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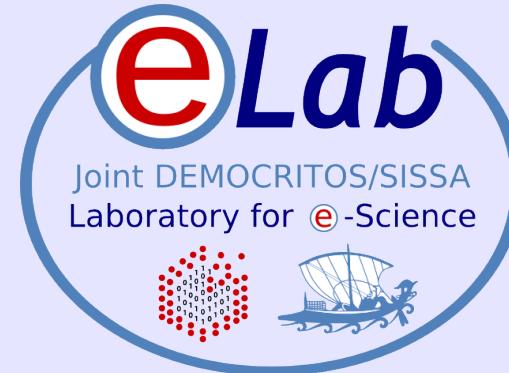
Advanced School in High Performance and GRID Computing

3 - 14 November 2008

Installation procedures for clusters.

BARICEVIC Moreno
S.I.S.S.A.
International School for Advanced Studies
Via Beirut 2-4
34014 Trieste
ITALY

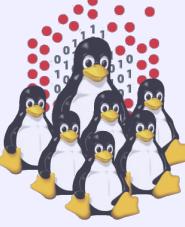
**Advanced School in
High Performance
and GRID Computing**



**Installation Procedures
for Clusters**

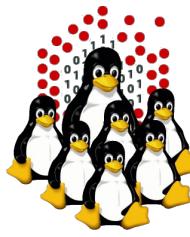
Moreno Baricevic

CNR-INFM DEMOCRITOS, Trieste

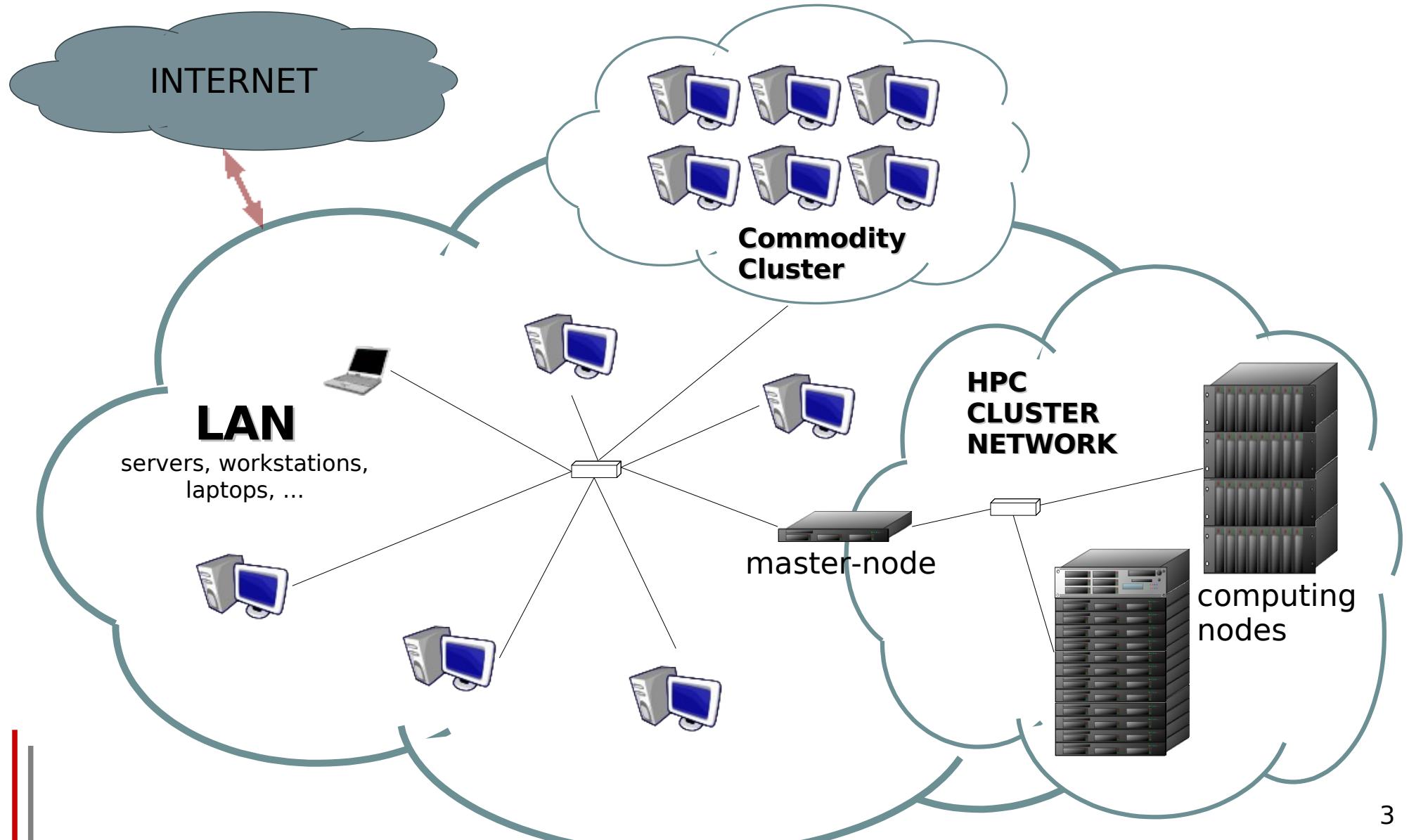


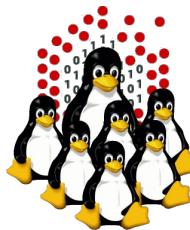
Agenda

- Cluster Services
- Overview on Installation Procedures
- Configuration and Setup of a NETBOOT Environment
- Troubleshooting
- Cluster Management Tools
- Notes on Security
- Hands-on Laboratory Session

