

# Linux File System Administration

©



DevOps G

# This course is for you because...

- You are a Linux user with a basic understanding of the Linux operating system and..
- You want to learn advanced operating system topics such as...
- ACLs, quotas, file archive, file links, creating and mounting disk partitions and partition types such as...
- LVM and RAID

# You Will Understand

- Linux filesystem concepts and tools
- How to find and search files
- The inode table and file links
- The difference between a hard link and a symbolic link

# You Will Be Able To

- Modify file permissions and ACLs
- Use file quotas
- Archive and back up files
- Create and mount disk partitions
- Implement LVMs and RAID

# You Should Know and Have

- Know basics of the Linux shell and the Linux filesystem
- Know basic shell commands
- Have access to a Linux installation (I will be using Ubuntu) and...
- Have installed Linux with plenty of unused disk space (we will create several new disk partitions)

# File Permissions

# File Permissions

- We will discuss:
  - File permission basics
  - Use of `chmod` and `chown`
  - SUID / SGID
  - The often misunderstood writeable directory and the sticky bit
  - Simultaneous file edits



# File Permission Basics

File permissions are shown with `ls -l`:

```
student$ ls -l
total 64
-rwxrwxr-x 1 student student 832 Oct  2 16:26 backup.sh
-rwxr-xr-x 1 student student  70 Mar  6 2016 hello.pl
-rwxr-xr-x 1 student student 30832 Mar  6 2016 largefile.txt
-rwxr-xr-x 1 student student  53 Mar  6 2016 quote.txt
-rwxr-xr-x 1 student student 142 Mar  6 2016 records.data
-rw-rw-r-- 1 student student  8 Oct 15 08:54 regex.txt
-rwxr-xr-x 1 student student  53 Mar  6 2016 sed.out
-rwxr-xr-x 1 student student  76 Mar  6 2016 wallquote.txt
```

# File Permission Basics

- `r` - read  
`w` - write  
`x` - execute

The first character can be:

- `-` - regular file
- `d` - directory
- `l` - symbolic link
- `b` - block file
- `c` - character device file
- `p` - named pipe
- `s` - socket

# chmod

Change file permissions with `chmod`:

```
student$ ls -l regex.txt  
-rw-rw-r-- 1 student student 8 Oct 15 08:54 regex.txt  
student$ chmod 600 regex.txt  
student$ ls -l regex.txt  
-rw----- 1 student student 8 Oct 15 08:54 regex.txt
```

# chmod

The numeric value represents:

6	0	0
110	000	000
rw-	---	---

For 751:

7	5	1
111	101	001
rwX	r-X	--X

```
student$ chmod 751 regex.txt
```

```
student$ ls -l regex.txt
```

```
-rwxr-x--x 1 student student 8 Oct 15 08:54 regex.txt
```

# chmod

Symbolic notation can also be used:

```
student$ ls -l regex.txt
-rwxr-x--x 1 student student 8 Oct 15 08:54 regex.txt
student$ chmod -x regex.txt
student$ ls -l regex.txt
-rw-r----- 1 student student 8 Oct 15 08:54 regex.txt
student$ chmod g+w regex.txt
student$ ls -l regex.txt
-rw-rw---- 1 student student 8 Oct 15 08:54 regex.txt
student$ chmod gu-r regex.txt
student$ ls -l regex.txt
--w--w---- 1 student student 8 Oct 15 08:54 regex.txt
```

# chmod

```
student$ ls -l regex.txt
```

```
--w--w---- 1 student student 8 Oct 15 08:54 regex.txt
```

```
student$ chmod g+r,o+x regex.txt
```

```
student$ ls -l regex.txt
```

```
--w-rw---x 1 student student 8 Oct 15 08:54 regex.txt
```

```
student$ chmod u+r,g-w,o-x regex.txt
```

```
student$ ls -l regex.txt
```

```
-rw-r----- 1 student student 8 Oct 15 08:54 regex.txt
```

# chown / chgrp

The `chown` command changes the owner - only `root` can do this:

```
root# ls -l regex.txt
-rw-r----- 1 student student 8 Oct 15 08:54 regex.txt
root# chown jdoe regex.txt
root# ls -l regex.txt
-rw-r----- 1 jdoe student 8 Oct 15 08:54 regex.txt
```

`chown` can also be used to change owner and group:

```
root# chown student:class regex.txt
root# ls -l regex.txt
-rw-r----- 1 student class 8 Oct 15 08:54 regex.txt
```

# chown / chgrp

The `chgrp` command changes the group associated with the file:

```
root# chgrp student regex.txt
```

```
root# ls -l regex.txt
```

```
-rw-r----- 1 student student 8 Oct 15 08:54 regex.txt
```



# chown / chgrp

The `chown` and `chgrp` commands can do their work recursively with the `-R` option:

```
root# ls -ld data
```

```
drwxrwxr-x 2 student student 4096 Nov  5 13:46 data
```

```
root# ls -l data
```

```
-rw-rw-r-- 1 student student 0 Nov  5 13:46 a.dat
```

```
-rw-rw-r-- 1 student student 0 Nov  5 13:46 b.dat
```

```
-rw-rw-r-- 1 student student 0 Nov  5 13:46 c.dat
```

```
root# chown -R jdoe data
```

```
root# ls -ld data
```

```
drwxrwxr-x 2 jdoe student 4096 Nov  5 13:46 data
```

```
root# ls -l data
```

```
-rw-rw-r-- 1 jdoe student 0 Nov  5 13:46 a.dat
```

```
-rw-rw-r-- 1 jdoe student 0 Nov  5 13:46 b.dat
```

```
-rw-rw-r-- 1 jdoe student 0 Nov  5 13:46 c.dat
```

# SUID and SGID

SUID (*Set User ID*) is an access flag that allows the executable to be executed with the permissions of the executable's owner or group.

SGID (*Set Group ID*) causes files and sub-directories to inherit the GID of the directory.

# SUID Executables

SUID is necessary when normal users are executing programs that require elevated privileges, such as the `passwd` utility that modifies `/etc/shadow`:

```
$ ls -l /usr/bin/passwd
```

```
-rwsr-xr-x 1 root root 54256 May 16 19:37 /usr/bin/passwd
```

The `s` in place of the owner's `x` permission indicates the program SUID.

# SUID Executables

Consider the following C program (`setuid.c`) that will print the real user id and the effective user id:

```
#include <stdio.h>
#include <unistd.h>

int main() {
    int real = getuid();
    int euid = geteuid();
    printf("The REAL UID = %d\n", real);
    printf("The EFFECTIVE UID = %d\n", euid);
}
```

# SUID Executables

Let's execute this program and see how the effective user ID changes to the owner of the program:

```
student$ gcc -o /tmp/setuid setuid.c
student$ ls -l /tmp/setuid
-rwxr-xr-x 1 student student 8172 Oct 16 17:25 /tmp/setuid
student$ /tmp/setuid
The REAL UID = 1001
The EFFECTIVE UID = 1001
student$ su - jdoe
Password:
jdoe$ /tmp/setuid
The REAL UID = 1002
The EFFECTIVE UID = 1002
jdoe$ exit
```

# SUID Executables

A file is set to SUID with `chmod`. Note the `x` replaced with `s`:

```
student$ chmod u+s /tmp/setuid
student$ ls -l /tmp/setuid
-rwsr-xr-x 1 student student 8172 Oct 16 17:25 /tmp/setuid
student$ su - jdoe
Password:
jdoe$ /tmp/setuid
The REAL UID = 1002
The EFFECTIVE UID = 1001
jdoe$ exit
```

Using numeric notation (4xxx):

```
student$ chmod 4755 /tmp/setuid
```

# SGID Directories

Setting the SGID permission on a directory causes new files and subdirectories created within it to inherit its GID. The SGID bit is also inherited. This only affects new directories created, not currently existing directories.

```
student$ mkdir /tmp/test
student$ chmod 777 /tmp/test
student$ ls -l /tmp/test
total 0
student$ ls -ld /tmp/test
drwxrwxrwx 2 student student 4096 Oct 16 18:36 /tmp/test
jsmith$ su - jdoe
Password:
jdoe$ mkdir /tmp/test/fool
jdoe$ ls -ld /tmp/test/fool
drwxrwxr-x 2 jdoe jdoe 4096 Mar  4 18:36 /tmp/test/fool
jdoe$ exit
```

# SGID Directories

```
student$ chmod g+s /tmp/test
student$ ls -ld /tmp/test
drwxrwsrwx 3 student student 4096 Oct 16 18:36 /tmp/test
student$ su - jdoe
Password:
jdoe$ mkdir /tmp/test/foo2
jdoe$ ls -ld /tmp/test/*
drwxrwxr-x 2 jdoe jdoe 4096 Oct 16 18:36 /tmp/test/foo1
drwxrwsr-x 2 jdoe student 4096 Oct 16 18:38 /tmp/test/foo2
jdoe$ exit
```

Using numeric notation (2xxx):

```
student$ chmod 2775 /tmp/test
```



# Writeable Directory

The writeable directory is often misunderstood.

One can write into and delete files owned by others from a directory that is writeable, even if the file is not readable or writeable:

```
student$ ls -ld /tmp/mydirectory
drwxrwxrwx 2 jdoe jdoe 17 Oct 16 16:17 my directory
student$ ls -l /tmp/mydirectory
-rw----- 1 jdoe jdoe 17 Oct 16 16:19 myfile.txt
student$ cat /tmp/mydirectory/myfile.txt
cat: /tmp/mydirectory/myfile.txt: Permission denied
student$ rm /tmp/mydirectory/myfile.txt
rm: remove write-protected regular file '/tmp/mydirectory/myfile.txt'? y
student$ cat /tmp/mydirectory/myfile.txt
cat: /tmp/mydirectory/myfile.txt: No such file or directory
```

# Writeable Directory

Solved with the “sticky bit” created with `chmod +t`. Notice the “other” `x` changes to a `t`:

```
jdoe$ chmod +t /tmp/mydirectory
jdoe$ ls -ld /tmp/mydirectory
drwxrwxrwt 2 jdoe jdoe 4096 Oct 16 17:07 /tmp/mydirectory
jdoe$ touch /tmp/mydirectory/myfile.txt
jdoe$ chmod 600 /tmp/mydirectory/myfile.txt
jdoe$ su - student
Password:
student$ cat /tmp/mydirectory/myfile.txt
cat: /tmp/mydirectory/myfile.txt: Permission denied
student$ rm /tmp/mydirectory/myfile.txt
rm: remove write-protected regular empty file '/tmp/mydirectory/myfile.txt'? y
rm: cannot remove '/tmp/mydirectory/myfile.txt': Operation not permitted
```

`/tmp` is an example of a directory with a sticky bit.

# Writeable Directory

Numeric notation can be used to set the sticky bit (1xxx):

```
jdoe$ chmod 1777 /tmp/mydirectory
```

# Simultaneous File Edits

- files simultaneously edited by two users follow the “last one wins” rule
- if more than one user is editing the same file, the last write overwrites all other writes
- the only way to resolve this issue is by locking files

# Exercise

1. Given the following permissions, write the numeric `chmod` argument to create them:

`rxrxw-r--`

`r-xr--r--`

`rw-rw-rw-`

`rw-rw-r--`

`r---w---x`

`r-----`

`r--r--r--`

`chmod`

`chmod`

`chmod`

`chmod`

`chmod`

`chmod`

`chmod`

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# Exercise

2. Given the following permissions, write the symbolic `chmod` argument to create them (cumulative, meaning from the recent permissions to the desired permissions):

— — — — —

rw-r--r--

rw-rw-r--

rw-rw-rw-

r---w---x

r-----

r--r--r--

rwXrw-r--

r-xr--r--

chmod

chmod

chmod

chmod

chmod

chmod

chmod

chmod

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# Exercise

3. Compile the program `setuid.c`. Run it as a non-SUID program as another user. Then SUID it, run it again.
4. Create a directory and set the sticky bit (as `root`) with the numeric notation.

# File Attributes and ACLs



# File Attributes and ACLs

- file attributes
  - the `lsattr` command
  - the `chattr` command
- Access Control Lists (ACLs)
  - the `getfacl` command
  - the `setfacl` command

# File Attributes

Linux supports additional file attributes beyond `r`, `w`, `x` and include (see `man chattr` for a complete list):

- `a` - only use append for writing
- `A` - no atime updates
- `c` - automatically compress on disk
- `d` - don't backup with `dump (8)`
- `i` - file cannot be modified (immutable)
- `j` - data journaling
- `s` - when file is deleted, zero out disk

# lsattr and chattr

The `lsattr` command lists the attributes. The `chattr` command changes attributes:

```
root# touch test.txt
root# lsattr test.txt
-----e-- test.txt
root# chattr +i test.txt
root# lsattr test.txt
----i-----e-- test.txt
root# echo hello >> test.txt
-bash: test.txt: Operation not permitted
```

# lsattr and chattr

```
root# echo this is a test >> test.txt
-bash: test.txt: Permission denied
root# chattr +a -i test.txt
root# lsattr test.txt
-----a----- test.txt
root# echo this is a test > test.txt
-bash: test.txt: Operation not permitted
root# echo this is a test >> test.txt
root# chattr -a test.txt
root# lsattr test.txt
-----e----- test.txt
```

# Access Control Lists

Access Control Lists (ACLs) provide more granularity for controls on file and directory permissions, for example:

- remove read/write permissions on a file from the group and others, but
- allow one or two users to have read/write permissions

# getfacl Command

The `getfacl` command shows a file's ACLs:

```
student$ touch test.txt
student$ chmod 750 test.txt
student$ ls -l test.txt
-rwxr-x--- 1 student student 0 Oct  6 08:54 test.txt
student$ getfacl test.txt
# file: test.txt
# owner: student
# group: student
user::rwx
group::r-x
other::---
```

# setfacl Command

Now let's give read/write permission to the user `jdoe`, who at this time has no permissions for this file (since that user is in the "other" category):

```
student$ setfacl -m user:jdoe:rw- test.txt  
student$ getfacl --omit-header test.txt  
user::rwx  
user:jdoe:rw-  
group::r-x  
mask::rwx  
other:---
```

