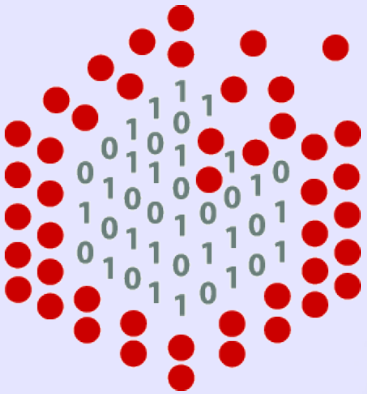
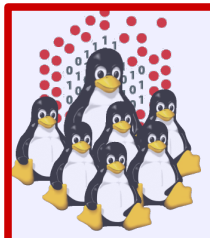


Advanced School in High Performance Computing Tools for e-Science


Installation Procedures for Clusters

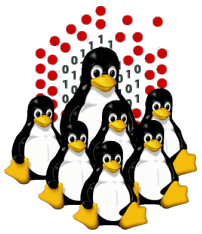
Moreno Baricevic

CNR-INFM DEMOCRITOS, Trieste

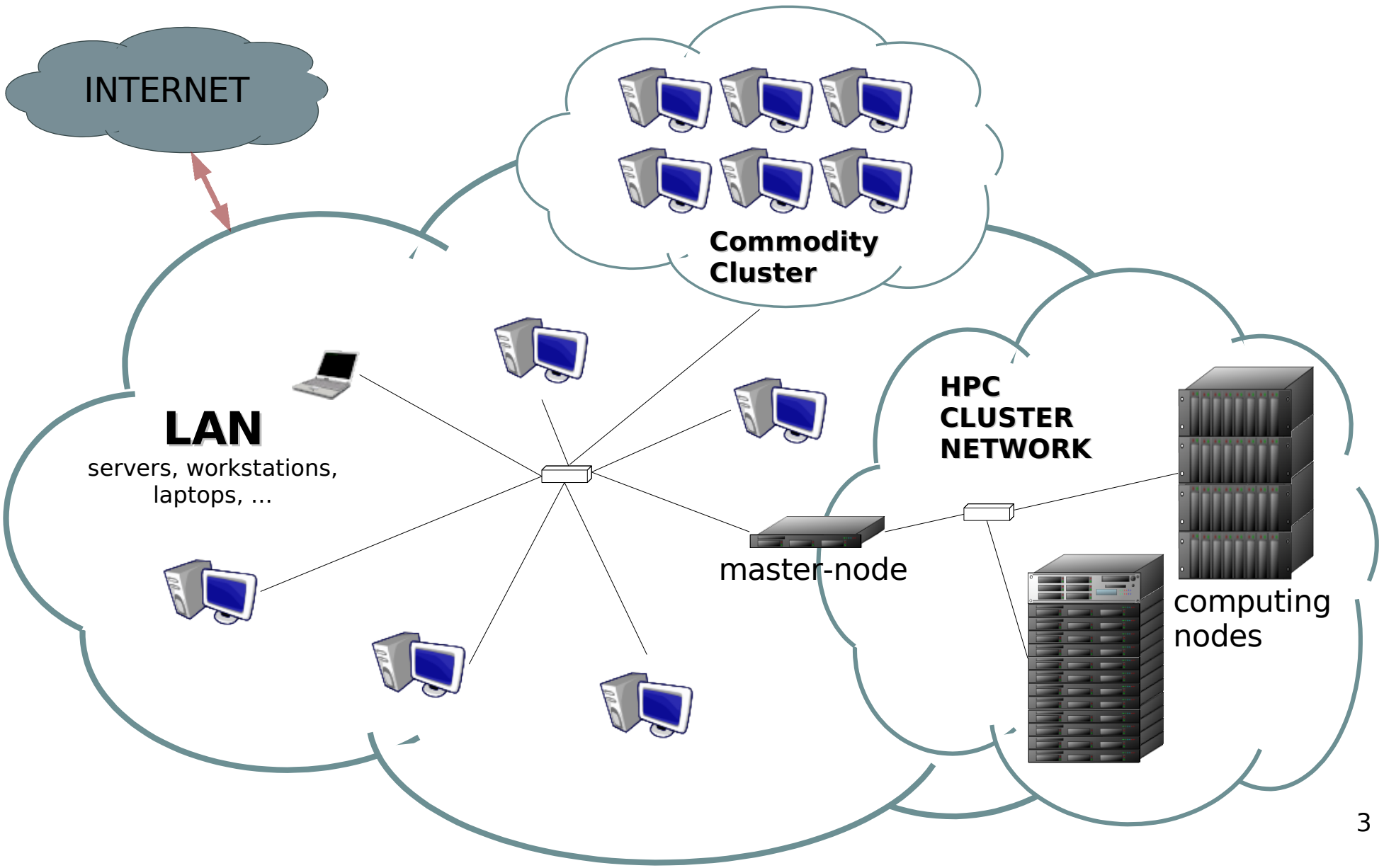


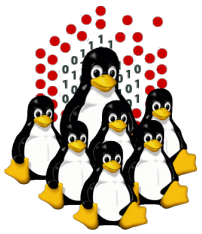
Agenda

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

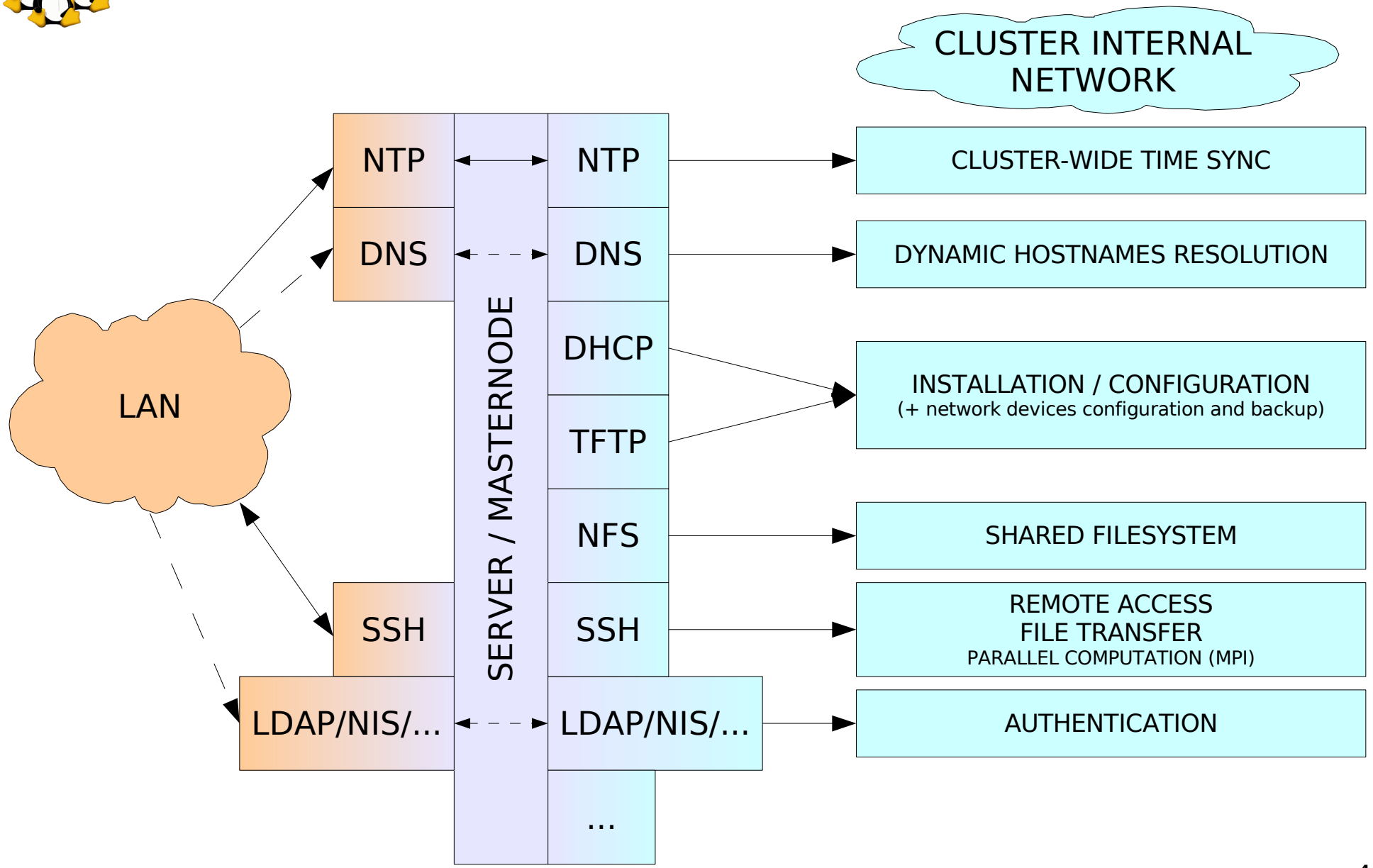


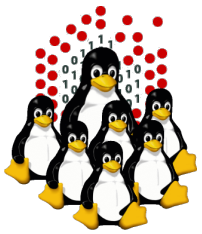
What's a cluster?