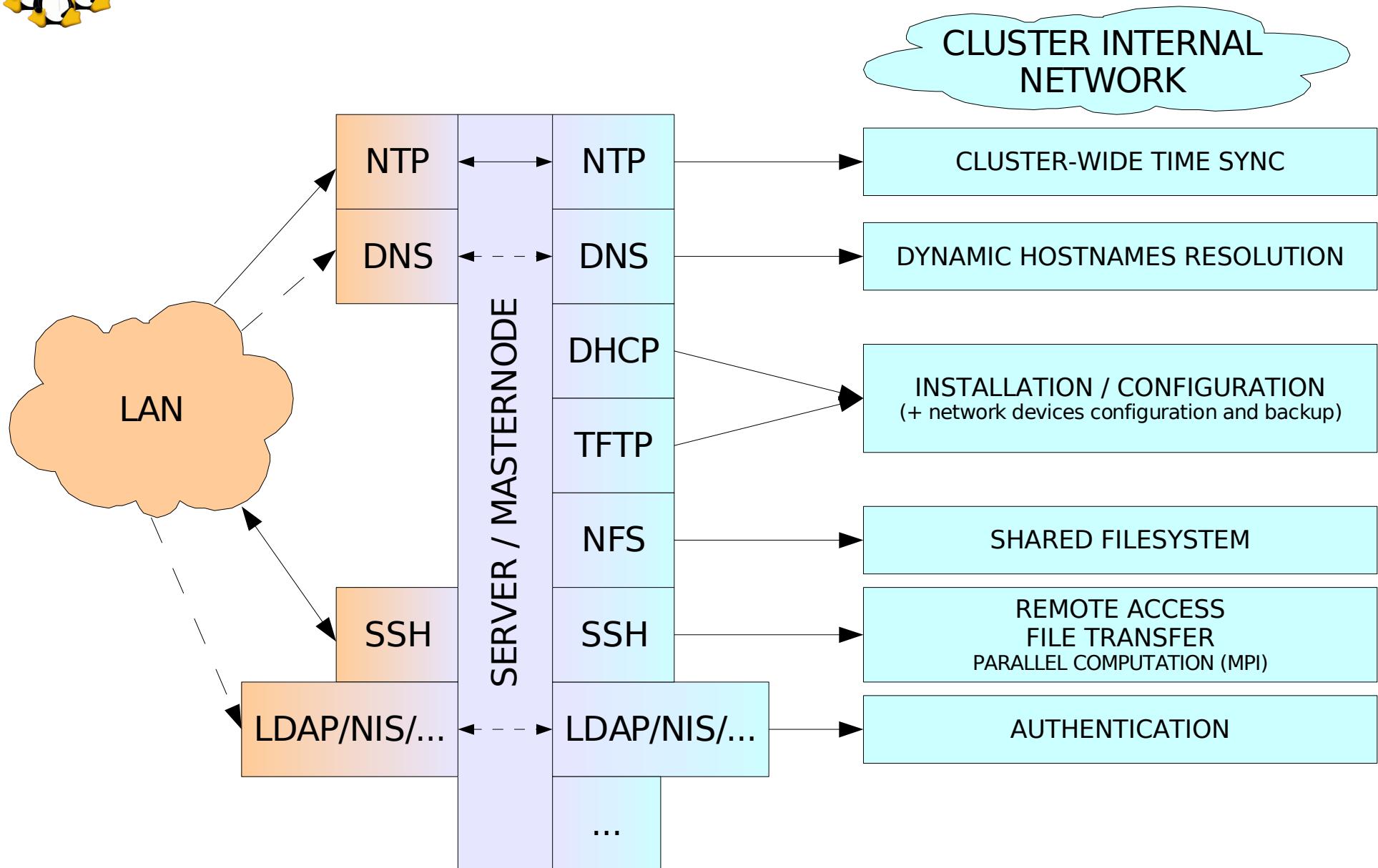


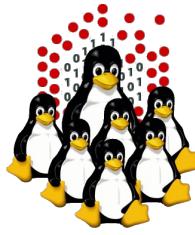
What's a cluster?