# setfacl Command

Notice the change in the `ls -l` output (the addition of the `+` character):

```
student$ ls -l test.txt  
-rwxrwx---+ 1 student student 0 Oct  6 08:54 test.txt
```



# setfacl Command

Now the user `jdoe` can modify the file:

```
student$ su - jdoe
```

```
Password:
```

```
jdoe$ echo hi >> /tmp/test.txt
```

```
jdoe$ exit
```

# setfacl Command

We can also apply ACLs to directories. Let's create a directory that `jdoe` cannot write into:

```
student$ mkdir /tmp/acl
student$ chmod 700 /tmp/acl
student$ getfacl --omit-header /tmp/acl
getfacl: Removing leading '/' from absolute path names
# file: tmp/acl
# owner: student
# group: student
user::rwx
group:---
other:---
```

# setfacl Command

Let's see if jdoe can write into it:

```
student$ su - jdoe
```

```
Password:
```

```
jdoe$ touch /tmp/acl/test.txt
```

```
touch: cannot touch `/tmp/acl/test.txt': Permission denied
```

# setfacl Command

Let's give jdoe read/write permission:

```
student$ setfacl -m user:jdoe:rwx /tmp/acl
student$ getfacl --omit-header /tmp/acl
getfacl: Removing leading '/' from absolute path names
user::rwx
user:jdoe:rwx
group:---
mask::rwx
other:---
student$ ls -ld /tmp/acl
drwxrwx---+ 2 student student 4096 Mar  6 09:26 /tmp/acl
```

# setfacl Command

```
student$ su - jdoe
```

```
Password:
```

```
jdoe$ touch /tmp/acl/test.txt
```

```
jdoe$ ls -l /tmp/acl/test.txt
```

```
-rw-rw-r-- 1 jdoe jdoe 0 Mar  6 09:26 /tmp/acl/test.txt
```

```
jdoe$ exit
```

# Exercise

1. Create a file. Using `chattr`, make it immutable. Then try to write to it.
2. Using `chattr`, make the file mutable but only appendable. Then try to write to it. Then try to append to the file.
3. Using `chattr`, make the file automatically compressed. Compare the output of these commands:

```
student$ du test.dat
```

```
student$ du --apparent-size test.dat
```

# Exercise

4. Create a file. Set the permissions so that only the owner can read and write. Using `setfacl`, allow the user `jdoe` to read and write the file.
5. Create a directory. Set the permissions so only the owner can create files in the directory. Using `setfacl`, allow `jdoe` to create files in the directory, but not able to list its contents.

# Locating and Searching Files



# Locating and Searching Files

- the `which` command
- the `whatis` command
- the `find` command
- the `locate` command
- `grep` and regular expressions (aka. regexes)

# which Command

- use `which` to locate an executable

```
student$ which date  
/bin/date
```

- `which` searches all directories in the `PATH` variable and prints first found - use `-a` (or `--all`) to print all executables:

```
student$ ls ~/bin/date  
~/bin/date  
student$ which -a date  
/bin/date  
~/bin/date
```

# whatis Command

- a `man` page database can be created with `/usr/sbin/makewhatis` and can be searched with `whatis` - it will display the `man` pages for utilities that exactly match the argument:

```
student$ whatis printf
```

```
printf (1) - format and print data
```

```
printf (3) - formatted output conversion
```

```
student$ whatis prin
```

```
prin: nothing appropriate
```

# man -k Command

- `what is` finds exact matches - for partial matches, use `man -k` (aka `apropos`)

```
student$ man -k print
```

```
banner (6) - print large banner on printer
```

```
base64 (1) - base64 encode/decode data and print to standard output
```

```
blkid (8) - command-line utility to locate/print block device attributes
```

```
cat (1) - concatenate files and print on the standard output
```

```
date (1) - print or set the system date and time
```

# man -K Command

- `man -K` searches the content of man pages (not just titles):

```
student$ man -K Linux
```

```
--Man-- next: git-read-tree(1) [ view (return) | skip (Ctrl-D) | quit (Ctrl-C) ]
```

```
--Man-- next: git-describe(1) [ view (return) | skip (Ctrl-D) | quit (Ctrl-C) ]
```

```
--Man-- next: git-diff-tree(1) [ view (return) | skip (Ctrl-D) | quit (Ctrl-C) ]
```

# find Command

- `find` searches for files - it has a lot of options, but a simple use is to look in `/usr` for the file `zip`:

```
student$ find /usr -name zip  
/usr/bin/zip  
/usr/share/doc/zip
```

- if there is standard error output, it can be suppressed with:

```
student$ find /usr -name zip 2>/dev/null
```

# find Command

- here are some examples of using `find`:

```
# find all files that have been accessed more than  
# 1 day ago  
find / -atime 1
```

```
# find all files created this year  
touch --date="12:00 am jan 1 2020" /tmp/ref_time  
find / -newer /tmp/ref_time
```

```
# get list of all newly updated videos  
find /filer/videos -type f -mtime 1
```

# find Command

```
# strip suid bits from anything in /home
find /home -perm -4000 -exec chmod u-s {} \;

# fix the permissions on /var/www/htdocs
# make it so that everyone in www-data group can
# create and edit all files, and sgid bit on dir
# assures that all files are created with www-data
# group ownership as well
chown -R www-data:www-data /var/www/htdocs
find /var/www/htdocs -type d -exec chmod 2775 {} \;
find /var/www/htdocs -type f -exec chmod 664 {} \;
```



# locate Command

- the `locate` command quickly searches for files on the system by searching the database created by `updatedb`
- **note:** `updatedb` should be run by `root` daily and is usually done so through `cron`

```
student$ locate locate  
/bin/ntfsfallocate  
/etc/alternatives/locate  
/etc/alternatives/locate.1.gz  
/etc/cron.daily/mlocate  
/usr/bin/fallocate  
/usr/bin/locate  
/usr/bin/mlocate  
...
```

# locate Command

- `locate` has many options:
  - `-i` - case insensitive search
  - `-n` - limit the lines of output to the provided number
  - `-e` - exclude provided directories
  - `-r` - filter output with supplied regex
  - `-d` - path of databases to search

# Regular Expressions

- a regular expression (aka *regex*) is a sequence or pattern of characters that is compared against a string of text
- regexes are used to perform text matching, text replacement, text extraction and various other text manipulation operations
- the `grep` command uses regexes to look for text in files; this example displays all lines of the file `a.dat` that match the regex `xyz`:

```
student$ grep xyz a.dat
```

# Patterns: Single Characters

- most characters match themselves:
  - `a` - matches “a” anywhere
  - `ab` - matches “ab” anywhere
  - `abc` - matches “abc” anywhere
- there are some special characters:
  - `.` - (the period) matches any character but newline
  - `^` - matches the beginning of the string
  - `$` - matches the end of the string

# Patterns: Character Classes

- created using square brackets - matches one occurrence of any character in the class:
  - `[abcde]` - matches one of either "a", "b", "c", "d" or "e"
  - `[a-e]` - the same
  - `[0-9]` - matches one digit
- if the caret (^) is the first character in the class, it matches any character except what is in the class:
  - `[^abcde]` - any character except "a", "b", "c", "d" and "e"
  - `[^a-e]` - the same
  - `[^0-9]` - matches one non-digit

# Patterns: Quantifiers

- the number of characters can be specified with *quantifiers*:
  - $*$  - 0 or more
  - $+$  - 1 or more
  - $?$  - 0 or 1
  - $\{m\}$  - **exactly**  $m$
  - $\{m, \}$  -  $m$  or more
  - $\{m, n\}$  -  $m$  through  $n$ , inclusive

# Patterns: Quantifiers

## Examples:

```
# one or more e in a row in largefile.txt  
grep e+ largefile.txt
```

```
# exactly 2 e in a row in largefile.txt  
grep "e\{2\}" largefile.txt
```

```
# 2 or more vowels in a row in largefile.txt  
grep "[aeiou]\{2,\}" largefile.txt
```

```
# one or more lower or upper e at the beginning  
# of the line in largefile.txt  
grep ^[eE]+ largefile.txt
```

# grep Command

The `grep` command attempts to match every line of a file against a regular expression. If the regex matches, the line is printed:

```
student$ grep abc file.txt
```

The `-i` option ignores case:

```
student$ grep -i abc file.txt
```

The `-v` prints all lines that do not match:

```
student$ grep -v abc file.txt
```



# grep Command

If no file argument is provided, then read from standard input:

```
student$ ls -l | grep ^d
```

The -f option uses the regexes in the provided file:

```
student$ cat regex.txt
```

```
thou
```

```
^G
```

```
student$ grep -f regex.txt largefile.txt
```

# Exercise

1. For these words:

red  
reed  
read  
dread  
bread  
head  
lead

Determine with words match each of these regexes:

`^ead`  
`^.ead`  
`^[ea]+d`  
`r[a-z]\{4\}`  
`.[a-z]\{3,4\}`  
`[b-z]\{1,5\}`

# Exercise

2. Create regexes to do the following:

- 0 or 1 "a" followed by any number of "b"
- one or more digits followed by one or more alpha characters

# Exercise

3. Search for the following text using `grep`:

- all lines of `largefile.txt` with the text "thee"
- all lines of `largefile.txt` with the text "thee" regardless of case (hint: `-i` is helpful)
- all the blank lines in `largefile.txt`
- all lines of `largefile.txt` with two vowels next to one another, but not 3 vowels

# Exercise

4. Find the location of these programs when executed from the shell

- `who`
- `date`
- `ifconfig`

5. Find all files that were modified 2 days ago

# Inodes, Links and Low-level File Data

# Inodes, Links and Low-level File Data

- inodes
- hard links
- symbolic links
- low-level file data (`stat`, `readlink`)

# Inodes

An *inode* is a unique number given to every file (or directory, etc.) stored on the disk. To display a file's inode number, use `ls -li`:

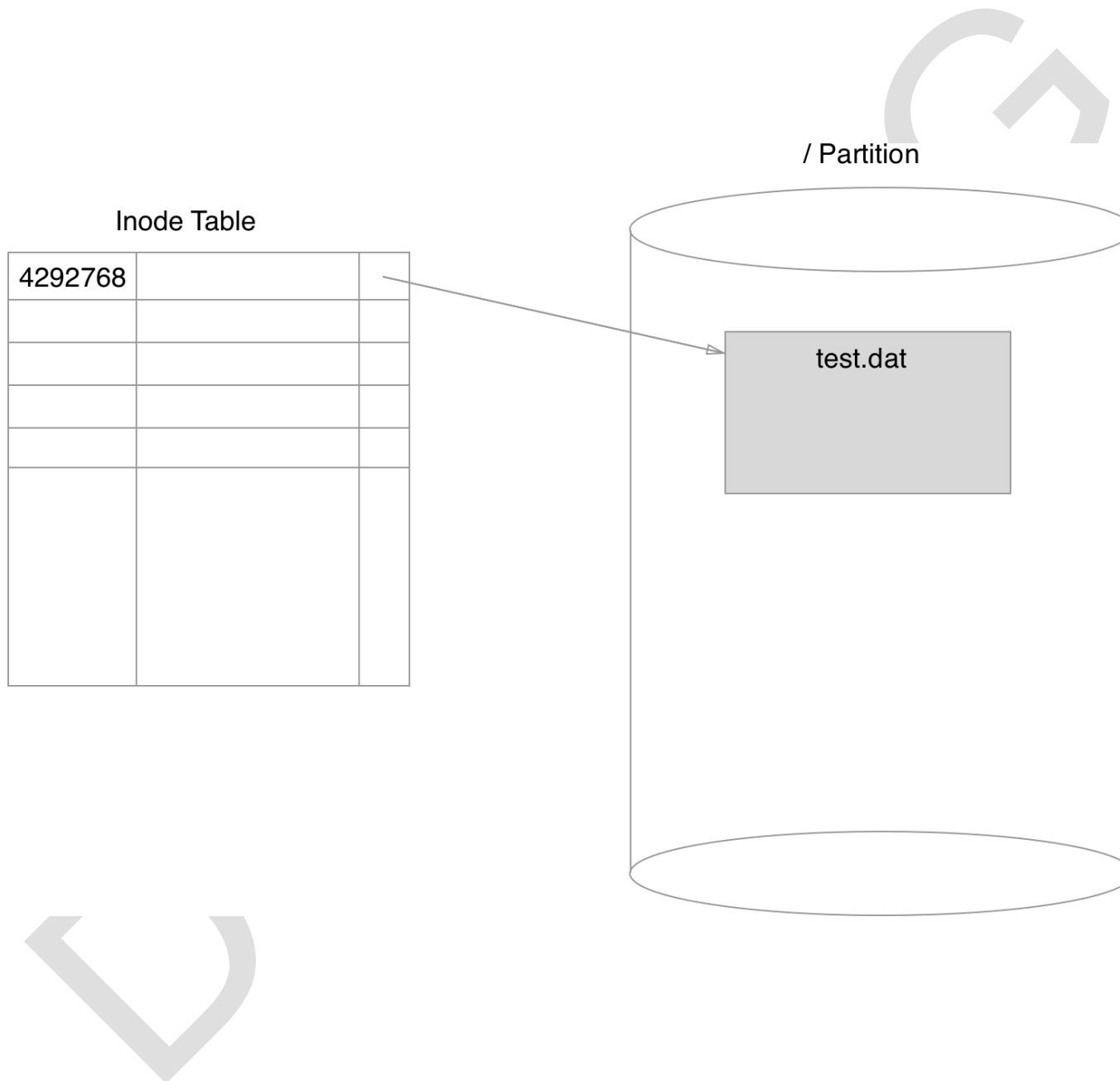
```
student$ touch test.dat
```

```
student$ ls -li test.dat
```

```
4292768 -rw-rw-r-- 1 student student 0 Apr 16 13:07 test.dat
```