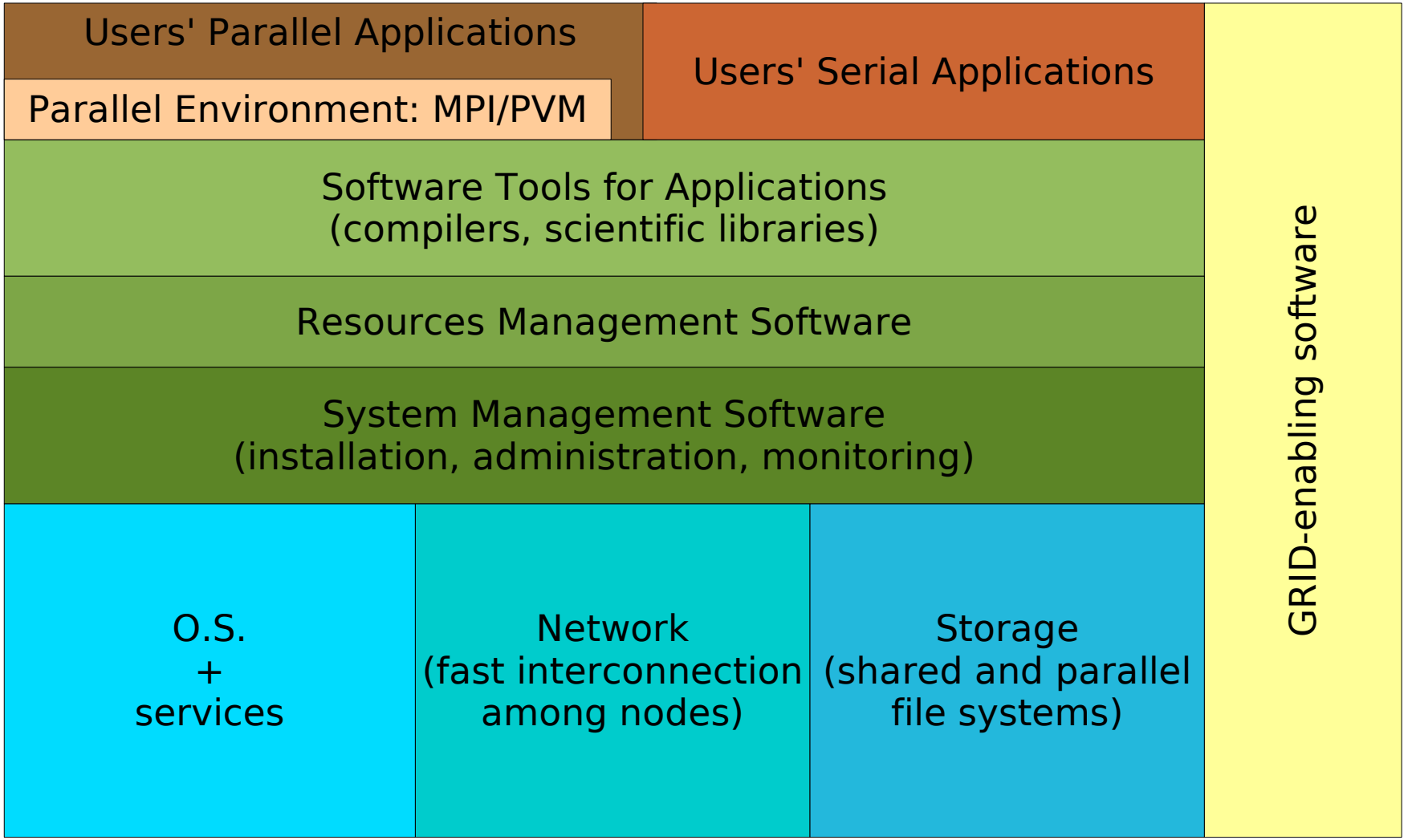


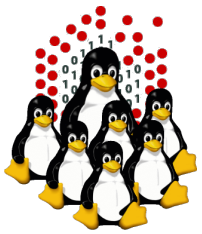
CLUSTER SERVICES



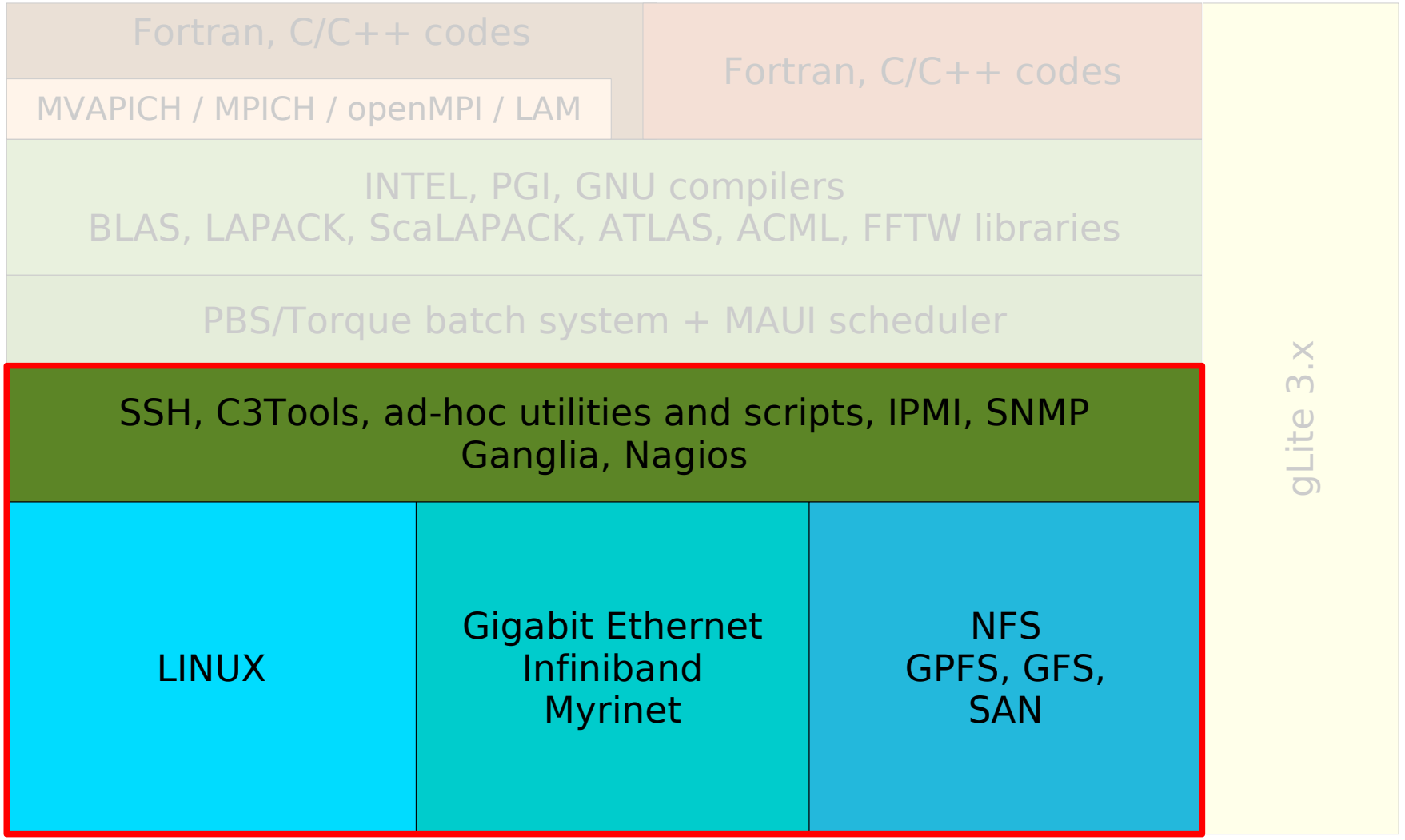


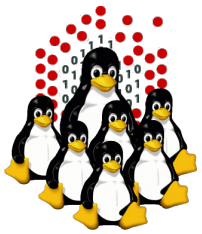
HPC SOFTWARE INFRASTRUCTURE
Overview





HPC SOFTWARE INFRASTRUCTURE
Overview (our experience)





CLUSTER MANAGEMENT
Installation

Installation can be performed:

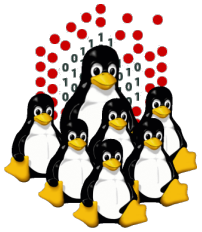
- interactively
- non-interactively

- **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:

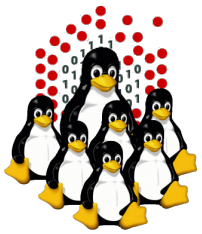
- local devices (CD-ROM, DVD-ROM, Floppy, ...)
- network based (PXE+DHCP+TFTP+NFS/HTTP/FTP)

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)



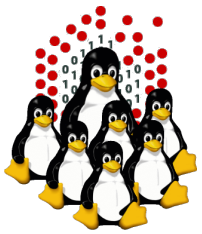
CLUSTER MANAGEMENT
Cluster Nodes Installation

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)

