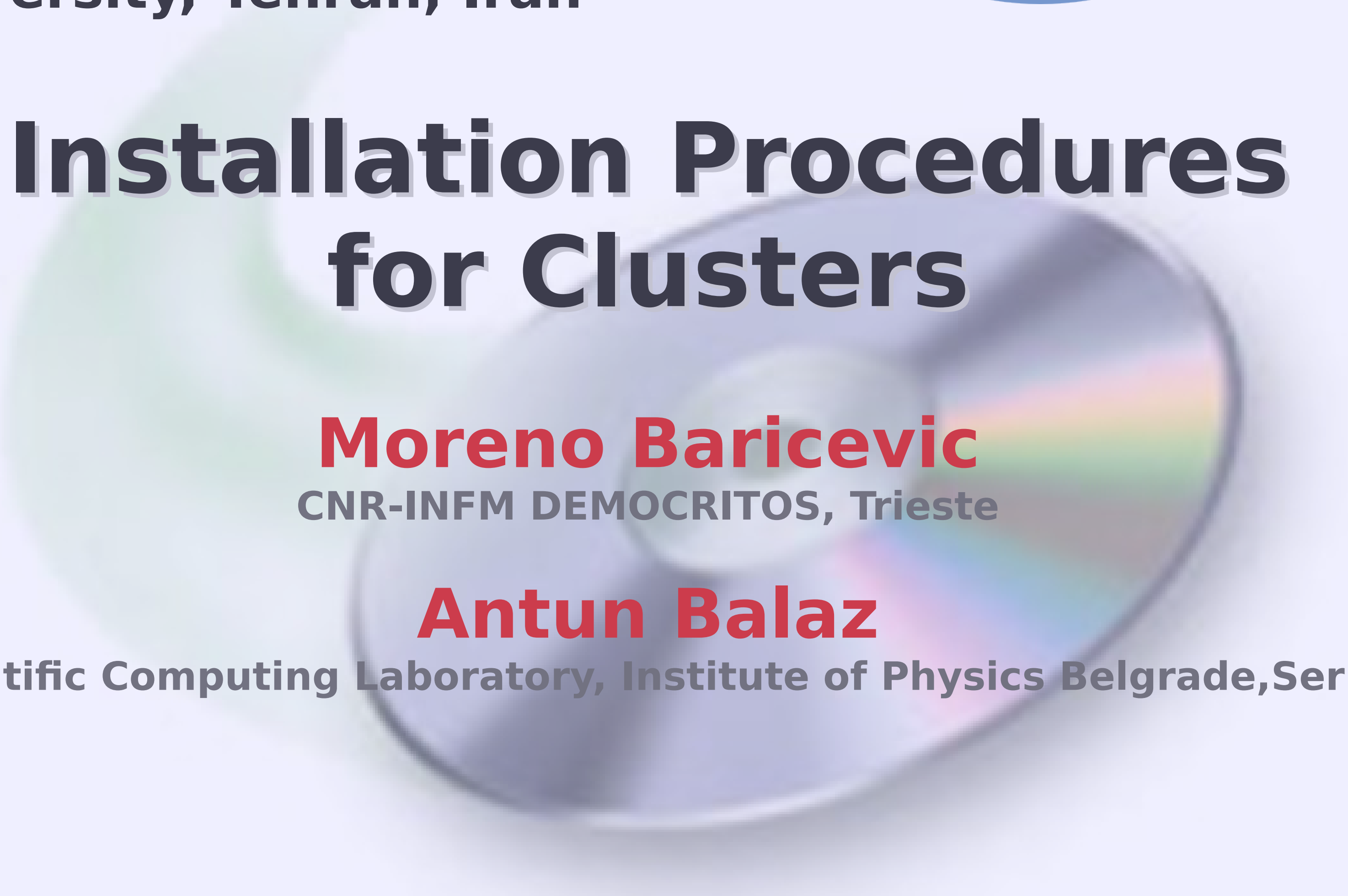
The 2nd Workshop on High Performance Computing, IPM & Shahid Beheshti University, Tehran, Iran

Joint DEMOCRITOS/SISSA Laboratory for e-Science

Installation Procedures for Clusters



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CNR-INFM DEMOCRITOS, Trieste

