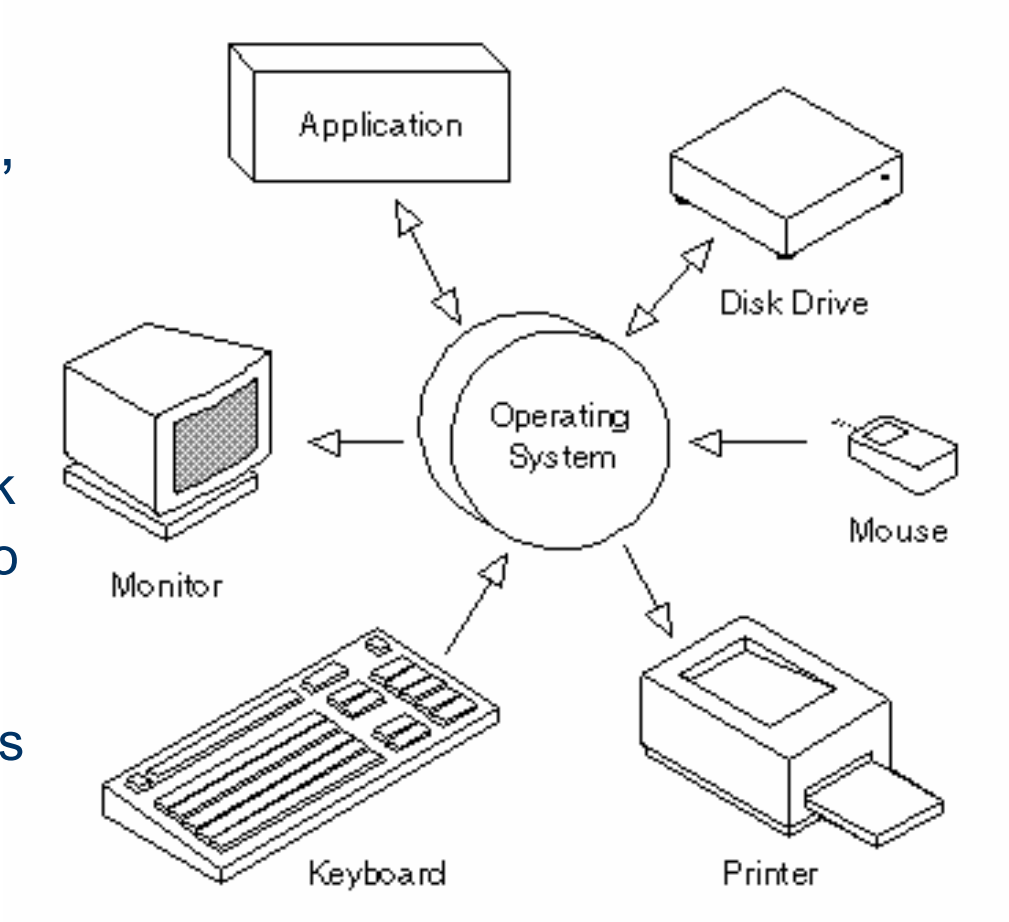
# 2. Operating System Case Study: Linux

# Reference

- S.M. Sarwar, R. Koretsky and S.A. Sarwar, *Linux – The Textbook*, Addison Wesley, 1st ed, 2002

# Features of modern OS

- To facilitate easy, efficient, fair, orderly, and secure use of resources
  - Provide a user interface
  - Organize files on disk
  - Allocating resource to different users with security control
  - Co-ordinate programs to work with devices and other programs



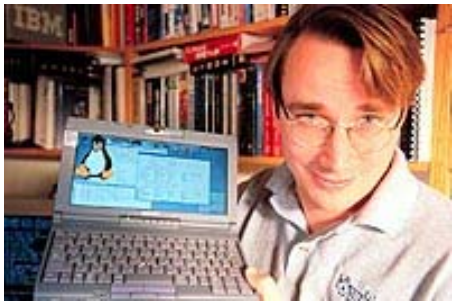
# Case study: Linux

## A. Development of Linux

- Before Linux
  - In 80's, Microsoft's DOS was the dominated OS for PC
    - single-user, single-process system
  - Apple MAC is better, but expensive
  - UNIX is much better, but much much expensive. Only for minicomputer for commercial applications
  - People was looking for a UNIX based system, which is cheaper and can run on PC
  - Both DOS, MAC and UNIX are proprietary, i.e., the source code of their kernel is protected
    - No modification is possible without paying high license fees

- GNU project
  - Established in 1984 by Richard Stallman, who believes that software should be free from restrictions against copying or modification in order to make better and efficient computer programs
  - GNU is a recursive acronym for "GNU's Not Unix"
  - Aim at developing a complete Unix-like operating system which is free for copying and modification
  - Companies make their money by maintaining and distributing the software, e.g. optimally packaging the software with different tools (Redhat, Slackware, Mandrake, SuSE, etc)
  - Stallman built the first free GNU C Compiler in 1991. But still, an OS was yet to be developed

- Beginning of Linux
  - A famous professor Andrew Tanenbaum developed Minix, a simplified version of UNIX that runs on PC
  - Minix is for class teaching only. No intention for commercial use
  - In Sept 1991, Linus Torvalds, a second year student of Computer Science at the University of Helsinki, developed the preliminary kernel of Linux, known as Linux version 0.0.1
  - It was put to the Internet and received enormous response from worldwide software developers
  - By December came version 0.10. Still Linux was little more than in skeletal form.



- Confrontation and Development
  - Message from Professor Andrew Tanenbaum
    - " I still maintain the point that designing a monolithic kernel in 1991 is a fundamental error. Be thankful you are not my student. You would not get a high grade for such a design :-)" (Andrew Tanenbaum to Linus Torvalds)
    - "Linux is obsolete".

      (Remark made by Andrew Tanenbaum)
  - But work went on. Soon more than a hundred people joined the Linux camp. Then thousands. Then hundreds of thousands
  - It was licensed under GNU General Public License, thus ensuring that the source codes will be free for all to copy, study and to change.

- Linux Today
  - Linux has been used for many computing platforms
    - PC, PDA, Supercomputer,…
  - Current kernel version 2.6.13
  - Not only character user interface but graphical user interface, thanks to the X-Window technology
  - Commercial vendors moved in Linux itself to provide freely distributed code. They make their money by compiling up various software and gathering them in a distributable format
    - Red Hat, Slackware, etc
  - Chinese distribution of Linux also appeared in Taiwan and China - CLE, Red Flag Linux

# Linux Pros and Cons

- Advantages over Windows
  - It's almost free to relatively inexpensive
  - Source code is included
  - Bugs are fixed quickly and help is readily available through the vast support in Internet
  - Linux is more stable than Windows
  - Linux is truly multi-user and multi-tasking
    - multiuser: OS that can simultaneously serve a number of users
    - multitasking: OS that can simultaneously execute a number of programs
  - Linux runs on equipment that other operating systems consider too underpowered, e.g. 386 systems, PDA, etc

# Linux Pros and Cons (Cont)

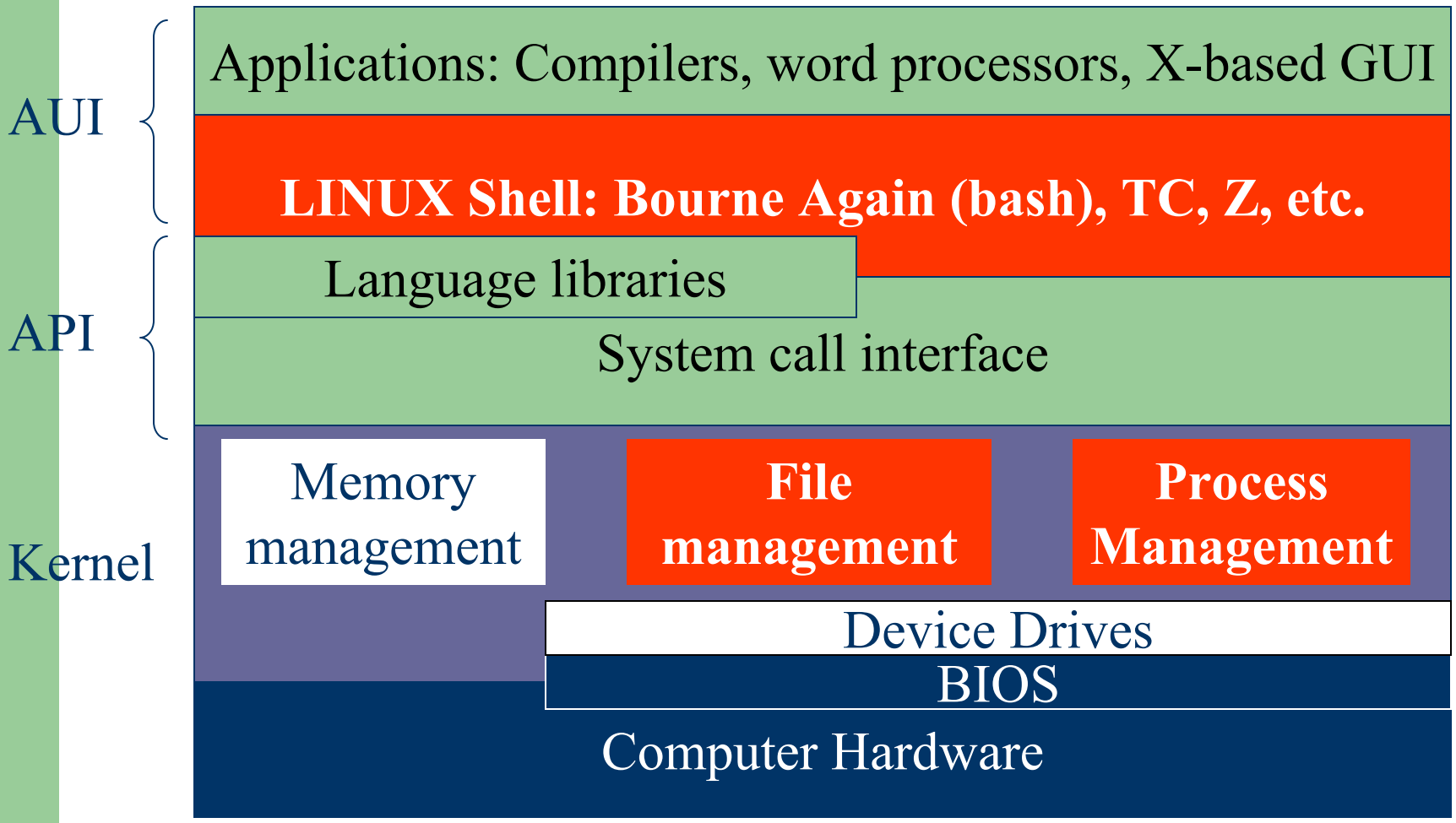
- Disadvantages compared with Windows
  - Isn't as popular as Windows
  - No one commercial company is responsible for Linux
  - Linux is relatively hard to install, learn and use

- Hence currently, Linux is mainly used in commercial applications, server implementation
- More than 75% current network servers are developed based on Linux or Unix systems
  - Due to the relatively high reliability



# Case study: Linux

## B. Linux System Architecture


AUI
API
Kernel
Applications: Compilers, word processors, X-based GUI
LINUX Shell: Bourne Again (bash), TC, Z, etc.
Language libraries
System call interface
Memory management
File management
Process Management
Device Drives
BIOS
Computer Hardware