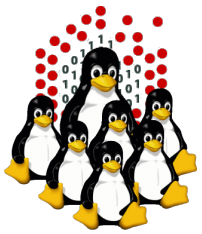


CLUSTER MANAGEMENT
Existent toolkits

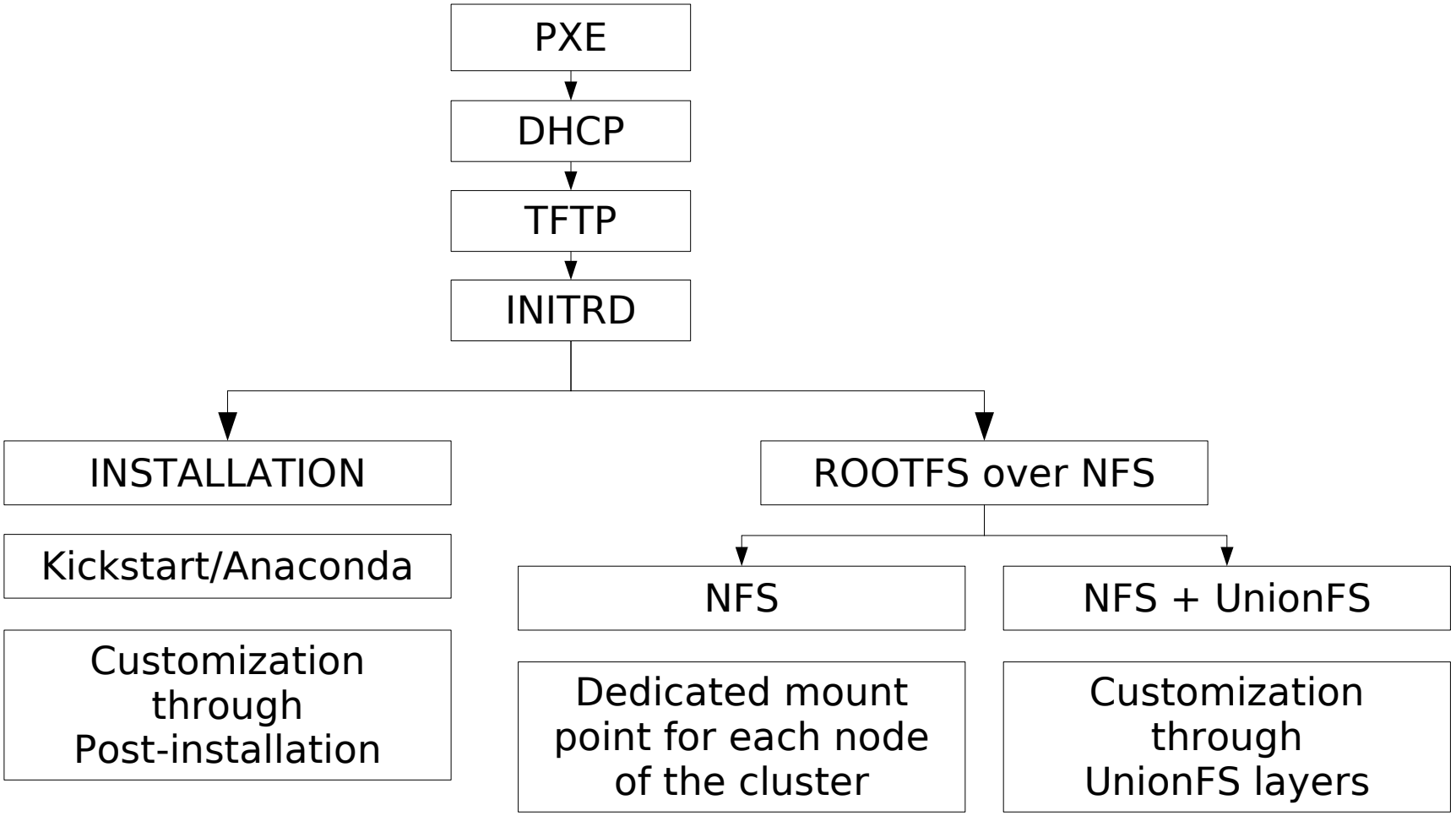
Are generally made of an ensemble of already available software packages thought for specific tasks, but configured to operate together, plus some add-ons.

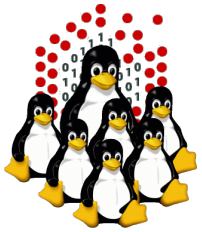
Sometimes limited by rigid and not customizable configurations, often bound to some specific LINUX distribution and version. May depend on vendors' hardware.

- Free and Open
  - OSCAR (Open Source Cluster Application Resources)
  - NPACI Rocks
  - xCAT (eXtreme Cluster Administration Toolkit)
  - Warewulf
  - FAI (Fully Automatic Installation) for Debian
  - SystemImager
- Commercial
  - Scyld Beowulf
  - IBM CSM (Cluster Systems Management)
  - HP, SUN and other vendors' Management Software...

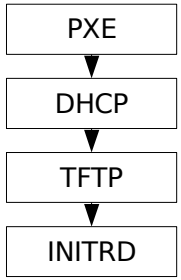


Network-based Distributed Installation
Overview

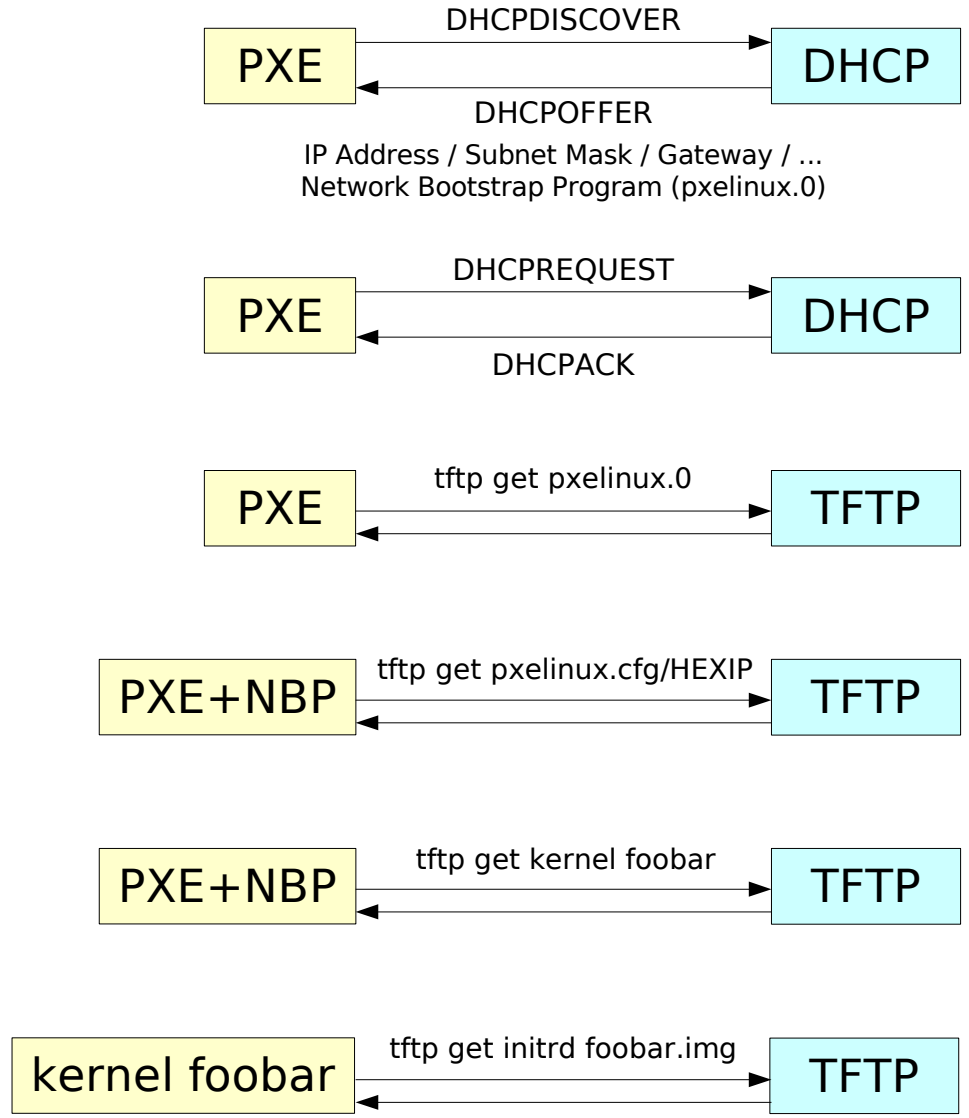




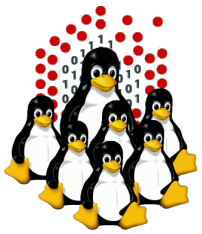
Network booting (NETBOOT)
PXE + DHCP + TFTP + KERNEL + INITRD