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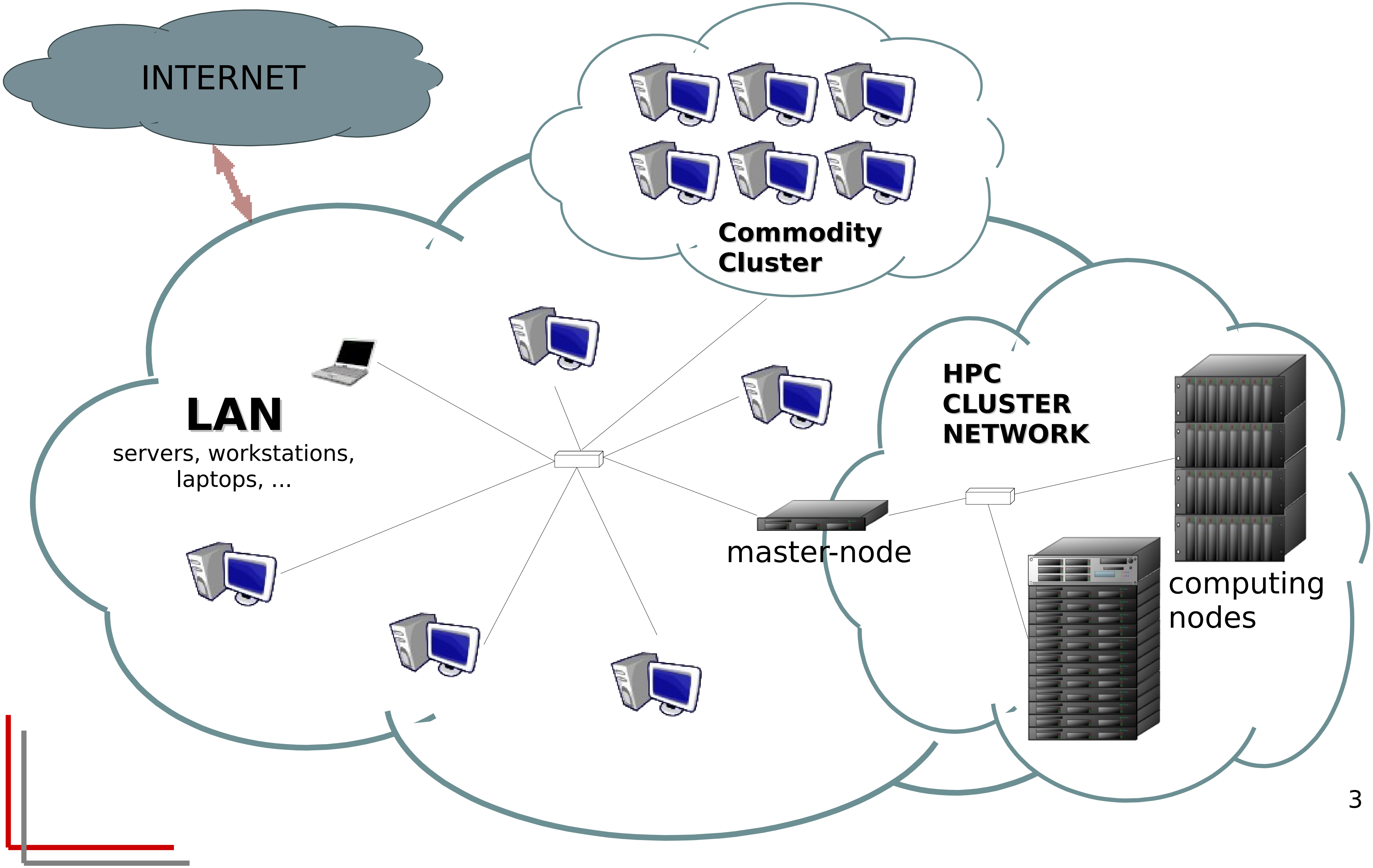
Scientific Computing Laboratory, Institute of Physics Belgrade,Serbia