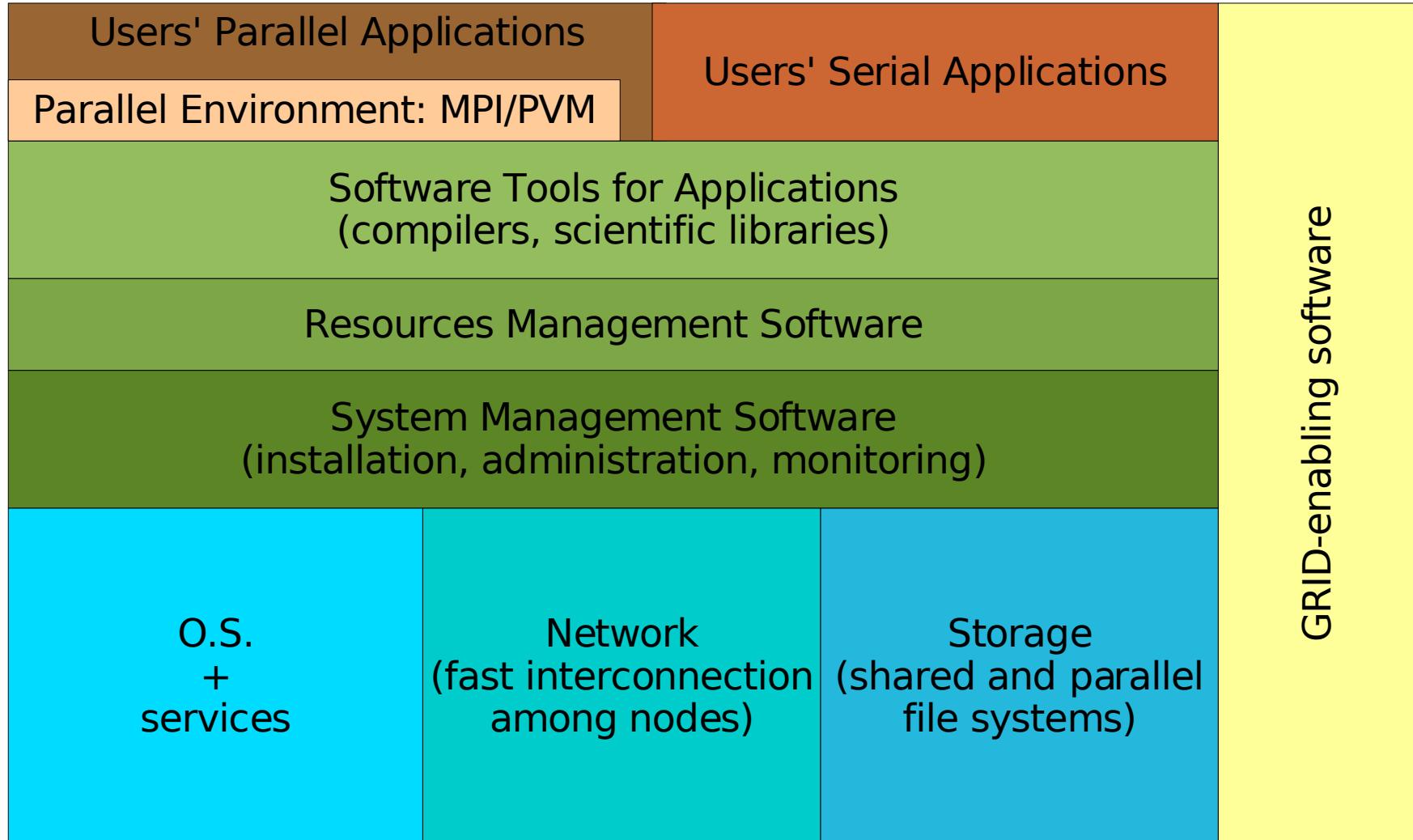
CLUSTER SERVICES

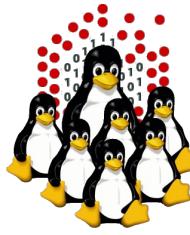




HPC SOFTWARE INFRASTRUCTURE

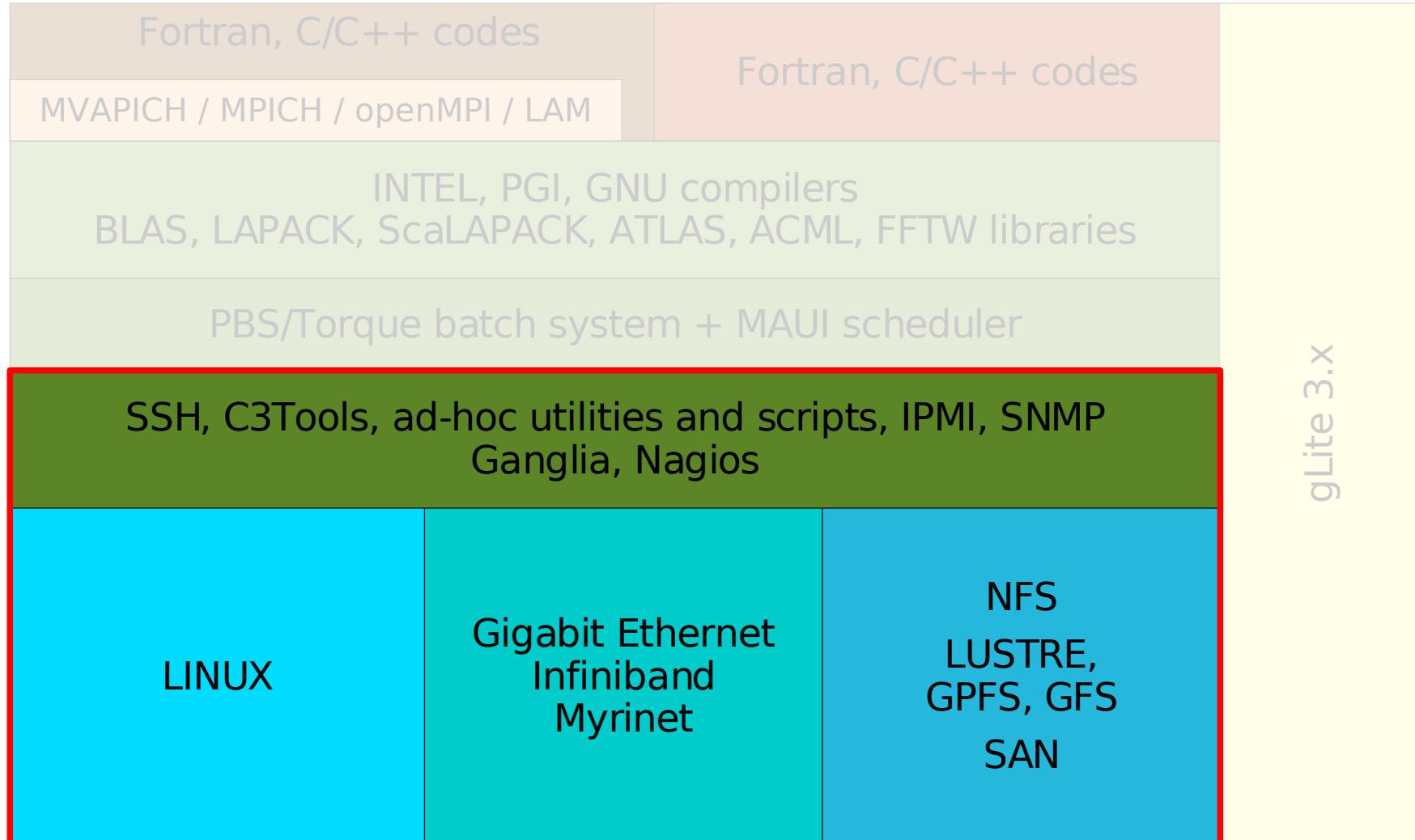
Overview

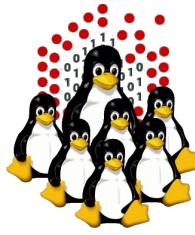




HPC SOFTWARE INFRASTRUCTURE

Overview (our experience)



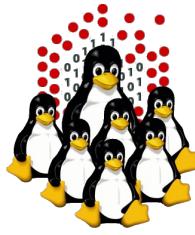


CLUSTER MANAGEMENT

Installation

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



CLUSTER MANAGEMENT

Installation

MASTERNODE

Ad-hoc installation once forever (hopefully), usually interactive:

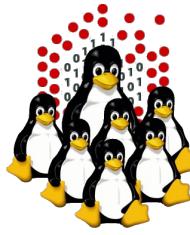
- local devices (CD-ROM, DVD-ROM, Floppy, ...)
- network based (PXE+DHCP+TFTP+NFS/HTTP/FTP)

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)



CLUSTER MANAGEMENT

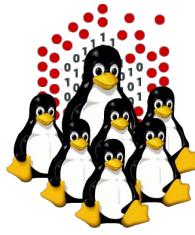
Cluster Nodes Installation

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/HTTP/FTP
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
- ROOTFS over NFS
- ROOTFS over NFS + UnionFS
- initrd (RAM disk)



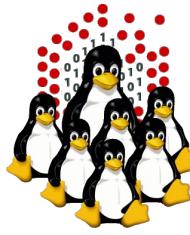
CLUSTER MANAGEMENT

Existent toolkits

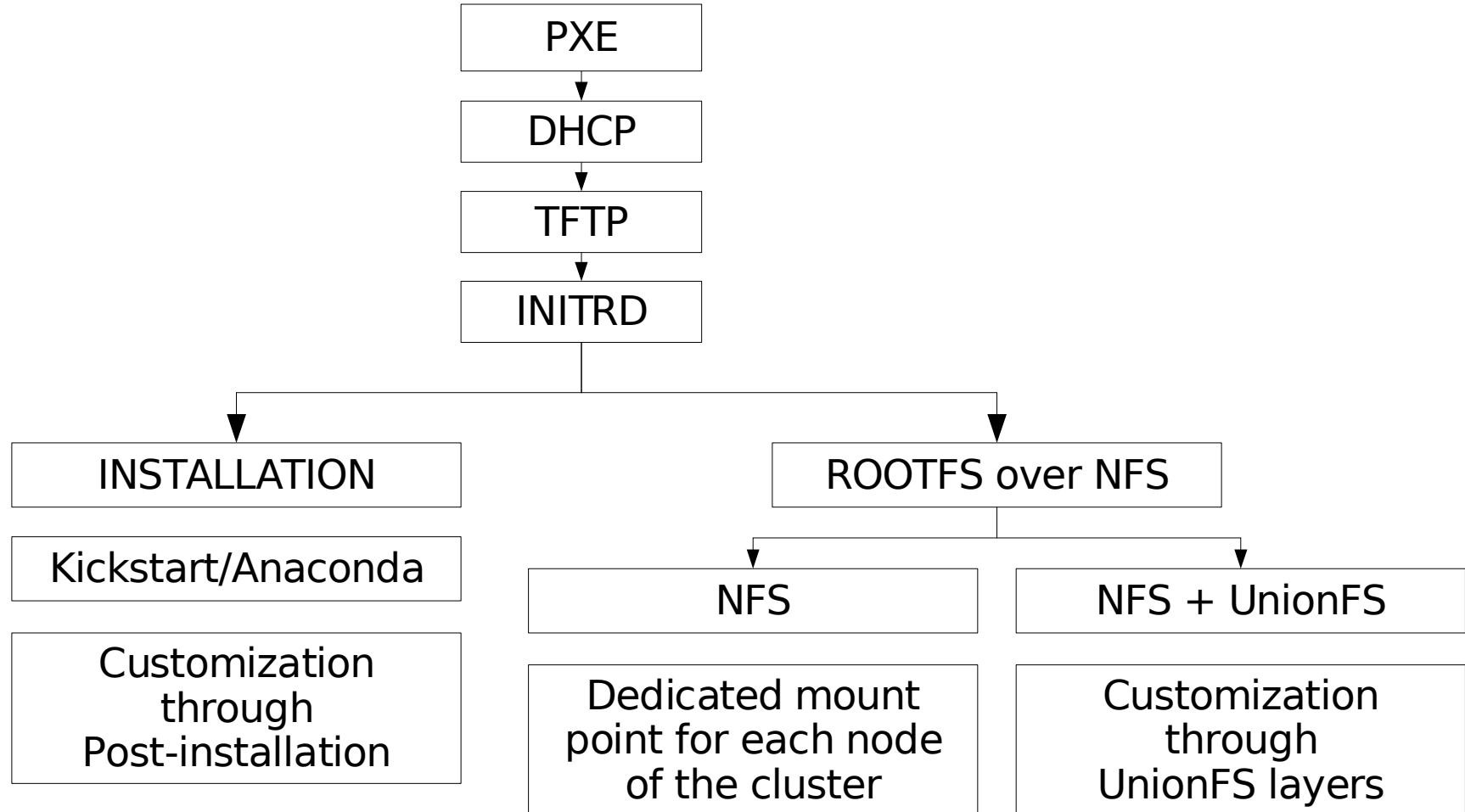
Are generally made of an ensemble of already available software packages thought for specific tasks, but configured to operate together, plus some add-ons.

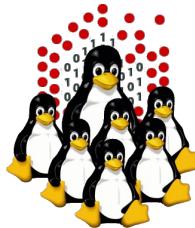
Sometimes limited by rigid and not customizable configurations, often bounded to some specific LINUX distribution and version. May depend on vendors' hardware.

- Free and Open
 - OSCAR (Open Source Cluster Application Resources)
 - NPACI Rocks
 - xCAT (eXtreme Cluster Administration Toolkit)
 - Warewulf/PERCEUS
 - SystemImager
 - Kickstart (RH/Fedora), FAI (Debian), AutoYaST (SUSE)
- Commercial
 - Scyld Beowulf
 - IBM CSM (Cluster Systems Management)
 - HP, SUN and other vendors' Management Software...