# Inodes



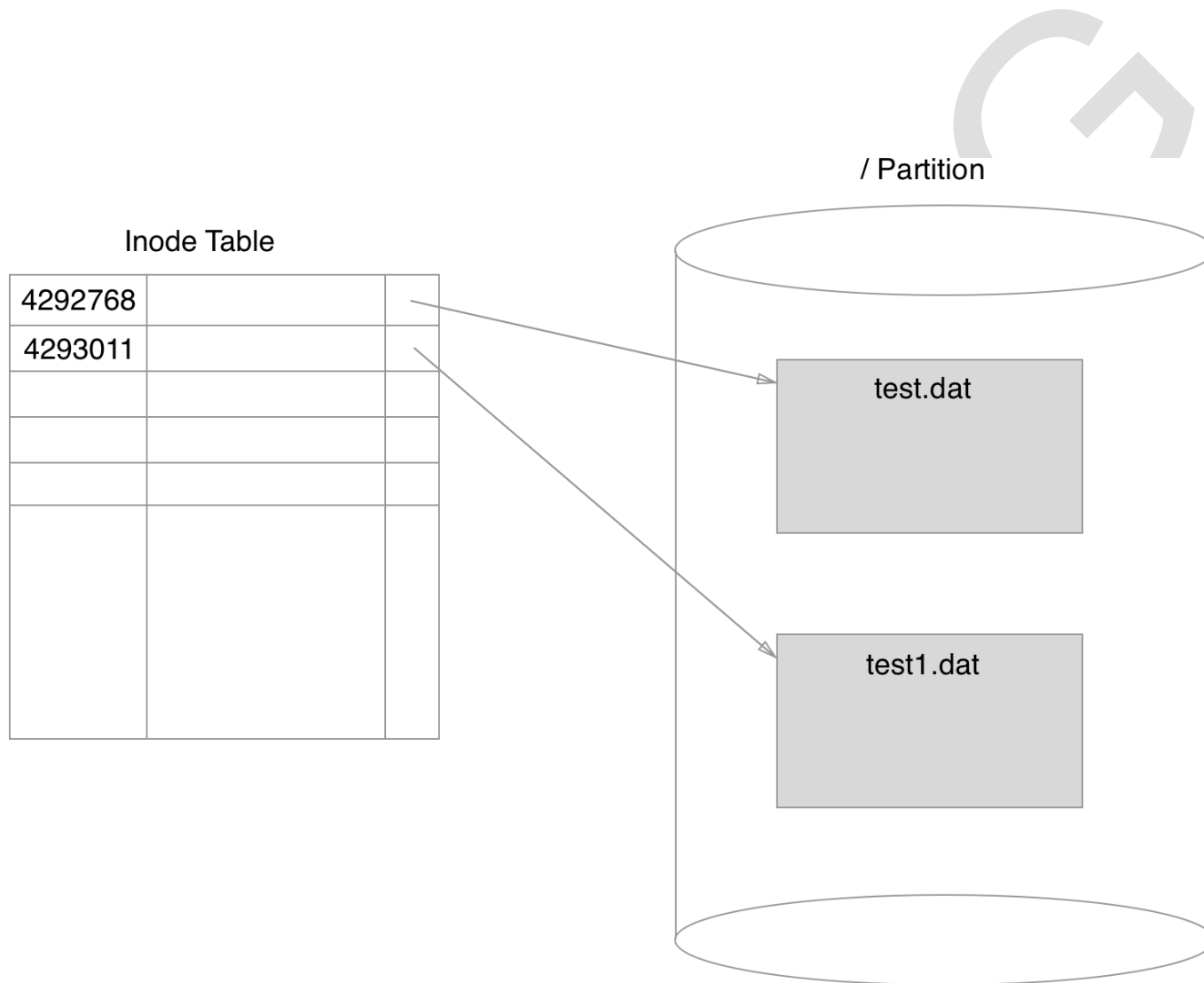
# Inodes

When a file is copied, another file is created, with its own unique inode number:

```
student$ cp test.dat test1.dat
student$ ls -il test*.dat
4293011 -rw-rw-r-- 1 student student 0 Oct 6 13:07 test1.dat
4292768 -rw-rw-r-- 1 student student 0 Oct 6 13:07 test.dat
```

When a file is removed, the inode number is released, and if there are no other inodes pointing to it, the file is deleted from disk.

# Inodes



# Inodes

A directory is a special file that lists other files in the directory and their inode numbers:

```
student$ mkdir inode.dir  
student$ ls -lid inode.dir  
4293848 drw-rw-r-- 1 student student 0 Oct 6 13:07 inode.dir  
student$ touch inode.dir/a.dat  
student$ touch inode.dir/b.dat  
student$ touch inode.dir/c.dat
```

# Inodes

Using `vim` to edit the directory:

```
student$ vim inode.dir
```

We would see:

```
" =====
" Netrw Directory Listing                                     (netrw v125)
"   /home/student/inode.dir
"   Sorted by      name
"   Sort sequence: [\\/]$,\\.h$,\\.c$,\\.cpp$,*,\\.o$,\\.obj$,\\.info$,\\.swp$,\\.bak$,\\~
"   Quick Help: <F1>:help  -:go up dir  D:delete  R:rename  s:sort-by  x:exec
" =====
../
a.dat
b.dat
c.dat
```

# Links

Linux has two types of links:

- hard links
  - not a new file on disk
  - an entry in its directory that has the same inode as the physical file to which it is linked
  - must reside on the same disk partition as the file to which it is linked

# Links

- symbolic links
  - a new file on disk
  - an alias to another file
  - its “content” is the name of the file to which it is linked
  - can reside on a different disk partition as the file to which it is linked

# Links

- they are both create using the `ln` command
- advantages
  - can save disk space - one copy of the file exists on the disk
  - if link to the file is edited, the file is modified for **all** links



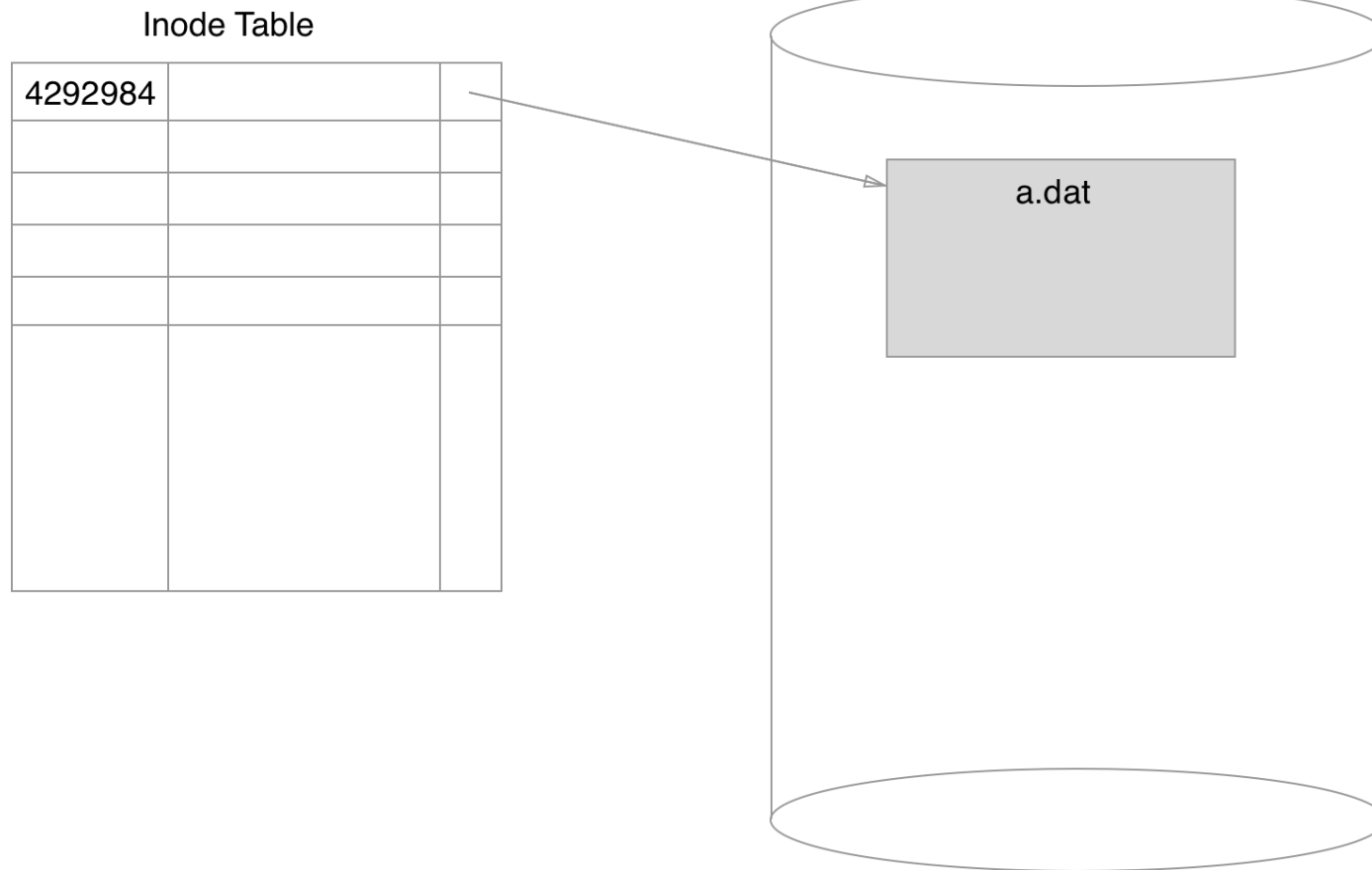
# Hard Links

A hard link is another entry in a directory with the same inode as the file to which it links. Consider this file:

```
student$ cat a.dat  
this is the file a.dat  
student$ ls -li a.dat  
4292984 -rw-rw-r-- 1 student student 23 Oct  6 16:02 a.dat
```

This shows that the inode number of this file is 4292984 and the number of hard links to this file (the number just to the left of the username) is 1. This means that this file's inode number is only listed in one directory (the current directory).

# Hard Links



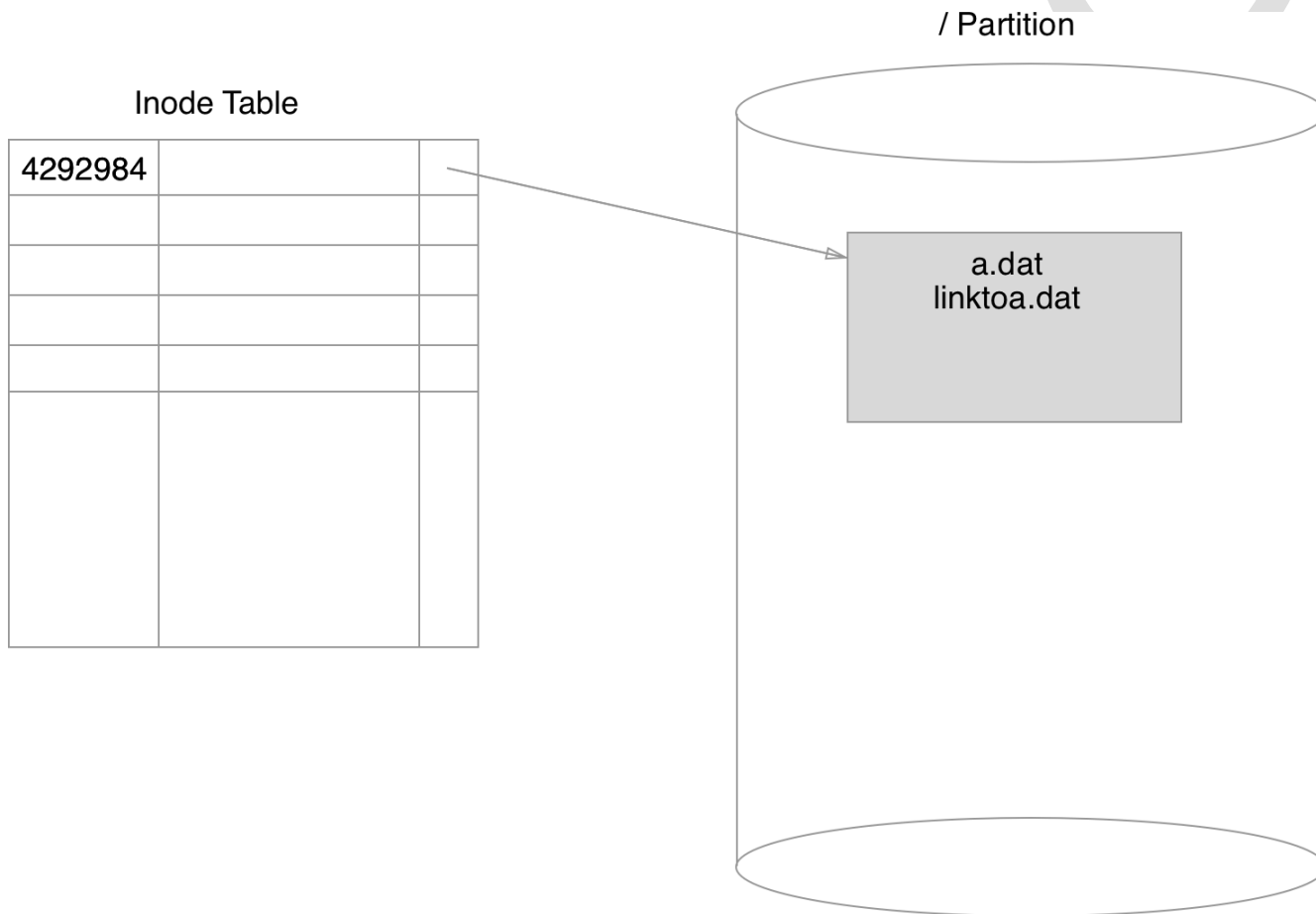
# Hard Links

Let's create a hard link to this file - we'll call it `linktoa.dat`:

```
student$ ln a.dat linktoa.dat
student$ ls -li a.dat linktoa.dat
4292984 -rw-rw-r-- 2 student student 23 Oct  6 16:02 a.dat
4292984 -rw-rw-r-- 2 student student 23 Oct  6 16:02 linktoa.dat
```

Notice that the inode numbers of these files are the same (which means they are the same file physically on the disk). Also notice the number to the left of the username is now 2 since there are now 2 links to the file.