Agenda

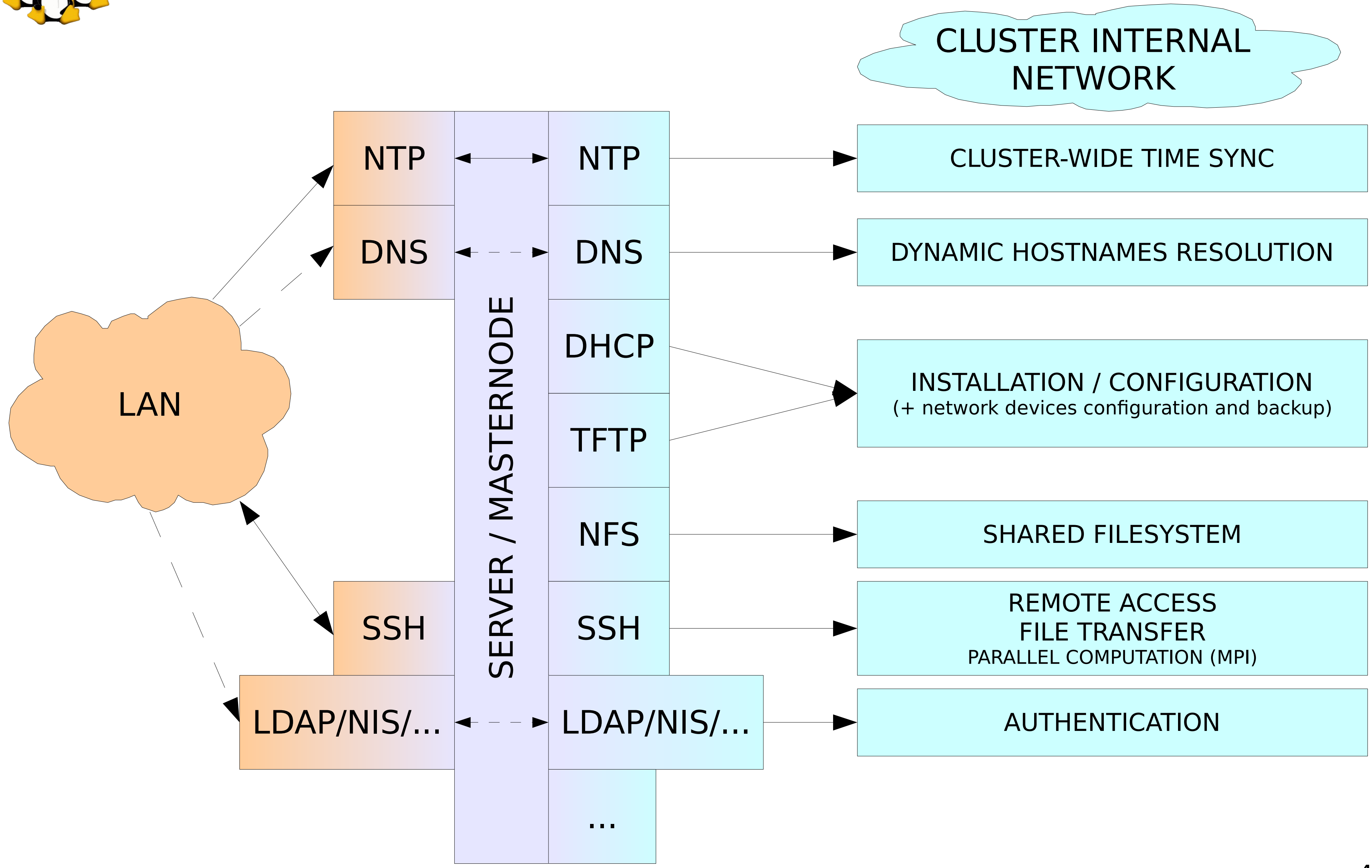
- Cluster Services
- Overview on Installation Procedures
- Configuration and Setup of a NETBOOT Environment
- Troubleshooting
- Cluster Management Tools
- Notes on Security

- Hands-on Laboratory Session

What's a cluster?



CLUSTER SERVICES



CLUSTER INTERNAL NETWORK

LAN

SERVER / MASTERNODE

NTP

DNS

SSH

LDAP/NIS/...

NTP

DNS

DHCP

TFTP

NFS

SSH

LDAP/NIS/...

...

CLUSTER-WIDE TIME SYNC

DYNAMIC HOSTNAMES RESOLUTION

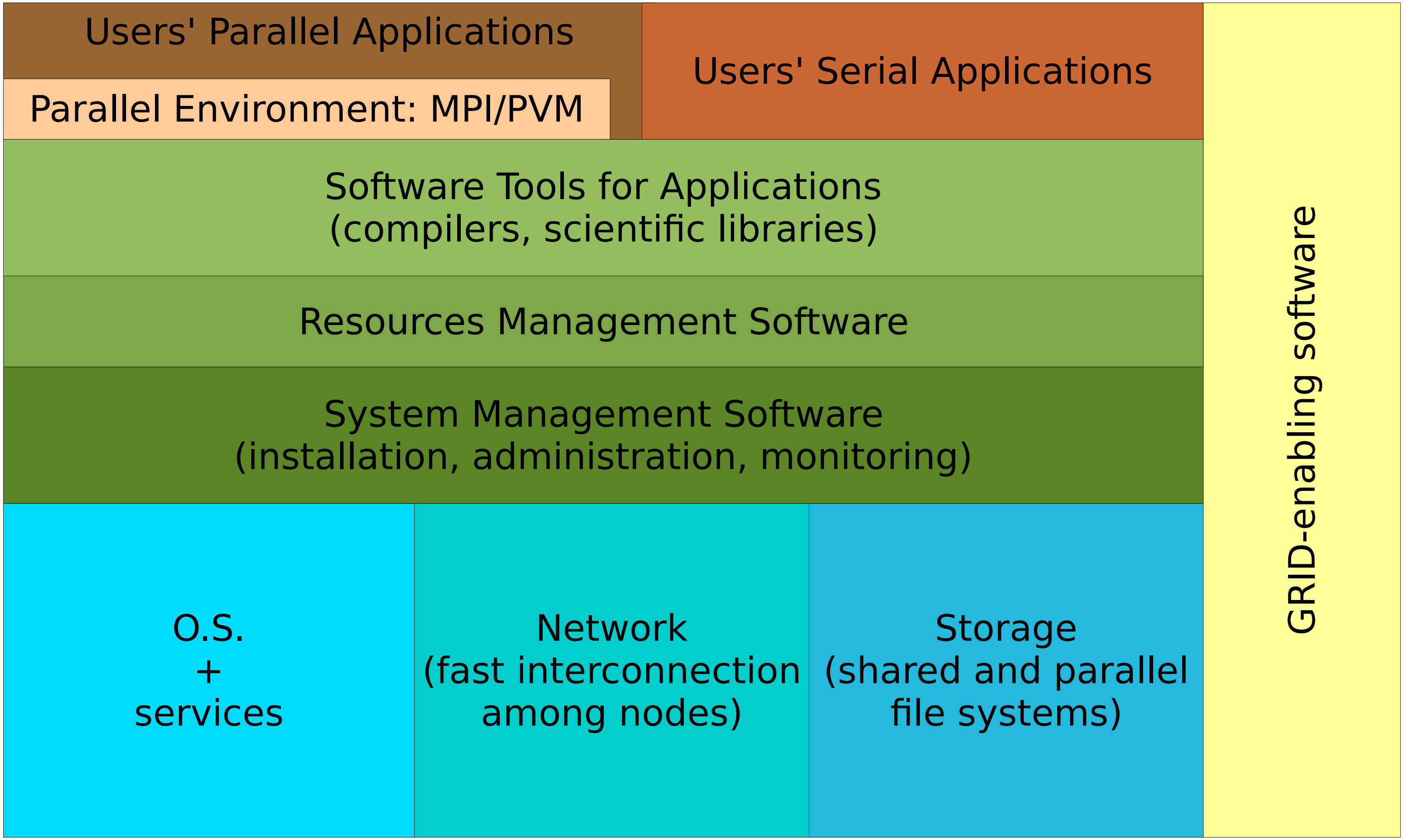
INSTALLATION / CONFIGURATION
(+ network devices configuration and backup)

