database is distributed across a logical network of servers.
- Each server holds part of the naming database - primarily data for the local domain.

DNS - Name Servers

- Most queries concern computers in the local domain, and are satisfied by servers within that domain.
- However, each server records the domain names and addresses of other name servers, so that queries pertaining to objects outside the domain or in a separately administered sub-domains can be satisfied.

DNS Name Servers

- Naming data is divided into zones - each zone contains the following:
  - Attribute data for names in a domain.
  - The names and addresses of servers that provide authoritative (reliable) data for the zone.
  - The names and addresses of servers that hold data for delegated sub-zones.
  - Zone management parameters, such as those governing the caching and replication of zone data.

Types of DNS query/response

Name	Description	Remarks
A	IP address	To query / response the IP address of a host name.
NS	name server	To query / response the authoritative name server for a domain.
CNAME	canonical name	To query / response the alias of a host name
PTR	pointer control	To query / response the host name of an IP address.
HINFO	host info	To query / response the host information. The response is two arbitrary strings specifying the CPU and operating system.
MX	mail exchange record	To query / response the mail relay domain of a particular domain.

DNS Name Servers

- The DNS architecture specifies that each zone must be replicated authoritatively in at least two failure-independent servers.
- There are two types of server that are considered to provide authoritative data:
  - Primary (*master*) servers are the ones that read zone data directly from a local master file.
  - Secondary (*slave*) servers download zone data from a primary server.

DNS Name Servers

- Servers communicate periodically with the primary server, to check whether their stored version matches that held by the primary server.
- If a secondary's copy is out of date, the primary sends it the latest version.
- The frequency of the secondary's check is set by administrators as a zone parameter, and its value is typically once or twice a day.

DNS Name Servers

- Any server is free to cache data from any other server, this avoids having to contact them again when the same data is required - this *cache is set as non-authoritative data*.
- Entries in a zone have a time-to-live value.
- When a non-authoritative server obtains data from a authoritative server, it notes the time-to-live.

DNS Name Servers

- It will only provide its cached data to clients for up to this time; when queried after the time period has expired, it re-contacts the authoritative server to check its data.

DNS - Navigation and Query Processing

- In DNS, the user agent is called a resolver.
- It accepts queries, formats them into messages expected under DNS protocols, and communicates with one or more name servers in order to satisfy the queries.
- A simple request-reply protocol is used, typically using UDP (using port 42/53).

DNS - Navigation and Query Processing

- The resolver times out and resends its query if necessary - primary/secondary name servers.
- DNS protocol allows multiple queries to be packed into a single request packet - saves network bandwidth.

DNS - BIND

- The Berkeley Internet Name Domain (BIND) is an implementation of DNS for systems running BSD UNIX.
- Client programs link in library software to act as the DNS resolver.
- DNS "name server" computers run the *named* daemon.
- BIND allows for three categories of name server: primary, secondary and caching-only servers.

Case Study RCDS

- Resource Cataloging and Distribution System (RCDS)
- Used to publish "metadata" or just web pages on the internet
  - Used as a publishing tool for documents
  - Used by SNIPE for internal and external data
    - External = how to contact me, what I offer, and more on how, who and why
  - Used by HARNESS for repository location

"It doesn't work when I click here!"

- URLs become stale
- Web servers fail or become overloaded
- Network links fail or become congested
- The server might be halfway across the world

Why Good URLs Go Bad

- Web pages move from one host to another
- Directory structures get re-organized
- Hostnames change or are re-assigned
- Sometimes the resource no longer exists

Sources of Failure

- A URL is tied to a particular server, and…
  - not a location independent name
- Everyone uses the same server…
- The network fails… or
- The server becomes overloaded…
- Links to the server become congested ...
- Users cancel and restart their downloads...
- Can you say "snowball effect"?