# Hard Links



# Hard Links

Let's show the contents of `linktoa.dat`:

```
student$ cat linktoa.dat  
this is the file a.dat
```

Now let's delete the original file `a.dat` and show that the physical file still exists:

```
student$ rm a.dat  
student$ ls -li linktoa.dat  
4292984 -rw-rw-r-- 1 student student 23 Oct  6 16:02 linktoa.dat  
student$ cat linktoa.dat  
this is the file a.dat
```

# Hard Links

Now the link count is down to 1. Once the link count decreases to 0, the file is removed from disk.

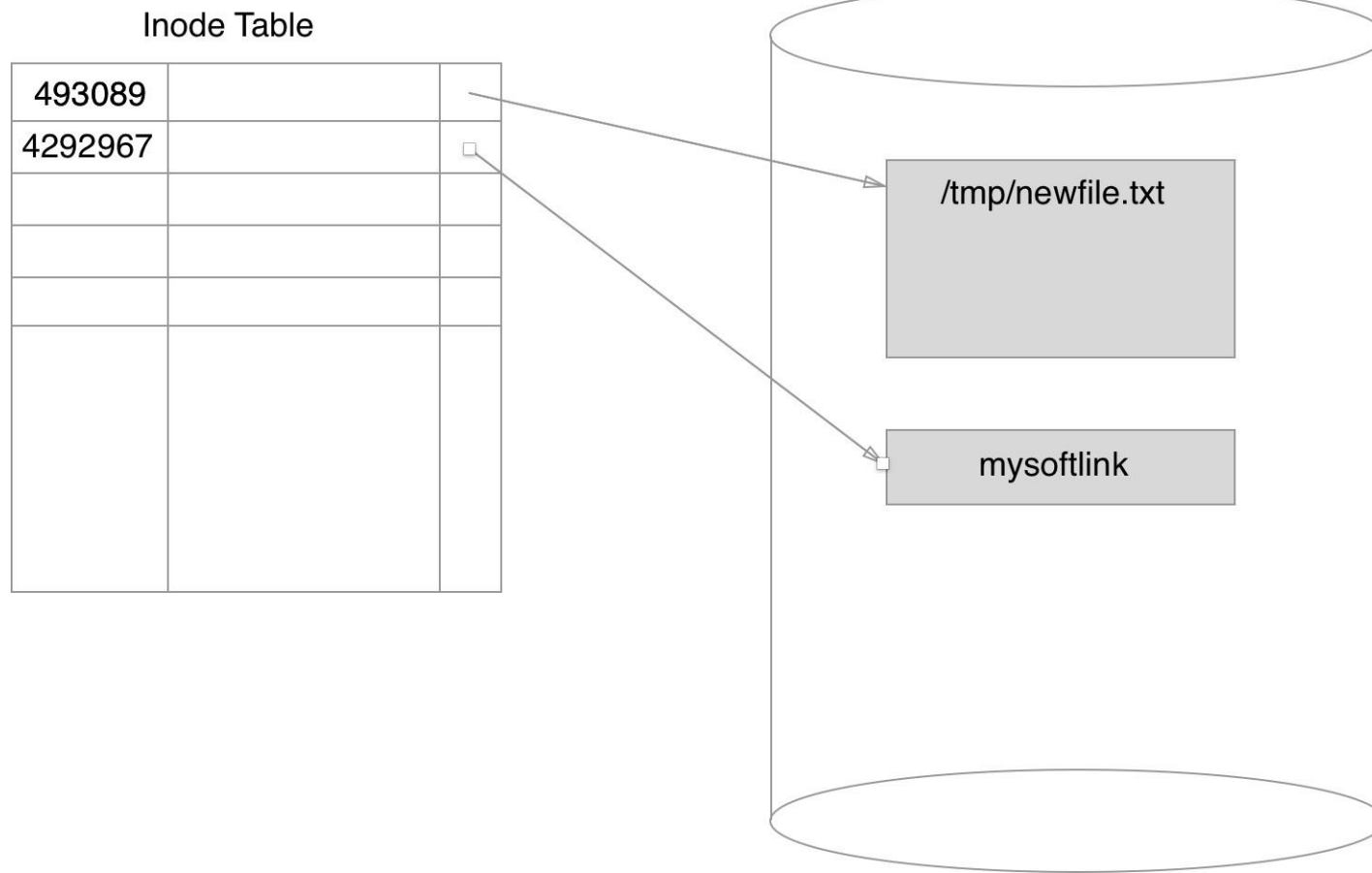
# Symbolic Links

A symbolic link (aka *soft link*) is entirely new file with its own inode, however it is a special type of file. Its "content" is the name of the file to which it is linked. It is created with

`ln -s:`

```
student$ echo this is a test of symbolic link > /tmp/newfile.txt
student$ cat /tmp/newfile.txt
this is a test of symbolic link
student$ ls -il /tmp/newfile.txt
493089 -rw-rw-r-- 1 student student 28 Apr  3 18:02 /tmp/newfile.txt
student$ ln -s /tmp/newfile.txt mysoftlink
student$ ls -il /tmp/newfile.txt mysoftlink
4292967 lrwxrwxrwx 1 student student 16 Apr  3 18:03 mysoftlink -> /tmp/newfile.txt
 493089 -rw-rw-r-- 1 student student 28 Apr  3 18:02 /tmp/newfile.txt
student$ cat mysoftlink
this is a test of symbolic link
```

# Symbolic Links





# Symbolic Links

Note:

- `/tmp/newfile.txt` has the inode number 493089
- when a symbolic link is linked to it, the symbolic link has a different inode number (here 4292967), so it is an entirely new file on disk
- the first character of the permissions is an `l` and not a dash
- the size of the link is 16, the number of characters in the filename `/tmp/newfile.txt`

# Symbolic Links

When the link is `cat`-ed out, it shows the content of the file to which it is linked.

It is possible to delete the file that the sim link is linked to, and the sim link will still exist, although it now links to a non-existent file:

```
student$ rm /tmp/newfile.txt
student$ ls -li mysoftlink
4292967 lrwxrwxrwx 1 student student 16 Oct  6 18:03 mysoftlink -> /tmp/newfile.txt
jdoe$ cat mysoftlink
cat: mysoftlink: No such file or directory
```

# Inode Pointer Structure

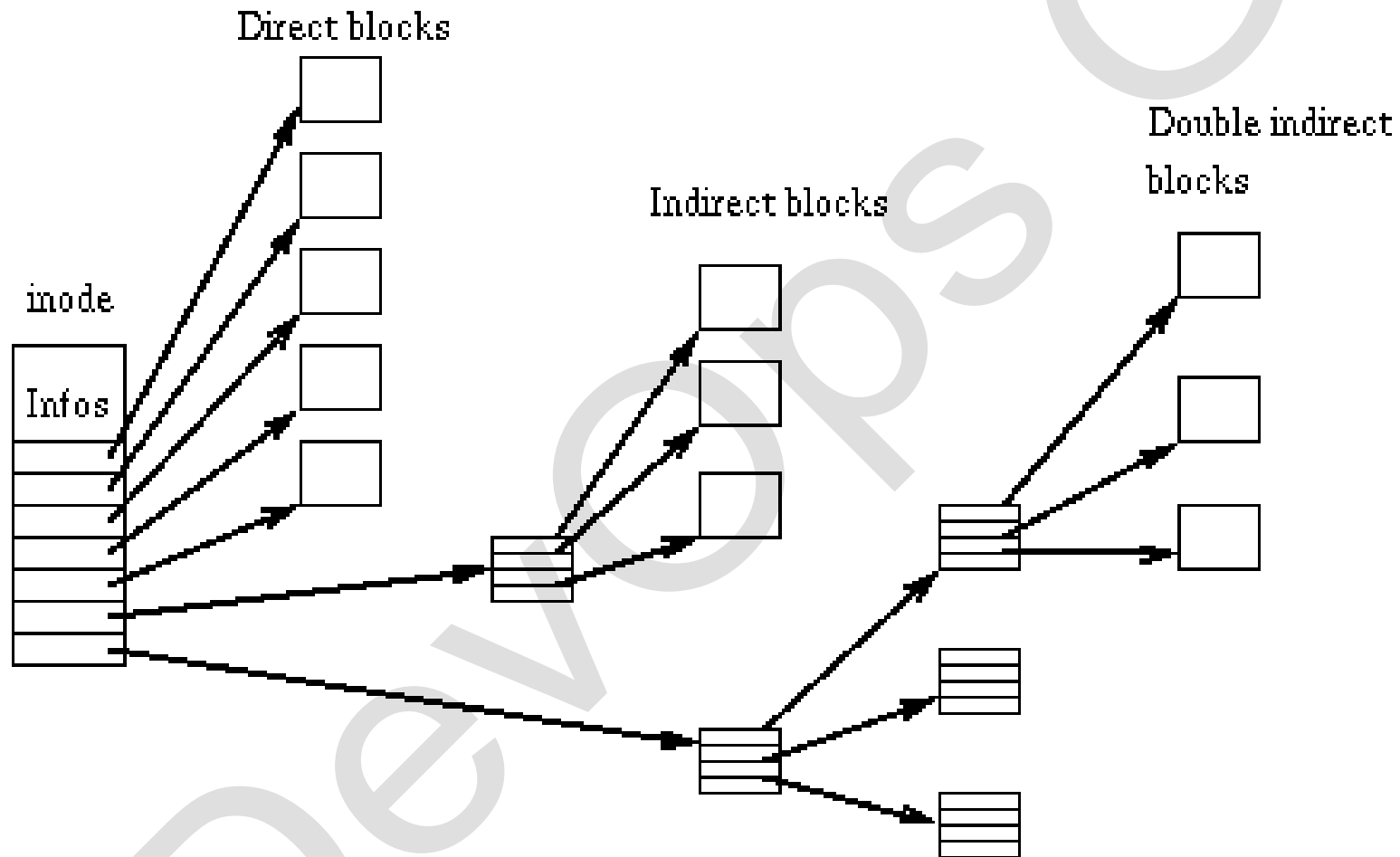


Image from Wikipedia

# Low Level File Data

File meta data is available through several low level file commands including:

- `stat`
- `readlink`

# stat

The stat command displays a file's system status:

```
student$ stat regex.txt
```

```
  File: 'regex.txt'  
  Size: 8          Blocks: 8          IO Block: 4096   regular file  
Device: 802h/2050d Inode: 436131      Links: 1  
Access: (0640/-rw-r-----)  Uid: ( 1000/student)   Gid: ( 1000/student)  
Access: 2017-11-05 15:58:01.192000000 -0500  
Modify: 2017-10-15 08:54:25.893694474 -0400  
Change: 2017-11-05 13:44:30.628000000 -0500  
Birth: -
```

```
student$ stat -t regex.txt
```

```
regex.txt 8 8 81a0 1000 1000 802 436131 1 0 0 1509915481 1508072065  
1509907470 0 4096
```

# stat

The `-f` option shows status of a file system:

```
student$ stat -f /dev/sda1
```

```
File: "/dev/sda1"
```

```
  ID: 0          Namelen: 255      Type:  tmpfs
```

```
Block size: 4096      Fundamental block size: 4096
```

```
Blocks: Total: 249974      Free: 249974      Available: 249974
```

```
Inodes: Total: 249974      Free: 249516
```

```
student$ stat /dev/sda1
```

```
File: '/dev/sda1'
```

```
Size: 0           Blocks: 0           IO Block: 4096   block special file
```

```
Device: 6h/6d   Inode: 11567       Links: 1       Device type: 8,1
```

```
Access: (0660/brw-rw----)  Uid: (   0/   root)   Gid: (   6/   disk)
```

```
Access: 2017-11-06 07:24:05.148000000 -0500
```

```
Modify: 2017-11-06 07:24:05.148000000 -0500
```

```
Change: 2017-11-06 07:24:05.148000000 -0500
```

```
Birth: -
```

# stat

The `--format` constructs a format string (for all options, see `man stat`):

```
student$ stat --format=%g regex.txt  
1000
```

```
student$ stat --format=%G regex.txt  
student
```

```
student$ stat --format=%i regex.txt  
436131
```

```
student$ stat --format="%g %G %i" regex.txt  
1000 student 436131
```

# readlink

The `readlink` command shows the file a symbolic link links to:

```
student$ ls -l /etc/rc2.d/S02cron
lrwxrwxrwx 1 root root 14 Sep 28 15:38 /etc/rc2.d/S02cron -> ../init.d/cron
student$ readlink /etc/rc2.d/S02cron
../init.d/cron
```



# Exercise

1. Create a hard link to `regex.txt`. Show the inode for `regex.txt` and the link. Show the contents of the link. Edit the link, then show the contents of `regex.txt`. Show information about the link and `regex.txt` using `stat`. Remove the link.
2. Create a sim link to `regex.txt`. Edit the sum link, then show the contents of `regex.txt`. Show the size of the link and of `regex.txt`. Show information about the link and `regex.txt` using `stat`. Show the file that is linked with `readlink`. Remove the link.

# Exercise

3. Using `vim`, view the contents of the current directory.

# Archive and Backups

# Archive and Backups

- It is common to archive files and directories for the following reasons:
  - backing up files and directories
  - transporting or copying files and/or directories from one machine to another
- we will discuss these three archive commands:
  - `zip / unzip`
  - `gzip / gunzip`
  - `tar`

# zip/ unzip

A common compression utility on Linux is `zip`. It will compress using an algorithm compatible with PKZIP used in the Windows world.

To compress a file:

```
student$ zip largefile.zip largefile.txt
  adding: largefile.txt (deflated 57%)
student$ ls -l largefile.*
-rwxr-xr-x 1 student student 30832 Oct  1 16:56 largefile.txt
-rw-rw-r-- 1 student student 13285 Oct  2 08:23 largefile.zip
```

# zip/ unzip

To recursively compress the contents of a directory:

```
student$ zip -r temp.zip temp.dir  
  adding: temp.dir/ (stored 0%)  
  adding: temp.dir/temp.dat (stored 0%)  
student$ ls -l temp.zip  
-rw-rw-r-- 1 student student 347 Oct  2 08:35 temp.zip
```

See `man zip` for details.