SHARED FILESYSTEM

REMOTE ACCESS
FILE TRANSFER
PARALLEL COMPUTATION (MPI)

AUTHENTICATION

HPC SOFTWARE INFRASTRUCTURE
Overview



Users' Parallel Applications

Parallel Environment: MPI/PVM

Users' Serial Applications

Software Tools for Applications
(compilers, scientific libraries)

Resources Management Software

System Management Software
(installation, administration, monitoring)

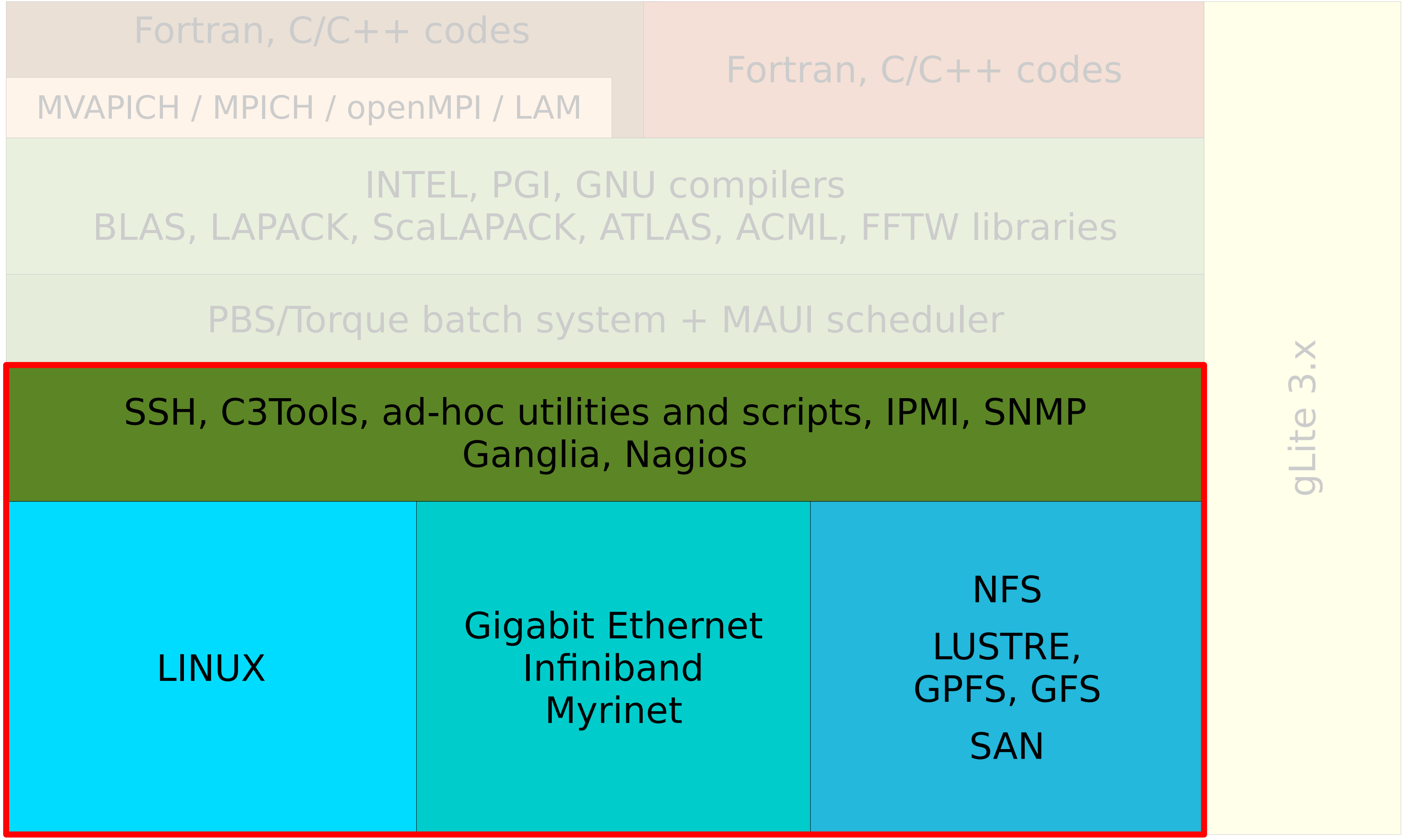
O.S.
+
services

Network
(fast interconnection
among nodes)