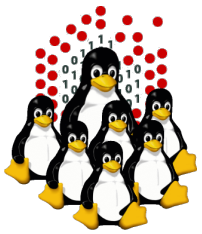
CLIENT / COMPUTING NODE



SERVER / MASTERNODE



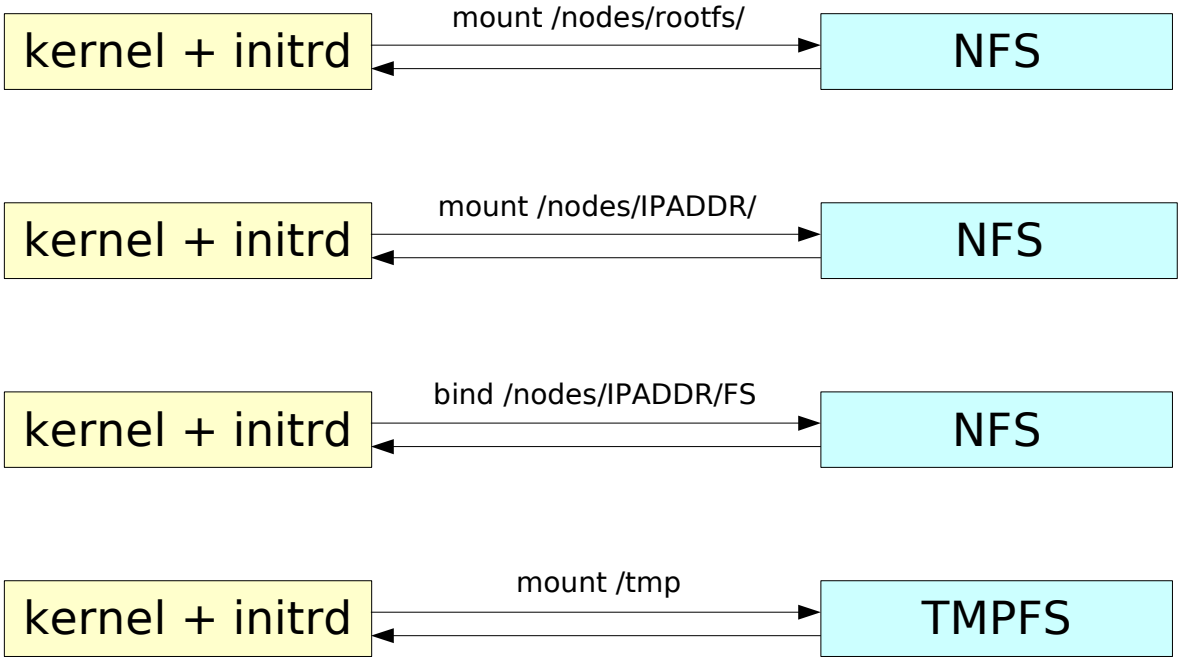
Network-based Distributed Installation
NETBOOT + KICKSTART INSTALLATION