- Kernel
  - The part of an OS where the real work is done
- System call interface
  - Comprise a set of functions (often known as Application Progarmmer's Interface API) that can be used by the applications and library routines to use the services provided by the kernel
- Application User's Interface
  - Interface between the kernel and user
  - Allow user to make commands to the system
  - Divided into text based and graphical based

- File Management
  - Control the creation, removal of files and provide directory maintenance
  - For a multiuser system, every user should have its own right to access files and directories
- Process Management
  - For a multitask system, multiple programs can be executed simultaneously in the system
  - When a program starts to execute, it becomes a process
  - The same program executing at two different times will become two different processes
  - Kernel manages processes in terms of creating, suspending, and terminating them
  - A process is protected from other processes and can communicate with the others

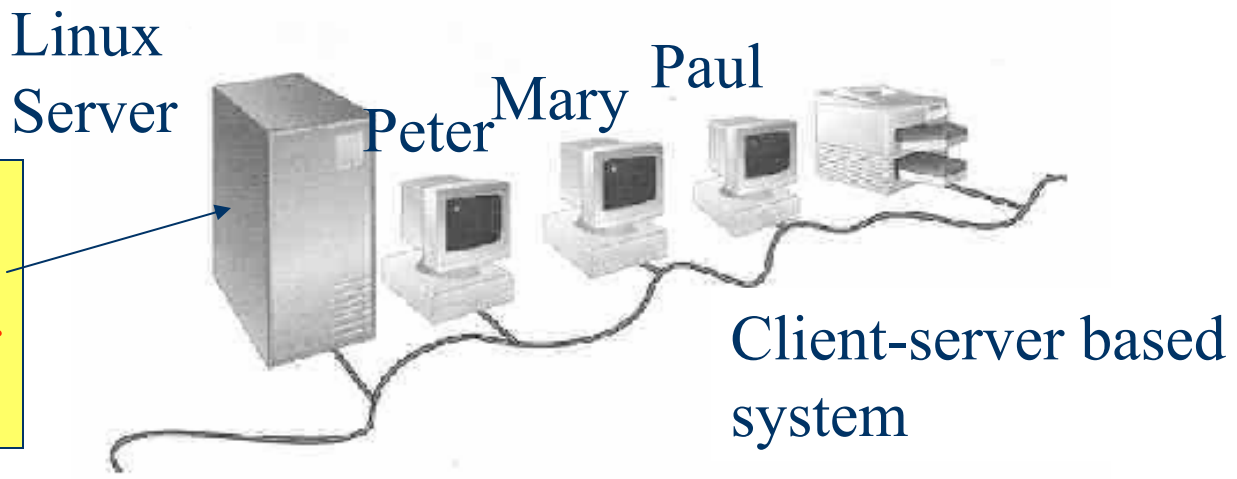
- Memory management
  - Memory in a computer is divided into main memory (RAM) and secondary storage (usually refer to hard disk)
  - Memory is small in capacity but fast in speed, and hard disk is vice versa
  - Data that are not currently used should be saved to hard disk first, while data that are urgently needed should be retrieved and stored in RAM
  - The mechanism is referred as memory management
- Device drivers
  - Interfaces between the kernel and the BIOS
  - Different device has different driver

# Case study: Linux

## B.1 User interface

# Linux User Login

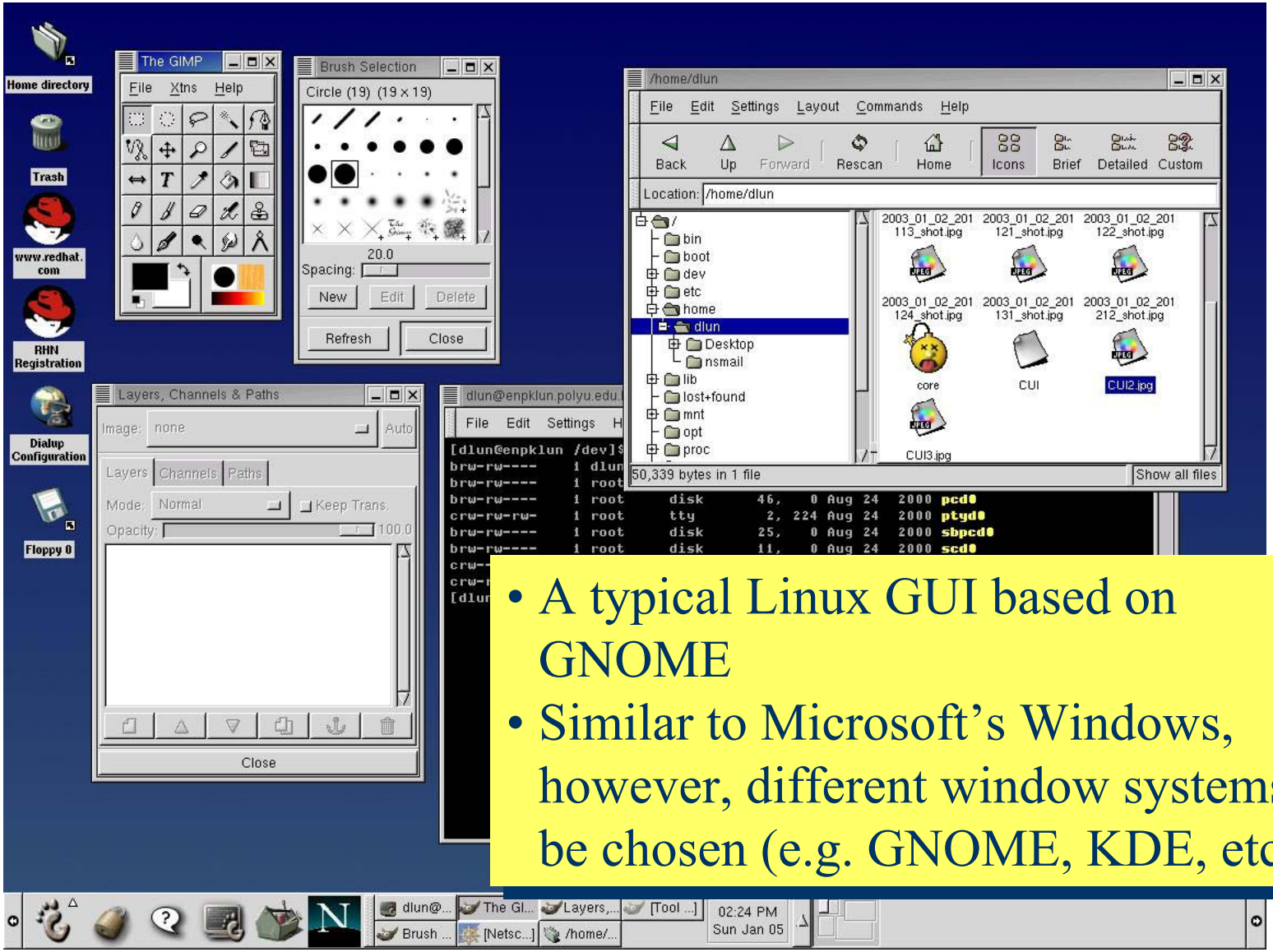
- Linux is a multiuser OS
- Allow multiple users to use the resource of a computer at the same time
- Every user needs to login the system with the password provided to identify their right in using the resource
- Require for both client-server based system or desktop



# Linux User Interface

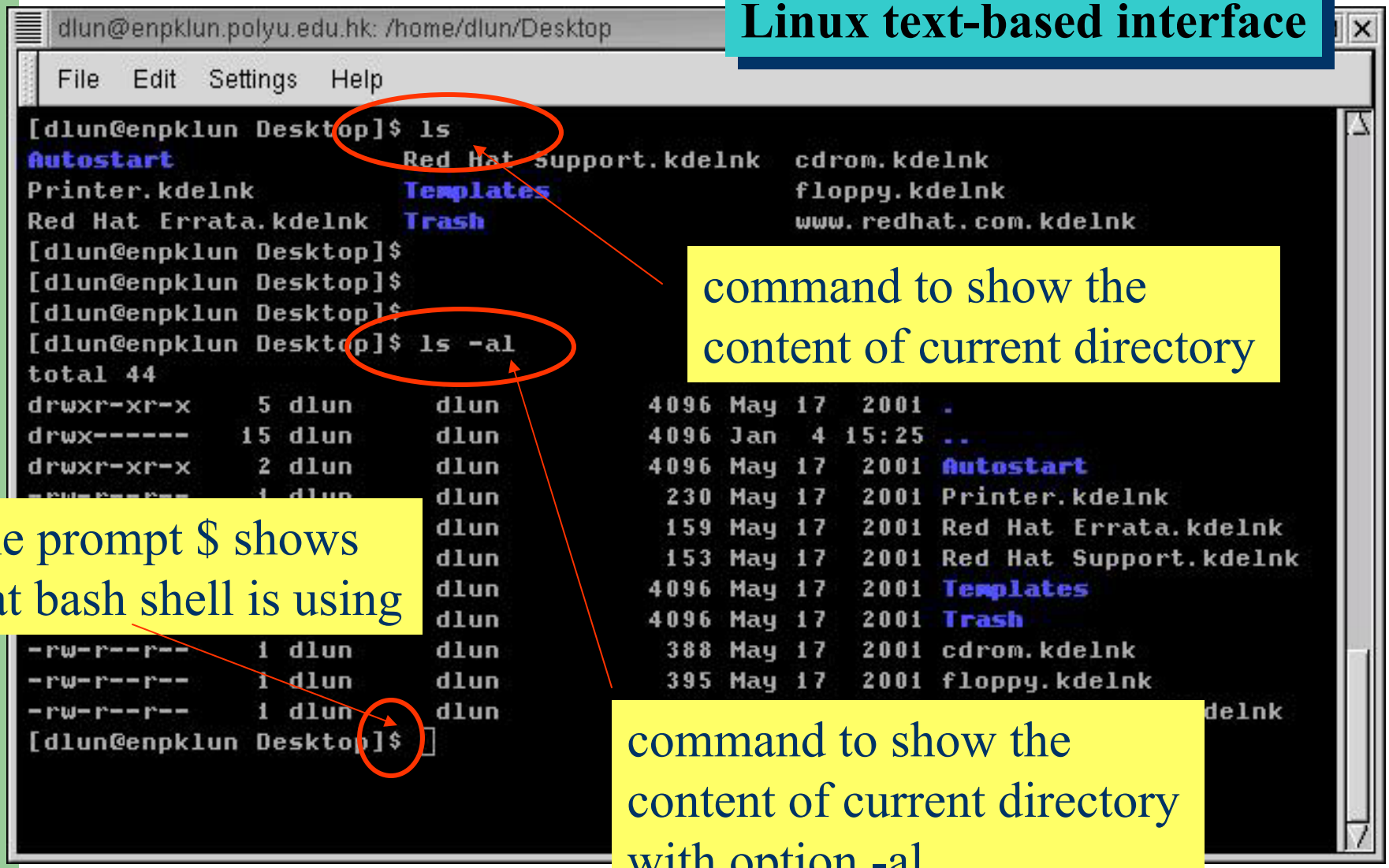
- Traditional Linux (Unix also) uses command-driven interface (or text-based interface)
  - User needs to type lines of command to instruct the computer to work, similar to DOS
  - Advantage: fast in speed. Very few resource is required for its implementation
  - Disadvantages: user needs to type, hence can easily make error. Besides, user needs to memorize all commands
  - Suitable for expert users and for the systems that interaction with user is not frequent, such as servers

- By adopting the X-Window technology, graphical user interface (GUI) is available for Linux:
  - Uses pointing devices (e.g. mouse) to control the system, similar to Microsoft's Windows
  - Provide menu-driven and/or icon-driven interfaces
    - menu-driven: user is provided with a menu of choices. Each choice refers to a particular task
    - icon-driven: tasks are represented by pictures (icon) and shown to user. Click on an icon invokes one task
  - Advantages: No need to memorize commands. Always select task from menus or icons
  - Disadvantages: Slow and require certain resource for its implementation
  - Suitable for general users and systems, such as PC




- A typical Linux GUI based on GNOME
- Similar to Microsoft's Windows, however, different window systems can be chosen (e.g. GNOME, KDE, etc)

# Linux text-based interface

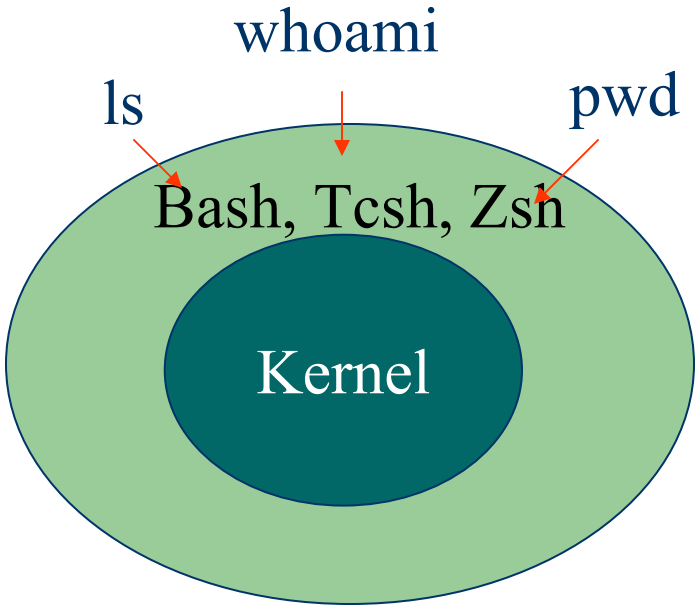



command to show the content of current directory

The prompt $ shows that bash shell is using

command to show the content of current directory with option -al

# Linux Shell




- Shell interprets the command and request service from kernel
- Similar to DOS but DOS has only one set of interface while Linux can select different shell
  - Bourne Again shell (Bash), TC shell (Tcsh), Z shell (Zsh)
- Different shell has similar but different functionality
- Bash is the default for Linux
- Graphical user interface of Linux is in fact an application program work on the shell

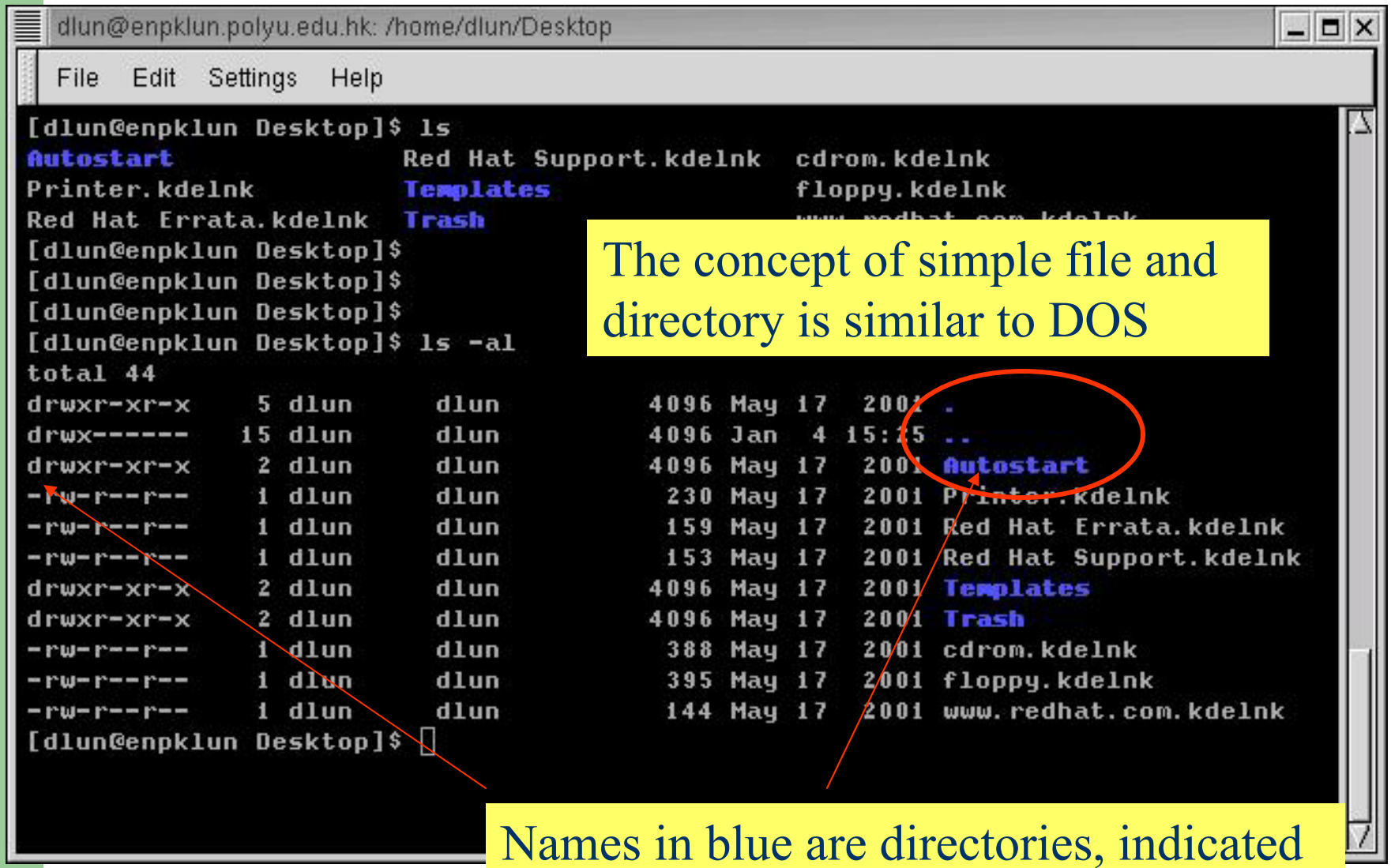
- Frequently used commands available in most shells:
  - ls : to show (list) the names of the file in the current directory
  - cd : change directory,
    - e.g. cd / change to the root directory
      cd .. change to the parent of that directory
  - cp : copy one file to another
    - e.g. cp abc.txt xyz.txt copy abc.txt to xyz.txt
  - rm : remove a file
  - man : ask for the manual (or help) of a command
    - e.g. man cd ask for the manual of the command cd
  - pwd : show the name of the present working directory
  - cat : to show the content of a text file
    - e.g. cat abc.txt show the content of abc.txt
  - whoami : to show the username of the current user

# Case study: Linux

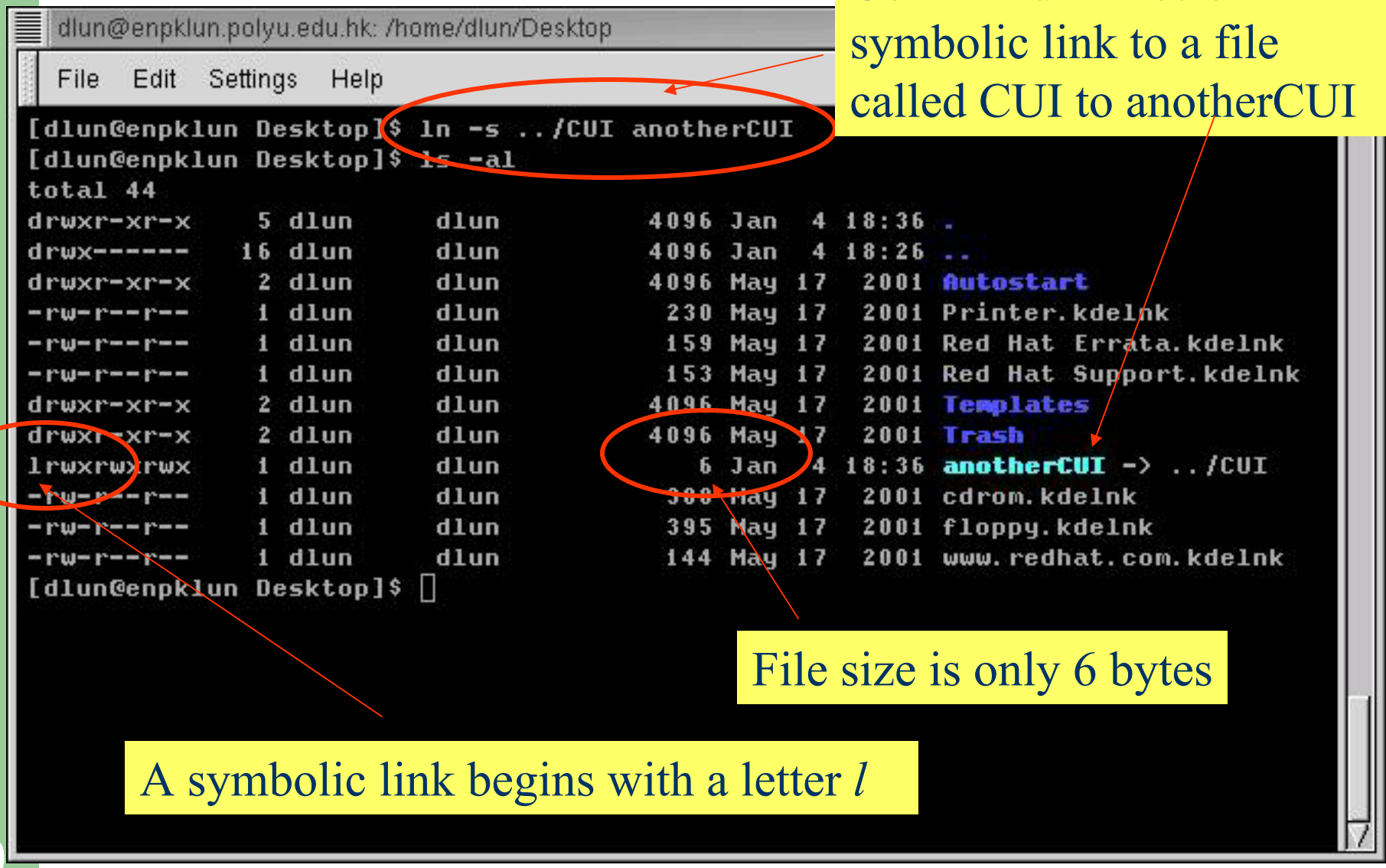
## B.2 File management

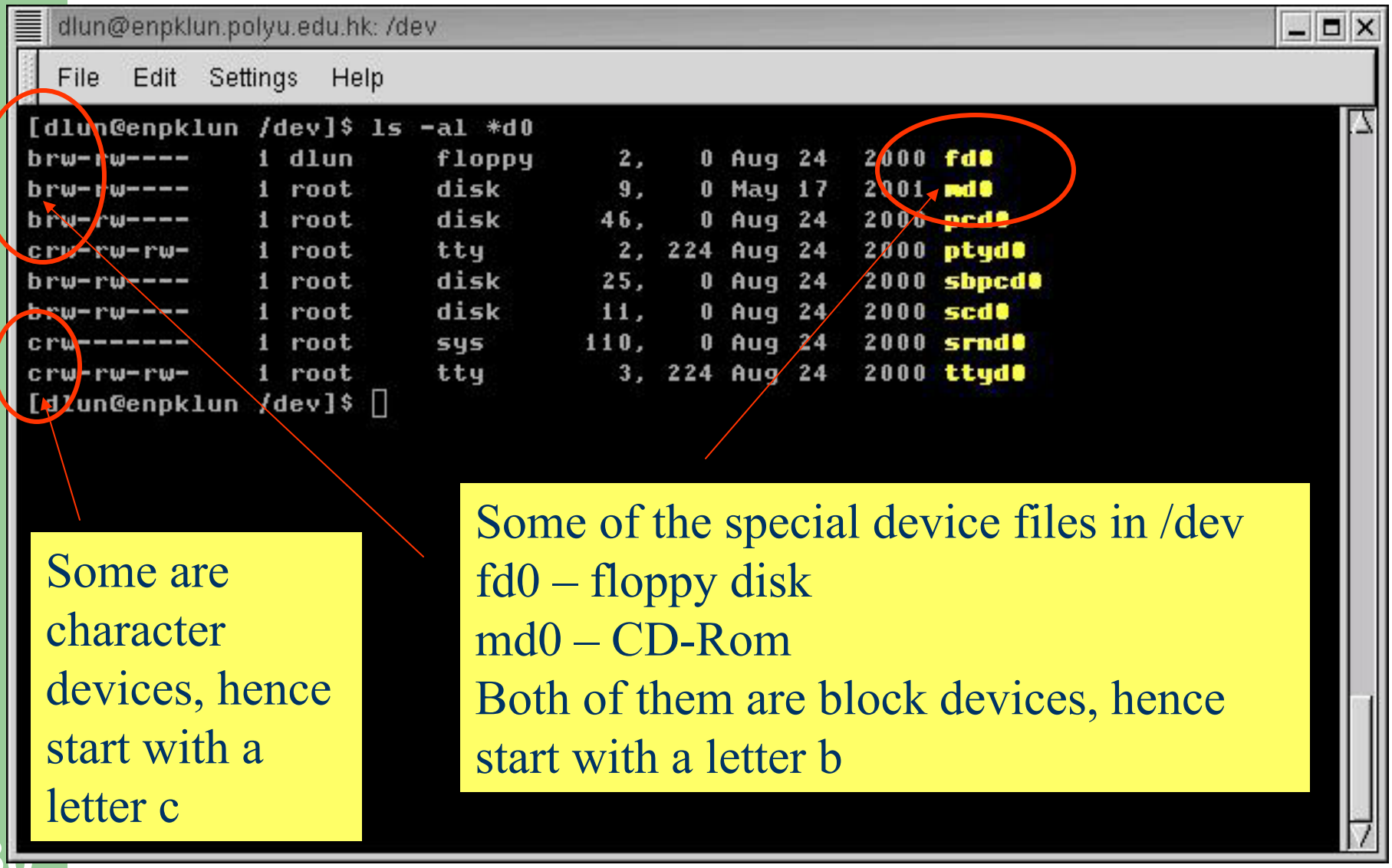
# Linux File Management

- In Linux, file is defined as simply the thing that deals with a sequence of bytes
- Hence everything are files
  - An ordinary file is a file; a directory is also file; a network card, a hard disk, any device are also files since they deal with a sequence of bytes
- Linux supports five types of files
  - simple/ordinary file (text file, c++ file, etc)
  - directory
  - symbolic (soft) link
  - special file (device)
  - named pipe (FIFO)


dlun@enpklun.polyu.edu.hk: /home/dlun/Desktop
File Edit Settings Help
[dlun@enpklun Desktop]$ ls
Autostart Red Hat Support.kdelnk cdrom.kdelnk
Printer.kdelnk Templates floppy.kdelnk
Red Hat Errata.kdelnk Trash
[dlun@enpklun Desktop]$
[dlun@enpklun Desktop]$
[dlun@enpklun Desktop]$
[dlun@enpklun Desktop]$ ls -al
total 44
drwxr-xr-x 5 dlun dlun 4096 May 17 2001 .
drwx------ 15 dlun dlun 4096 Jan 4 15:15 ..
drwxr-xr-x 2 dlun dlun 4096 May 17 2001 Autostart
-rw-r--r-- 1 dlun dlun 230 May 17 2001 Printer.kdelnk
-rw-r--r-- 1 dlun dlun 159 May 17 2001 Red Hat Errata.kdelnk
-rw-r--r-- 1 dlun dlun 153 May 17 2001 Red Hat Support.kdelnk
drwxr-xr-x 2 dlun dlun 4096 May 17 2001 Templates
drwxr-xr-x 2 dlun dlun 4096 May 17 2001 Trash
-rw-r--r-- 1 dlun dlun 388 May 17 2001 cdrom.kdelnk
-rw-r--r-- 1 dlun dlun 395 May 17 2001 floppy.kdelnk
-rw-r--r-- 1 dlun dlun 144 May 17 2001 www.redhat.com.kdelnk
[dlun@enpklun Desktop]$
The concept of simple file and directory is similar to DOS
Names in blue are directories, indicated by a letter d at the beginning of the line

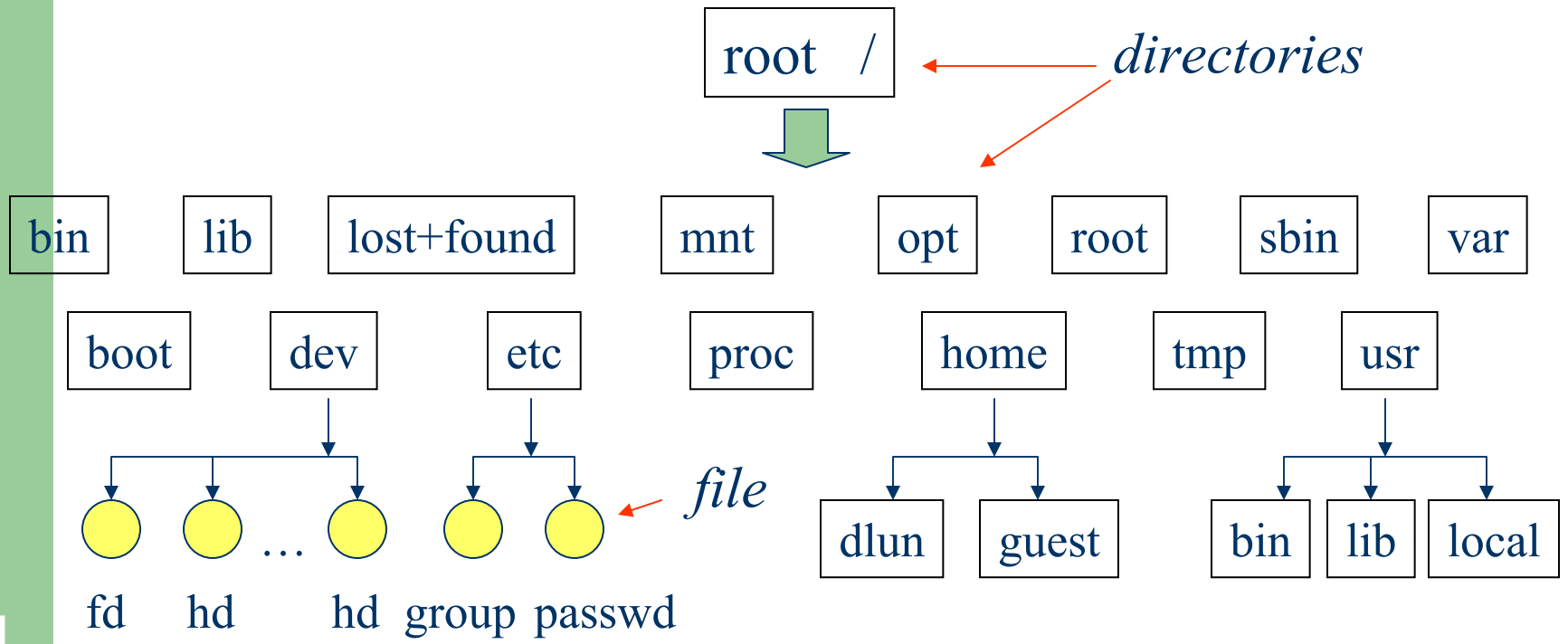
- Symbolic (soft) link
  - Not a real file, just a link to another file
  - Allow giving another name to a file without actually duplicates it – hence save memory space
- Special file (device)
  - Each hardware device, e.g. keyboard, hard disk, CD-ROM, etc is associated with at least one file
  - Usually store in /dev directory
  - Applications can read and write any devices by reading and writing their associate file – hence the access method is known as device independent
  - Divide into two types: character special files, e.g. keyboard, and block special files, e.g. disk


dlun@enpklun.polyu.edu.hk: /home/dlun/Desktop
File Edit Settings Help
[dlun@enpklun Desktop]$ ln -s ../CUI anotherCUI
[dlun@enpklun Desktop]$ ls -al
total 44
drwxr-xr-x 5 dlun dlun 4096 Jan 4 18:36 .
drwx------ 16 dlun dlun 4096 Jan 4 18:26 ..
drwxr-xr-x 2 dlun dlun 4096 May 17 2001 Autostart
-rw-r--r-- 1 dlun dlun 230 May 17 2001 Printer.kdelnk
-rw-r--r-- 1 dlun dlun 159 May 17 2001 Red Hat Errata.kdelnk
-rw-r--r-- 1 dlun dlun 153 May 17 2001 Red Hat Support.kdelnk
drwxr-xr-x 2 dlun dlun 4096 May 17 2001 Templates
drwxr-xr-x 2 dlun dlun 4096 May 17 2001 Trash
lrwxrwxrwx 1 dlun dlun 6 Jan 4 18:36 anotherCUI -> ../CUI
-rw-r--r-- 1 dlun dlun 308 May 17 2001 cdrom.kdelnk
-rw-r--r-- 1 dlun dlun 395 May 17 2001 floppy.kdelnk
-rw-r--r-- 1 dlun dlun 144 May 17 2001 www.redhat.com.kdelnk
[dlun@enpklun Desktop]$
Command that sets a symbolic link to a file called CUI to anotherCUI
File size is only 6 bytes
A symbolic link begins with a letter l


dlun@enpklun.polyu.edu.hk: /dev
File Edit Settings Help
[dlun@enpklun /dev]$ ls -al *d0
brw-rw---- 1 dlun floppy 2, 0 Aug 24 2000 fd0
brw-rw---- 1 root disk 9, 0 May 17 2001 md0
brw-rw---- 1 root disk 46, 0 Aug 24 2000 pcd0
crw-rw-rw- 1 root tty 2, 224 Aug 24 2000 ptyd0
brw-rw---- 1 root disk 25, 0 Aug 24 2000 sbpcd0
brw-rw---- 1 root disk 11, 0 Aug 24 2000 scd0
crw------- 1 root sys 110, 0 Aug 24 2000 srnd0
crw-rw-rw- 1 root tty 3, 224 Aug 24 2000 ttyd0
[dlun@enpklun /dev]$
Some are character devices, hence start with a letter c
Some of the special device files in /dev
fd0 – floppy disk
md0 – CD-Rom
Both of them are block devices, hence start with a letter b

# Linux File System Structure

- According to the File System Standard (FSSTND) proposed in 1994, every LINUX system should contain a set of standard files and directories



- Root Directory ( / )
  - Top of the file system. Similar to \ in DOS
- /bin
  - Contain the binary (executable code) of most essential Linux commands, e.g. bash, cat, cp, ln, ls, etc.
- /boot
  - Contain all the files needed to boot the Linux system, including the binary of the Linux kernel. E.g., on Red Hat Linux 6.1, the kernel is in /boot/vmlinux-2.2.5-15 file
- /dev
  - Contain the special files for devices, e.g. fd0, hd0, etc.

- /etc
  - Contain host-specific files and directories, e.g. information about system configuration
  - /etc/passwd
    - This file contains login information of users in the system
    - For every user, one line of record is stored in the following format:

login_name : dummy_or_encrypted_password : user_ID : group_ID : user_info : home_directory : login_shell

- E.g. davis:x:134:105:James A Davis:/home/davis:/bin/bash
  - davis : login name
  - x : means that it is a dummy password. The encrypted password is stored in /etc/shadow. This field can also be used to store the actual encrypted password. In any case, the original (unencrypted) password cannot be seen by anyone, including the administrator
  - 134 : a user id given to that user. Range from 0 to 65535. 0 is assigned to super-user. 1 to 99 are reserved
  - 105 : a group id given to that user to indicate which group he belongs to. Range from 0 to 65535. 0 to 99 reserved
  - James A Davis : user info, usually user's full name
  - /home/davis : home directory of the user
  - /bin/bash : the location of the shell the user is using

- /home
  - Contain the home directories of every user in the system, e.g. dlun, guest, etc
- /lib
  - Store all essential libraries for different language compilers
- /lost+found
  - Contain all the files on the system not connected to any directory.
  - System administrator should determine the fate of the files in this directory

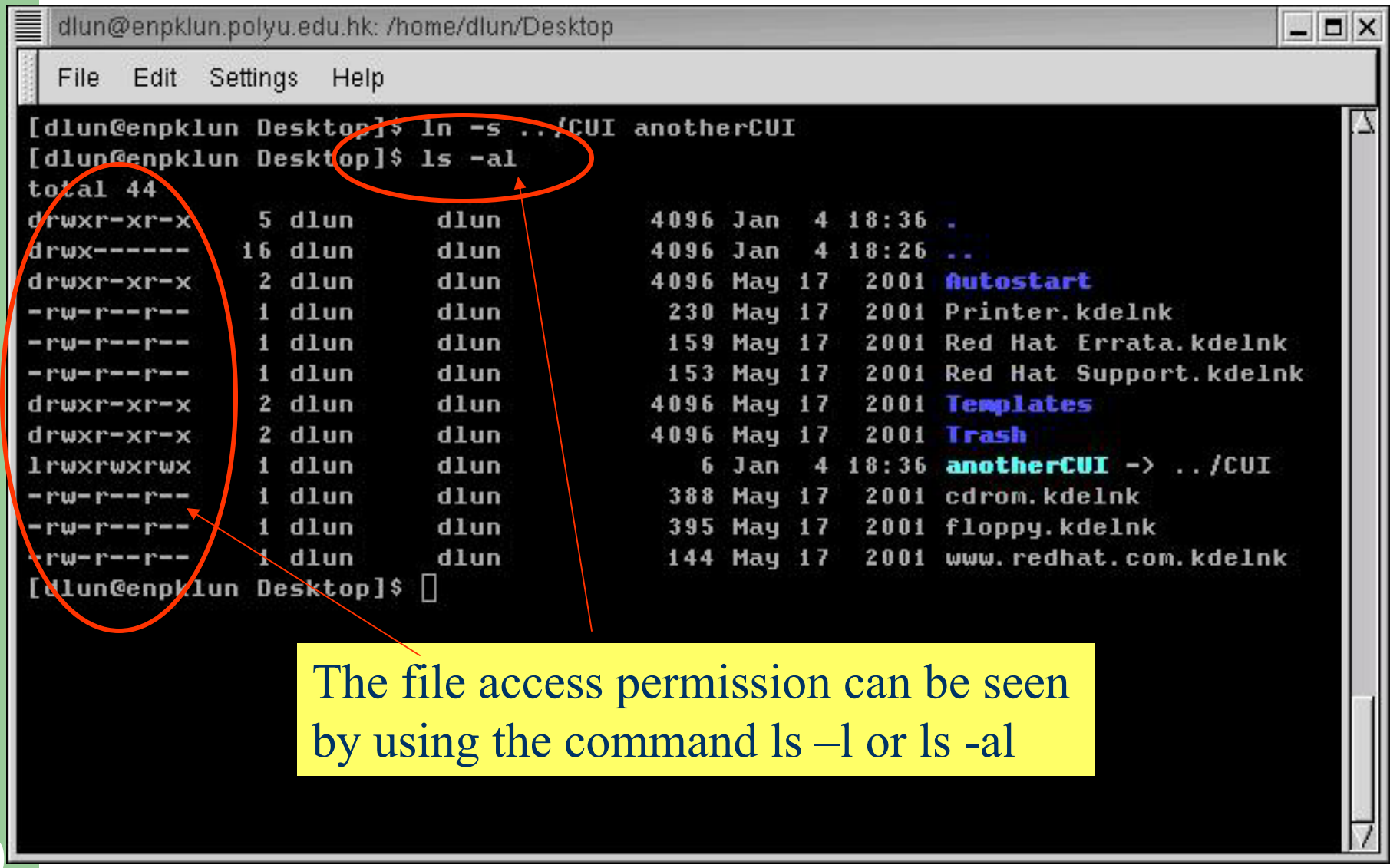
- /mnt
  - Use by system administrator to mount file systems temporarily by using the mount command
  - Before using any devices, they have to be mounted to the system for registration
  - For example, after mounting a CD-ROM, the file system in it will be mapped to /mnt/cdrom directory
  - User can then read and write files in the CD-ROM by accessing this directory
  - Similar to mapping a drive letter to a CD-ROM in Windows
  - Different from the special file in /dev. Special file is only a place where data of the CD-ROM is transferred or stored. No file system concept

- /opt
  - Use to install add-on software packages, e.g. star office, etc.
- /proc
  - Contain process and system information
- /root
  - Home directory of the user root, usually the administrator
- /sbin
  - The directories /sbin, /usr/sbin, and /usr/local/sbin contain system administration tools, utilities and general root only commands, such as halt, reboot and shutdown

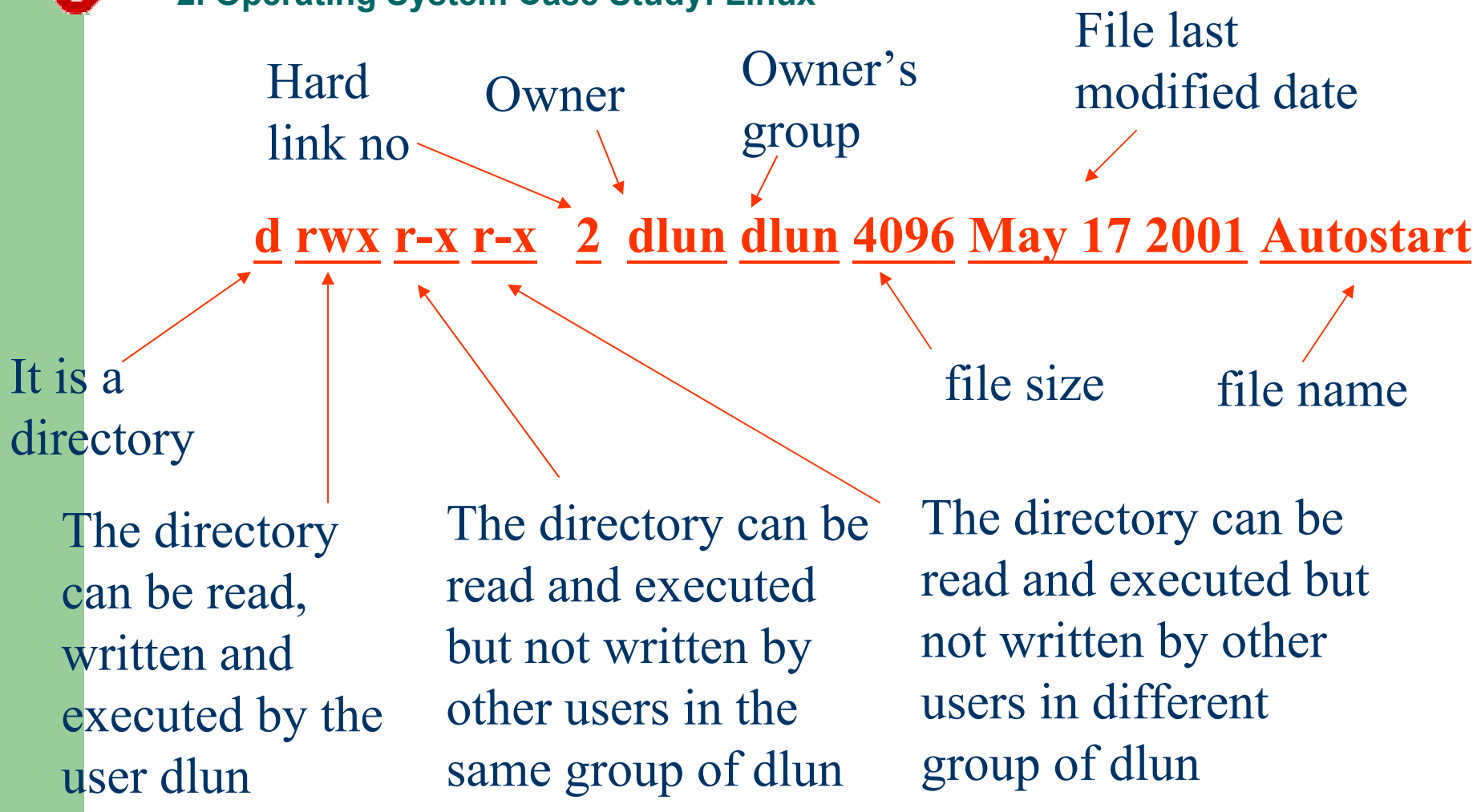
- /tmp
  - Contain temporary files. Usually files in this directory will be deleted from time to time to avoid the system fills with temp files
- /usr
  - One of the largest sections of the Linux file system
  - Contain read-only data that are shared between various users, e.g. the manual pages needed for the command man. Stored in /usr/man direcrtory
- /var
  - Contain data that keeps on changing as the system is running. E.g. /var/spool/mail directory keeps the mail of user

# Linux File Access Privilege

- Linux is a multiuser system, the files of all users are stored in a single file structure
- Mechanism is required to restrict one user to access the files of another user, if he is not supposed to
- User can impose access permission to each file to restrict its access
- The term “access permission” refers to
  - read permission
  - write permission
  - execute permission




The file access permission can be seen by using the command ls –l or ls -al




**The group of a user is assigned by the administrator when a user is added to the system**

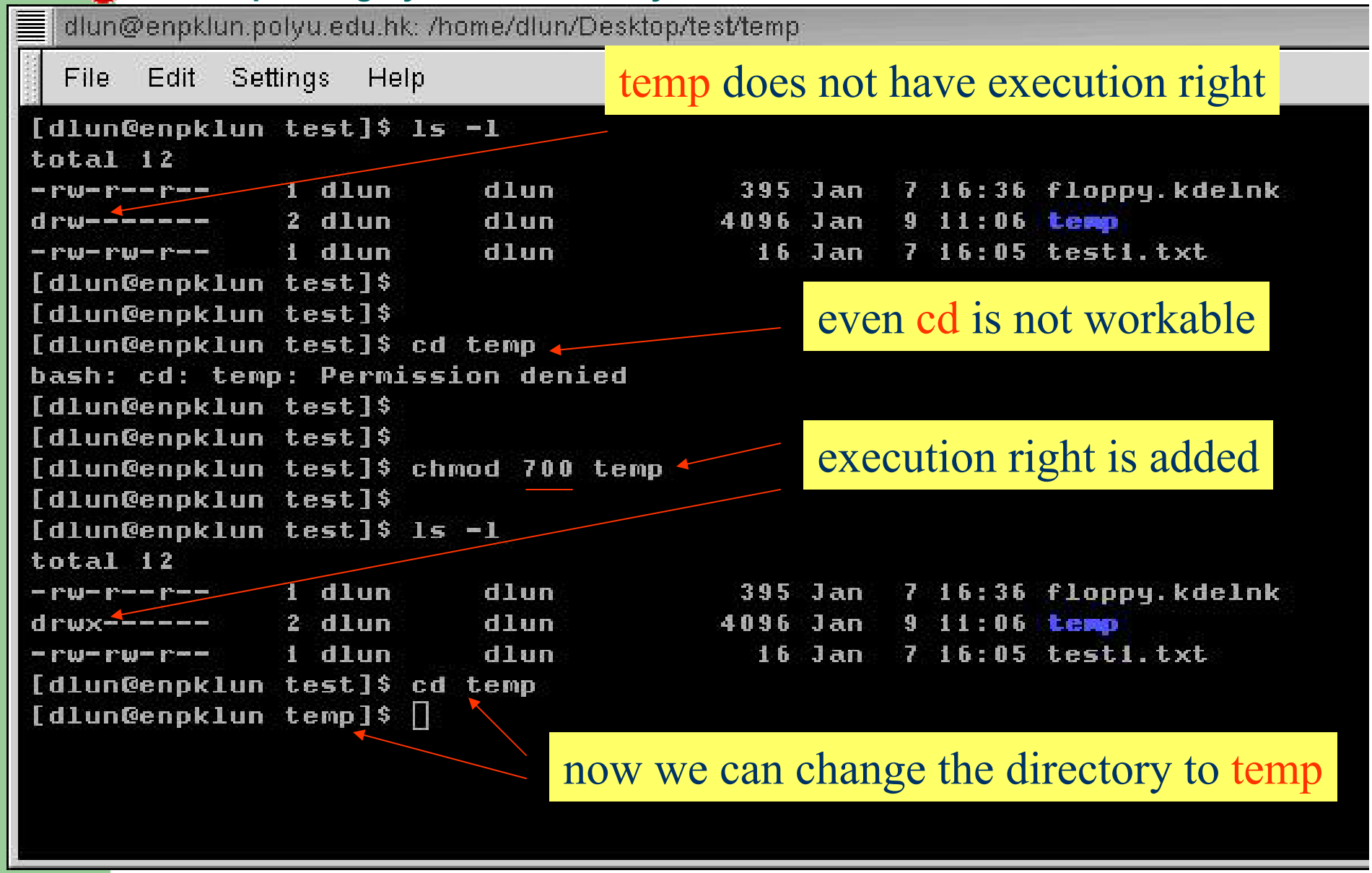
- Access permission can also be assigned to a directory
- Directory is also a file that contains the attributes of the files inside it
- If read permission is not given to a directory
  - cannot show the structure of this directory
  - e.g. cannot use ls
- If write permission is not given to a directory
  - cannot modify anything of the directory structure
  - e.g. cannot copy a file into this directory since it will modify the directory structure by adding one more file
- If execute permission is not given to a directory
  - nearly nothing can be done with this directory, even cd

- The access permission of a file or directory can be changed by using the command

**chmod xyz filename/directory name**

- xyz refers 3 digit in octal form
- E.g.

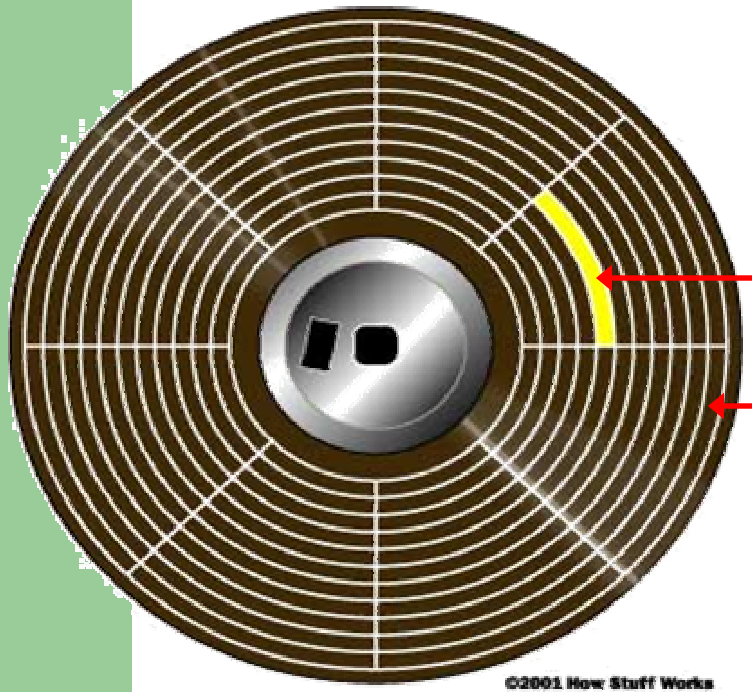
```
660 :  110 110 000
    ⇒  rw- rw- ---
545 :  101 100 101
    ⇒  r-x r-- r-x
```




```
[dlun@enpklun test]$ ls -l
total 12
-rw-r--r--    1 dlun     dlun          395 Jan  7 16:36 floppy.kdelnk
drw-------    2 dlun     dlun         4096 Jan  9 11:06 temp
-rw-rw-r--    1 dlun     dlun           16 Jan  7 16:05 test1.txt
[dlun@enpklun test]$
[dlun@enpklun test]$
[dlun@enpklun test]$ cd temp
bash: cd: temp: Permission denied
[dlun@enpklun test]$
[dlun@enpklun test]$
[dlun@enpklun test]$ chmod 700 temp
[dlun@enpklun test]$
[dlun@enpklun test]$ ls -l
total 12
-rw-r--r--    1 dlun     dlun          395 Jan  7 16:36 floppy.kdelnk
drwx------    2 dlun     dlun         4096 Jan  9 11:06 temp
-rw-rw-r--    1 dlun     dlun           16 Jan  7 16:05 test1.txt
[dlun@enpklun test]$ cd temp
[dlun@enpklun temp]$
```

# File Storage in Linux

- Data storage on hard disk
  - Data in a hard disk are stored on a magnetic flat plate
  - Disk's surface needs to be partitioned and labeled so that computer can go directly to a specific point on it
  - Achieve by low level formatting the disk
    - Create magnetic concentric circles called tracks
    - Each track is split into smaller parts called sectors and numbered
- Each sector: hold 512 bytes data
  - E.g. 80 tracks (from outer to inner 0 .. 79), 18 sectors disk can store 80x18x512 bytes data.

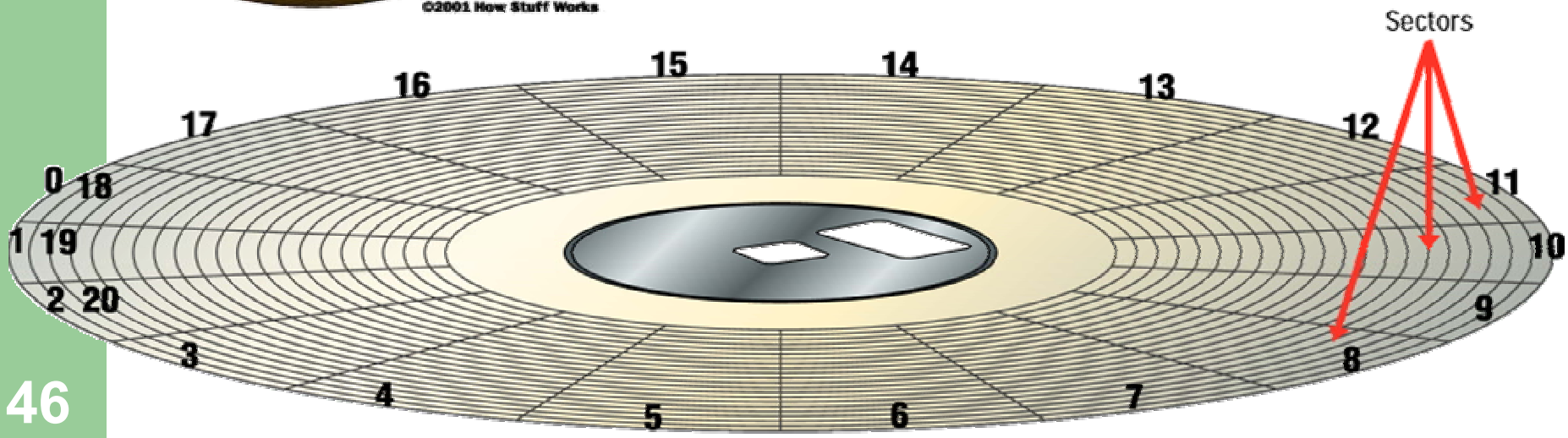



# Formatted Disk

Sector

Track

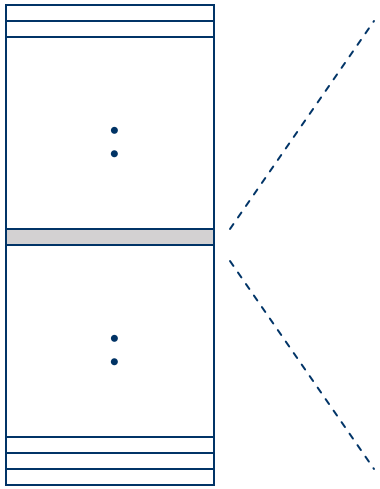
Density of data is higher for inner tracks than outer tracks



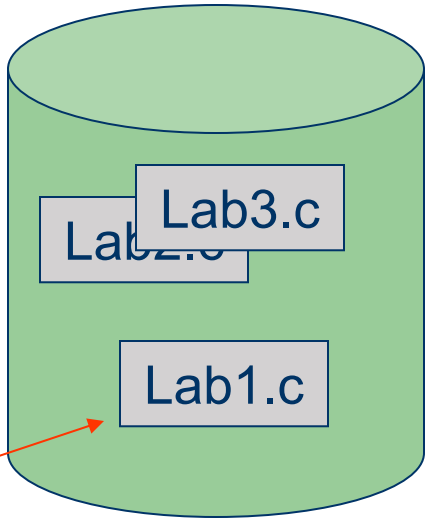
- Must read or write whole sector at a time
- OS allocates groups of sectors called cluster to files
- Files smaller than the cluster will still be allocated the whole cluster, but the rest left unused
- In Linux, every file is associated with an inode that records its location in the disk
- The inode of all files are put together in a data structure called inode table
- In the directory, every file is associated with a inode number that points to an entry of the inode table

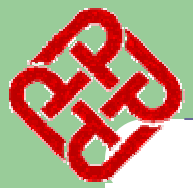
# Contents of the directory /home/dlun

| | |
|---|---|
| 1076 | … |
| 2083 | … |
| 13059 | lab1.c |
| 17488 | lab2.c |
| 18995 | lab3.c |



Number of links
File mode
User ID
Time created
Time last updated
:
Location on disk







# Case study: Linux

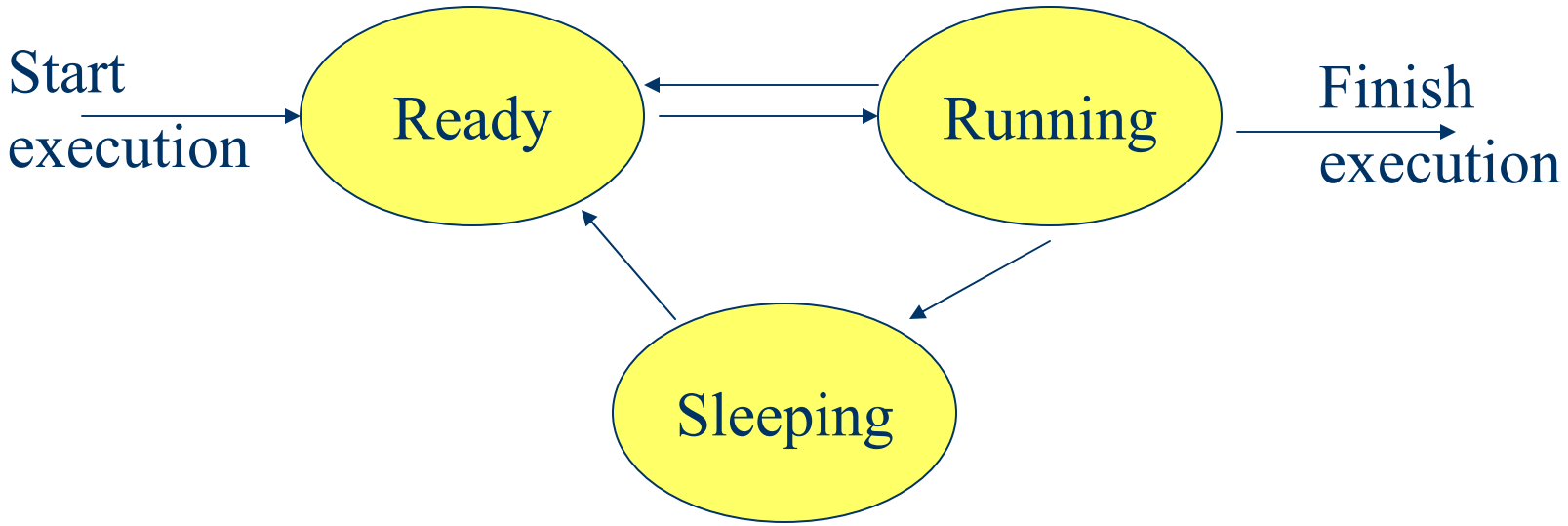
## B.3 Process management

# Linux Process Management

- Linux is a multitasking system
- Multiple programs can be executed at the same time
- Ultimately, a program needs to be executed by a CPU
- If there is only one CPU, how multiple programs can be executed at the same time?

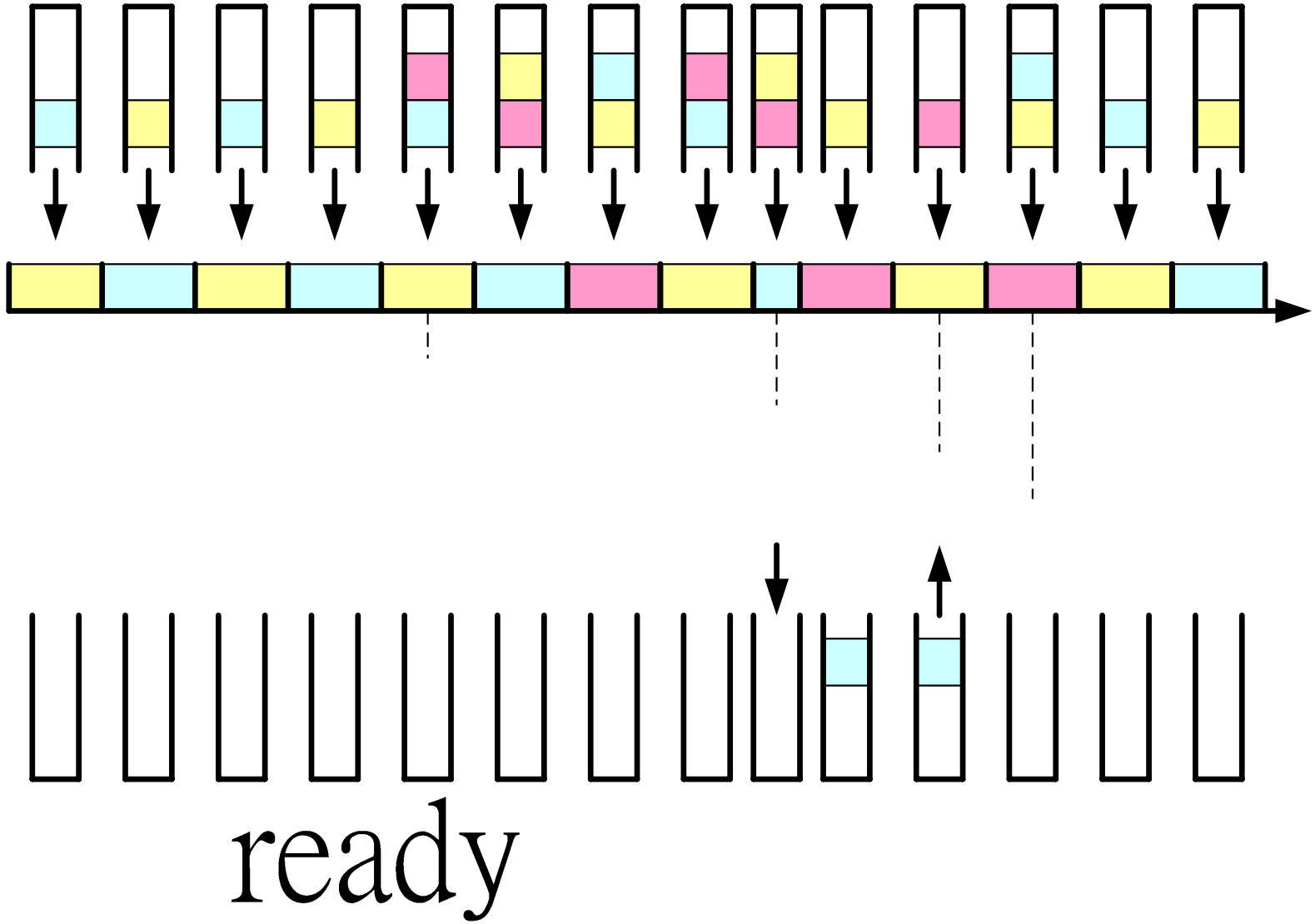
  ⇒ By time sharing
- That is, all programs are claimed to be executing. In fact, most of them are waiting for the CPU

- A program that is claimed to be executing is called a process
- For a multitasking system, a process has at least the following three states:



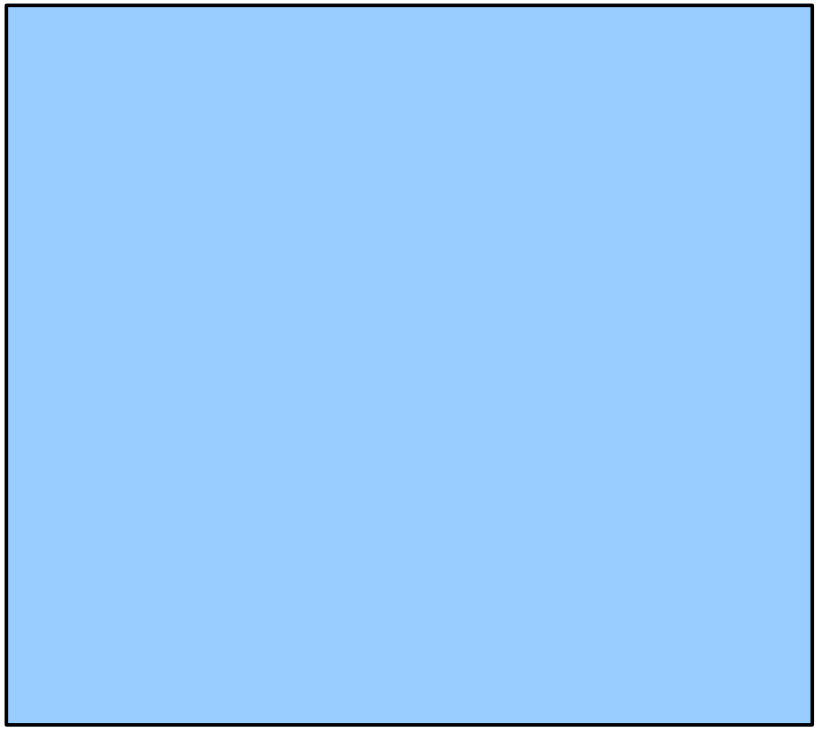
- Ready state
  - All processes that are ready to execute but without the CPU are at the ready state
  - If there is only 1 CPU in the system, all processes except one are at the ready state
- Running state
  - The process that actually possesses the CPU is at the running state
  - If there is only 1 CPU in the system, at most there is only one process is at the running state
- Sleeping state
  - The process that is waiting for other resources, e.g. I/O, is at the sleeping state

- Processes will alternatively get into the CPU one after the other (called the round robin scheme)
- A process will be “in” a CPU for a very short time (quantum)
  - For Linux, each quantum is about 100msec
- At the time that a process is selected to be “in” the CPU
  - It goes from ready state to running state
- After that, it will be swapped out
  - It goes from running state back to ready state
- Or it may due to the waiting of an I/O device, e.g. mouse
  - It goes from running state to sleeping state
- When obtaining the required resource
  - It goes from sleeping state to ready state

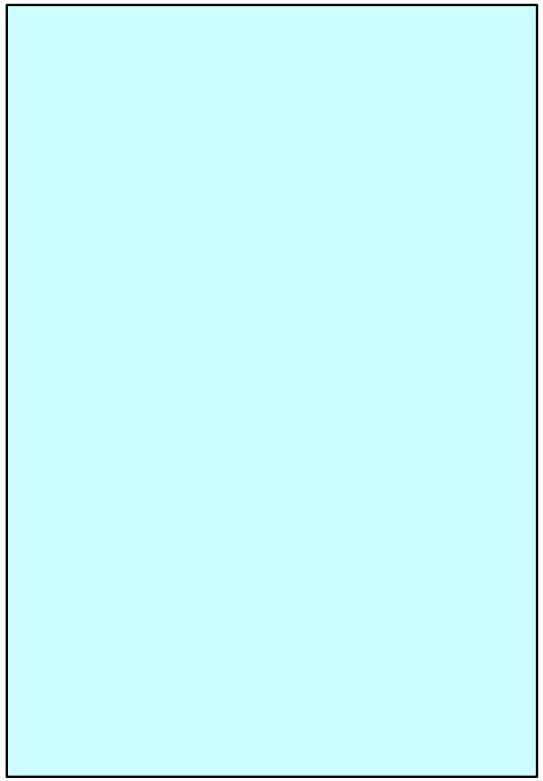

ready

- The mechanism to determine which process should "get into" the CPU is called Process scheduling
- For example,

Program A

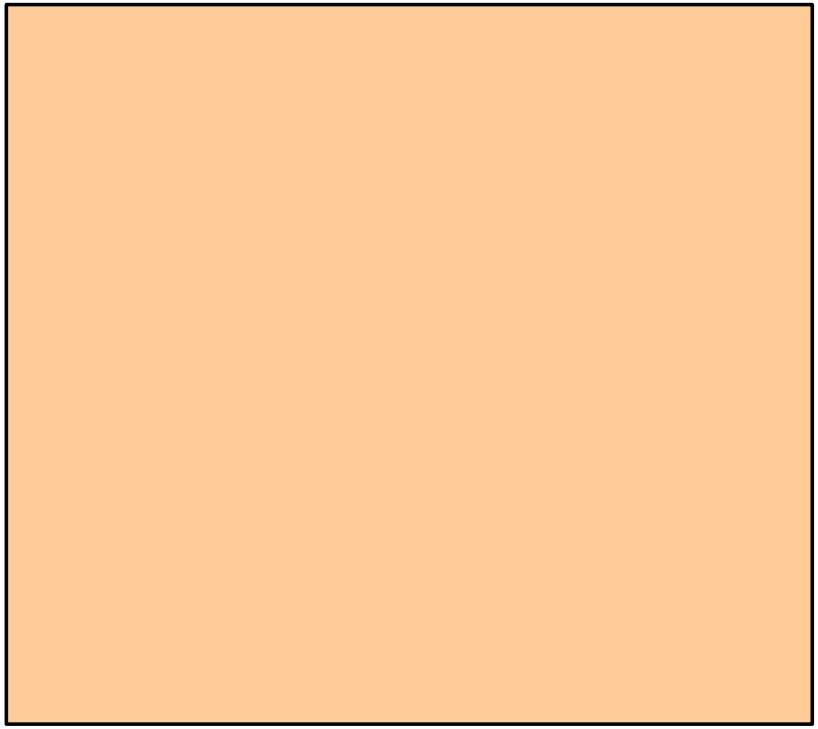


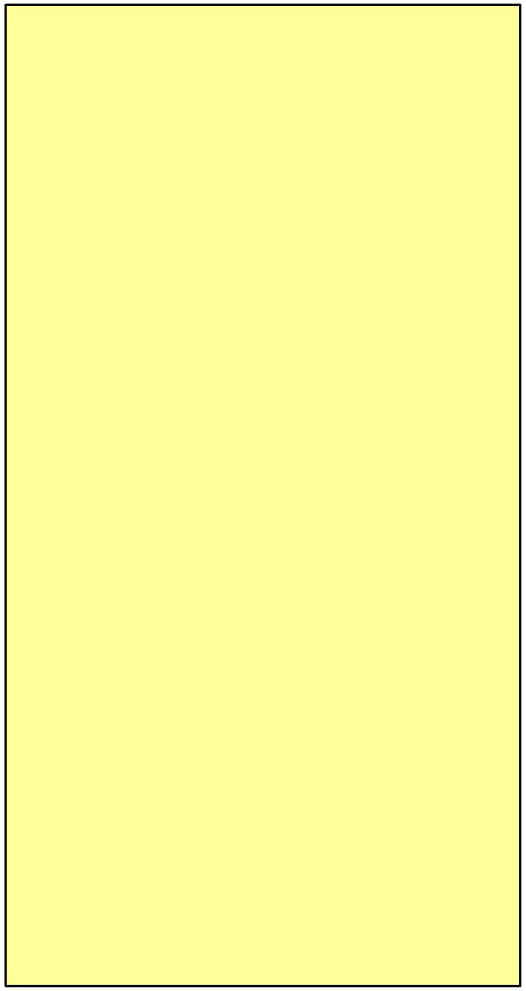
Actual sequence of operations



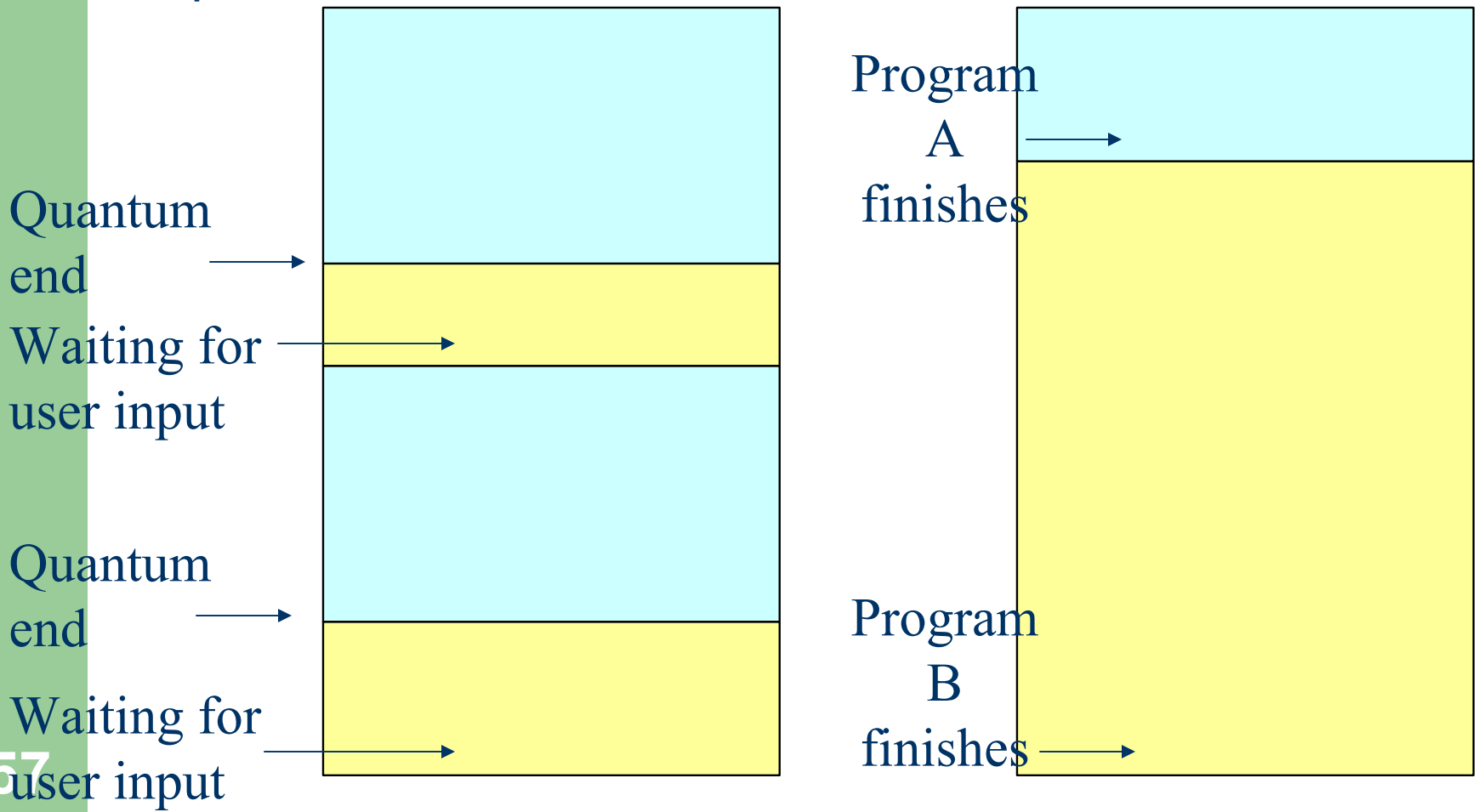
Actual sequence of operations

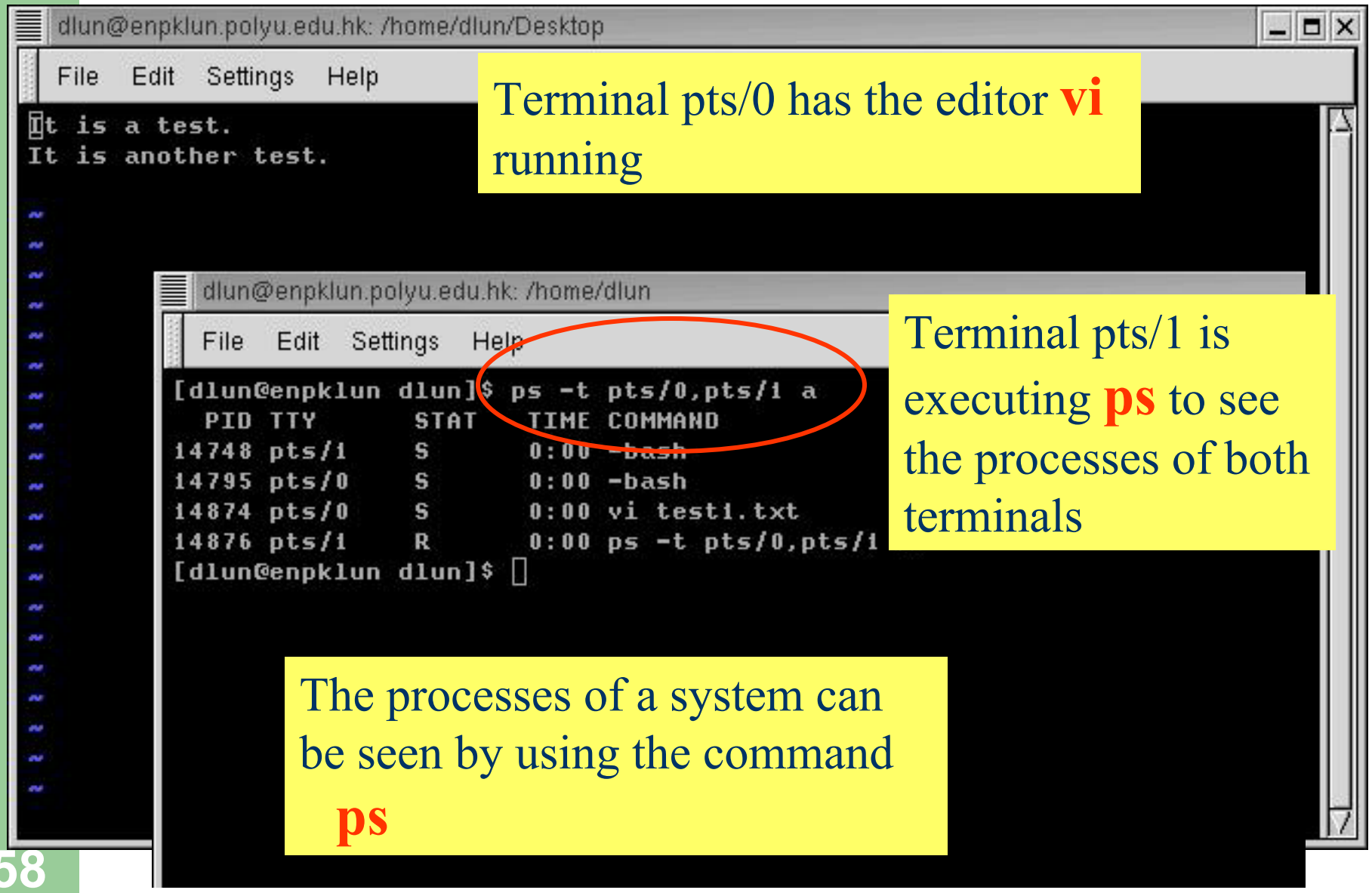
Program B





- Program A and B will be at the running state alternatively, depends on the quantum size and the availability of the required resource






Terminal pts/0 has the editor **vi** running

Terminal pts/1 is executing **ps** to see the processes of both terminals

The processes of a system can be seen by using the command

**ps**

```
  PID   TTY      STAT   TIME COMMAND
14748   pts/1    S      0:00 -bash
14795   pts/0    S      0:00 -bash
14974   pts/0    S      0:00 vi test1.txt
14876   pts/1    R      0:00 ps …
```

Process ID

Terminal name

State:
S – Sleeping (waiting for input)
R – Running

How much time the process is continuously executing

- For the example above, both bash processes, which are the shell of both terminals, are waiting for the input of user. They must be in the sleeping state
- The vi process, which is an editor, is also waiting for the input of user. Hence it is also in sleeping state
- When ps reporting the processes in the system, it is the only process that is running. Hence it is in running state

- A process can be forced to terminate by using the command kill -9 *PID*