Storage
(shared and parallel
file systems)

GRID-enabling software

HPC SOFTWARE INFRASTRUCTURE
Overview (our experience)



Fortran, C/C++ codes

MVAPICH / MPICH / openMPI / LAM

Fortran, C/C++ codes

INTEL, PGI, GNU compilers
BLAS, LAPACK, ScaLAPACK, ATLAS, ACML, FFTW libraries

PBS/Torque batch system + MAUI scheduler

SSH, C3Tools, ad-hoc utilities and scripts, IPMI, SNMP
Ganglia, Nagios

LINUX

Gigabit Ethernet
Infiniband
Myrinet

NFS

LUSTRE,
GPFS, GFS

SAN

gLite 3.x

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.

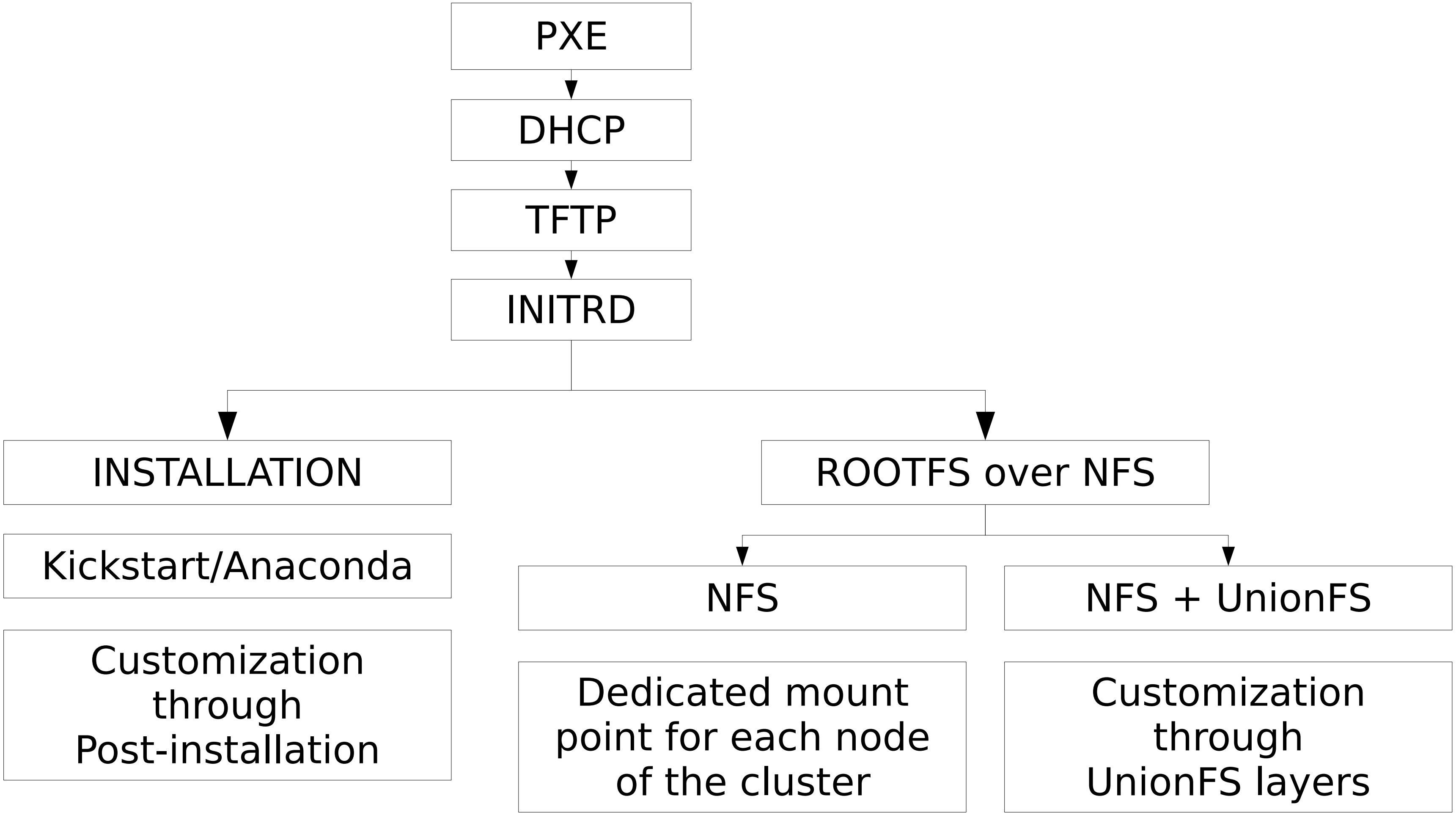
Sometimes limited by rigid and not customizable configurations, often bounded to some specific LINUX distribution and version. May depend on vendors' hardware.