Inefficient Network Utilization

- TCP has over a 10× overhead (short xfers)
  - TCP connect send to machine and disconnect = 1.4mSec under Linux
  - UDP packet to and from machine 100uSec
- TCP does not degrade gracefully during connection establishment and slow-start
- HTTP cannot be multicast
- Web browsers do not exploit mirror sites

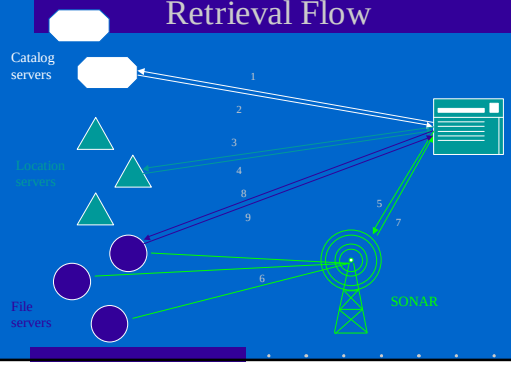
The RCDS Approach

- Resources are replicated to multiple servers (which may be geographically dispersed)
- Location database is updated when replicas are created or deleted
- SONAR helps users and apps find which replicas are nearby
- Resource descriptions contain integrity checks and are cryptographically signed

RCDS Components

- Publication Tools
- Replication ("mirroring") Tools
- Collection Managers
- Catalog Servers
- Location Servers
- File Servers (http, ftp, etc.)
- Clients (web browser, proxy server, etc.)

Retrieval Flow



RCDS Innovative Features

- Resolution of URLs, URNs and LIFNs
- Scalable replication of Location and Catalog info
- Multiple transfer protocols for a single resource
- Multiple representations for a single resource
- Robustness/fault-tolerance features
- Support for correct caching
- Easy deployment

URLs, URNs, and LIFNs

- URL - string encoding of an access protocol
- URN - stable, resolvable, resource name
  - name-to-resource binding can change
- LIFN - stable, resolvable resource name
  - name-to-resource binding never changes
  - all replicas of the resource are identical

Location Independent File Name (LIFN)

- A LIFN is a kind of URN
- Names a particular sequence of octets
- Once assigned, it can never be changed
- Used for communication within RCDS
  - replication tools need an exact file name
  - location information is indexed by LIFN
  - resource descriptions contain LIFNs which precisely describe instances of the resource

URN Resolution

(works for URLs and LIFNs too!)

`urn:inet:netlib.org:pvm3`

How to resolve URNs of type `inet`? → DNS

```
NAPTR s/([^:]*):.*/ \1/
```

Where do I find servers for `netlib.org`? → DNS

```
SRV rcds.cs.utk.edu
SRV rcds.epm.ornl.gov
SRV rcds.cs.rice.edu
```

Tell me about `urn:inet:netlib.org:pvm3` → RCDS

```
Title: Parallel Virtual Machine
Author: Robert Manchek
Content-Type: application/x-tar
MD5: 30a480cff1035ba0343a8..
LIFN: netlib.org:199606041143.3434
```

How LIFNs are Used

URN:netlib.org:pvmv3

Title: Parallel Virtual Machine
Author: Robert Manchek
Content-Type: application/x-tar
MD5: 30a480cff1035ba0343a8..
LIFN: netlib.org:199606041143.3434
Copying-Policy: free
Netlib.Language: C

LIFN: netlib.org:199606041143.3434

ftp://netlib.cs.utk.edu/pvm3/pvm3.11.tar.gz
ftp://netlib.att.com/pvm3/pvm3.11.tar.gz
ftp://netlib1.epm.ornl.gov/pvm3/pvm3.11.tar.gz
ftp://www.hensa.ac.uk/netlib/pvm3/pvm3.11.tar.gz

resource description

locations

How LIFNs are Used

URN:netlib.org:pvmv3

Title: Parallel Virtual Machine
Author: Robert Manchek
Content-Type: application/x-tar
MD5: 30a480cff1035ba0343a8..
LIFN: netlib.org:199608151542.9236
Copying-Policy: free
Netlib.Language: C

LIFN: netlib.org:199606041143.3434

ftp://netlib.cs.utk.edu/pvm3/pvm3.11.tar.gz
ftp://netlib.att.com/pvm3/pvm3.11.tar.gz
ftp://netlib1.epm.ornl.gov/pvm3/pvm3.11.tar.gz
ftp://www.hensa.ac.uk/netlib/pvm3/pvm3.11.tar.gz

LIFN: netlib.org:199608151542.9236

ftp://netlib.cs.utk.edu/pvm3/pvm3.12.tar.gz
ftp://netlib1.epm.ornl.gov/pvm3/pvm3.12.tar.gz

When a resource is changed, a new LIFN is issued...