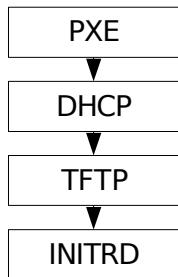
Network-based Distributed Installation Overview



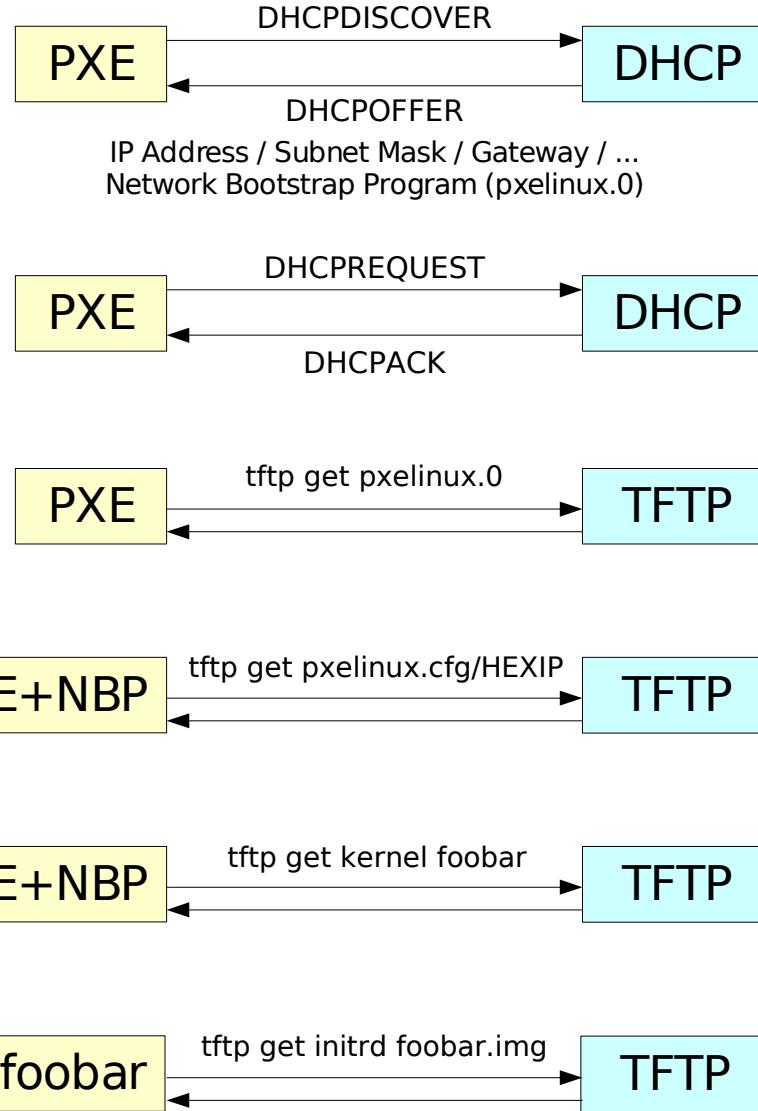


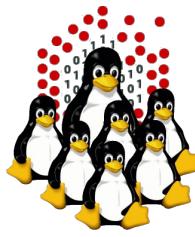
Network booting (NETBOOT) PXE + DHCP + TFTP + KERNEL + INITRD

