Distributed Applications, Web Services, Tools and GRID Infrastructures for Bioinformatics

HPC Infrastructures

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NETTAB 2006 - Santa Margherita di Pula (CA) - July 10-13, 2006
SOFTWARE INFRASTRUCTURE
Overview

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SOFTWARE INFRASTRUCTURE
Overview (Michelangelo @ CILEA)

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<tr>
<th>Fortran, C/C++ codes</th>
<th>Fortran, C/C++ codes</th>
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<td>MVAPICH</td>
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- INTEL, PGI, GNU compilers
- BLAS, LAPACK, ScaLAPACK, ATLAS, ACML, FFTW libraries

- C3Tools, SSH, \textit{blade}, ad-hoc scripts
  - Ganglia, Nagios
  - PBS/TORQUE batch system + MAUI scheduler

- LINUX CentOS
- InfiniBand, Gigabit Ethernet
- NFS
  - SAN + GFS

- LCG-2 / gLite (EGEE II)
COMPATIBILITY ISSUES
Kernel vs new hardware

- Latest vanilla kernel: **2.6.16.9**
- CentOS kernel: **2.6.9-22**
- UnionFS v1.1.4 ↔ kernel **2.6.9 ÷ 2.6.14**
- InfiniBand IBGD-1.8.2 ↔ kernel ≤ **2.6.11**
- GFS cluster 1.01 ↔ kernel ≤ **2.6.14**
- GFS cluster 1.02 ↔ kernel **2.6.15** patched by FC5
- Qlogic qla2xxx (severe bug fixed) ↔ kernel ≥ **2.6.15**
- AMD CPU Dual Core 275 ↔ kernel ≥ **2.6.12**

[Up to May 2006]
COMPATIBILITY ISSUES
Kernel vs new hardware

kernel version 2.6. ... 9 10 11 12 13 14 15 16 ...

- Latest vanilla kernel
- CentOS kernel 2.6.9
- UnionFS v1.1.4 2.6.9 ÷ 2.6.14
- InfiniBand IBGD-1.8.2 \( \leq 2.6.11 \)
- GFS cluster 1.01 \( \leq 2.6.14 \)
- GFS cluster 1.02 2.6.15 (patched by FC5)
- Qlogic qla2xxx (severe bug fixes) \( \geq 2.6.15 \)
- AMD CPU Dual Core 275 \( \geq 2.6.12 \)

[Up to May 2006]
COMPATIBILITY ISSUES
Kernel vs new hardware

Roll up your own kernel and patch as needed!

- vanilla kernel **2.6.16.16**
- UnionFS 1.1.4 (patched)
- IBGD 1.8.2 (patched)
- GFS cluster 1.02 (patched)
- Qlogic qla2xxx (bug fixed)
- AMD CPU Dual Core 275 (supported)
CLUSTER SERVICES

SERVER / MASTERNODE

NTP -> NTP
DNS <-> DNS
DHCP
TFTP
NFS
SSH
LDAP/NIS/...

LAN

PRIVATE NETWORK

CLUSTER-WIDE TIME SYNC
DYNAMIC HOSTNAMES RESOLUTION
INSTALLATION / CONFIGURATION (+switches backup and configuration)
SHARED FILESYSTEM
REMOTE ACCESS FILE TRANSFER PARALLEL COMPUTATION (MPI)
AUTHENTICATION

LDAP/NIS/...
Installation can be performed:
- interactively
- non-interactively

**Interactive** installations:
- finer control

**Non-interactive** installations:
- minimize human intervention and let you save a lot of time
- are less error prone
- are performed using programs (such as RedHat Kickstart) which:
  - “simulate” the interactive answering
  - can perform some post-installation procedures for customization
MASTERNODE
Ad-hoc installation once forever (hopefully), usually interactive:
  - local devices (CD-ROM, DVD-ROM, Floppy, ...)
  - network based (PXE+DHCP+TFTP+NFS)

CLUSTER NODES
One installation reiterated for each node, usually non-interactive.
Nodes can be:
  1) disk-based
  2) disk-less (not to be really installed)
1) Disk-based nodes

- CD-ROM, DVD-ROM, Floppy, ...
  Time expensive and tedious operation

- HD cloning: mirrored raid, dd and the like
  A “template” hard-disk needs to be swapped or a disk image needs to be available for cloning, configuration needs to be changed either way

- Distributed installation: PXE+DHCP+TFTP+NFS
  More efforts to make the first installation work properly (especially for heterogeneous clusters), (mostly) straightforward for the next ones

2) Disk-less nodes

- Live CD/DVD/Floppy
- NFS
- NFS + UnionFS
- initrd (RAM disk)
CLUSTER MANAGEMENT

Existential toolkits

Are generally made of an ensemble of already available software packages thought for specific tasks, but configured to operate together, plus some add-ons.