How LIFNs are Used

URN:netlib.org:pvmv3

Title: Parallel Virtual Machine
Author: Robert Manchek
Content-Type: application/x-tar
MD5: 30a480cff1035ba0343a8..
LIFN: netlib.org:199608151542.9236
Copying-Policy: free
Netlib.Language: C

LIFN: netlib.org:199606041143.3434

ftp://netlib.att.com/pvm3/pvm3.11.tar.gz
ftp://www.hensa.ac.uk/netlib/pvm3/pvm3.11.tar.gz

LIFN: netlib.org:199608151542.9236

ftp://netlib.cs.utk.edu/pvm3/pvm3.12.tar.gz
ftp://netlib1.epm.ornl.gov/pvm3/pvm3.12.tar.gz
ftp://netlib.att.com/pvm3/pvm3.12.tar.gz

As replicas of the new resource are created,
they are added to the list of locations for the new LIFN

How LIFNs are Used

URN:netlib.org:pvmv3

Title: Parallel Virtual Machine
Author: Robert Manchek
Content-Type: application/x-tar
MD5: 30a480cff1035ba0343a8..
LIFN: netlib.org:199608151542.9236
Copying-Policy: free
Netlib.Language: C

LIFN: netlib.org:199606041143.3434

ftp://www.hensa.ac.uk/netlib/pvm3/pvm3.11.tar.gz

LIFN: netlib.org:199608151542.9236

ftp://netlib.cs.utk.edu/pvm3/pvm3.12.tar.gz
ftp://netlib1.epm.ornl.gov/pvm3/pvm3.12.tar.gz
ftp://netlib.att.com/pvm3/pvm3.12.tar.gz
ftp://www.hensa.ac.uk/netlib/pvm3/pvm3.12.tar.gz

Copies of obsolete resources may be deleted as
new resources are propagated to servers

Choosing from Multiple Representations

URN:netlib.org:pvmv3

```
Title: Parallel Virtual Machine
Author: Robert Manchek
Num-Representations: 3
Content-Type[1]: application/x-tar
MD5[1]: a152f65789972d23ed2b6a58940b6c29
LIFN[1]: netlib.org:199608151542.9236
Content-Type[2]: application/x-shar
MD5[2]: 1887c1bc3f0b1c8cc2e1630d1bc1ed42
LIFN[2]: netlib.org:199608151542.9237
Content-Type[3]: application/x-zip
MD5[3]: 8979dfe0ba9480fc0df23f3ba146ac98
LIFN[3]: netlib.org:199608151542.9238
Copying-Policy: free
Netlib.Language: C
```

A resource can have multiple representations. The description of a resource will contain a summary of the available representations. The client can choose the representation that best suits the user's needs.

Choosing from Multiple Transfer Protocols

LIFN: netlib.org:1996081515 42.9236

```
ftp://netlib.cs.utk.edu/pvm3/pvm3.12.tar.gz
http://netlib.cs.utk.edu/pvm3/pvm3.12.tar.gz
webnfs://netlib.cs.utk.edu/pvm3/pvm3.12.tar.gz
smb://netlib1.epm.ornl.gov/pvm3/pvm3.12.tar.gz
ftp://netlib1.epm.ornl.gov/pvm3/pvm3.12.tar.gz
ftp://netlib.att.com/pvm3/pvm3.12.tar.gz
http://netlib.att.com/pvm3/pvm3.12.tar.gz
ftp://www.hensa.ac.uk/netlib/pvm3/pvm3.12.tar.gz
http://www.hensa.ac.uk/netlib/pvm3/pvm3.12.tar.gz
```

A resource may be available via multiple protocols. The client can use a high performance protocol if it supports it, or it can fall back to http or ftp.