CLIENT / COMPUTING NODE



SERVER / MASTERNODE

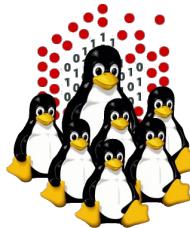




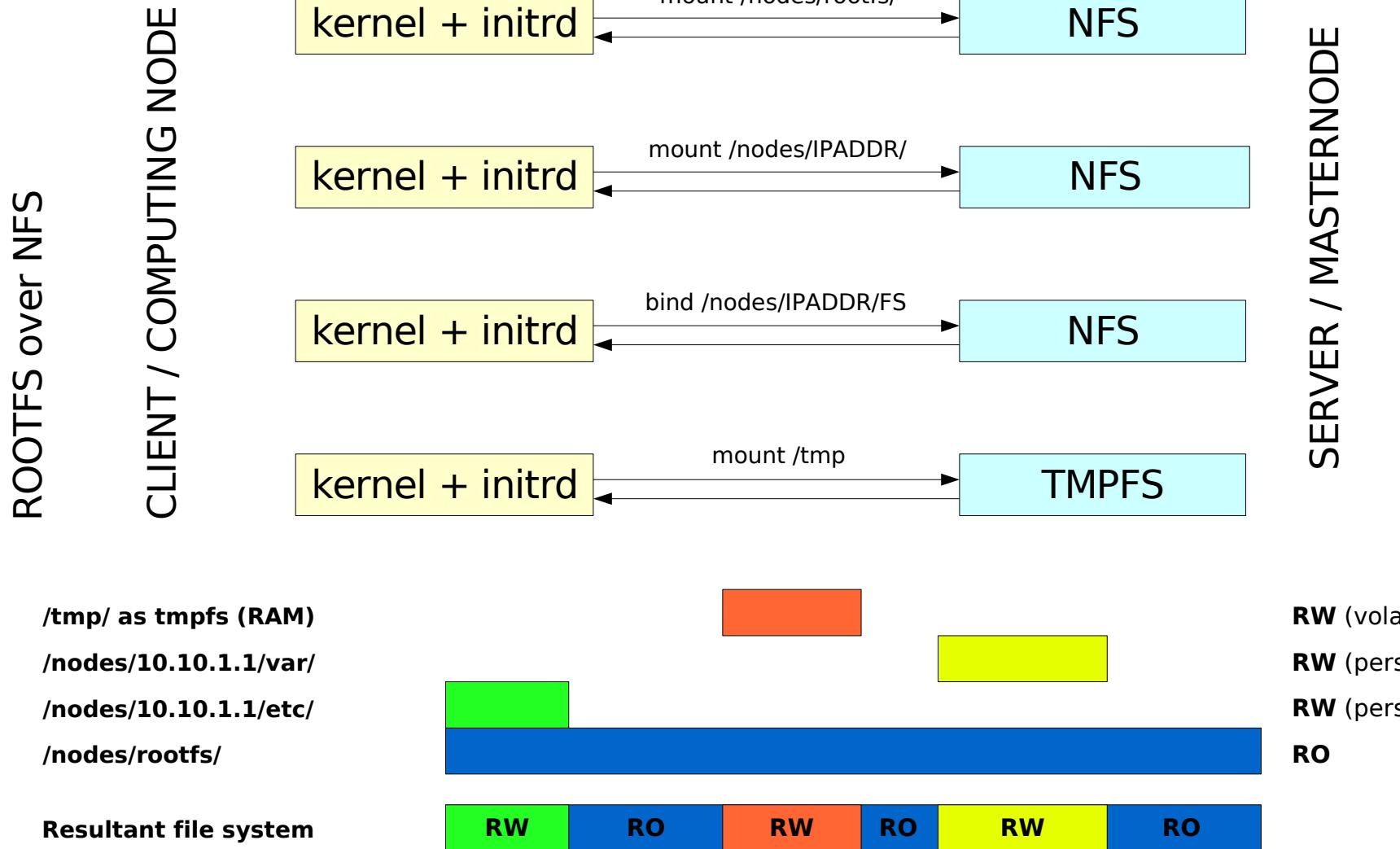
Network-based Distributed Installation

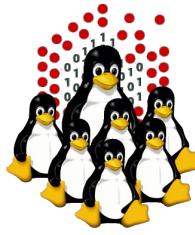
NETBOOT + KICKSTART INSTALLATION



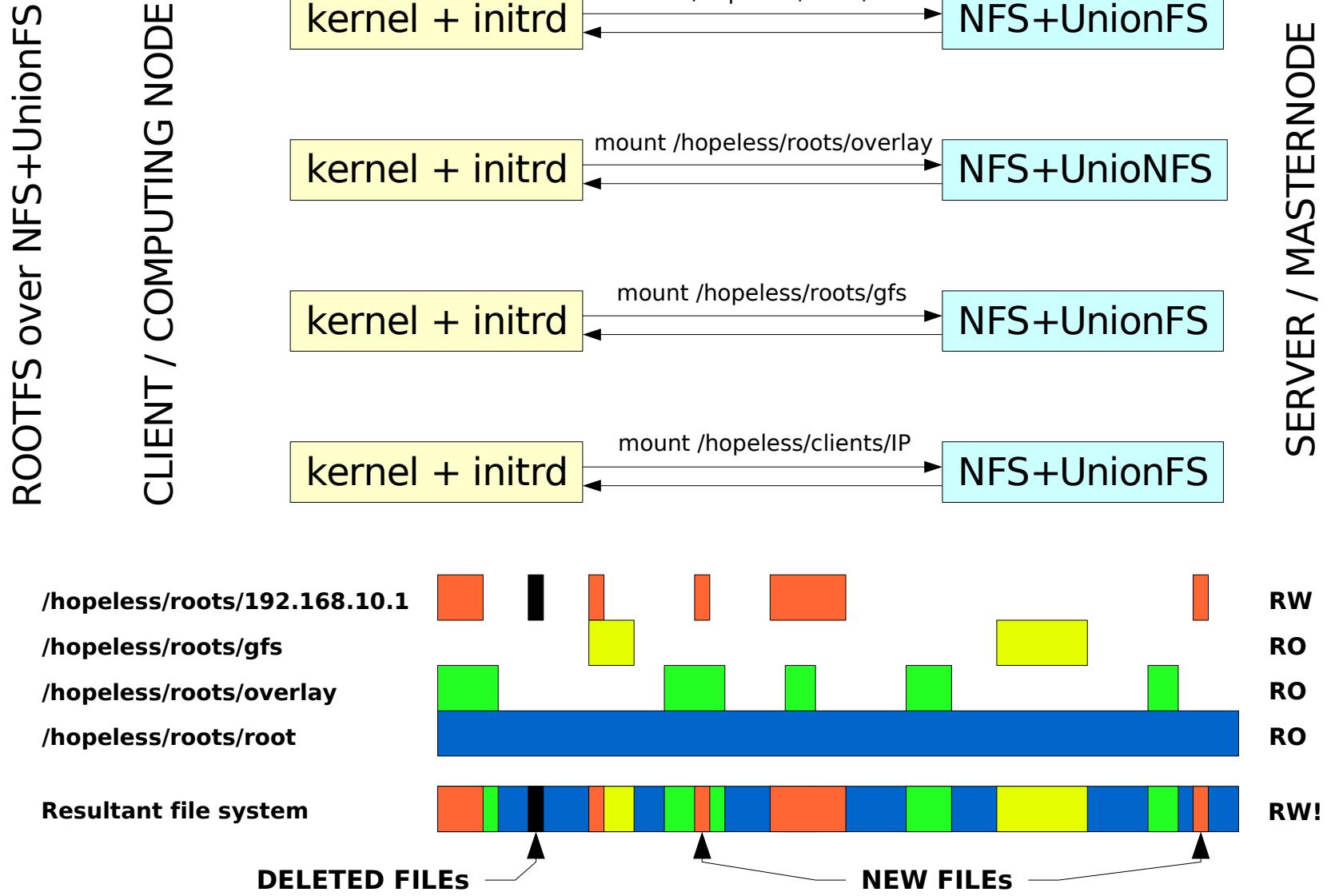


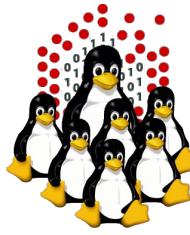
Diskless Nodes NFS Based NETBOOT + NFS





Diskless Nodes NFS+UnionFS Based NETBOOT + NFS + UnionFS





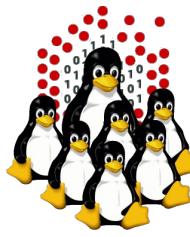
Drawbacks

- Removable media (CD/DVD/floppy):
 - not flexible enough
 - needs both disk and drive for each node (drive not always available)
- ROOTFS over NFS:
 - NFS server becomes a single point of failure
 - doesn't scale well, slow down in case of frequently concurrent accesses
 - requires enough disk space on the NFS server
- ROOTFS over NFS+UnionFS:
 - same as ROOTFS over NFS
 - some problems with frequently random accesses
- RAM disk:
 - need enough memory
 - less memory available for processes
- Local installation:
 - upgrade/administration not centralized
 - need to have an hard disk (not available on disk-less nodes)

Configuration and setup of NETBOOT services

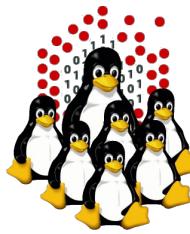


- **client setup**
 - **PXE**
 - **BIOS**
- **server setup**
 - **DHCP**
 - **TFTP + PXE**
 - **NFS**
 - **Kickstart**



Setting up the client

- NIC that supports network booting (or etherboot)
- BIOS boot-sequence
 1. Floppy
 2. CD/DVD
 3. USB/External devices
 4. NETWORK
 5. Local Hard Disk
- Information gathering (client MAC address)
 - documentation (don't rely on this)
 - motherboard BIOS (if on-board)
 - NIC BIOS, initialization, PXE booting (need to monitor the boot process)
 - network sniffer (suitable for automation)



Collecting MAC addresses

```
# tcpdump -c1 -i any -qtep port bootpc and port  
bootps and ip broadcast
```

tcpdump: verbose output suppressed, use -v or -vv for full protocol decode

listening on any, link-type LINUX_SLL (Linux cooked), capture size 96 bytes

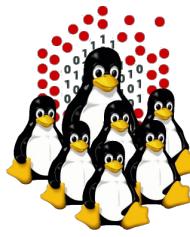
```
B 00:30:48:2c:61:8e 592: IP 0.0.0.0.bootpc >  
255.255.255.255.bootps: UDP, length 548
```

1 packets captured

1 packets received by filter

0 packets dropped by kernel

(see /etc/services for details on ports assignment)



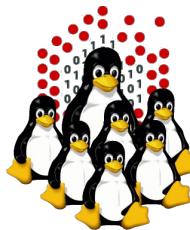
Setting up DHCP

- It's a protocol that allows the dynamic configuration of the network settings for a client
- We need DHCP software for both the server and the clients (PXE implements a DHCP client internally)
- Steps needed
 - DHCP server package
 - DHCP configuration
 - client configuration
 - a TFTP server to supply the PXE bootloader

```
ddns-update-style    none;
ddns-updates        off;
authoritative;
deny unknown-clients;

# cluster network
subnet 10.10.0.0 netmask 255.255.0.0 {
    option domain-name          "cluster.network";
    option domain-name-servers 10.10.0.1;
    option ntp-servers         10.10.0.1;
    option subnet-mask          255.255.0.0;
    option broadcast-address   10.10.255.255;
    # TFTP server
    next-server                10.10.0.1;
    # NBP
    filename                   "/pxe/pxelinux.0";
    default-lease-time         -1;
    min-lease-time             864000;
}

# client section
host node01.cluster.network {
    hardware ethernet           00:30:48:2c:61:8e;
    fixed-address               10.10.1.1;
    option host-name            "node01";
}
```



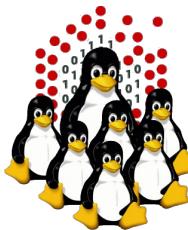
Setting up DHCP

```
ddns-update-style      none;
ddns-updates          off;
authoritative;
deny unknown-clients;
```

```
# cluster network
subnet 10.10.0.0 netmask 255.255.0.0 {
    option domain-name           "cluster.network";
    option domain-name-servers  10.10.0.1;
    option ntp-servers          10.10.0.1;
    option subnet-mask           255.255.0.0;
    option broadcast-address    10.10.255.255;
    # TFTP server
    next-server                 10.10.0.1;
    # NBP
    filename                    "/pxe/pxelinux.0";
    default-lease-time          -1;
    min-lease-time              864000;
}
```

```
# client section
host node01.cluster.network {
    hardware ethernet 00:30:48:2c:61:8e;
    fixed-address     10.10.1.1;
    option host-name  "node01";
}
```

Parameters starting with the `option` keyword correspond to actual DHCP options, while parameters that do not start with the `option` keyword either control the behavior of the DHCP server or specify client parameters that are not optional in the DHCP protocol.
(man `dhcpd.conf`)



TFTP and PXE

- What is TFTP

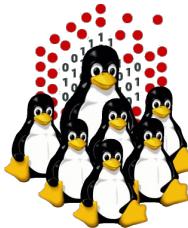
- Trivial File Transfer Protocol: is a simpler, faster, session-less and “unreliable” (based on UDP) implementation of the File Transfer Protocol;
- lightweight and simplicity make it the preferred way to transfer small files to/from network devices.