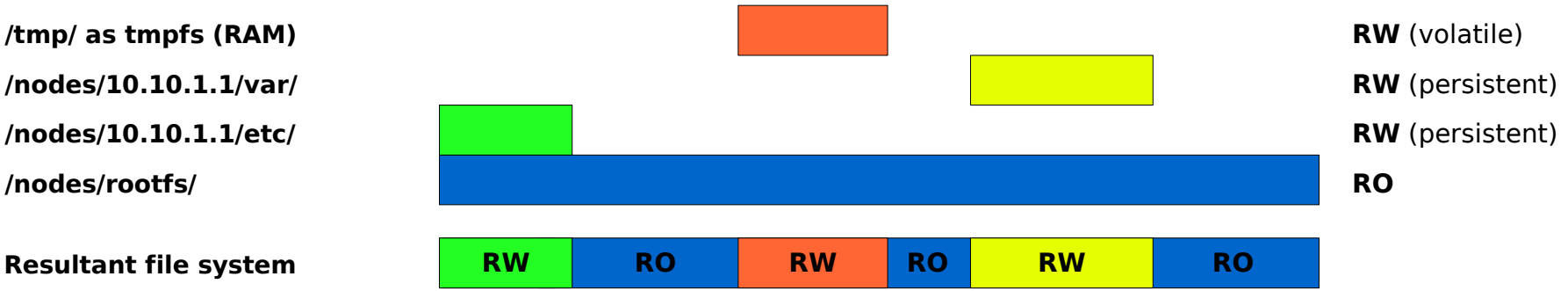
Diskless Nodes NFS Based
NETBOOT + NFS

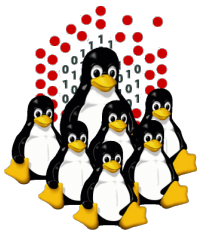
ROOTFS over NFS

CLIENT / COMPUTING NODE

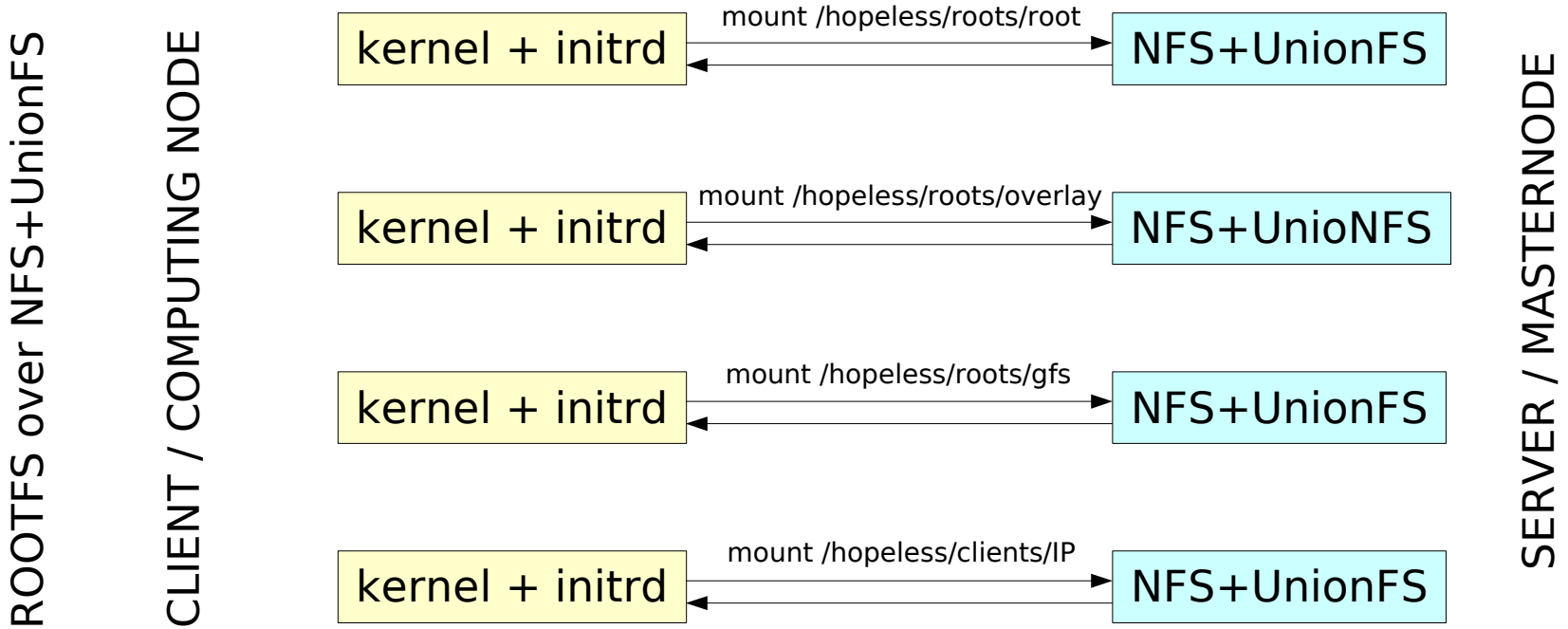


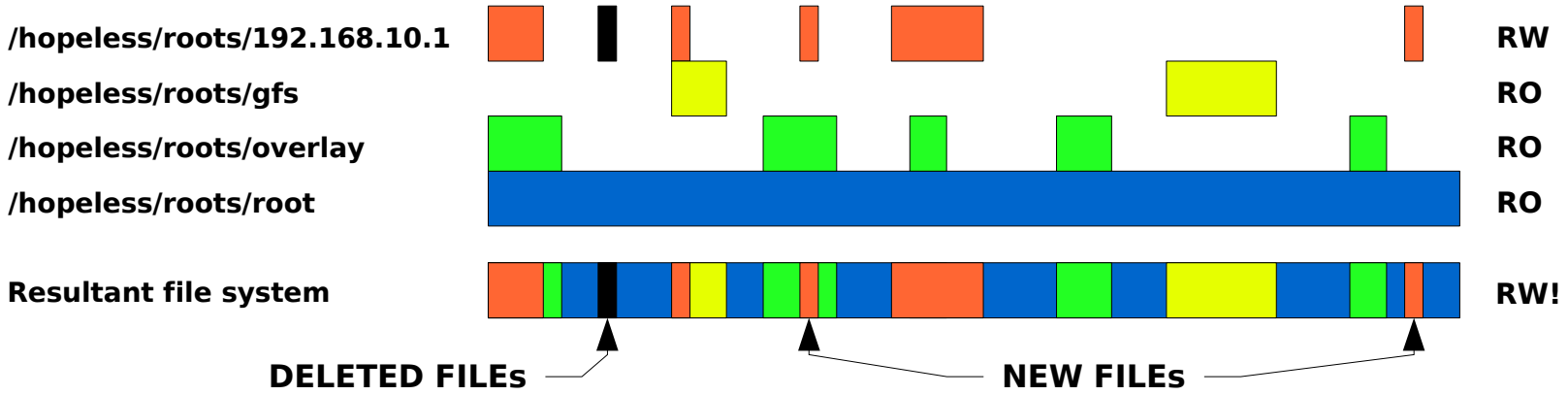
SERVER / MASTERNODE

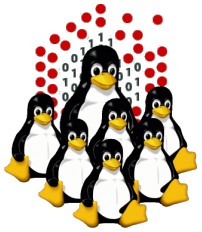




Diskless Nodes NFS+UnionFS Based
NETBOOT + NFS + UnionFS



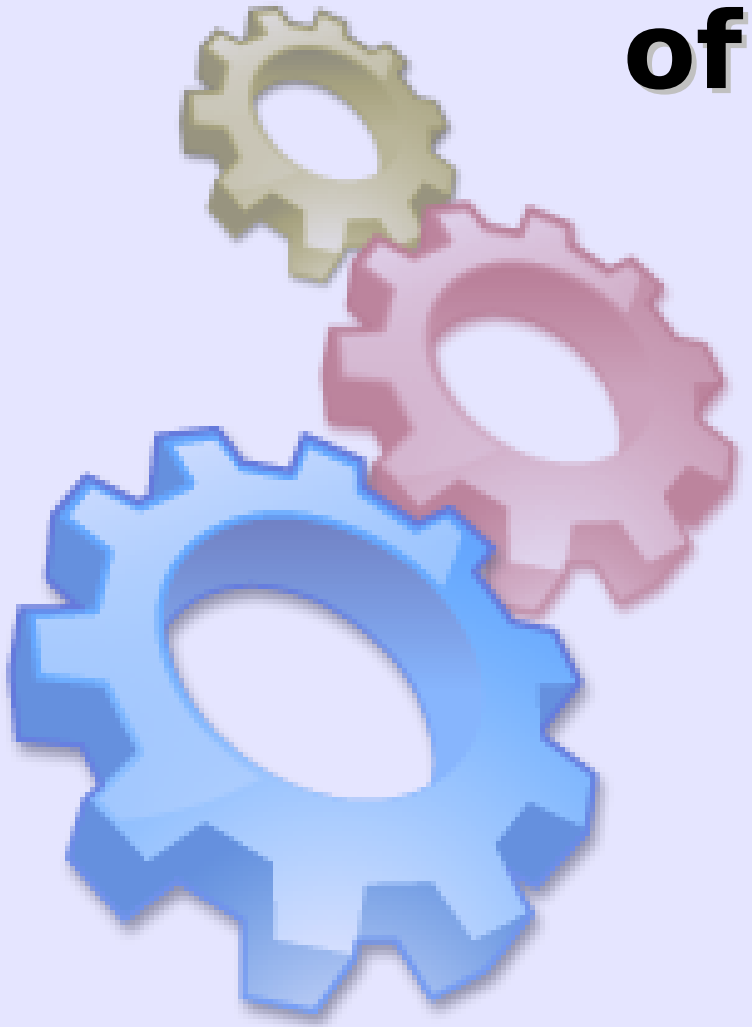




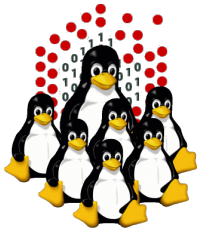
Drawbacks

- 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

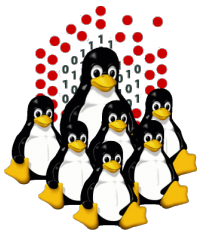


- client setup
- server setup
  - DHCP
  - TFTP + PXE
  - NFS
  - Kickstart



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

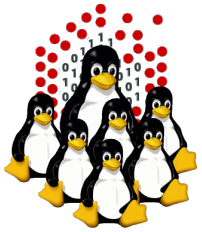
B **00:30:48:2c:61:8e** 592: IP 0.0.0.0.bootpc > 255.255.255.255.bootps: UDP, length 548