Robustness / Fault-Tolerance

- Clients are not bound to any particular location, catalog, file, or SONAR server
  - can randomize server choices and fail-over to alternate servers
- Collection Manager (on file server) periodically checks all files for integrity
  - Missing/damaged files can be restored from any other server with a copy of that resource

Cache Support

- LIFN-to-file binding is immutable; If LIFN is current, and client has a cached copy of that file, then the file is current.
- Inexpensive URN-to-LIFN lookup
- Description of resource contains TTL and expire-date for each URN-to-LIFN binding

Ease of Deployment

- For providers:
  - update DNS servers (new version of named)
  - install RCDS servers
  - register RCDS servers in DNS
  - register resources in RCDS
- For repositories:
  - switch to RCDS-aware mirror tools
- For users:
  - install RCDS-aware proxy, SONAR

RCDS use within SNIPE

- Used to store information about all entities such as hosts, file servers, repositories, processes, classes of processes.
- Examples:
  - x-snipe://cs.utk.edu/snipe_app/fagg/sol/29481/10674.183121/
  - serial 7
  - assertion 0 SNIPE_COMM_TCP_FBACK [latin1] = "sol.cs.utk.edu:7647" 10674.15821983 10681.15821983 1 5
  - assertion 1 SNIPE_STATE [latin1] = "2" 10674.15821950 10681.15821950 1 4
  - sol> query_name_test "c*" x-snipe://cs.utk.edu/snipe-reg/appl/class/
  - urn x-snipe://cs.utk.edu/snipe-reg/appl/class/
  - serial 11
  - assertion 0 class-count [latin1] = "2" 10641.3953375 10648.3953375 1 10
  - assertion 1 class:0 [latin1] = "demo0" 10641.3203285 10648.3203285 1 9
  - assertion 2 class:1 [latin1] = "benchmarking-dist" 10641.3953392 10648.3953392 1 11

RCDS use within HARNESS

- Used as a method of resolving requests for Java class libraries at run time

Harness at SC 98

- Built a replicated repository of class libraries that Emory`s system used to dynamically download during execution
  - Had a few hiccups such as the system needed only specify a single URL as the Java loaded only expected the class libraries to be on a single web server or file system.
  - System was built from the old RCDS web-personal proxy

Harness at SC 98

- How it worked
  - The Emory system asked for class libraries from a specific web server
- edu/Emory/mathcs/harness/services/H_RemoteRunnable.class
- http://proxy/rcds-urn/harness/edu/Emory/mathcs/harness/services/H_RemoteRunnable.class
- The URN is then associated with multiple LIFNs (Location Independent File Names) which each point to a URL where each copy of the repository is.

Harness at SC 98

- Each repository is a copy of the class libraries
  - may only be a partial copy if disk space is to be conserved or if only the commonly used plug-ins (class libraries) are to be replicated
- 3 Replicated copies at SC98 + 2 else where
  - one on the Emory machine (Solaris)
  - one on the ORNL machine (sunu6f? Solaris)
  - one on a UTK laptop (Apache under Linux)
  - + sol.utk.edu and another at mathcs.Emory.edu

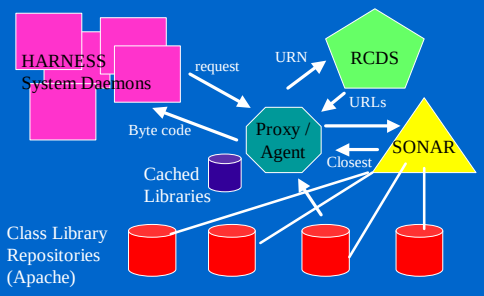
Harness at SC 98

- Once the URL had been requested, the proxy/agent would get the list of other URLs from the RCDS server.
- The list could then be sorted via connectivity using SONAR

Harness at SC 98

- As the Java run-time was unable to understand a redirect, and only excepted the binary class library, the proxy would get the class and then forward it.
  - Allowing caching… which is very very useful if one part of the system needs a certain class library (plug-in) then so will the rest if we are maintaining a comprehensive synchronous system.