- What is PXE

- Pre-boot eXecution Environment, API burned-in into the PROM of the NIC
- provides a light implementation of some protocols (IP, UDP, DHCP, TFTP)

- What we need

- *tftp-server*, enabled as stand-alone daemon or through (x)inetd
- *pxelinux.0* from *syslinux* package (and *system-config-netboot*)
- the kernel (*vmlinuz*) and the initial ramdisk (*initrd.img*) from the installation CD
- a way to handle the node configuration file (<HEXIP>)
 - through TFTP
 - daemon on the server waiting for a connection from the installed node or *port-knocking*
 - CGI or PHP script (requires a web server)
 - directory exported via NFS



PXE client configuration

/tftpboot/pxe/pxelinux.cfg/default

```
prompt 1
timeout 100

display /pxelinux.cfg/bootmsg.txt

default local
```

```
label local
LOCALBOOT 0
```

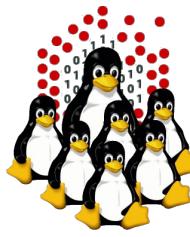
```
label install
kernel vmlinuz
append vga=normal selinux=0 network ip=dhcp
  ksdevice=eth0 ks=nfs:10.1.0.1:/distro/ks/nodes.ks \
  load_ramdisk=1 prompt_ramdisk=0 ramdisk_size=16384 \
  initrd=initrd.img
```

```
label memtest
kernel memtest
```

configuration fall-back (MAC -> HEXIP -> default)
/tftpboot/pxe/pxelinux.cfg/

```
/01-00-30-48-2c-61-8e # MAC address
/0A0A0101               # 10.10.1.1 (IP ADDRESS)
/0A0A010                # 10.10.1.0-10.10.1.15
/0A0A01                 # 10.10.1.0-10.10.1.255
/0A0A0                  # 10.10.0.0-10.10.15.255
/0A0A                   # 10.10.0.0-10.10.255.255
/0A0                     # 10.0.0.0-10.15.255.255
/0A                      # 10.0.0.0-10.255.255.255
/0                       # 0.0.0.0-15.255.255.255
/default                # nothing matched
```

Note: '\' means that the line
continue, but it should be
actually written on one line.

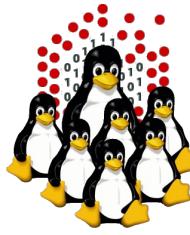


Setting up the TFTP tree

- Populating the filesystem tree...

```
/  
  '-- tftpboot/  
    '-- pxe/  
      '-- vmlinuz  
      '-- initrd.img  
      '-- memtest  
      '-- pxelinux.0  
      '-- pxelinux.cfg/  
        '-- 0A0A0101  
        '-- bootmsg.txt  
        '-- default -> default.local  
        '-- default.install  
        '-- default.local
```

- **Permissions:** world readable for “get”; writable flags and ownerships depend on how the <HEXIP> file is handled (tftp, web, nfs, daemon, ...)
 - tftp: needs world writable <HEXIP> file (for “put”)
 - nfs: directory exported (and mounted) as RW
 - daemon: ownerships and permissions depend on the UID
 - web: ownerships for the web server user

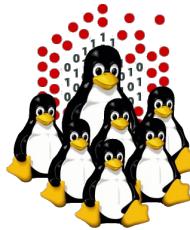


Setting up NFS

- Create a local repository for RPM packages
- Copy the RPMs from the installation CDs/DVD or the ISO image(s), or just export the loop-mounted iso image(s)
- Export the repository to the cluster internal network
- Export the directory on which the kickstart resides
- Start/restart NFS service (or just “`exportfs -r`”)

Configuration sample (`/etc/exports`)

```
/distro          10.10.0.0/16(ro,root_squash)
```



Setting up KICKSTART

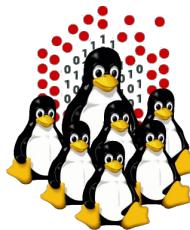
- Part of RedHat installation suite (Anaconda)
- Based on RPM packages and supported by all RH-based distros
- Allows non-interactive batch installation
- `system-config-kickstart` permit to create a template file

The kickstart configuration file, among other things, allows:

- network setup
- HD partitioning
- basic system configuration
- packages selection (%packages)

```
@<package-group>
  <package>          ( add )
  -<package>        ( remove )
```

- pre-installation operations (%pre)
 - HW setup
 - specific configuration
- post-installation operations (%post)
 - post configuration, customization
 - stop the automated installation procedure



KICKSTART example

/distro/ks/nodes.ks

```
install
nfs --server=10.10.0.1 --dir=/distro/WB4/
text
lang en_US
langsupport --default=en_US en_US
keyboard us
network --device eth0 --bootproto dhcp
network --device eth1 --bootproto dhcp
...
bootloader --location=mbr --append selinux=0
clearpart --all --initlabel
zerombr yes
part swap --size=4096 --asprimary
part / --fstype "ext3" --size=4096 --asprimary
part /local_scratch --fstype "ext3" --size=100 --grow
...
skipx

%packages --resolvedeps
ntp
openssh
openssh-server
-sendmail
...
%pre
hdparm -d1 -u1 /dev/hda 2>&1
```

```
%post --nochroot
cp /tmp/ks.cfg /mnt/sysimage/root/install-ks.cfg
cp /proc/cmdline /mnt/sysimage/root/install-cmdline

%post --interpreter=/bin/bash

exec 1>/root/post.log
exec 2>&1
set -x
export MASTER=10.10.0.1

tftp_get() { tftp $MASTER -v -c get $1 $2 ; }
tftp_put() { tftp $MASTER -v -c put $1 $2 ; }

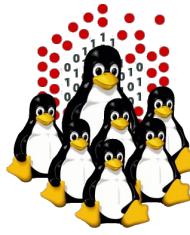
ip_to_hex() {
    /sbin/ip addr show dev $1
    sed -r '\|\s+inet\s([^\/]+)\.*|!d;s/\$/'
    awk -F. '{printf("%02X%02X%02X%02X",$1,$2,$3,$4);}'
}

for eth in eth0 eth1 eth2
do
    HEX=`ip_to_hex $eth`
    test "x$HEX" != "x" && break
done

tftp_get /pxe/pxelinux.cfg/default.local /tmp/$HEX
tftp_put /tmp/$HEX /pxe/pxelinux.cfg/$HEX
```

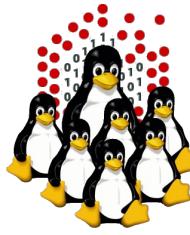


Trouble shooting



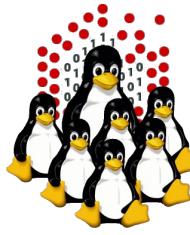
System logs

- Check system logs for:
 - DHCP negotiation (DISCOVER, OFFER, REQUEST, ACK/NACK)
 - DHCP leases (`/var/lib/dhcp/dhcpd.leases`)
 - TFTP transfers (enable verbose logging with `-vvv`)
 - denied/successful NFS mount (`showmount`)
 - connections rejected by server(s) configuration,
TCPwrapper, firewall rules