Sometimes limited by rigid and not customizable configurations, often bounded to some specific LINUX distribution and version. May depend on vendors' hardware.

- **Free and Open**
  - OSCAR (Open Source Cluster Application Resources)
  - NPACI Rocks
  - xCAT (eXtreme Cluster Administration Toolkit)
  - OpenSCE (Open Scalable Cluster Environment)
  - Warewulf

- **Commercial**
  - IBM CSM (Cluster Systems Management)
  - Scyld Beowulf
  - HP, SUN and other vendors' Management Software...
CLUSTER MANAGEMENT
Network-based Distributed Installation

- PXE
- DHCP
- TFTP
- INITRD

- INSTALLATION
  - Kickstart/Anaconda
  - Customization through Post-installation

- ROOTFS OVER NFS
  - NFS + UnionFS
  - Customization through UnionFS layers
CLUSTER MANAGEMENT
Network-based Distributed Installation

**Network Bootstrap Program (pxelinux.0)**
- DHCPDISCOVER
- DHCP
- DHCPOFFER
  - IP Address / Subnet Mask / Gateway / ...
  - Network Bootstrap Program (pxelinux.0)
- DHCPREQUEST
- DHCPACK
- tftp get pxelinux.0
  - PXE
  - DHCP
  - TFTP

**CLIENT / COMPUTING NODE**
- tftp get pxelinux.cfg/HEXIP
  - PXE+NBP
  - TFTP
- tftp get kernel foobar
  - PXE+NBP
  - TFTP
- tftp get initrd foobar.img
  - kernel foobar
  - TFTP

**SERVER / MASTERNODE**
CLUSTER MANAGEMENT
Network-based Distributed Installation

- Server / Master Node
  - get NFS: kickstart.cfg
  - NFS
  - get RPMs
  - NFS
  - tftp get tasklist
  - TFTP
  - tftp get task#1
  - TFTP
  - tftp get task#N
  - TFTP
  - tftp get pxelinux.cfg/default
  - TFTP
  - tftp put pxelinux.cfg/HEXIP
  - TFTP

- Client / Computing Node
  - kernel + initrd
  - NFS
  - anaconda + kickstart
  - NFS
  - kickstart: %post
  - TFTP
  - kickstart: %post
  - TFTP
  - kickstart: %post
  - TFTP
  - kickstart: %post
  - TFTP
  - kickstart: %post
  - TFTP
CLUSTER MANAGEMENT
Network-based Distributed Installation

ROOTFS over NFS+UnionFS

CLIENT / COMPUTING NODE

SERVER / MASTERNODE

kernel + initrd

mount /hopeless/roots/root
NFS+UnionFS

kernel + initrd

mount /hopeless/roots/overlay
NFS+UnionFS

kernel + initrd

mount /hopeless/roots/gfs
NFS+UnionFS

kernel + initrd

mount /hopeless/clients/IP
NFS+UnionFS

/hopeless/roots/192.168.10.1
RW

/hopeless/roots/gfs
RO

/hopeless/roots/overlay
RO

/hopeless/roots/root
RO

Resultant file system

RW!

DELETED FILEs

NEW FILEs
CLUSTER MANAGEMENT
Administration Tools

Requirements:
✔ cluster-wide command execution
✔ cluster-wide file distribution and gathering
✔ must be simple, efficient, easy to use for CLI addicted

C3 tools - The Cluster Command and Control tool suite
- allows configurable clusters and subsets of machines
- concurrently execution of commands
- supplies many utilities
  - cexec (parallel execution of standard commands on all cluster nodes)
  - cexecs (as the above but serial execution, useful for troubleshooting and debugging)
  - cpush (distribute files or directories to all cluster nodes)
  - cget (retrieves files or directory from all cluster nodes)
  -crm (cluster-wide remove)
  - ... and many more

DSH - Distributed Shell
CLUSTER MANAGEMENT

Monitoring Tools

- Ad-hoc scripts (BASH, PERL, ...) + cron

- Ganglia
  - excellent graphic tool
  - XML data representation
  - web-based interface for visualization
  - http://ganglia.sourceforge.net/