Harness at SC 98



RPC

- RPC makes it possible for a client to access a remote service by simply calling a local procedure.
- The RPC interface makes it possible for client programs to be written in a simple way, familiar to most programmers.
- RPC makes it easy to run existing codes in distributed environments with few, if any, changes.

Writing a Client and a Server

- The RPC system consists of a number of components, including languages, libraries, daemons and utility programs.
- Together these make it possible to write client and servers.
- In the client/server system, the glue that holds everything together is the interface definition.

Interface Definition Language

- Interface Definitions are written in a language named IDL.
- It permits procedure declarations in a form closely resembling function prototypes in ANSI C.
- IDL files can also contain type definitions, constant declarations, and other information needed to correctly marshall parameters and unmarshall results.

Interface Definition Language

- A crucial element in every IDL file is an identifier that uniquely identifies the interface - the client sends this identifier in the first RPC message and the server verifies that it is correct.
- In this way, if a client in-advertantly tries to bind to the wrong server, or even to an older version of the right server, the server will detect the error and the binding will not take place.

Interface Definition Language

- The first step in writing a client/server application is usually calling the *uuidgen* program, asking it to generate a prototype IDL file containing an interface identifier guaranteed never to be used again in any interface anywhere generated by uuidgen.
  - Universal Unique Identifier - 128 bits.
  - Contains a timestamp and a host identifier.
  - Used to uniquely identify a service.
  - **e.g., uuid**

Interface Definition Language

- The next step is editing the IDL file, filling in the names of the remote procedures and their parameters.
- When the IDL file is complete, the IDL compiler is called to process it - this outputs three files:
  - A header file (e.g. `interface.h` in C terms).
  - The client stub.
  - The server stub.

Interface Definition Language

- The header file contains the uuid, type definition, constant definition, and function prototypes.
- The client stub contains the actual procedures that the client program will call - these procedures are responsible for collecting and packing the parameters into the outgoing message and then calling the runtime system to send it.

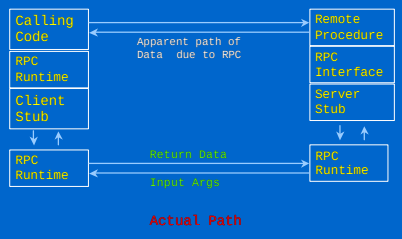
Interface Definition Language

- The server stub contains the procedures called by the runtime system on the server machine when an incoming message arrives - these, in turn, call the actual server procedures that do the work.
- The next step is for the application writer to write the client and server code - both of these are then compiled, as are the two stub procedures.

Interface Definition Language

- The resulting client code and stub object files are then linked with the runtime library to produce the client executable.
- A similar procedure happen with the server side code.
- At runtime, the client and server are started to make the application run.

Effect of the IDL and RPC Runtime



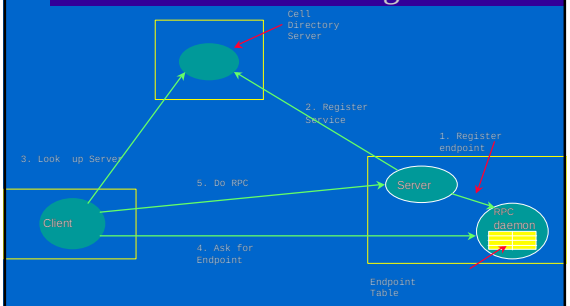
DCE RPC

- Interface Definition Language - The usual...
- Uuidgen:
  - Generates a prototype IDL file containing unique ID (embedding location and timestamp)
    - ONC version is just called rpcgen
    - Timestamps help with security
- IDL compiler produces - Header file, Client and Server stubs.
- Semantics:
  - At-most-once (default).
  - At-least-once (for important operations, such as read).