Network traffic analysis

- Sniff the network activity with:
 - tcpdump
 - wireshark/ethereal (tshark/tethereal)
- Look for:
 - client's ethernet MAC address (any packet sent by the node)
 - DHCP negotiation (DISCOVER, REQUEST, NACK)
 - TFTP UDP traffic
 - (NFS traffic)



Client virtual consoles (anaconda)

FIRST STAGE

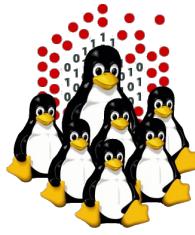
- CTRL+ALT+F1 BOOT, TEXTUAL CONFIGURATION
- CTRL+ALT+F2,F3 LOGS

SECOND STAGE

- CTRL+ALT+F1 LAUNCH X, REBOOT LOGS
- CTRL+ALT+F2 **SHELL**
- CTRL+ALT+F3,F4,F6 LOGS, DEBUG
- CTRL+ALT+F7 GRAPHICAL CONFIGURATION (X)

Cluster management tools





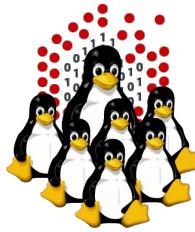
CLUSTER MANAGEMENT

Administration Tools

Requirements:

- ✓ cluster-wide command execution
- ✓ cluster-wide file distribution and gathering
- ✓ password-less environment
- ✓ must be simple, efficient, easy to use for CLI addicted

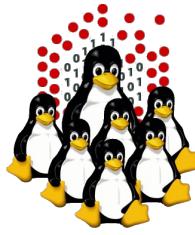




CLUSTER MANAGEMENT Administration Tools

- 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
- PDSH – Parallel Distributed SHeLL
 - ◆ same features as C3 tools, few utilities
 - pdsh, pdcp, rpdcp, dshbak
- Cluster-Fork – NPACI Rocks
 - ◆ serial execution only
- ClusterSSH
 - ◆ multiple xterm windows handled through one input grabber
 - ◆ Spawn an xterm for each node! DO NOT EVEN TRY IT ON A LARGE CLUSTER!

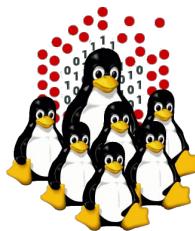




CLUSTER MANAGEMENT

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 /1

DEMOCRITOS/SISSA Grid > --Choose a Source ▾

Name / Info

DEMOCRITOS/SISSA Grid (4 sources) [\(tree view\)](#)

Hosts up: 113
(276 CPUs Total)

Hosts down: 1

cerbero (physical view)

Cluster Localtime:
July 2, 2006, 9:19 pm

Hosts up: 70
(188 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)

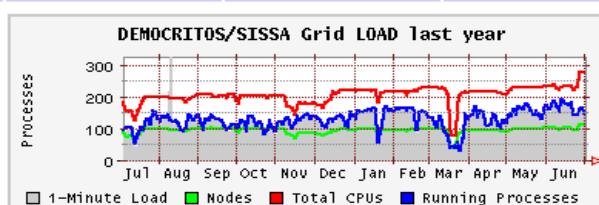
Cluster Localtime:
July 2, 2006, 9:19 pm

Hosts up: 29
(58 CPUs Total)

Hosts down: 0

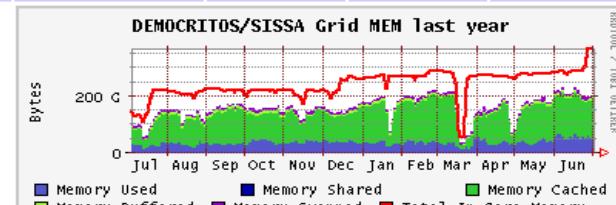
Load Averages

124.76 124.33 124.26



%CPU User, Nice, System, Idle

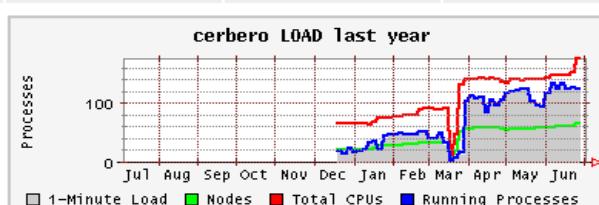
45.5 1.3 1.0 52.6



111.72

111.80

112.15

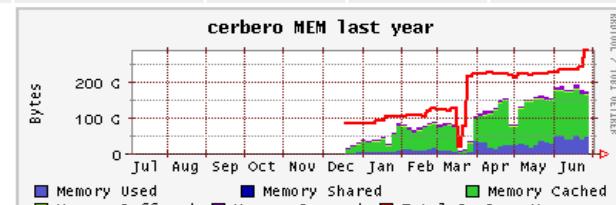


65.4

2.1

1.5

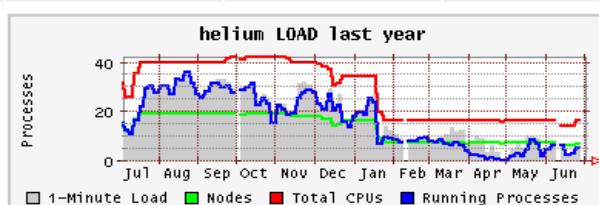
29.7



4.00

4.00

3.75

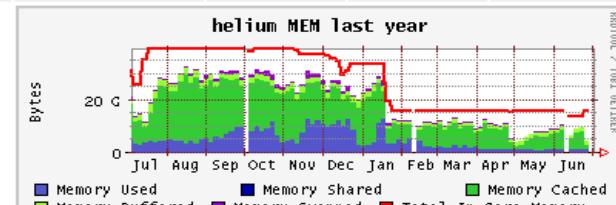


28.6

0.0

0.0

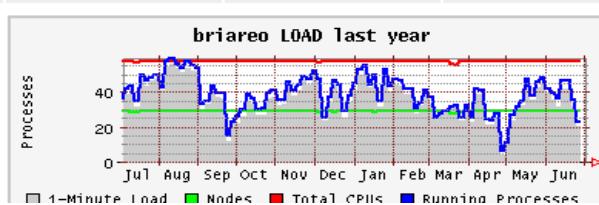
71.4



8.73

8.49

8.35

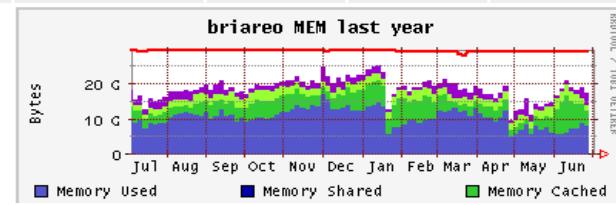


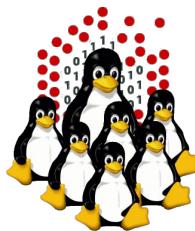
12.4

0.0

0.4

92.1





CLUSTER MANAGEMENT

Ganglia at work /2

[DEMOCRITOS/SISSA Grid > cerbero > a103.hpc](#)

a103.hpc Overview

This node is up and running

Name	Value
boottime	Thu, 27 Apr 2006 08:50:03 +0200
gexec	OFF
machine_type	x86_64
os_name	Linux
os_release	2.6.13.3
sys_clock	Thu, 27 Apr 2006 08:51:14 +0200
uptime	66 days, 12:33

Time and String Metrics

Name	Value
cpu_idle	17.5 %
cpu_num	4
cpu_speed	2192 MHz
mem_total	4059676 KB
mtu	1500 B
swap_total	4192956 KB

Constant Metrics

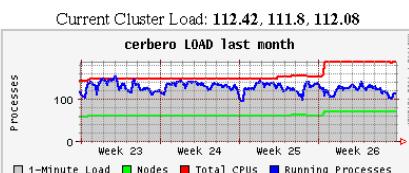
Name	Value
bytes_in	3.0 k
bytes_out	3.0 k
cpu_idle	3.0