- 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



PXE

DHCP

TFTP

INITRD

INSTALLATION

Kickstart/Anaconda

Customization through Post-installation

ROOTFS over NFS

NFS

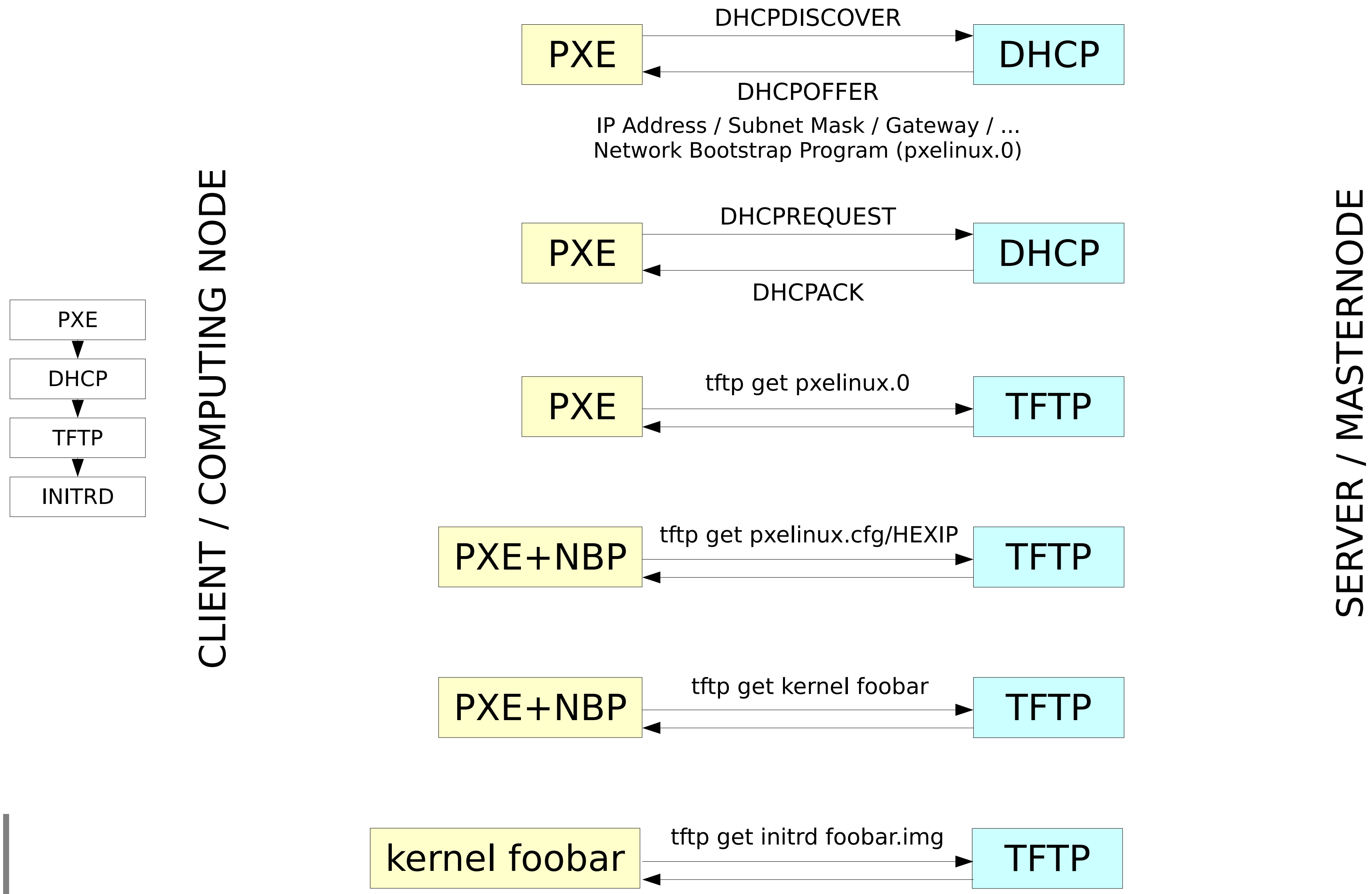
Dedicated mount point for each node of the cluster

NFS + UnionFS

Customization through UnionFS layers

Network booting (NETBOOT)

PXE + DHCP + TFTP + KERNEL + INITRD



PXE

DHCP

TFTP

INITRD

CLIENT / COMPUTING NODE

PXE → DHCPDISCOVER → DHCP

DHCP → DHCPOFFER → PXE

IP Address / Subnet Mask / Gateway / ...
Network Bootstrap Program (pxelinux.0)