RPC Binding

- Server registers with local RPC daemon
  - Passes endpoint (port) to daemon (1).
- Server registers with Cell directory (2).
- Client looks up service's location with directory server (3).
- Client goes to well-known port to ask RPC daemon for endpoint of service (4).
- Client performs RPC using endpoint (5).

Client-to-Server Binding in DCE



Other Interface Designs

- Encapsulate the whole server in such a way that you can manipulate it as a complete entity (object/component)
  - Requires more daemons for naming and resolution services
  - communications may have to be indirect to allow for security and translation
  - interfaces may be *dynamic*, I.e. not known until run-time (linking) or even at call (invoke) time.
    - Not compiled in.

Component Based Distributed Computing

- OO Distributed Technologies
- CORBA
- DCE vs CORBA
- JavaBeans

Distributed Technologies

- Rather it is the distributed object technology which can build general multi-tiered enterprise intranet and internet applications.
- CORBA (Common Object Request Broker Architecture) is turning from a sleepy heavyweight standards initiative to a major competitive development activity that battles with COM and JavaBeans to be the core distributed object technology.

Distributed Technologies

- The commercial architecture is evolving rapidly and is exploring several approaches which co-exist in today's (and any realistic future) distributed information system.
- The most powerful solutions involve *distributed objects*.
- There are three important commercial object systems - CORBA, COM and JavaBeans.

OO Programming Languages

- An object-oriented program, for example in Smalltalk , Java or C++ consists of a collection of interacting objects, each of which provides a service specified by its interface.
  - *Like* a server interfaced by RPC

OO Programming Languages

- **Objects communicate with one another by sending messages.**
  - A message is a request for an object to perform one of its methods (operations).
  - It is the object that receives a message – not the sender – that determines how to carry out the method.
  - The set of messages to which an object can respond is called its interface.

OO Programming Languages

- **Objects "encapsulate" data and the "code" of their methods.**
  - In other words, the sender of a message requesting a method does not know how it is carried out.

Object Identity

- Each object has an 'identifier' in the underlying object system, for example the value of a Java object reference is an object identifier or OID.
- The identifier of an object enables it to be indicated as the target of a message.
- Object-oriented programming systems support enquiries as to whether one OID refers to the same object as another. (e.g. *equals* in Java).

Actions

- **An action in an object-oriented program is initiated by an object sending a message to another requesting a *method invocation*.**
- **The object invoked executes the appropriate method and then returns control to the invoking object.**
- **An invocation of a method can have two effects:**
  - The state of the object may be changed.
  - Further invocations on methods in other objects may take place.

Actions

- As an invocation can lead to further invocations of methods in other objects, an action is a chain of related invocations each of which eventually returns.
- A message is a request for an action and can have additional information (arguments) needed to carry out the action.

Actions

- The receiver will perform some method (execute its code) to carry out the request.
- The interpretation of a message can vary with different recipients:
  - e.g. a message to an object to draw itself would result in a different action according to whether the object is a square or a circle.

Classes and Instances

- Since classes are used to create new objects, each object is an instance of a class.
- All the instances of a class use the same methods and can share the code of the implementation, but each instance has its own set of instance variables with their own values.
- Classes in programs can be organised as a hierarchy in which one class can make use of the code of another.

Classes and Instances

- Single inheritance allows a class to make use of the code of one other class - that is it can be a sub-class.
- A sub-class specifies that all of its instances will be the same as instances of another class (its superclass) except for differences explicitly stated.

Classes and Instances

- These differences may consist of simple extensions (extra data and methods) or they may consist of re-definitions (overrides) of the methods of the parent class.
- For example, a class `Shape` may define the properties common to all graphical objects and the classes `Circle`, `Square`, etc. will define the properties specific to circles and squares.

Interface versus Implementation

- The users of an object just see **the interface view of its class**, whereas the implementers **see the details of how the data is represented and manipulated.**
- Provided that the two views are independent, the implementer is free to improve the implementation at any time, either by adding functionality or by altering the data representation.