- Nagios
  - complex but can interact with other software
  - configurable alarms, SNMP, E-mail, SMS, ...
  - optional web interface
  - http://www.nagios.org/
CLUSTER MANAGEMENT

Ganglia at work

<table>
<thead>
<tr>
<th>Name / Info</th>
<th>Load Averages</th>
<th>%CPU User, Nice, System, Idle</th>
</tr>
</thead>
<tbody>
<tr>
<td>DEMOCRITOS/SISSA Grid (4 sources)</td>
<td>124.76, 124.33, 124.26</td>
<td>45.5, 2.1, 1.5, 29.7</td>
</tr>
<tr>
<td>Hosts up: 113 (276 CPUs Total)</td>
<td>Hosts down: 1</td>
<td></td>
</tr>
</tbody>
</table>

**cerbero (physical view)**

- Cluster Localtime: July 2, 2006, 9:19 pm
- Hosts up: 70 (186 CPUs Total)
- Hosts down: 0

**helium (physical view)**

- Cluster Localtime: July 2, 2006, 9:19 pm
- Hosts up: 7 (16 CPUs Total)
- Hosts down: 0

**briareo (physical view)**

- Cluster Localtime: July 2, 2006, 9:19 pm
- Hosts up: 29 (88 CPUs Total)
- Hosts down: 0
CLUSTER MANAGEMENT

Ganglia at work /2

There are 70 nodes (188 CPUs) up and running. There are no nodes down.
A shared file system to ease management and supply a centralized repository:
- NFS – Network File System

A file system to deal with intensive I/O operations both serial and parallel (parallel file system).
Available choices:
- GFS – Global File System
- GPFS – Global Parallel File System
- PVFS – Parallel Virtual File System
- Lustre

Performance is not an issue!
Performance IS an issue!
Central repository for:

- packages (installation/updates)
- cluster-wide configurations
- libraries
- non-critical executables (not needed at boot-up)
- sporadic non I/O intensive operations
- ...

Can supply the root file system (and/or UnionFS layers) for disk-less nodes and can export the /home file system as well.
STORAGE
Parallel File System: GFS - Features

- designed from scratch as a cluster-based distributed file system
- works in a SAN/LAN environment
- single system image style view of the file system (consistency)
- fully 64bit
- journaled
- works with LVM volume managers
- scalable
STORAGE
Parallel File System: GFS - Michelangelo

Storage Array #1

S A N

Fibre Channel

Storage Array #2

GNBD servers

node00

node07

node63

GNBD clients

node01 node02 node03 node04 node05 node06

node08 node09 node10 node11 node12 node13

node64 node65 node66 node67 node68 node69
STORAGE
Parallel File System: GFS - Components

CMAN (Cluster MANager)
- manages membership (join/leave actions, broadcast/multicast heartbeat)
- uses quorum to avoid “split brain” situations (each node has configurable number of votes)
- if the quorum is lost, the file system becomes unavailable and most cluster applications (GFS related) will not operate until the cluster is again inquorate
- doesn't scale well

Fence
- ensures data integrity of shared storage devices by fencing failing nodes
- makes sure that a node is gone before recovering data (power fencing!)
- if heartbeats among machines are lost, the nodes will attempt to fence each other...

Note: we wrote our own fence agents (BASH and PERL scripts) that interact with a small utility, *blade*, that allows remote hardware control of the blade chassis.

Locking – CMAN/DLM (Distributed Lock Manager) – GULM (Grand Unified Lock Manager)
- ensures that nodes in the cluster who share the data on the SAN don't corrupt each other's data (makes atomic operations possible)

Device mapper – LVM2 (Logical Volume Manager, GFS-aware)
- handle physical volumes providing software RAID (striping, mirroring)

Network block device – GNBD (Global Network Block Device)
- allows to export a block device over TCP
We have a pool of users and a pool of resources, then what?
- some software that control available resources
- some other software that decide which application to execute based on available resources
- some other software devoted to actually execute applications

The resource manager allows:
- better resource control
- better resource utilization
- better access control

The scheduler should have:
- **Fair Share mechanism**
- **Backfill scheduling algorithm**
- reservations for high priority jobs
- more control parameters on users
- commands for querying the scheduler
RESOURCES MANAGEMENT
The Queue System - PBS/TORQUE + MAUI

- General Components
  - A resource manager (PBS server)
  - A scheduler (MAUI scheduler)
  - Many “executors” (PBS MOMs)

Suggestions
Requests

Orders!!!