# zip/ unzip

To uncompress a file that was compressed with `zip`, use `unzip`:

```
student$ mkdir newtemp.dir
student$ cp largefile.zip temp.zip newtemp.dir
student$ cd newtemp.dir
student$ unzip largefile.zip
Archive:  largefile.zip
  inflating: largefile.txt
student$ ls -l largefile.*
-rwxr-xr-x 1 student student 30832 Oct  1 16:56 largefile.txt
-rw-rw-r-- 1 student student 13285 Oct  2 08:46 largefile.zip
```

# zip/ unzip

```
student$ unzip temp.zip
```

```
Archive:  temp.zip
```

```
  creating: temp.dir/
```

```
  extracting: temp.dir/temp.dat
```

```
student$ ls -Rl temp.dir
```

```
temp.dir:
```

```
total 4
```

```
-rw-rw-r-- 1 student student 17 Oct  2 08:35 temp.dat
```

**See** `man unzip` for details.



# gzip/ gunzip

Alternatives to `zip` and `unzip` are the GNU programs:  
`gzip` and `gunzip`.

```
$ ls -l largefile.txt
```

```
-rwxr-xr-x 1 student student 30832 Nov  7 14:39 largefile.txt
```

```
$ gzip largefile.txt
```

```
$ ls -l largefile.txt.gz
```

```
-rwxr-xr-x 1 student student 13141 Nov  7 14:39 largefile.txt.gz
```

```
$ gunzip largefile.txt.gz
```

```
$ ls -l largefile.txt
```

```
-rwxr-xr-x 1 student student 30832 Nov  7 14:39 largefile.txt
```

# gzip/ gunzip

Notice what happens when you recursively zip up a directory:

```
$ gzip -rv data
```

```
data/a.dat:          0.0% -- replaced with data/a.dat.gz
```

```
data/b.dat:          0.0% -- replaced with data/b.dat.gz
```

```
data/c.dat:          0.0% -- replaced with data/c.dat.gz
```

```
$ ls data
```

```
a.dat.gz  b.dat.gz  c.dat.gz
```

# tar

- The most common Linux archive utility is `tar` (Tape ARchive) - it will take a collection of files and directories (and their contents) and collect them together into a single file

# tar

```
student$ tar cvf /tmp/mystuff.tar *  
class/  
class/quote.txt  
class/sed.out  
class/wallquote.txt  
class/hello.pl  
class/records.data  
class/largefile.txt  
Desktop/  
Documents/  
Downloads/  
examples.desktop  
Music/  
Pictures/  
Public/  
Templates/  
Videos/
```

# tar

- this command uses the `cvf` options which "creates, verbose, file" `mystuff.tar`
- file details:

```
student$ file /tmp/mystuff.tar
/tmp/mystuff.tar: POSIX tar archive (GNU)
student$ ls -l /tmp/mystuff.tar
-rw-rw-r-- 1 student student 61440 Oct  1 16:56 /tmp/mystuff.tar
```

# tar Options

- here are some common options:

- `c` - createfile
- `x` - extractfile
- `f` - filename
- `v` - verbose
- `z` - zip (compress)
- `r` - append
- `t` - list contents

# tar Append

Here is an example of appending a file to our tarfile `/tmp/mystuff.tar`, and then listing its contents:

```
student$ tar rvf /tmp/mystuff.tar /etc/passwd
tar: Removing leading `/' from member names
/etc/passwd
student$ tar tf /tmp/mystuff.tar
class/
class/quote.txt
class/sed.out
class/wallquote.txt
class/hello.pl
class/records.data
class/largefile.txt
Desktop/
Documents/
Downloads/
examples.desktop
...
etc/passwd
```

# tar Extract

- we can then extract the tar file

```
student$ mkdir /tmp/tartest
student$ cd /tmp/tartest
student$ tar xvf /tmp/mystuff.tar
class/
class/quote.txt
class/sed.out
class/wallquote.txt
class/hello.pl
class/records.data
class/largefile.txt
...
Videos/
etc/passwd
student$ ls -F
class/ Desktop/ Documents/ Downloads/ etc/ examples.desktop
Music/ Pictures/ Public/ Templates/ Videos/
```



# tar Compression

- compression is done with the `z` option
- the compressed file is much smaller than the uncompressed file
- the file is usually named either `.tar.gz` or `.tgz`

# tar Compression

```
student$ tar czf /tmp/mystuff.tar.gz *
```

```
student$ tar czf /tmp/mystuff.tgz *
```

```
student$ ls -l /tmp/mystuff.*
```

```
-rw-rw-r-- 1 student student 61440 Oct  1 16:56 /tmp/mystuff.tar  
-rw-rw-r-- 1 student student 18158 Oct  1 16:59 /tmp/mystuff.tar.gz  
-rw-rw-r-- 1 student student 18158 Oct  1 16:59 /tmp/mystuff.tgz
```

# tar Compression

Note: a `.tar.gz` file can be unzipped with `gunzip`:

```
student$ ls -l mystuff.tar.gz
-rw-rw-r-- 1 student student 18158 Oct  1 17:38 mystuff.tar.gz
student$ gunzip mystuff.tar.gz
student$ ls -l mystuff.tar*
-rw-rw-r-- 1 student student 61440 Oct  1 17:38 mystuff.tar
```

# Backup Strategies

- Failures happen:
  - hardware failure
  - power failure
  - theft
  - fire / earthquake / etc
  - security breach

# Backup Strategies

- Backup to another location:
  - another piece of hardware
  - server in the cloud
  - backup service

# Backup Strategies

- Backup regularly:
  - machine on the network
  - server in the cloud
  - backup service

# Exercise

1. Zip up the `class` directory (using `zip`). Unzip it in `/tmp` (using `unzip`) and verify that all the files were transferred.
2. Do the same with `tar`.
3. Compare the size of a `.zip` file to a `.tgz` file.

**End of Day 1**



# Day 2 Topics

- filesystem types
- disk partitioning
- swap space
- quotas
- LVM
- RAID

# Filesystem Types

# Filesystem Types

- ext{2,3,4}
- JFS
- ReiserFS
- Btrfs
- xfs

# ext{2,3,4}

ext - the extended file system, was the first filesystem specifically created for the Linux kernel

- created in April 1992
- included in Linux version 0.96c
- inspired by the Unix File System (UFS), designed to overcome Minix limitations (max 64 MB and 14 character filenames)
- could handle filesystems up to 2 Gig and 255 character filenames
- no support of separate timestamps for file access, inode modification, and data modification

# ext{2,3,4}

ext2 - the second extended file system

- developed in January 1993 for Linux kernel 0.99, designed with extensibility in mind
- added support for separate timestamps for file access, inode modification, and data modification
- still recommended over journaling file systems (like ext3) on bootable USB flash drives (faster access)
- max partition size: 4TB, max file size: 2GB-2TB (depending on kernel)
- with Large File Support (LFS) - max partition size: 2TB-32TB; max file size: 2GB-2TB

# ext{2,3,4}

ext3 - the third extended file system

- released in November 2001 for Linux kernel 2.4.15
- added journaling (keeps track of uncommitted changes in a journal)
  - improves reliability
  - eliminates the need to check the file system after an unclean shutdown
- ext2 can be changed to ext3 by adding journaling with (be sure to modify /etc/fstab):

```
tune2fs -j /dev/
```

# ext{2,3,4}

ext4 - the fourth extended file system

- released on 25 December 2008 in the 2.6.28 kernel
- features include
  - partition size up to 1 EiB ( $2^{60}$  bytes); file size up to 16 TiB (Redhat recommends xfs for large files)
  - uses extents - a single extent can map up to 128 MiB of contiguous space with a 4 KiB block size
  - backward compatible with ext2 and ext3 - can mount ext2 or ext3 as ext4
  - persistent pre-allocation and delayed allocation
  - unlimited number of sub-directories

# JFS

JFS - Journaled File System - 64 bit journaling filesystem created by IBM.  
Features include:

- June 2001 kernel 2.4.18pre9-ac4
- fast and reliable with good performance under different kinds of loads
- unlike ext3, journaling was built in from the start
- uses a B+ Tree
- dynamic inode allocation
- extents
- most chose ext4 over JFS



# ReiserFS

ReiserFS was developed by Hans Reiser and a team at Namesys. The first Linux version was Reiser3, followed by Reiser4.

- kernel 2.4.18
- metadata-only journaling (block journaling since kernel 2.6.8)
- online resizing
- tail packing to reduce internal fragmentation
- faster than ext2 and ext3

# Btrfs

Btrfs is based on the copy-on-write (COW) principle. Initially designed by Oracle for Linux in 2007.

- version 1.0 accepted into kernel in 2009
- ext4 developer Theodor T'so said Btrfs is better than ext4 because "it offers improvements in scalability, reliability, and ease of management"
- default filesystem for SUSE
- deprecated in RHEL 7.4 in August 2017

# Btrfs

- features include:
  - copy-on-write (shadowing)
  - auto-defrag
  - online growth/shrinking
  - offline filesystem check
  - data scrubbing - find and auto-fix errors
  - RAID {0,1,10}

# xfs

- eXtents File System (xfs) - development begun by Silicon Graphics in 1993
- merged into Linux kernel 2.4.25 in Feb 2004
- default file system for RHEL 7.0 released in June 2014

# xfs

- features include:
  - 64-bit file system, max size 8 EiB
  - journaling
  - allocation groups providing scalability and parallelism
  - striped allocation
  - extent based allocation
  - online defragmentation (with `xfs_fsr`) and resizing (with `xfs_growfs`)

# Disk Partitioning

# Disk Partitioning

- adding a disk partition
- formatting a disk partition
- mounting a disk partition

# Disk Partitioning

A disk partition is a portion of a physical disk. The partition can be formatted and mounted. The benefits of having more than one disk partition:

- each partition has a limited number of inodes, so it is possible to run out them - having multiple partitions means there are more inodes
- put similar “files” together
- share a part of the file system on the network



# Disk Partitioning

The number of currently mounted partitions are shown with the `df` command:

```
student$ df
```

Filesystem	1K-blocks	Used	Available	Use%	Mounted on
udev	999896	0	999896	0%	/dev
tmpfs	204596	21920	182676	11%	/run
/dev/sda1	9481444	4949280	4027488	56%	/
...					

In this example, `/dev/sda1` is mounted on `/`.

# Disk Partitioning

The `df` command can show inode information:

```
student$ df -i
Filesystem      Inodes    IUsed   IFree  IUse% Mounted on
udev            249974     448  249526    1% /dev
tmpfs           255743     655  255088    1% /run
/dev/sda1       610800  261998  348802   43% /
...
```

Notice that more than 43% of the available nodes on `/` are used. If we create a large number of files on that partition, we will run out inodes.

# Create New Partition

We can partition the disk with the `fdisk`:

```
root# fdisk -l /dev/sda
```

```
Disk /dev/sda: 40.0 GiB, 42949672960 bytes, 83886080 sectors
```

```
Units: sectors of 1 * 512 = 512 bytes
```

```
Sector size (logical/physical): 512 bytes / 512 bytes
```

```
I/O size (minimum/optimal): 512 bytes / 512 bytes
```

```
Disklabel type: dos
```

```
Disk identifier: 0x74b2e1ea
```

Device	Boot	Start	End	Sectors	Size	Id	Type
/dev/sda1	*	487424	20019199	19531776	9.3G	83	Linux
/dev/sda2		20019200	24018943	3999744	1.9G	82	Linux swap / Solaris

This output shows 2 partitions. The one we have not seen is `/dev/sda2`, our swap space (more on swap later).

# Create New Partition

To create a new partition:

- create partition on the disk with `fdisk`
- tell the kernel about the new partition with `partprobe`
- format the new partition with `mkfs.*`
- mount the new partition with `mount`
- add new partition to `/etc/fstab`

# Create New Partition

To create a new partition on disk with `fdisk` (`p` prints the partition table):

```
root# fdisk /dev/sda
```

```
Welcome to fdisk (util-linux 2.27.1).
```

```
Changes will remain in memory only, until you decide to write them.
```

```
Be careful before using the write command.
```

```
Command (m for help): p
```

```
Disk /dev/sda: 40.0 GiB, 42949672960 bytes, 83886080 sectors
```

```
...
```

Device	Boot	Start	End	Sectors	Size	Id	Type
/dev/sda1	*	487424	20019199	19531776	9.3G	83	Linux
/dev/sda2		19531776	23531519	3999744	1.9G	82	Linux swap / Solaris

```
Command (m for help):
```

# Create New Partition

n creates a new partition:

Command (m for help): **n**

Partition type

p primary (2 primary, 0 extended, 2 free)

e extended (container for logical partitions)

Select (default p): **p**

Partition number (3,4 default 3): **3**

First sector (23531520-83886079, default 23531520): **<enter>**

Last sector, +sectors or +size{K,M,G,T,P} (23531520-83886079, default 83886079): **+1G**

Created a new partition 3 of type 'Linux' and of size 1 GiB.

# Create New Partition

Let's make sure it was created correctly:

Command (m for help): **p**

Disk /dev/sda: 40.0 GiB, 42949672960 bytes, 83886080 sectors

Device	Boot	Start	End	Sectors	Size	Id	Type
/dev/sda1	*	487424	20019199	19531776	9.3G	83	Linux
/dev/sda2		19531776	23531519	3999744	1.9G	82	Linux swap / Solaris
/dev/sda3		23531520	25628671	2097152	1G	83	Linux

Command (m for help):

# Create New Partition

Write the new information:

Command (m for help): **w**

The partition table has been altered.  
Syncing disks.



# Tell the Kernel

We need to tell the kernel about the changes. We can use `partprobe`. Or we can reboot the system.

```
root# partprobe
```

Note: some distributions (such as CentOS) require either executing `partx` (not recommended) or `areboot`.