Interface versus Implementation

Interface of stack

```
int pop ()
void push (int n)
```

Implementation of stack

```
int stack [];
int stackpointer;
public final int STACKSIZE = 20;
public push(int n) {
  stack[stackpointer++]= n;
};
```

Multiple Inheritance

- Multiple inheritance allows a class to make use of the code of several other classes.
- Java does not provide multiple inheritance - but allows classes to implement several *interfaces* as well as inheriting from one class.
  - In Java, an interface is an abstract definition of the signatures of a set of methods.
  - Java interfaces are allowed to extend one or more other interfaces.

Distributed Technologies

- These have similar approaches and it is not clear if the future holds a single such approach or a set of inter-operable standards.
  - CORBA is a distributed object standard managed by the OMG (Object Management Group) comprised of **700+** companies.

Distributed Technologies

- COM is Microsoft's distributed object technology initially aimed at Window machines.
- JavaBeans (augmented with RMI and other Java 1.2 features) is the "pure Java" solution - cross platform but unlike CORBA, not really cross-language!

CORBA

- The OMG (Object Management Group), formed in 1989:
  - Aimed to encourage the adoption of distributed objects systems to gain the benefits of OO for software development and to make use of distributed systems which were becoming widespread.
- By this time, client-server architectures were very widely used.
- The OMG advocated the use of open systems based on standard OO interfaces.

CORBA

- The OMG introduced a metaphor - the *object request broker* whose role is to help a client to invoke a method on an object.
- This role involves:
  - Locating the object.
  - Activating the object if necessary.
  - Communicating the client's request to the object which carries it out and replies.
- The CORBA specification includes an IDL (Interface Definition Language).

CORBA

- Object interfaces are defined in IDL, thus enabling clients and objects to be implemented in different languages.
- Note - that interface languages were already widely used to enable clients to communicate by means of RPC with servers in different languages.

CORBA

- A major difference between CORBA and earlier RPC systems is that CORBA IDL is intended for defining interfaces to remote objects whereas the earlier IDLs were designed for specifying interfaces to servers.
- Therefore CORBA IDL provides a type allowing Remote-Object IDs (ROID) to be passed as arguments and results in RMI.

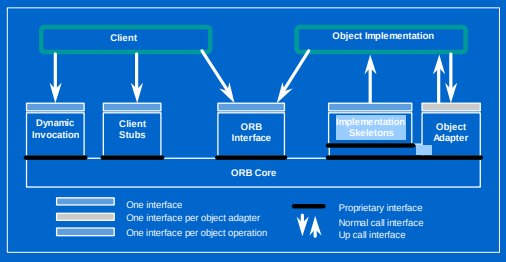
CORBA

- Another difference is that CORBA IDL provides a special client interface which allows client messages to be bound dynamically at run time.
- In 1991, a specification for an object request broker known as CORBA (Common Object Request Broker Architecture) was agreed by a group of companies including DEC, HP, Hyperdesk, NCR , Object Design and Sun.

CORBA

- The CORBA 2.0 and 3.0 Specifications are available on the OMG Web site Web at the following URL:
  `http://www.omg.org/corbask.htm`
- The OMG home page and a list of technical reports can be accessed from there.

Object Request Broker (ORB)



CORBA Components

- Client stub - Each stub represents an object operation (a possible request) which a client invokes in a language - dependent manner (e.g., by calling a subroutine which represents the operation).
- Dynamic Invocation - Alternatively, a client may dynamically construct and invoke request objects which can represent any object operation.
- Implementation Skeleton - Each skeleton provides the interface through which a method receives a request.
- Object Adapter - Each object adapter provides access to those services of an ORB (such as activation, deactivation, object creation, object reference management) used by a particular ilk of object implementation.
- ORB Interface- The interface to the small set of ORB operations common to all objects, e.g., the operation which returns an object's interface type.

Writing a CORBA Application

- The development process for writing a CORBA based application comprises of the following steps (typical):
  - Define IDL.
  - Generating client stub and server skeleton using IDL compiler
  - Object implementation (server).
  - Client implementation.
  - Register Server with an ORB daemon.
  - Run client by contacting an ORB daemon.