Some info collections
A typical job session

1) User submits job with qsub command

2) Server places job into execution queues and asks scheduler to examine job queues

3) MAUI queries MOMs for determining available resources (memory, CPU, load, ...)

4) Examines job queues, and eventually allocates resources for job, returning job ID and resource list to server for execution

5) Server instructs MOM Superior to execute the command section of the batch script

6) MOM Superior executes batch commands, monitors resource usage of child processes and reports back to server

7) Server e-mails the user notifying job end
Fairshare is a mechanism which allows historical resource utilization information to be incorporated into job feasibility and priority decisions.

Fairshare information only affects the job's priority relative to other jobs.

Using the standard fairshare target
- the priority of jobs of a particular group which has used too many resources over the specified fairshare window is lowered
- the priority of jobs which have not received enough resources will be increased
RESOURCES MANAGEMENT
Fair sharing – How it works

- At the beginning all the jobs are created equals (in term of priority)
- However some jobs are more/less equal than others
- Priority is increased/decreased when the fair sharing quota is below/above from its target
- Gain/lost in priority:
  - is configurable
  - 1% far from fair share means 4 hours on queues (DEMOCRITOS example)

Assume groupA has 50% of fairshare usage. When it use more resources than those assigned, the priority of the jobs will be decreased; when it uses less resources, the priority of its jobs will be increased.

When a group is not computing, the other group can benefit from the available resources

- better resource utilization
- no idle CPUs

GROUPCFG[groupA]  FSTARGET=50%  PRIORITY=5000
GROUPCFG[groupB]  FSTARGET=50%  PRIORITY=5000
Backfill is a scheduling optimization which allows a scheduler to make better use of available resources by running jobs out of order.

Consider this example with a 10 CPUs machine:

Job1 ( priority=20 walltime=10 nodes=6 )
Job2 ( priority=50 walltime=30 nodes=4 )
Job3 ( priority=40 walltime=20 nodes=4 )
Job4 ( priority=10 walltime=10 nodes=1 )

1) When Maui schedules, it prioritizes the jobs in the queue according to a number of factors and then orders the jobs into a 'highest priority first' sorted list.

Sorted list:

Job2 ( priority=50 walltime=30 nodes=4 )
Job3 ( priority=40 walltime=20 nodes=4 )
Job1 ( priority=20 walltime=10 nodes=6 )
Job4 ( priority=10 walltime=10 nodes=1 )
2) It starts the jobs one by one stepping through the priority list until it reaches a job which it cannot start.

3) All jobs and reservations possess a start time and a wallclock limit, so MAUI can determine:
   - the completion time of all jobs in the queue
   - the earliest the needed resources will become available for the highest priority job to start (time X)
   - which jobs can be started without delaying this job (job4)

➔ Enabling backfill allows the scheduler to start other, lower-priority jobs so long as they do not delay the highest priority job, essentially filling in holes in node space.

➔ Backfill offers significant scheduler performance improvement:
   - increased system utilization by around 20% and improved turnaround time by an even greater amount in a typical large system
   - backfill tends to favor smaller and shorter running jobs more than larger and longer running ones: It is common to see over 90% of these small and short jobs backfilled.
Computational Software

Compilers
- INTEL → icc, ifc/ifort
- PGI → pgcc, pgf77
- GNU → gcc, g77, g95

Scientific Libraries
- BLAS / LAPACK / ScaLAPACK / ...
- ATLAS / ACML (optimized)
- FFTW

Parallel Environment
- MVAPICH (MPI over InfiniBand)
How can the complexity of an heterogeneous compilation environment be handled?

- shell variables set by system (of all the nodes) in:
  - /etc/profile
  - /etc/csh.login, /etc/csh.cshrc
  - /etc/bashrc

- and consider files in /etc/profile.d/

- shell variables set by users in users' profile files:
  - $HOME/.bash_profile, $HOME/.bashrc
  - $HOME/.tchsrc

- for new users, modify prototype profile files in /etc/skel/

What if one needs to change the environment during the same session?

- $ export PATH=/some/bin/dir:/some/other/bin/dir:$PATH
- $ export LD_LIBRARY_PATH=/some/lib/dir:/some/other/lib/dir:$LD_LIBRARY_PATH
- $ export SOME_LICENCE_FILE=/some/license/file
- $ export VOODOO_ENV_VAR=1

...
The Modules package is a set of scripts and information files that provides a simple command interface for modifying the environment.