PXE → DHCPREQUEST → DHCP

DHCP → DHCPACK → PXE

PXE ↔ tftp get pxelinux.0 ↔ TFTP

PXE+NBP ↔ tftp get pxelinux.cfg/HEXIP ↔ TFTP

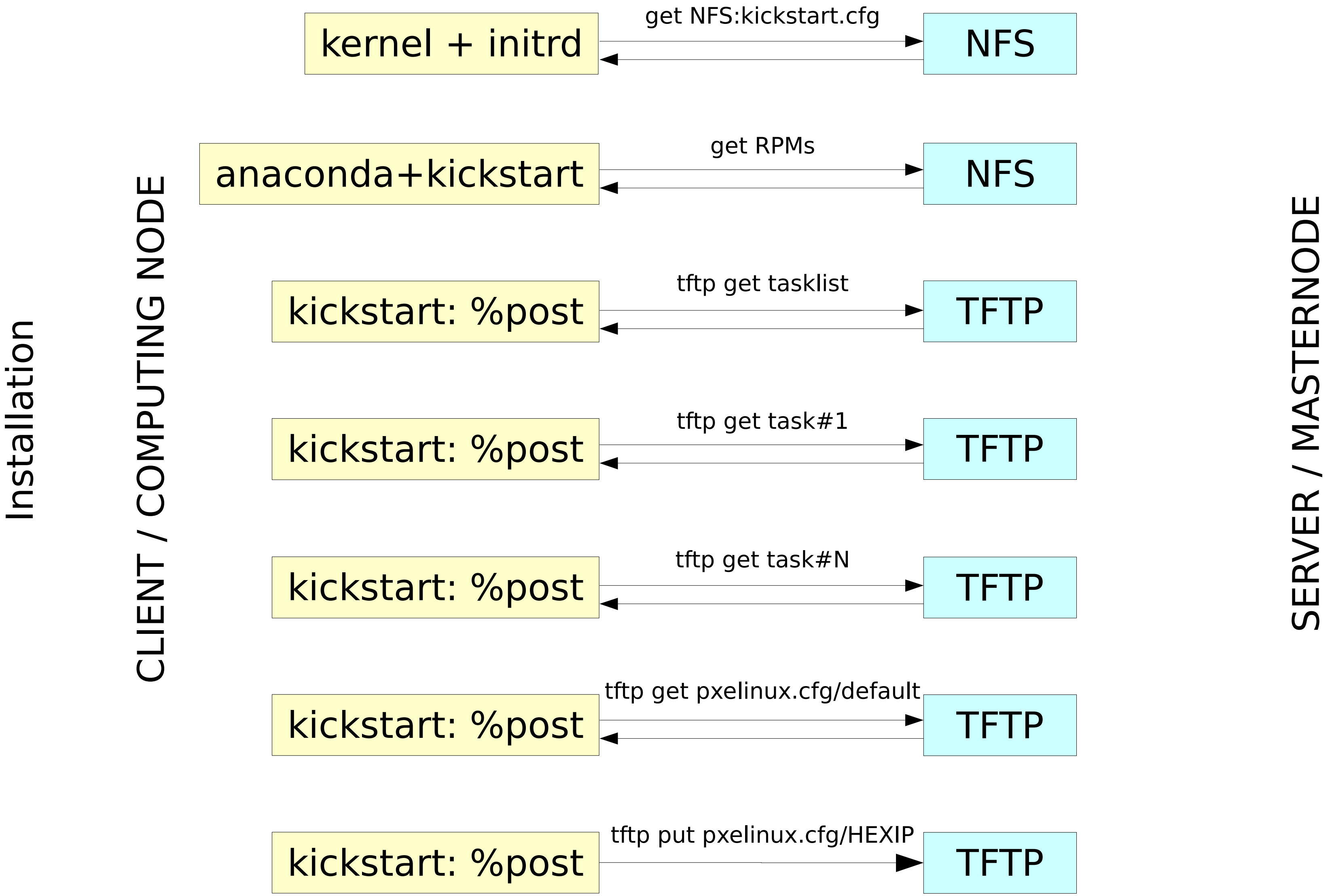
PXE+NBP ↔ tftp get kernel foobar ↔ TFTP

kernel foobar ↔ tftp get initrd foobar.img ↔ TFTP

SERVER / MASTERNODE

Network-based Distributed Installation

NETBOOT + KICKSTART INSTALLATION



Installation

CLIENT / COMPUTING NODE

SERVER / MASTERNODE

kernel + initrd — get NFS:kickstart.cfg — NFS

anaconda+kickstart — get RPMs — NFS

kickstart: %post — tftp get tasklist — TFTP

kickstart: %post — tftp get task#1 — TFTP

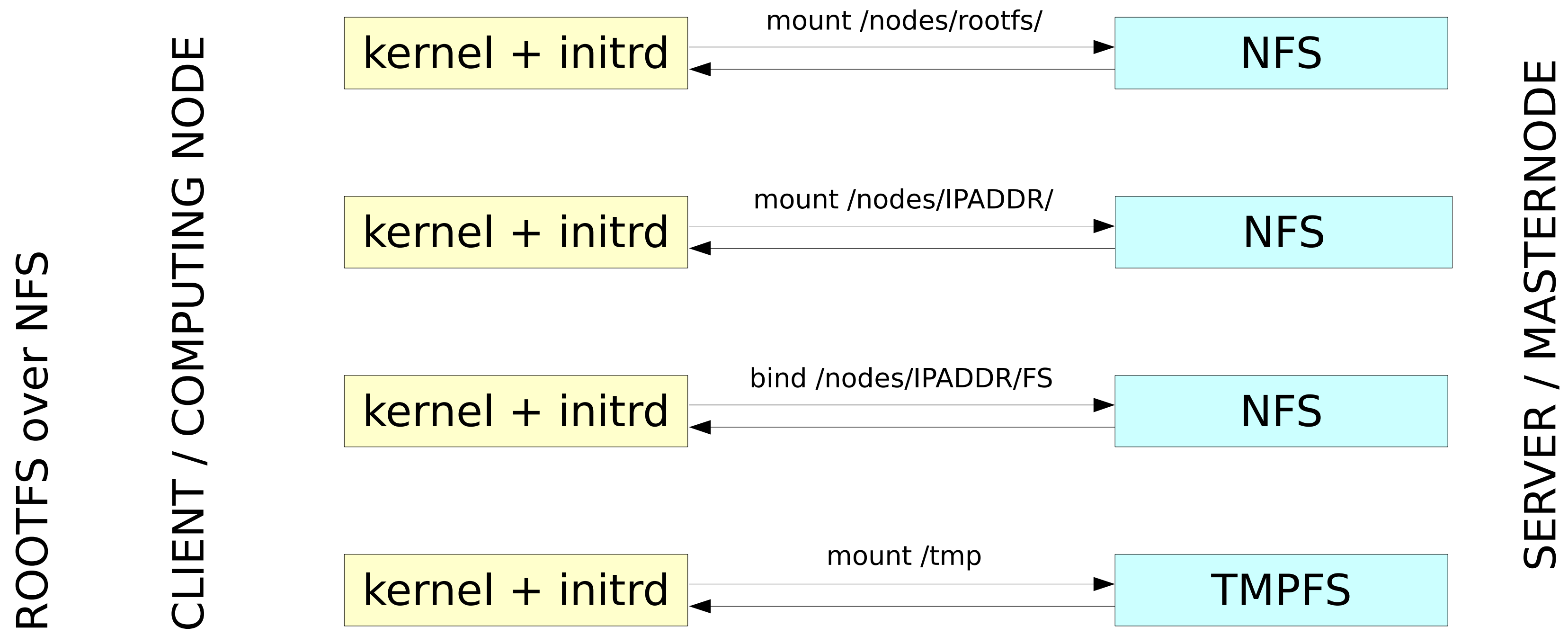
kickstart: %post — tftp get task#N — TFTP

kickstart: %post — tftp get pxelinux.cfg/default — TFTP

kickstart: %post — tftp put pxelinux.cfg/HEXIP — TFTP

Diskless Nodes NFS Based