1 packets captured

1 packets received by filter

0 packets dropped by kernel

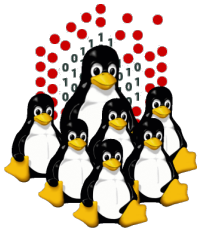
(see `/etc/services` for details on ports assignment)



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";
}
```

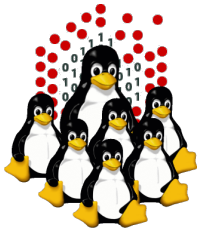


Setting up DHCP

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

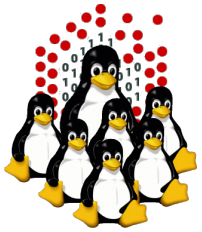
```
ddns-update-style   none;
ddns-updates        off;
authoritative;
deny unknown-clients;

# 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;
}
```

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*, enable it 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

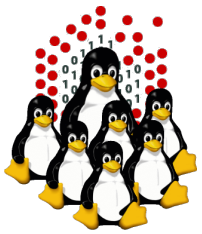
configuration fall-back (MAC -> HEXIP -> default)
/tftpboot/pxe/pxelinux.cfg/

```
/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
```

/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
```

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

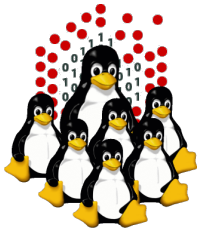


Setting up the TFTP tree

- 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

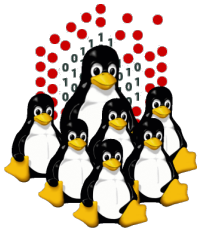


Setting up NFS

- 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

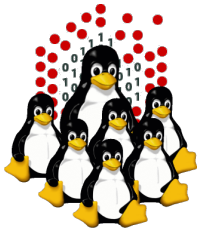
- Part of RedHat installation suite (Anaconda)
- Based on RPM packages and supported by all RH-based distros
- Allows non-interactive batch installation
- `system-config-kickstart` permit to create a template file

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



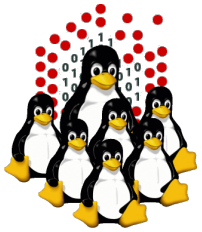
KICKSTART example

/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
```

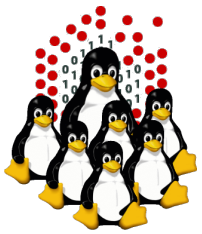
```
%post --nochroot
cp /tmp/ks.cfg /mnt/sysimage/root/install-ks.cfg
cp /proc/cmdline /mnt/sysimage/root/install-cmdline

%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//\1/'   |
  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



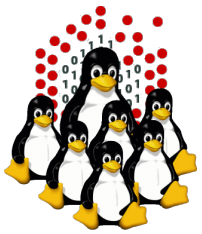
System logs

- 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)

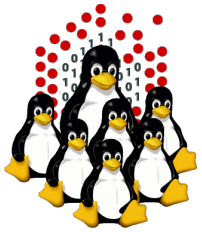
FIRST STAGE

- 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)

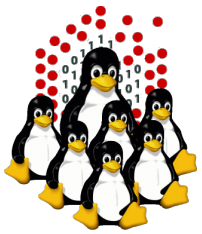
Cluster management tools



CLUSTER MANAGEMENT
Administration Tools

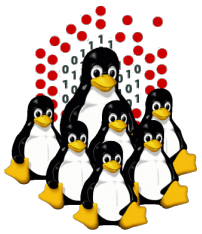
Requirements:

- ✔ 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!

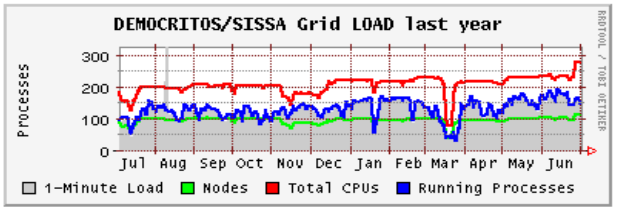
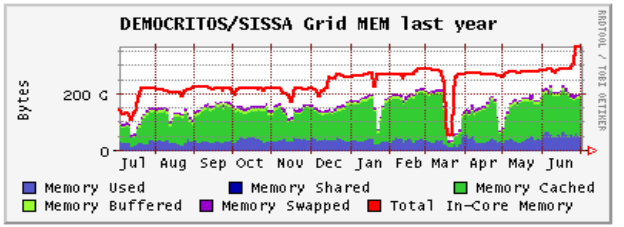
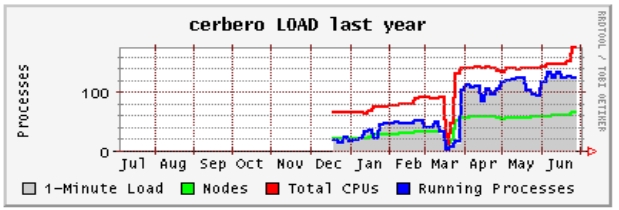
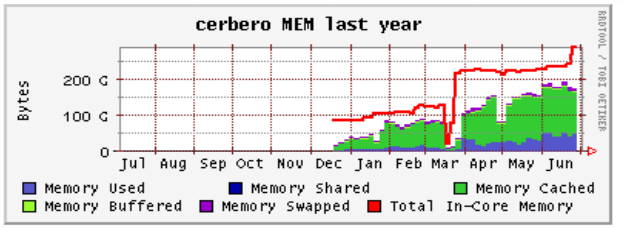
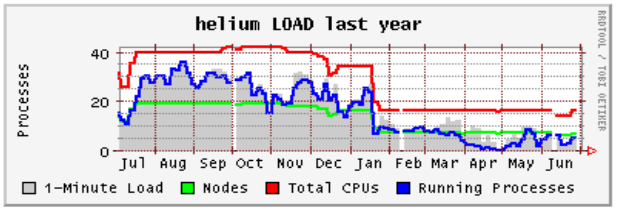
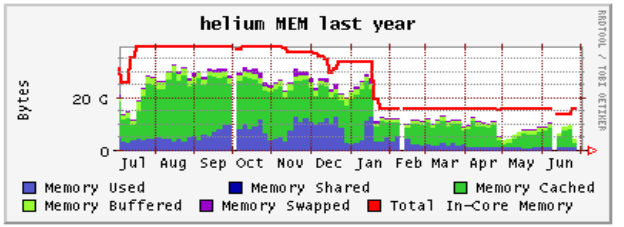
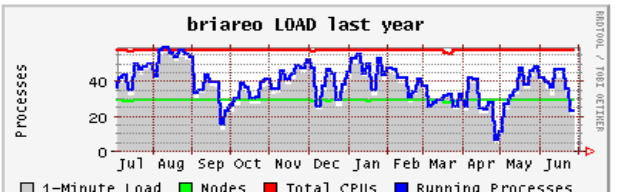
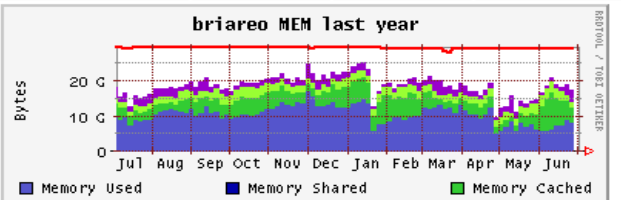