# Make a Filesystem

The next step is to format the new disk. We will format as `ext4`, but it can be formatted as other filesystem types. To format at `ext4`, use `mkfs.ext4`:

```
root# mkfs.ext4 /dev/sda3
mke2fs 1.42.13 (17-May-2015)
Creating filesystem with 262144 4k blocks and 65536 inodes
Filesystem UUID: 4214af50-bd61-413f-93d0-8936bad93e6d
Superblock backups stored on blocks:
    32768, 98304, 163840, 229376

Allocating group tables: done
Writing inode tables: done
Creating journal (8192 blocks): done
Writing superblocks and filesystem accounting information: done
```

# Mount the Partition

To make the partition available, it must be mounted. Many linux systems mount new partitions under `/mnt`. Make a new directory under `/mnt` and then use the `mount` command:

```
root# mkdir /mnt/newpartition
root# mount /dev/sda3 /mnt/newpartition
root# ls -ld /mnt/newpartition
drwxr-xr-x 3 root root 4096 Oct 14 11:01 /mnt/newpartition
root# ls -l /mnt/newpartition
total 16
drwx----- 2 root root 16384 Oct 14 11:01 lost+found
root# touch /mnt/newpartition/test.txt
root# ls /mnt/newpartition
lost+found  test.txt
```

# Check Our Work

Let's check `df`:

```
root# df -i
Filesystem      Inodes   IUsed   IFree  IUse% Mounted on
/dev/sda1       610800  262004  348796   43% /
/dev/sda3        65536     12   65524    1% /mnt/newpartition
```

Note the number of inodes. This number can be increased by using `mkfs.ext4 -N`.

# Mount When Booting

At this point, we have a mounted filesystem, but if the machine is rebooted, it won't be mounted. To make sure the filesystem is mounted on reboot, add a line to `/etc/fstab` (file system table):

```
/dev/sda3 /mnt/newpartition ext4 defaults 0 2
```

The last two numbers on that line:

- enable/disable backing up with `dump`
- the order `fsck` checks the filesystem (/ should always be 1, others either 0 (disable) or 2 (after /))

# Mount When Booting

Some systems use an UUID number (eg. Ubuntu). If that is true about your system, you can replace `/dev/sda3` with `UUID="id"` that is in the output of this command:

```
root# blkid /dev/sda3
```

# Mount When Booting

Reboot to verify:

```
root# reboot
```

When the system boots, log in and check the directory:

```
root# ls /mnt/newpartition
```

# Swap Space

Swap space is physical disk space used to store memory, usually when the RAM fills to capacity and the OS needs a place to put the content. Linux supports swap through either a disk partition or a file on disk.

We saw our swap space with `fdisk`:

```
root# fdisk -l
...
/dev/sda2          20019200 24018943   3999744   1.9G 82 Linux swap / Solaris
...
```



# Swap Space

We can see our swap space with `swapon`:

```
root# swapon -s
```

Filename	Type	Size	Used	Priority
/dev/sda2	partition	1999868	0	-1

# Swap Space

Let's create a new swap disk partition. Note: Because we have only one primary partition left, we will first create an extended partition with the rest of the disk, and we can then create partitions within it:

```
root# fdisk /dev/sda
Command (m for help): n
Partition type
   p   primary (3 primary, 0 extended, 1 free)
   e   extended (container for logical partitions)
Select (default e): e

Selected partition 4
First sector (25628672-83886079, default 25628672): <enter>
Last sector, +sectors or +size{K,M,G,T,P} (25628672-83886079, default 83886079): <enter>

Created a new partition 4 of type 'Extended' and of size 27.8 GiB.

Command (m for help):
```

# Swap Space

Let's see the new extended partition:

Command (m for help): **p**

Disk /dev/sda: 40.0 GiB, 42949672960 bytes, 83886080 sectors

Device	Boot	Start	End	Sectors	Size	Id	Type
/dev/sda1	*	487424	20019199	19531776	9.3G	83	Linux
/dev/sda2		19531776	23531519	3999744	1.9G	82	Linux swap / Solaris
/dev/sda3		23531520	25628671	2097152	1G	83	Linux
/dev/sda4		25628672	83886079	58257408	27.8G	5	Extended

Command (m for help):

# Swap Space

Now that we have the extended partition created, we can create partitions within it. We will make our new partition 1G in size:

```
Command (m for help): n
All primary partitions are in use.
Adding logical partition 5
First sector (25630720-83886079, default 25630720): <enter>
Last sector, +sectors or +size{K,M,G,T,P} (24020992-43741183,
default 43741183): +1G
```

Created a new partition 5 of type 'Linux' and of size 1 GiB.

```
Command (m for help): p
...
Device      Boot      Start          End      Sectors      Size Id Type
...
/dev/sda5    25630720 27727871    2097152        1G 83 Linux
```

# Swap Space

We have to change the type (t) of the disk 82, the value for swap.

```
Command (m for help): t
Partition number (1-5, default 5): 5
Hex code (type L to list all codes): 82
```

Changed type of partition 'Linux' to 'Linux swap / Solaris'

```
Command (m for help): p
```

```
...
Device      Boot      Start          End      Sectors      Size Id Type
...
/dev/sda5                25630720 27727871     2097152        1G 82 Linux swap / Solaris
```

# Swap Space

Write the new information. This time, a reboot is required:

```
Command (m for help): w
```

```
The partition table has been altered.
```

```
Calling ioctl() to re-read partition table.
```

```
Re-reading the partition table failed.: Device or resource busy
```

```
The kernel still uses the old partitions. The new table will be used at  
the next reboot.
```

```
Syncing disks.
```

```
root# reboot
```

# Swap Space

The `mkswap` command makes swap. Then we can turn it on with `swapon`:

```
root# mkswap /dev/sda5
```

```
Setting up swapspace version 1, size = 1024  
MiB (1073737728 bytes)
```

```
no label, UUID=a14f218f-041d-4abc-a739-  
d588f4988539
```

```
root# swapon /dev/sda5
```

```
root# swapon -s
```

Filename	Type	Size	Used	Priority
/dev/sda2	partition	1999868	0	-1
/dev/sda5	partition	1048572	0	-2

# Swap Space

Add to `/etc/fstab` (the UUID can also be used):

```
/dev/sda5 none swap sw 0 0
```

Reboot, then make sure swap got turned on:

```
root# swapon -s
```

Filename	Type	Size	Used	Priority
/dev/sda2	partition	1999868	0	-1
/dev/sda5	partition	1048572	0	-2



# Swap Space

A file can also be used for swap. Use the `dd` command to create it, make it with `mkswap`, then `swapon` to turn it on:

```
root# mkdir /swap
root# dd if=/dev/zero of=/swap/swap1 bs=512 count=4000
4000+0 records in
4000+0 records out
2048000 bytes (2.0 MB, 2.0 MiB) copied, 0.00563459 s, 363 MB/s
root# ls -l /swap/swap1
-rw-r--r-- 1 root root 2048000 Oct 14 11:58 /swap/swap1
```

# Swap Space

```
root# mkswap /swap/swap1
```

```
Setting up swapspace version 1, size = 2 MiB (2043904 bytes)  
no label, UUID=74811884-69d5-46de-b7aa-8e9d68fa4a67
```

```
root# chmod 600 /swap/swap1
```

```
root# swapon /swap/swap1
```

```
root# swapon -s
```

Filename	Type	Size	Used	Priority
/dev/sda2	partition	1999868	0	-1
/dev/sda5	partition	1048572	0	-2
/swap/swap1	file	1996	0	-3

# Swap Space

Add to `/etc/fstab` to have the swap space survive a reboot:

```
/swap/swap1 none swap sw 0 0
```

# Exercise

1. Create a new partition (you might have to first create an extended partition) of size 500M.
2. Format that partition as `ext4`.
3. Mount the partition at `/mnt/ex1`.
4. Add an entry to `/etc/fstab`, reboot, verify the partition mounted.

# Exercise

5. Create a new partition size 500M as type swap.
6. Make the swap, turn it on.
7. Add an entry to `/etc/fstab`, reboot, verify the swap is turned on.

Quotas

# Quotas

- Quotas overview
- Configuring quotas
- Managing quotas

# Quotas

- limit resources for a user or a group (eg. amount of disk space or number of files)
- two types of limits:
  - soft - when hit, the user is warned, and after a time period elapses without resolution, they will be locked out (denied the ability to create the resource)
  - hard - the user is locked out when the limit is hit



# Quotas

- limits are set per disk partition - typically, only certain partitions have quotas:
  - `/home`
  - `/tmp`
  - `/var/spool/lpd` - print spools
  - `/var/spool/mail` - mail spools
  - `/var/www` - web sites

# Quotas and SELinux

Note: SELinux must be turned off for quotas to be enabled:

```
root# setenforce 0
```

The `quota` package must be installed. For Debian:

```
root# apt install quota
```

For RHEL:

```
root# yum install quota
```

# Turning On Quotas

- step one: mount a partition with quota options (usrquota and grpquota):

```
root# umount /mnt/newpartition
root# mount /dev/sda3 /mnt/newpartition -o usrquota,grpquota
root# mount | grep newpartition
/dev/sda3 on /mnt/newpartition type ext4 (usrquota,grpquota)
```

- or:

```
root# mount -o remount usrquota,grpquota /dev/sda3
```

# Turning On Quotas

- step two:
  - execute `quotacheck` to create needed files:

```
root# quotacheck -acuvgm
```

- or create two files on the partition that are readable only by root:, then executed `quotacheck`:

```
root# touch /mnt/newpartition/aquota.user  
root# touch /mnt/newpartition/aquota.group  
root# chmod 0600 /mnt/newpartition/aquota.*  
root# quotacheck -auvgm
```

# Turning On Quotas

- step four: turn on quotas for the partition:

```
root# quotaon /dev/sda3
```

# Setting Quotas

- to set quotas, edit the quotas for a user with `edquota`:

```
root# edquota student
```

- this command brings up an editor with this content:

```
Disk quotas for user student (uid 502):
```

Filesystem	blocks	soft	hard	nodes	soft	hard
/dev/sda3	0	0	0	0	0	0

# Setting Quotas

- if a limit has a value of 0, there is no quota - let's give student some limits:

Disk quotas for user student (uid 502):

Filesystem	blocks	soft	hard	nodes	soft	hard
/dev/sda3	0	20	40	0	20	40

# Setting Quotas

- we can create quotas for a group:

```
root# edquota -g thisgroup
```

```
Disk quotas for user thisgroup (gid 509):
```

Filesystem	blocks	soft	hard	nodes	soft	hard
/dev/sda3	0	0	0	0	0	0



# Setting Quotas

- setting the grace periods:

```
root# edquota -t
```

```
Grace period before enforcing soft limits for users:
```

```
Time units may be: days, hours, minutes or seconds
```

Filesystem	Block grace period	Inode grace period
/dev/sda3	7days	7days

# Testing Quotas

- create a directory for student, switch to that user, and copy some files over:

```
root# mkdir /mnt/newpartition/forstudent
root# chown student:student /mnt/newpartition/forstudent
root# su - student
student$ cd /mnt/newpartition/forstudent
student$ cp -r /etc/pam.d .
cp: error writing './pam.d/chsh': Disk quota exceeded
cp: error writing './pam.d/cron': Disk quota exceeded
cp: error writing './pam.d/cups': Disk quota exceeded
cp: error writing './pam.d/gnome-screensaver': Disk quota exceeded
cp: error writing './pam.d/lightdm': Disk quota exceeded
cp: error writing './pam.d/lightdm-autologin': Disk quota exceeded
cp: error writing './pam.d/lightdm-greeter': Disk quota exceeded
cp: error writing './pam.d/login': Disk quota exceeded
cp: error writing './pam.d/newusers': Disk quota exceeded
```

# More On Quotas

- we can apply one user's quotas to other users:

```
root# edquota -p student jdoe jsmith
```

- to make quotas permanent, edit `/etc/fstab` and add the `usrquota,grpquota` options:

```
/dev/sda3 /mnt/newpartition ext4 usrquota,grpquota 0 2
```

# Exercise

1. Turn on quotas for `/mnt/ex1`.
2. Set up quotas for blocks (10 soft, 40 hard) and inodes (10 soft, 40 hard).
3. Copy enough data for the user to exceed one of the soft limits.
4. Copy enough data for the user to exceed one of the hard limits.
5. Create a new user, give that new user the same quotas.
6. Turn off quotas for `/mnt/ex1`.