- The administrator can setup some configuration files (in TCL) that allows *module* (when invoked) to set the needed environment variables for the running shell.

- Users can configure their own *modulefiles* with personalized environments and can switch environment with just few user-friendly commands.

```
$ module avail
----------------- /opt/modules-3.1.6/versions -----------------
3.1.6
----------------- /opt/modules-3.1.6/modulefiles -----------------
gnu       mpi   mpich-intel-p4   pgi-6.05
icc-9.0    mpich-gnu-gm  mpich-intel-shmem  pgi-6.12
icc64-9.0  mpich-gnu-p4  mpich-pgi-gm
ifc-9.0    mpich-gnu-shmem mpich-pgi-p4
ifc64-9.0  mpich-intel-gm mpich-pgi-shmem
```

```
$ module load icc-9.0
$ module load ifc-9.0
$ module load mpich-intel-gm
$ module list
Currently Loaded Modulefiles:
   1) icc-9.0   2) ifc-9.0   3) mpich-intel-gm
$ module unload icc-9.0 ifc-9.0
$ module load icc64-9.0 ifc64-9.0
$ module list
Currently Loaded Modulefiles:
   1) mpich-intel-gm   2) icc64-9.0   3) ifc64-9.0
```
The Michelangelo cluster is integrated into the LCG-2/gLite GRID using the following mechanism:

- an external server is acting as a Computing Element (CE)
  - standard Scientific LINUX 3.0.6 + LCG-2/gLite middleware
  - the Local Resource Manager system used by the CE is on the masternode (PBS/Torque)

- Each node of the cluster has installed the Worker Node (WN) middleware needed to run jobs coming from the CE.
That's All Folks!

( questions ; comments ) | mail baro@democritos.it -s uheilaaa

( complaints ; insults ) &>/dev/null
ACKNOWLEDGMENTS

MATTEO VIT - EXADRON, Amaro (UD)

STEFANO COZZINI - CNR-INFM DEMOCRITOS, Trieste

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REFERENCES AND USEFUL LINKS

Cluster Toolkits:
- OSCAR - Open Source Cluster Application Resources
  http://oscar.openclustergroup.org/
- NPACI Rocks
  http://www.rocksclusters.org/
- Scyld Beowulf
  http://www.beowulf.org/
- CSM - IBM Cluster Systems Management
  http://www.ibm.com/servers/eserver/clusters/software/
- xCAT - eXtreme Cluster Administration Toolkit
  http://www.xcat.org/
- OpenSCE - Open Scalable Cluster Environment
  http://www.opensce.org/
- Warewulf
  http://www.warewulf-cluster.org/

Resources Management:
- MAUI - Cluster Scheduler / TORQUE - Resource Manager
- PBS/OpenPBS - Portable Batch System
  http://www.openpbs.org/
- SGE – Sun Grid Engine
  http://gridengine.sunsource.net/

Monitoring Tools:
- Ganglia
  http://ganglia.sourceforge.net/
- Nagios
  http://www.nagios.org/
- Zabbix
  http://www.zabbix.org/

Cluster File Systems:
- CLUSTER/GFS - RH Cluster Suite and the Global File System
  http://sources.redhat.com/cluster/
  http://sources.redhat.com/cluster/gfs/
- PVFS - The Parallel Virtual File System
  http://www.parl.clemson.edu/pvfs/
- Lustre
  http://www.lustre.org/
- GPFS - The IBM Global Parallel File System

Management Tools:
- openssh/openssl
  http://www.openssh.com
  http://www.openssl.org
- C3 tools - The Cluster Command and Control tool suite
- DSH - Distributed SHell
  http://www.netfort.gr.jp/~dancer/software/dsh.html.en

- Hopeless, a system for building disk-less clusters (Christian Pellegrin, November 2005)
  http://sole.infis.univ.ts.it/~chri/hopeless.html
- CentOS - RH-based Linux distribution
  http://www.centos.org/
- UnionFS - A Stackable Unification File System
  http://www.unionfs.org
  http://www.fsl.cs.sunysb.edu/project-unionfs.html
Compilers:
- GNU – gcc/g77
  http://gcc.gnu.org/
- G95 – GNU f95 Compiler
  http://www.g95.org/
- PGI – Portland Group
  http://www.pgroup.com/
- Intel – icc/ifort
  http://www.intel.com/
- NAG – Numerical Algorithms Group
  http://www.nag.com/