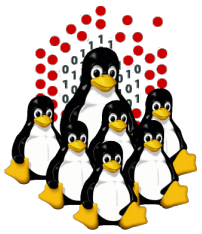
CLUSTER MANAGEMENT
Monitoring Tools

- 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	Load Averages			%CPU User, Nice, System, Idle			
DEMOCRITOS/SISSA Grid (4 sources) (tree view)	124.76	124.33	124.26	45.5	1.3	1.0	52.6
Hosts up: **113** (**276** CPUs Total) Hosts down: **1**						
cerbero (physical view)	111.72	111.80	112.15	65.4	2.1	1.5	29.7
Cluster Localtime: **July 2, 2006, 9:19 pm** Hosts up: **70** (**188** CPUs Total) Hosts down: **0**						
helium (physical view)	4.00	4.00	3.75	28.6	0.0	0.0	71.4
Cluster Localtime: **July 2, 2006, 9:19 pm** Hosts up: **7** (**16** CPUs Total) Hosts down: **0**						
briareo (physical view)	8.73	8.49	8.35	12.4	0.0	0.4	92.1
Cluster Localtime: **July 2, 2006, 9:19 pm** Hosts up: **29** (**58** CPUs Total) Hosts down: **0**						



CLUSTER MANAGEMENT
Ganglia at work /2

DEMOCRITOS/SISSA Grid > cerbero > a103.hpc

a103.hpc Overview

This node is up and running

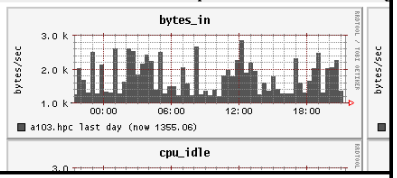
Time and String Metrics

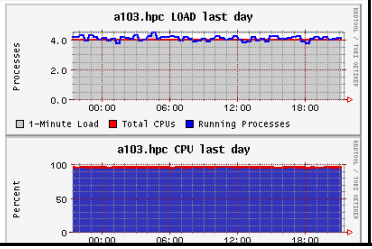
Name	Value
boottime	Thu, 27 Apr 2006 08:50:03 +0200
gexec	OFF
machine_type	x86_64
os_name	Linux
os_release	2.6.13.3
sys_clock	Thu, 27 Apr 2006 08:51:14 +0200
uptime	66 days, 12:33

Constant Metrics

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

Graphs of Volatile Metrics. Rang





DEMOCRITOS/SISSA Grid > cerbero > a103.hpc

a103.hpc Info

a103.hpc
10.1.2.3
Location: Unknown

Last heartbeat received 4 seconds ago.
Uptime 66 days, 12:33

Load: 3.84 4.00 3.99
1m 5m 15m

CPU Utilization: 94.2 4.0 1.6
user sys idle

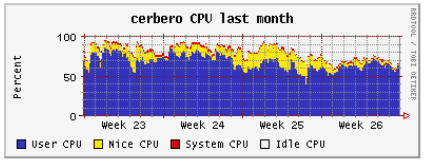
Hardware
CPUs: 4 x 2192 Mhz
Memory (RAM): 3964 MB
Local Disk: Using 17.074 of 68.024 GB
Most Full Disk Partition: 25.2% used.

Software
OS: Linux 2.6.13.3 (x86_64)
Booted: April 27, 2006, 8:50 am
Uptime: 66 days, 12:33
Swap: Using 8.7 of 4094.7 MB swap.

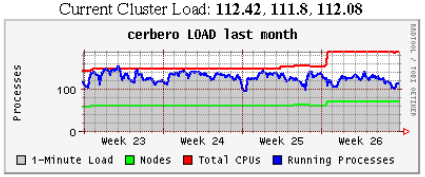
Physical View | Reload

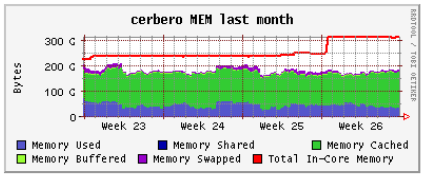
DEMOCRITOS/SISSA Grid > cerbero > --Choose a Node

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



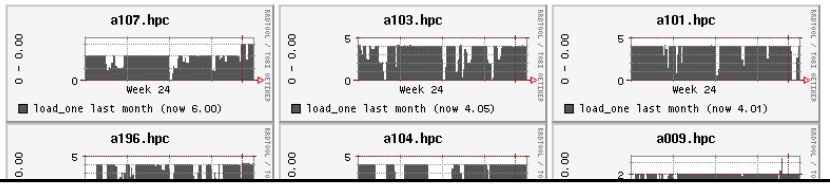
Current Cluster Load: **112.42, 111.8, 112.08**

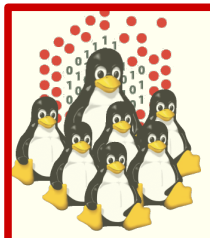




Snapshot of cerbero | Legend

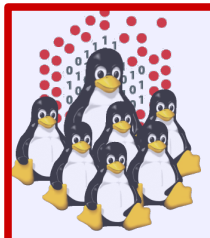
cerbero load_one





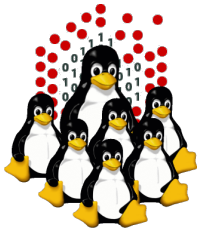
Security notes

- `/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, CDP and the like, ...



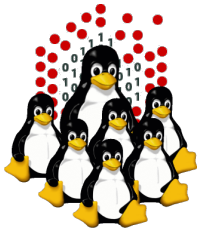
Hands-on Laboratory Session

- 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
  http://www.warewulf-cluster.org/

Installation Software:

- SystemImager http://www.systemimager.org/
- FAI http://www.informatik.uni-koeln.de/fai/

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
  http://www.llnl.gov/linux/pdsh/
- 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
- ethereal http://www.ethereal.com (obsolete)

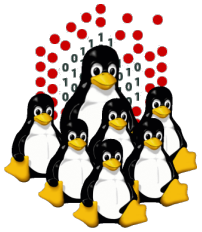
UnionFS:

- 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

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