Graphs of Volatile Metrics. Range

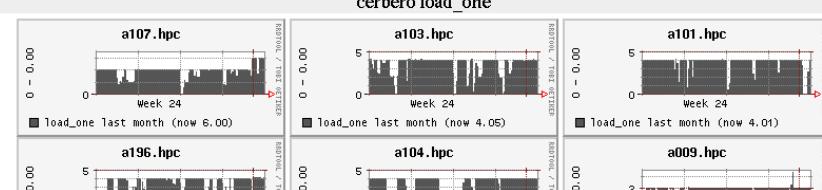
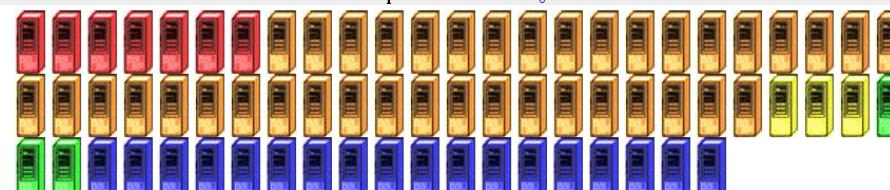
Graphs for bytes_in and cpu_idle over the last day.

[DEMOCRITOS/SISSA Grid > cerbero >](#) Choose a Node ▾

There are **70** nodes (**188** CPUs) up and running.
There are no nodes down.

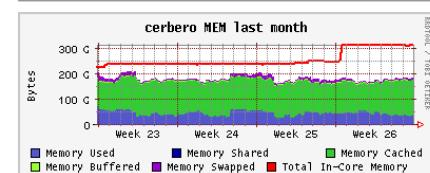
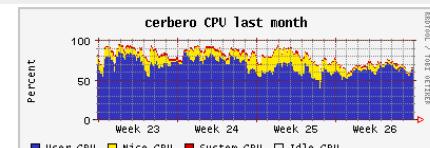
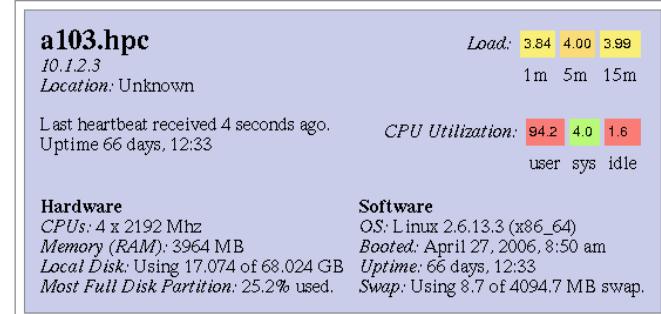


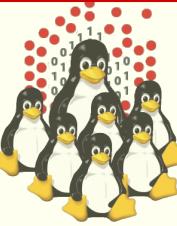
[Snapshot of cerbero](#) | Legend



[DEMOCRITOS/SISSA Grid > cerbero > a103.hpc](#)

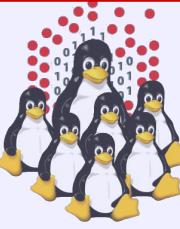
a103.hpc Info





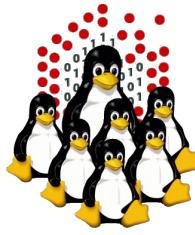
Security notes

- /etc/security/limits.conf: per-user resources limits (cputime, memory, ...)
- /etc/security/access.conf: which user from where
- /etc/ssh/sshd_config
- *TCPwrapper* (/etc/hosts.{allow,deny}): only for (x)inetd services
- firewall: OK on external network; overkill on the cluster network
- services: the least possible
- ownerships/permissions: local users+exported services, NFS *root_squash*
- *chroot jails*: for some services
- ...
- *grsec*: if you are really paranoid...
- network devices: default passwords, SNMP, SP/IPMI, CDP and the like, ...



Hands-on Laboratory Session

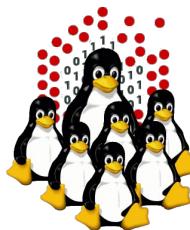
- Installation of a master node
- Post configuration of the master node
- Setting up NETBOOT services (DHCP, TFTP, PXE, NFS)
- Installing our first computing node
- Testing the cluster environment



That's All Folks!



(questions ; comments) | mail -s uheilaaa baro@democritos.it
(complaints ; insults) &>/dev/null



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/>
- Warewulf/PERCEUS
<http://www.warewulf-cluster.org/> <http://www.perceus.org/>

Installation Software:

- SystemImager <http://www.systemimager.org/>
- FAI <http://www.informatik.uni-koeln.de/fai/>
- Anaconda/Kickstart
<http://fedoraproject.org/wiki/Anaconda/Kickstart>

Management Tools:

- openssh/openssl
<http://www.openssh.com>
<http://www.openssl.org>
- C3 tools – The Cluster Command and Control tool suite
<http://www.csm.ornl.gov/torc/C3/>
- PDSH – Parallel Distributed SHell
<https://computing.llnl.gov/linux/pdsh.html>
- DSH – Distributed SHell
<http://www.netfort.gr.jp/~dancer/software/dsh.html.en>
- ClusterSSH
<http://clusterssh.sourceforge.net/>

Monitoring Tools:

- Ganglia <http://ganglia.sourceforge.net/>
- Nagios <http://www.nagios.org/>
- Zabbix <http://www.zabbix.org/>

Network traffic analyzer:

- tcpdump <http://www.tcpdump.org>
- wireshark <http://www.wireshark.org>

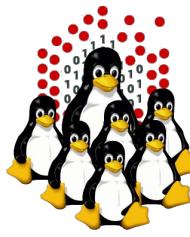
UnionFS:

- Hopeless, a system for building disk-less clusters
<http://www.evolware.org/chri/hopeless.html>
- UnionFS – A Stackable Unification File System
<http://www.unionfs.org>
<http://www.fsl.cs.sunysb.edu/project-unionfs.html>

RFC:

 (<http://www.rfc.net>)

- RFC 1350 – The TFTP Protocol (Revision 2)
<http://www.rfc.net/rfc1350.html>
- RFC 2131 – Dynamic Host Configuration Protocol
<http://www.rfc.net/rfc2131.html>
- RFC 2132 – DHCP Options and BOOTP Vendor Extensions
<http://www.rfc.net/rfc2132.html>
- RFC 4578 – DHCP PXE Options
<http://www.rfc.net/rfc4578.html>
- RFC 4390 – DHCP over Infiniband
<http://www.rfc.net/rfc4390.html>
- PXE specification
<http://www.pix.net/software/pxeboot/archive/pxespec.pdf>
- SYSLINUX <http://syslinux.zytor.com/>



Some acronyms...

ICTP – the Abdus Salam International Centre for Theoretical Physics

DEMOCRITOS – 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

RPM – RPM Package Manager

CLI – Command Line Interface

BASH – Bourne Again SHell

PERL – Practical Extraction and Report Language

PXE – Preboot Execution Environment

INITRD – INITial RamDisk

NFS – Network File System

SSH – Secure SHell

LDAP – Lightweight Directory Access Protocol

NIS – Network Information Service

DNS – Domain Name System

PAM – Pluggable Authentication Modules

LAN – Local Area Network

IP – Internet Protocol

TCP – Transmission Control Protocol

UDP – User Datagram Protocol

DHCP – Dynamic Host Configuration Protocol

TFTP – Trivial File Transfer Protocol

FTP – File Transfer Protocol

HTTP – Hyper Text Transfer Protocol

NTP – Network Time Protocol

SNMP – Simple Network Management Protocol

NIC – Network Interface Card/Controller

MAC – Media Access Control

OUI – Organizationally Unique Identifier

API – Application Program Interface

UNDI – Universal Network Driver Interface

PROM – Programmable Read-Only Memory

BIOS – Basic Input/Output System