Scientific Libraries:
- Netlib Repository
  http://www.netlib.org/
- LAPACK - Linear Algebra PACKage
  http://www.netlib.org/lapack/
- ScaLAPACK – Scalable LAPACK
  http://www.netlib.org/scalapack/
- BLAS - Basic Linear Algebra Subprograms
  http://www.netlib.org/blas/
- ATLAS - Automatically Tuned Linear Algebra Software
  http://math-atlas.sourceforge.net/
- FFTW - Fastest Fourier Transform in the West
  http://www.fftw.org/
- ACML - AMD Core Math Library
- MKL – Intel Math Kernel Library
  http://www.intel.com/

Modules - Environment Modules Project
http://modules.sourceforge.net/

Parallel Environment:
- MPI - The Message Passing Interface standard
  http://www-unix.mcs.anl.gov/mpi/
- OpenMPI – A High Performance Message Passing Library
  http://www.open-mpi.org/
- LAM / MPI – Parallel Computing
  http://www.lam-mpi.org/
- PVM – Parallel Virtual Machine
  http://www.csm.ornl.gov/pvm/

GRID Projects:
- EGEE II
  http://www.eu-egee.org/
- CERN Datagrid
  http://eu-datagrid.web.cern.ch/eu-datagrid/
- GRID.IT
  http://www.grid.it/
- EGRID
  http://www.egrid.it/

GRID Middleware
- LCG-2 / gLite
  http://lcg.web.cern.ch/LCG/
- gLite
  http://glite.web.cern.ch/
- GLOBUS
  http://www.globus.org/
Some acronyms...

**DEMACRITOS** – Democritos Modeling Center for Research In aTOmistic Simulations  
**INFM** – Istituto Nazionale per la Fisica della Materia (Italian National Institute for the Physics of Matter)  
**CNR** – Consiglio Nazionale delle Ricerche (Italian National Research Council)  

**HPC** – High Performance Computing  
**OS** – Operating System  
**LINUX** – LINUX is not UNIX  
**GNU** – GNU is not UNIX  
**PXE** – Preboot Execution Environment  
**DHCP** – Dynamic Host Configuration Protocol  
**TFTP** – Trivial File Transfer Protocol  
**NFS** – Network File System  
**INITRD** – Initial RamDisk  

**SSH** – Secure SHell  
**LDAP** – Lightweight Directory Access Protocol  
**NIS** – Network Information Service  
**DNS** – Domain Name System  
**NTP** – Network Time Protocol  

**SNMP** – Simple Network Management Protocol  
**TCP** – Transmission Control Protocol  
**UDP** – User Datagram Protocol  

**CLI** – Command Line Interface  
**BASH** – Bourne Again SHell  
**PERL** – Practical Extraction and Report Language  
**XML** – eXtensible Markup Language  
**TCL** – Tool Command Language  

**LAN** – Local Area Network  
**SAN** – Storage Area Network  
**NAS** – Network Attached Storage  

**GPFS** – Global Parallel File System  
**PVFS** – Parallel Virtual File System  

**GFS** – Global File System  
**LVM** – Logical Volume Manager  
**CMAN** – Cluster MANager  
**DLM** – Distributed Lock Manager  
**GNBD** – Global Network Block Device  
**GULM** – Grand Unified Lock Manager  
**LAPACK** – Linear Algebra PACKage  
**ScaLAPACK** – Scalable LAPACK  
**BLAS** – Basic Linear Algebra Subprograms  
**ATLAS** – Automatically Tuned Linear Algebra Software  
**FFTW** – Fastest Fourier Transform in the West  
**ACML** – AMD Core Math Library  
**PVM** – Parallel Virtual Machine  
**MPI** – Message Passing Interface  
**MPICH** – Message Passing Interface/CHameleon  
**MVAPICH** – MPI over VAPI  
**VAPI** – Verbs Level Interface  
**PBS** – Portable Batch System  
**MOM** – Machine Oriented Mini-server  
**EGEE** – Enabling Grids for E-sciencE  
**LCG** – LHC Computing Project  
**LHC** – Large Hadron Collider  

**CE** – Computing Element  
**WN** – Worker Node  
**SE** – Storage Element  
**LRM** – Local Resource Manager  
**GRM** – Global Resource Manager