# Logical Volume Manager

# LVM

LVM is a Logical Volume Manager - it manages disk drives, usually large ones. Some common uses are:

- similar to RAID 0, make a single logical volume out of multiple physical volumes, allowing for dynamic resizing
- add, replace, copy disks without disrupting service - good for large disk farms
- easily resize partitions as needed
- make backups (snapshots)

# LVM

- LVM is a layer of software on top of the disk and partitions, creating a logical, continuous disk that is easy to resize
- Any partition, with the exception of `/boot`, can be part of an LVM

# LVM

- many distributions support LVM during the installation:
  - Ubuntu - can select LVM
    - `/boot` partition as ext4
    - `/` partition as LVM
    - swap partition as LVM
  - Centos - default is LVM
    - `/boot` partition as xfs
    - `/` partition as LVM
    - swap partition as LVM



# LVM

- basic functionality:
  - create one or more Physical Volumes (PVs) using one or more disk partitions (on one or more disks)
  - create a Volume Group (VG) by combining one or more PVs
  - create one or more Logical Volumes (LVs) in a VG
  - VGs can be extended by adding additional PVs
  - LVs can be resized by adding or removing extents

# Working with LVMs

- It might be necessary to install the required software

- Debian

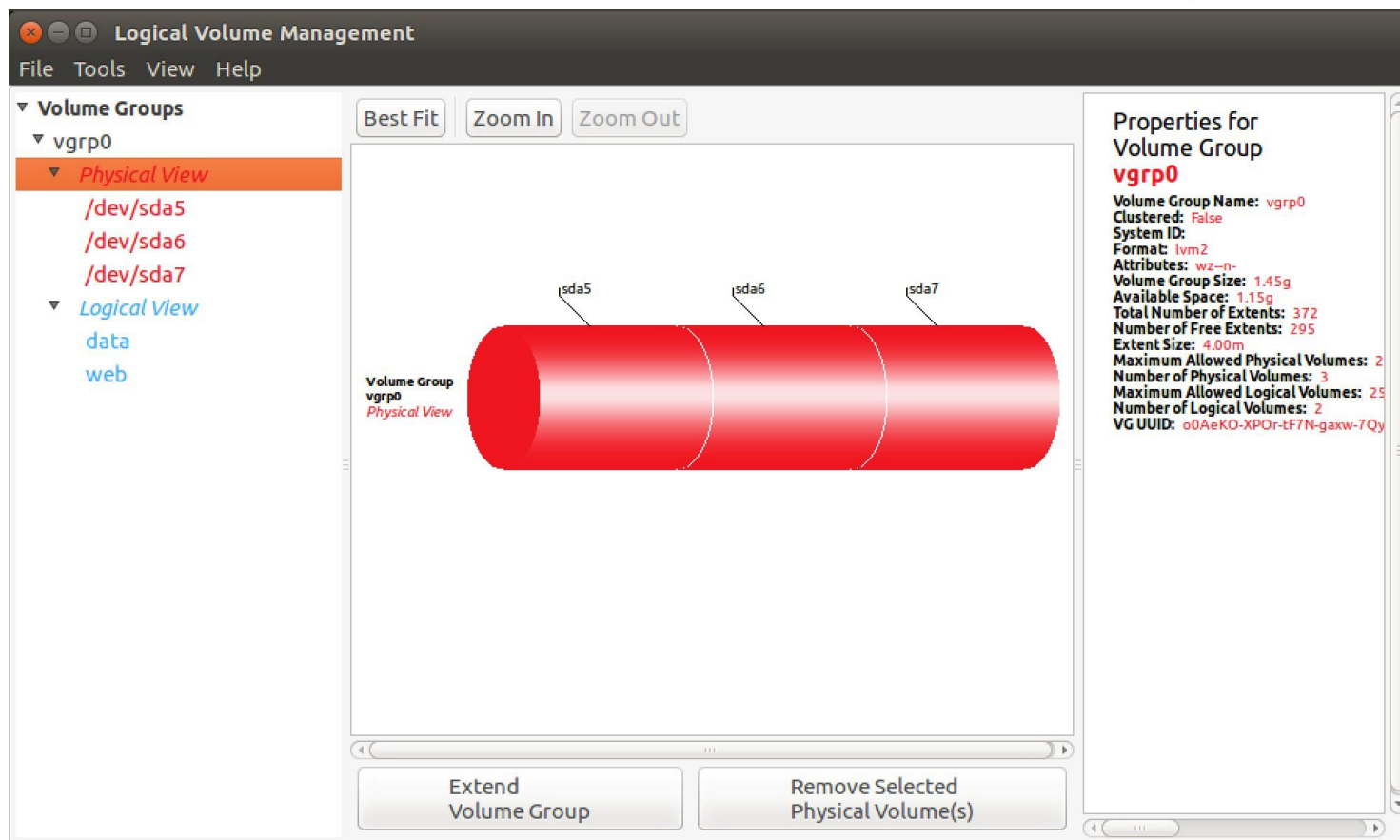
```
root# apt install lvm2 system-config-lvm
```

- RHEL

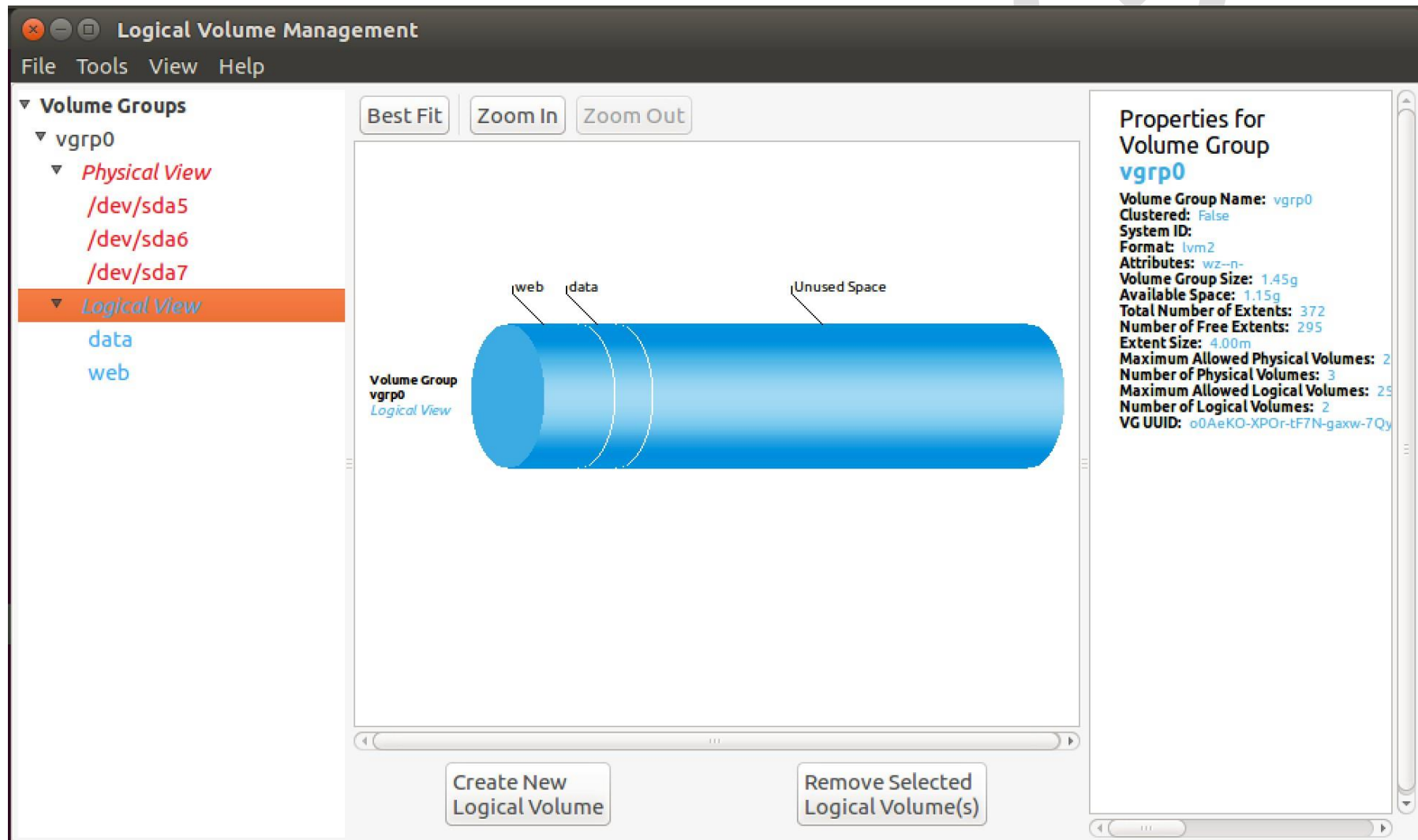
```
root# yum install lvm2 system-config-lvm
```

# Graphical Tools

- `system-config-lvm`



# Graphical Tools



# Working with LVMs

To create an LVM:

- create partitions and give them a type of `8e`
- initialize each physical volume with `pvcreate`
- create a volume group with `vgcreate`
- create mountable logical volumes with `lvcreate`
- format and mount the logical volumes

# Create LVM Partitions

The first step in creating an LVM is to create disk partitions that will be part of the volume group. These partitions can be on the same physical disk, or they can be on different physical disks. Create the partitions with type 8e, Linux LVM.

```
root# fdisk -l | grep LVM
/dev/sda6          24020992 25044991 1024000    500M 8e  Linux  LVM
/dev/sda7          25047040 26071039 1024000    500M 8e  Linux  LVM
/dev/sda8          26073088 27097087 1024000    500M 8e  Linux  LVM
root# partprobe
```

# Initialize LVM PV

- The next step in creating an LVM is to initialize each physical volume with `pvcreate`

```
root# pvcreate /dev/sda{6,7,8}
```

```
Physical volume "/dev/sda6" successfully created
```

```
Physical volume "/dev/sda7" successfully created
```

```
Physical volume "/dev/sda8" successfully created
```

# Initialize LVM PV

Let's look at one of the partitions with `pvdisplay` (with no argument, this command shows all PVs)

```
root# pvdisplay /dev/sda6
"/dev/sda6" is a new physical volume of "500.00 MiB"
--- NEW Physical volume ---
PV Name                /dev/sda6
VG Name
PV Size                500.00 MiB
Allocatable            NO
PE Size                0
Total PE              0
Free PE               0
Allocated PE          0
PV UUID                nno7Lt-9R3g-eKw4-kt66-IuDv-8q9Y-ahVsXn
```



# Create LVM VG

The next step in creating an LVM is to create a volume group that contains the physical volumes. The `-s` option is the size of the extents

```
root# vgcreate vgrp0 /dev/sda{6,7,8}
```

```
Volume group "vgrp0" successfully created
```



# Create LVM LV

The next step in creating an LVM is to create a mountable logical volume group (LVG) in an existing VG with `lvcreate`. This is a mountable volume.

```
root# lvcreate -L 200M -n web vgrp0  
Logical volume "web" created.
```

# Create LVM LV

```
root# lvdisplay /dev/vgrp0/web
```

```
--- Logical volume ---
```

```
LV Path                /dev/vgrp0/web
LV Name                 web
VG Name                 vgrp0
LV UUID                 eHoiBQ-hRMH-auG7-eLC1-oYjG-HY7K-A1xWOW
LV Write Access         read/write
LV Creation host, time ubuntu2, 2017-09-30 11:49:45 -0400
LV Status               available
# open                  0
LV Size                 200.00 MiB
Current LE              50
Segments                1
Allocation              inherit
Read ahead sectors      auto
- currently set to     256
Block device            253:0
```

# Create LVM LV

```
root# mkfs.ext4 /dev/vgrp0/web
root# mkdir /mnt/web
root# mount /dev/vgrp0/web /mnt/web
root# blkid | grep web
/dev/mapper/vgrp0-web:
UUID="4253b8b2-626d-4366-8e1c-15144a011236" TYPE="ext4"

# add to /etc/fstab
/dev/vgrp0/web /mnt/web ext4 defaults 0 2
```

# Create LVM LV

Let's create another LV:

```
# make 20 extents
root# lvcreate -l 20 -n data vgrp0
root# mkfs.ext4 /dev/vgrp0/data
root# mkdir /mnt/data
root# mount /dev/vgrp0/data /mnt/data

# add to /etc/fstab
/dev/vgrp0/data /mnt/data ext4 defaults 0 2
```

# Resizing Logical Volumes

Logical volumes can be resized without needing to reboot. They can be expanded without having to unmount (if the size is to be reduced, then it must be unmounted). The `lvextend` will increase the size of the volume, and `lvreduce` will decrease its size.

The `lvextend` option `-L` extends the volume by a given size, the `-l` option extends by the number of extents.

# Resizing Logical Volumes

```
root# lvextend -L +10M /dev/vgrp0/data
```

Rounding size to boundary between physical extents: 12.00 MiB

Size of logical volume vgrp0/data changed from 80.00 MiB (20 extents) to 92.00 MiB (23 extents).

Logical volume data successfully resized.

```
root# lvextend -l +4 /dev/vgrp0/data
```

Size of logical volume vgrp0/data changed from 96.00 MiB (24 extents) to 112.00 MiB (28 extents).

Logical volume data successfully resized.



# Resizing Logical Volumes

To reduce the size of a logical volume:

```
root# umount /mnt/data
root# lvreduce -L -5M /dev/vgrp0/data
    Rounding size to boundary between physical extents: 4.00 MiB
    WARNING: Reducing active logical volume to 108.00 MiB
    THIS MAY DESTROY YOUR DATA (filesystem etc.)
Do you really want to reduce data? [y/n]: y
    Size of logical volume vgrp0/data changed from 112.00 MiB
(28 extents) to 108.00 MiB (27 extents).
    Logical volume data successfully resized.
root# mount /dev/vgrp0/data /mnt/data
```

# Removing Logical Volumes

Logical volumes can be removed with `lvremove`:

```
root# umount /mnt/data
```

```
root# lvremove /dev/vgrp0/data
```

# Adding Physical Volumes

- first, create a new disk partition (in this example, 9):

```
root# fdisk -l | grep LVM
```

/dev/sda6	24020992	25044991	1024000	500M	8e	Linux	LVM
/dev/sda7	25047040	26071039	1024000	500M	8e	Linux	LVM
/dev/sda8	26073088	27097087	1024000	500M	8e	Linux	LVM
/dev/sda9	27099136	29147135	2048000	1000M	8e	Linux	LVM

```
root# partprobe
```

# Adding Physical Volumes

- next, create a physical volume:

```
root# pvccreate /dev/sda9
```

```
Physical volume "/dev/sda9" successfully created
```

- next, add the partition to the volume group with  
vgextend:

```
root# vgextend vgrp0 /dev/sda9
```

```
Volume group "vgrp0" successfully extended
```

# Display LVM Info

As a review, we can display information about our LVMs:

- physical volumes

```
root# pvdisplay /dev/sda6
```

- volume groups

```
root# vgdisplay vgrp0
```

- logical volumes

```
root# lvdisplay /dev/vgrp0/web
```

**RAID**

# Software RAID

- RAID (Redundant Array of Inexpensive Disks) came about because (as the story goes) an organization with little money and a lot of old hard drives needed some storage space. So the idea to combine the inexpensive disks into a single disk was born. These days, they are better known as Redundant Array of Independent Disks.
- RAID is often used as a term describing a way to divide and replicate data among multiple disks.