NETBOOT + NFS



ROOTFS over NFS

CLIENT / COMPUTING NODE

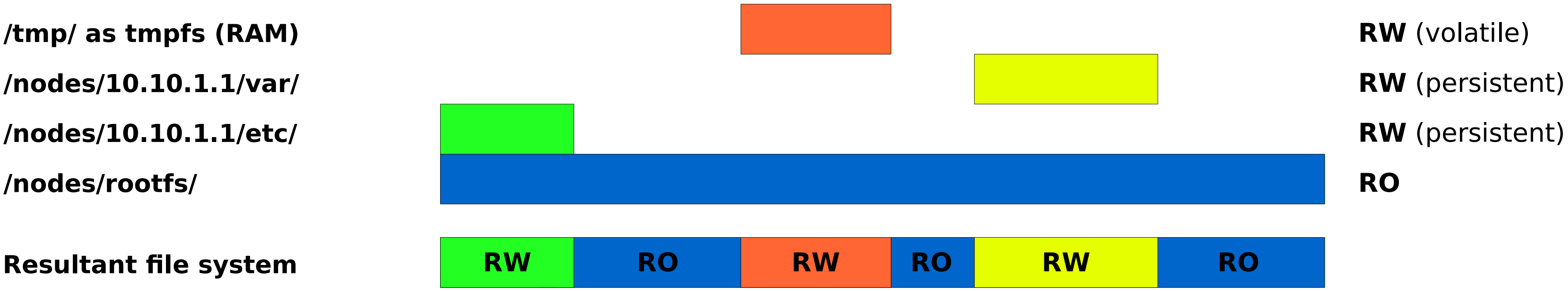
kernel + initrd → mount /nodes/rootfs/ → NFS

kernel + initrd → mount /nodes/IPADDR/ → NFS

kernel + initrd → bind /nodes/IPADDR/FS → NFS

kernel + initrd → mount /tmp → TMPFS

SERVER / MASTERNODE



/tmp/ as tmpfs (RAM) — **RW** (volatile)

/nodes/10.10.1.1/var/ — **RW** (persistent)

/nodes/10.10.1.1/etc/ — **RW** (persistent)

/nodes/rootfs/ — **RO**

Resultant file system — **RW** | **RO** | **RW** | **RO** | **RW** | **RO**

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

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
```

/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/

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

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