Future of CORBA

- Been incorporated into Netscape - accessed via Internet Inter-Orb Protocol (IIOP).
- Object Management Group looking at higher-level components of an Object Management Architecture - not just CORBA

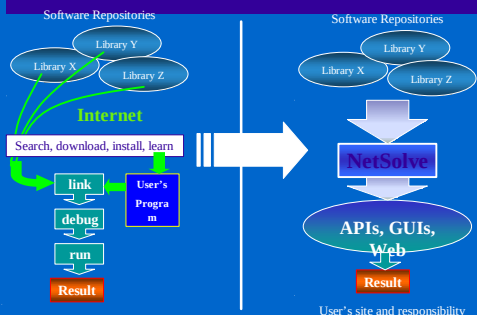
CORBA vs DCE

- Procedural v. Object-Oriented:
  - DCE IDL has no inheritance, parameterised exceptions.
- Access to distribution infrastructure:
  - CORBA has fewer facilities so far
  - Authentication, File services.
- DCE and CORBA can inter-operate.

Problem Solving Environments PSEs

- May use any of the technologies already discussed
- Provide a problem specific solution
  - I.e. an interface that suites a problem area very well, rather than a general API that may solve all most problems to some extent.
- Examples: Netsolve (UTK/UCSD) and ninf(Japan).
- If PSE were perfect, application users would only ever use them
  - Ease of use verses programming in HPF/MPI/SHMEM

Motivation for **NetSolve**

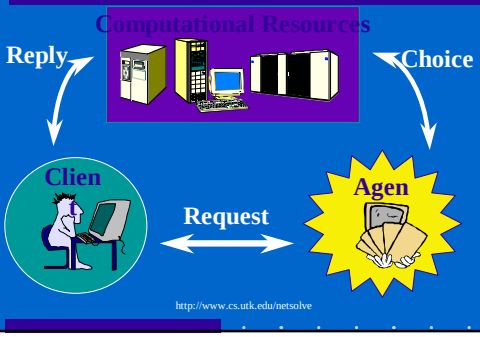


NetSolve - Some Basic Concepts

- Client-server **agent-based** global computing
- Multiple and simple client interfaces
- **Load Balancing** and basic **Fault Tolerance**
- Heterogeneity
- Non-hierarchical software architecture

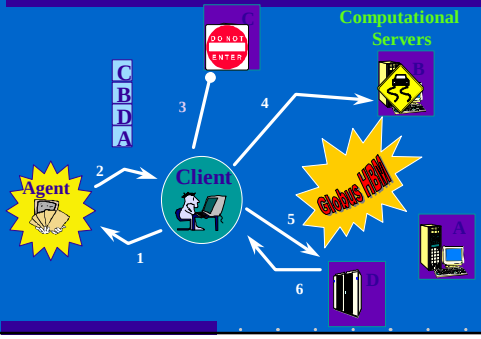
http://www.cs.utk.edu/netsolve

NetSolve - The big picture

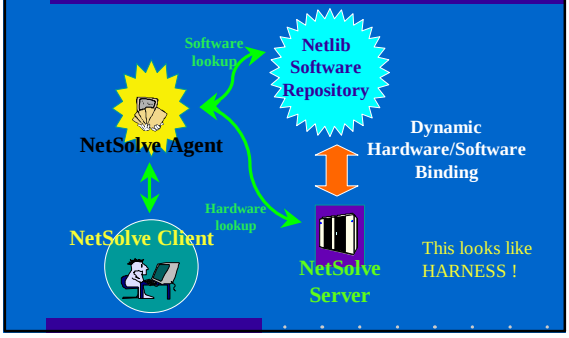


http://www.cs.utk.edu/netsolve

NetSolve - Failure Detection & Recovery



NetSolve-2 onwards



PSE / Computational Servers

- Performance is an issue…
  - People like better performance and if the end code/server is really just an MPI/PVM job then we do CARE how it is scheduled.
    - Hence Scheduling next