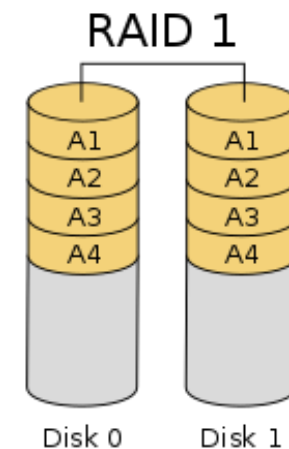
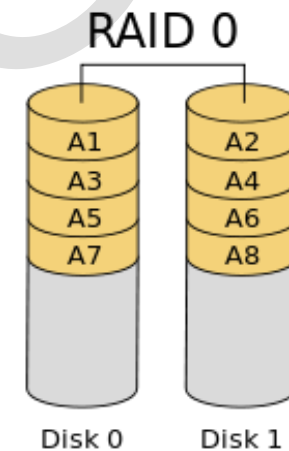
# Software Raid

- RAID redundancy is achieved through:
  - mirroring - writing the same data to multiple drives
  - parity data - extra data across multiple disks - for fault tolerance, data is computed on one or more disks and stored in another location



# Types of RAID Drives

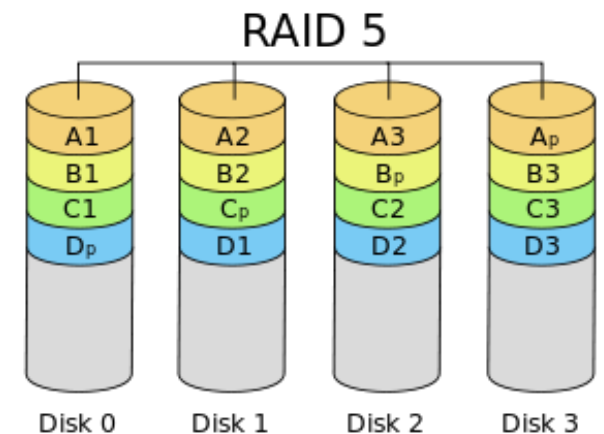
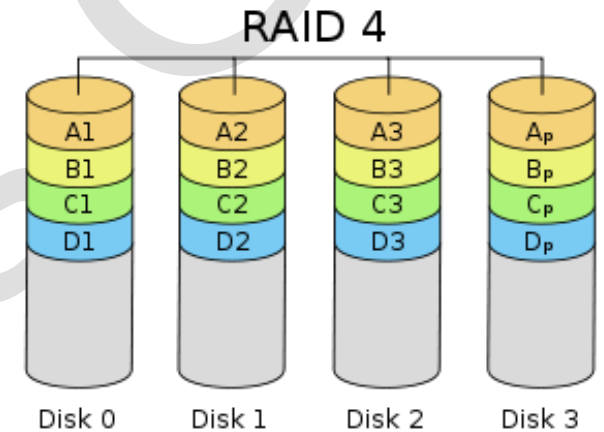
- Different types of RAID drives:
  - RAID 0 - striped disks - distribute data across all disks - no parity, redundancy or fault tolerance (for speed)
  - RAID 1 - mirrored disks - duplicates data across all disks in the array



*all RAID images from Wikipedia*

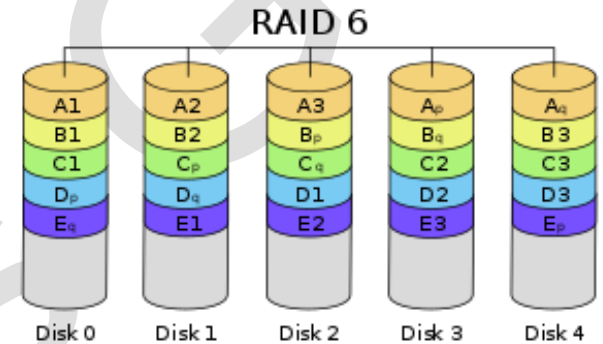
# Types of RAID Drives

- RAID 2 and 3 - rarely used
- RAID 4 - striping with a dedicated parity disk
- RAID 5 - striped disks with parity - combines 3 or more disks so that loss of one disk will not lose any data

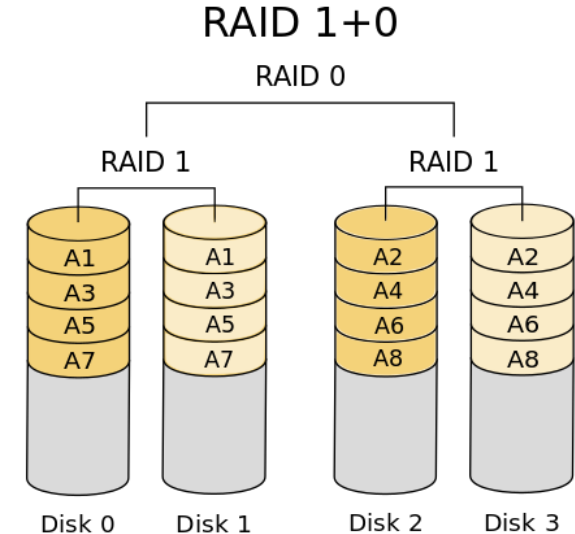


# Types of RAID Drives

- RAID 6 - striped disks with dual parity - can recover from the loss of two disks (uncommon)



- RAID 10 (1 + 0) - striped and mirrored disks - uses both striping and mirroring



# Software RAID

- Software RAID is when the various RAID levels are implemented within the kernel:
  - cheapest solution
- To create a software RAID:
  - create partitions
- create virtual device file
  - that device file is then mounted

# Creating a Software RAID

- install packages if necessary

```
root# apt install mdadm
root# yum install mdadm
```

- create 2 or more disk partitions of type fd:

```
root# fdisk /dev/sda
...
root# fdisk -l /dev/sda | grep fd
/dev/sda10      24020992 25044991   1024000    500M fd Linux raid autodetect
/dev/sda11      25047040 26071039   1024000    500M fd Linux raid autodetect
```

- tell the kernel about the new disk partitions:

```
root# partprobe
```

# Creating a Software RAID

- create the virtual device (device is /dev/md0, RAID 1, two disks):

```
root# mdadm --create --verbose /dev/md0 --level=1 \
      --raid-devices=2 /dev/sda10 /dev/sda11
mdadm: array /dev/md0 started.
```

- format the RAID:

```
root# mkfs.ext4 /dev/md0
```

- create a mount point and mount the partition:

```
root# mkdir /mnt/RAID
root# mount /dev/md0 /mnt/RAID
```

# Creating a Software RAID

- store new detail in configuration file

```
root# mdadm --detail --scan | \
    tee -a /etc/mdadm/mdadm.conf
```

- update the initial RAM file system so the array will be available during the early boot process

```
root# update-initramfs -u
```

- add a mount point to /etc/fstab:

```
root# echo '/dev/md0 /mnt/RAID ext4 \
    defaults,nofail,discard 0 0' | \
    tee -a /etc/fstab
```

# RAID Info

To show information about the RAID device

```
root# mdadm -D /dev/md0
```

```
/dev/md0:
```

```
Version : 1.2
Creation Time : Fri Sep 29 17:24:11 2017
Raid Level : raid1
Array Size : 511680 (499.77 MiB 523.96 MB)
Used Dev Size : 511680 (499.77 MiB 523.96 MB)
Raid Devices : 2
Total Devices : 2
Persistence : Superblock is persistent
```



# RAID Info

Update Time : Fri Sep 29 17:47:20 2017

State : clean

Active Devices : 2

Working Devices : 2

Failed Devices : 0

Spare Devices : 0

Name : ubuntu2:0 (local to host ubuntu2)

UUID : 9077a64b:ee2fcfc0:08fc26bd:5e9f1bd8

Events : 21

Number	Major	Minor	RaidDevice	State	
0	8	5	0	active sync	/dev/sda10
1	8	6	1	active sync	/dev/sda11

# Removing a RAID

- To remove a RAID:
  - unmount the device:

```
root# umount /dev/md0
```

- stop and remove the RAID:

```
root# mdadm --stop /dev/md0
```

```
root# mdadm --remove /dev/md0
```

# Removing a RAID

- remove the line added at the bottom of `mdadm.conf`:

```
root# vi /etc/mdadm/mdadm.conf
```

- update the initial RAM file system:

```
root# update-initramfs -u
```

- remove entry from `/etc/fstab`

# Exercise

## 1. Create an LVM:

- 3 partitions of size 1024M
- 1 volume group
- 2 logical volumes: vol1 (512M) and vol2 (100 extents)
- mount the volumes at `/mnt/vol1` and `/mnt/vol2`
- add them to `/etc/fstab`
- reboot to confirm they mount at boot

# Exercise

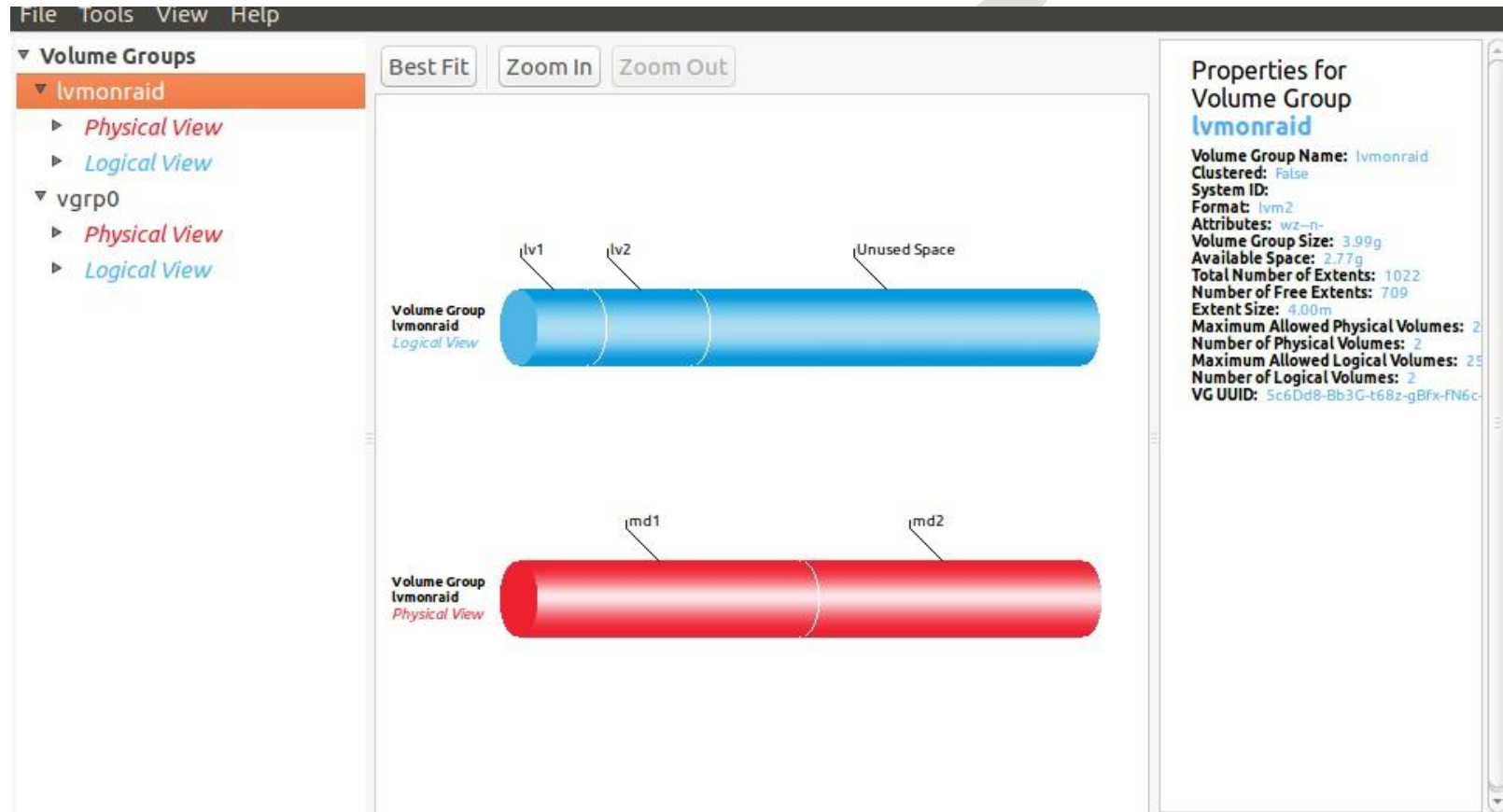
## 2. Create a RAID:

- 3 partitions of size 1024M
- RAID 0
- block size 2048
- stride 32
- mount it at `/mnt/RAID`
- add it to `/etc/fstab`
- reboot to confirm they mount at boot

# Supplemental: LVM on RAID

# LVM on RAID

Let's create an LVM from two partitions, each partition is a RAID with redundancy.



# LVM on RAID

1. Create partitions - use `fdisk` and create 4 2G partitions:

```
# fdisk -l /dev/sda
...
/dev/sda12      40278016 44472319 4194304      2G fd Linux raid autodetect
/dev/sda13      44474368 48668671 4194304      2G fd Linux raid autodetect
/dev/sda14      48670720 52865023 4194304      2G fd Linux raid autodetect
/dev/sda15      52867072 57061375 4194304      2G fd Linux raid autodetect
```

2. Create 2 RAIDS from these 4 partitions, 2 partitions each:

```
# mdadm --create --verbose /dev/md1 --level=1 \
  --raid-devices=2 /dev/sda12 /dev/sda13
# mdadm --create --verbose /dev/md2 --level=1 \
  --raid-devices=2 /dev/sda14 /dev/sda15
```



# LVM on RAID

3. Create create an LVM from these raids - first create PV:

```
# pvcreate /dev/md1 /dev/md2
```

4. Create a VG:

```
# vgcreate lvmonraid /dev/md1 /dev/md2
```

5. Create some LVs:

```
# lvcreate -L 500M -n lv1 lvmonraid
```

```
# lvcreate -L 750M -n lv2 lvmonraid
```

# LVM on RAID

6. Format these LVs:

```
# mkfs.ext4 /dev/lvmonraid/lv1  
# mkfs.ext4 /dev/lvmonraid/lv2
```

7. Mount them:

```
# mkdir /mnt/lv1  
# mkdir /mnt/lv2  
# mount /dev/lvmonraid/lv1 /mnt/lv1  
# mount /dev/lvmonraid/lv2 /mnt/lv2
```

# LVM on RAID

The result:

