Operating Systems

Introduction to Computer

Yu-Ting Wu

(with some slides borrowed from Prof. Tian-Li Yu)

Outline

- What is an operating system
- The history of operating systems
- Operating system architecture
- Coordinating the machine’s activities
- Handling competition among processes
- Security

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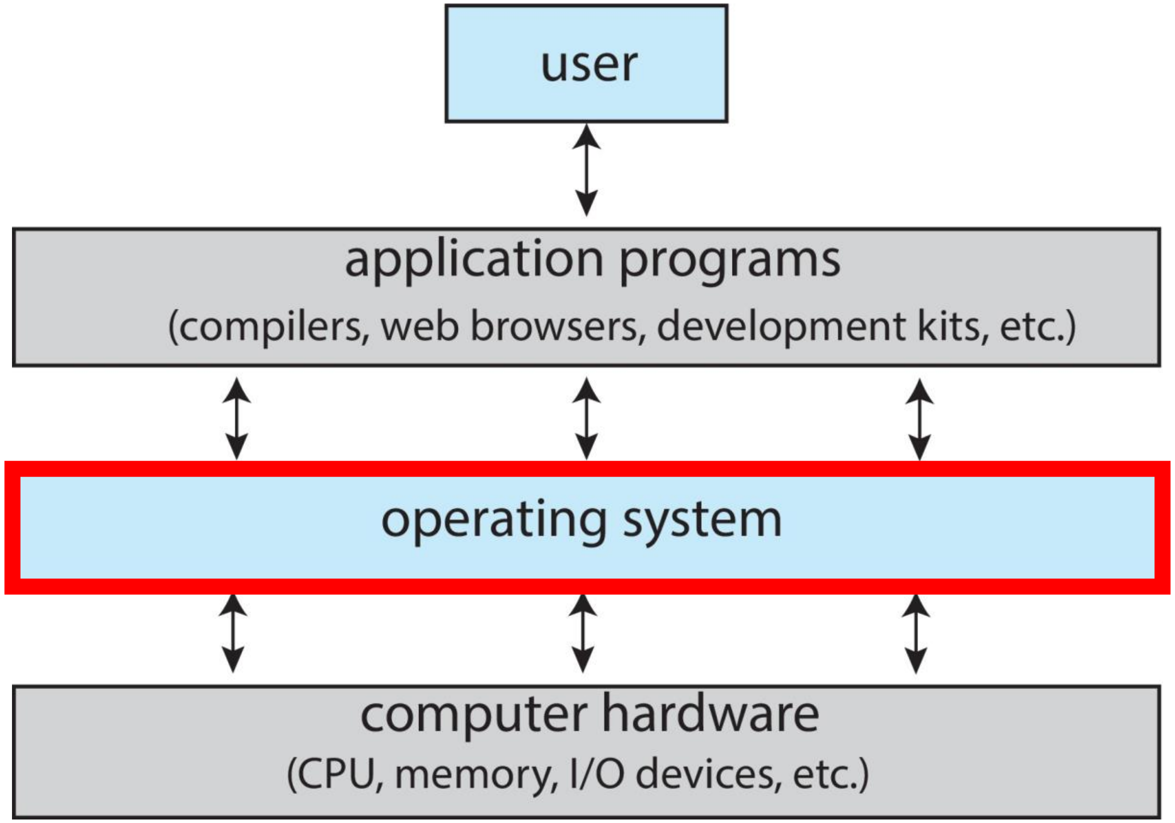
What is an Operating System

- An operating system (OS) is a **software program** that acts as an **intermediary** between a user and the computer hardware
  - Execute user programs
  - Make the computer system convenient to use
    - Such that users can focus on their problems
  - Use the computer hardware in an efficient manner

What is an Operating System (cont.)

- An operating system (OS) can be considered as a government or environment provider


user
application programs
(compilers, web browsers, development kits, etc.)
operating system
computer hardware
(CPU, memory, I/O devices, etc.)

Features of Operating Systems

- User view: varies by the types of the computers

Personal Computer (PC)

↓

ease of use

Mainframe, Workstation

↓

reliability
efficiency
fair sharing

Handheld Computer

↓

individual usability
battery life

Embedded Computer

↓

run without user intervention

Features of Operating Systems (cont.)

- System view: a resource allocator and control program

- **Resource allocator**
  - CPU time
  - Memory space
  - File storage
  - I/O devices

- **Control program**
  - Control execution of user programs
  - Prevent errors and misuse

Examples of Operating Systems

- Windows
- UNIX
- Mac OS
- Solaris
- Linux
- Apple iOS
- Windows phone
- BlackBerry OS
- Nokia Symbian OS
- Google Android

Free and Open-Source OSes

- OS with available source
    - Otherwise: closed-source OS. E.g., MS Windows, iOS
- Examples: GNU/Linux, BSD, UNIX, etc.
- Arguably issues on bugs, security, support

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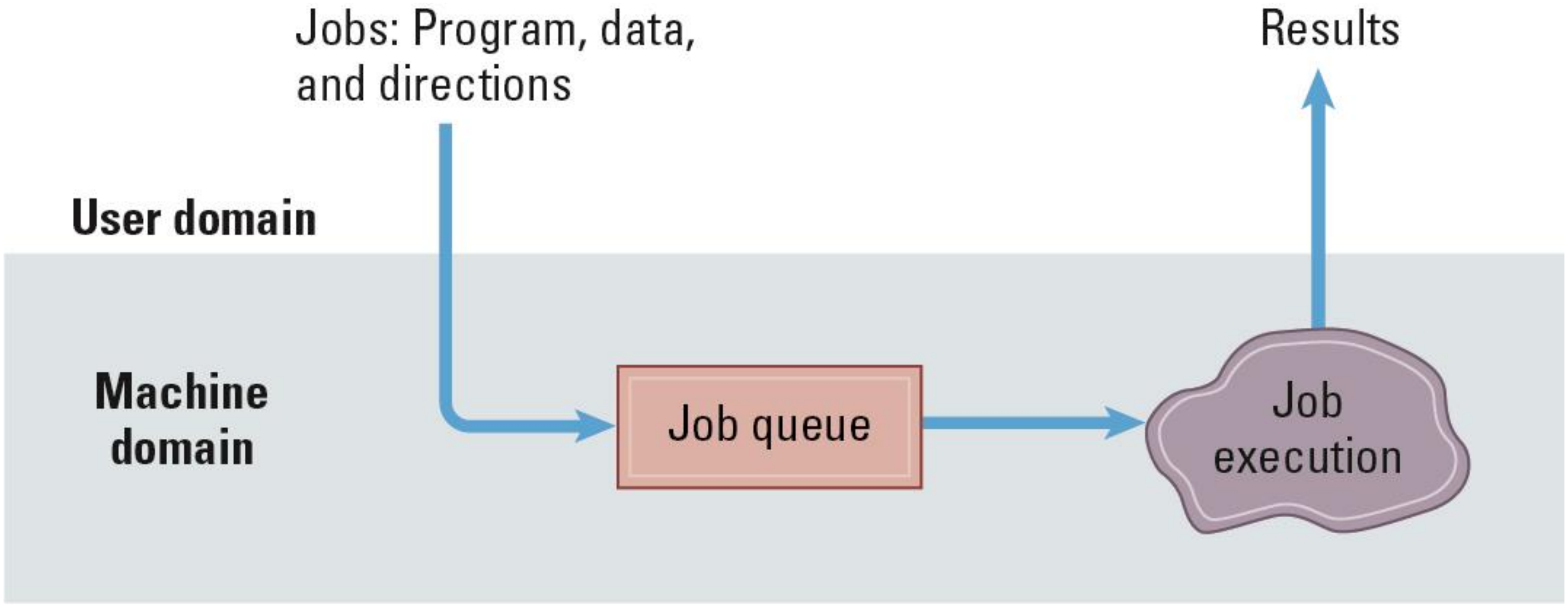
History of Operating Systems

- Batch processing (job queue)
- Interactive and (real-time) processing
- Multi-tasking and time-sharing and
- Multiprocessor machines
- Embedded Systems (specific devices)

Batching Process

- Each program is called a “job”
  - Feed by computer operators
- First-in, first-out (FIFO)

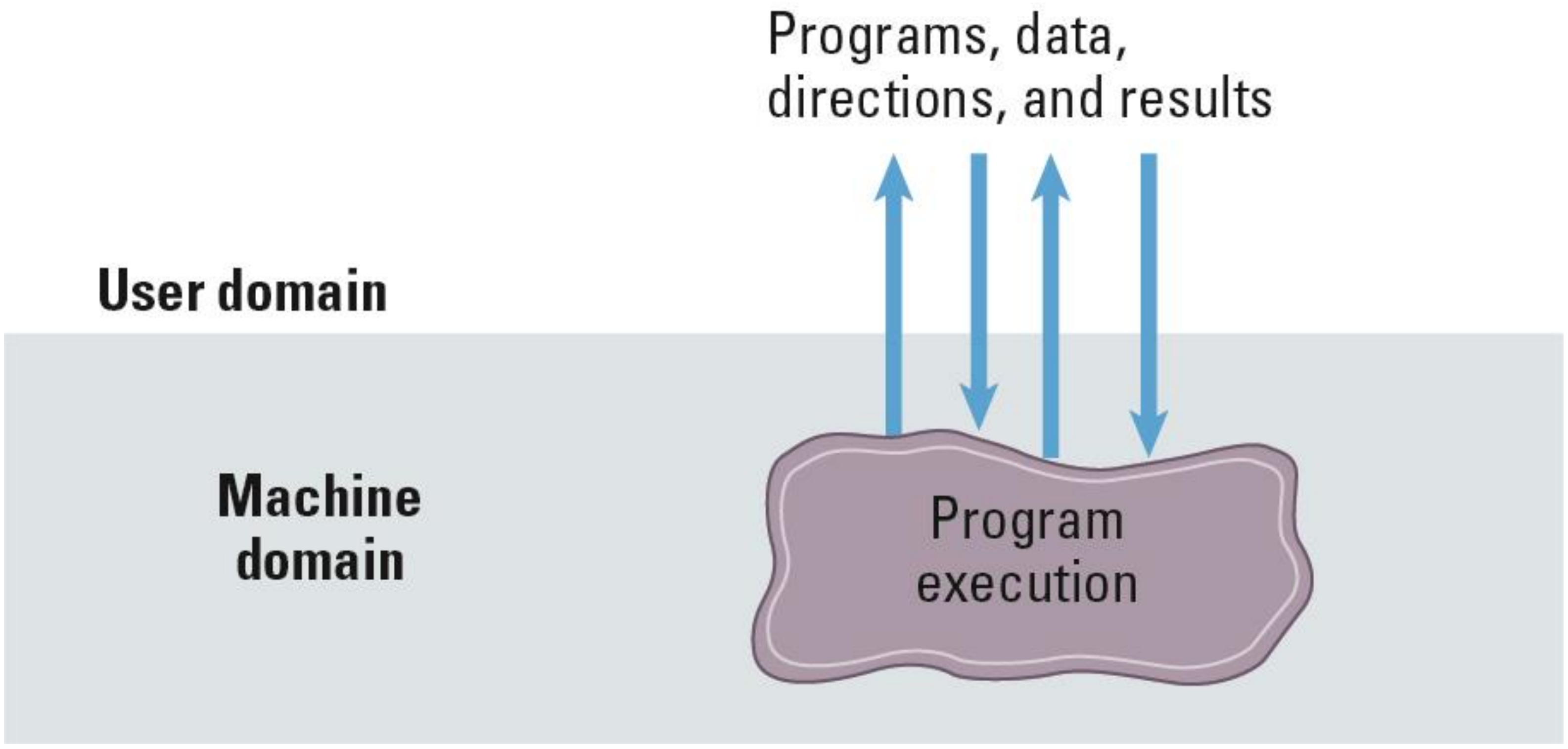


Batching Process (cont.)

Punch card operator

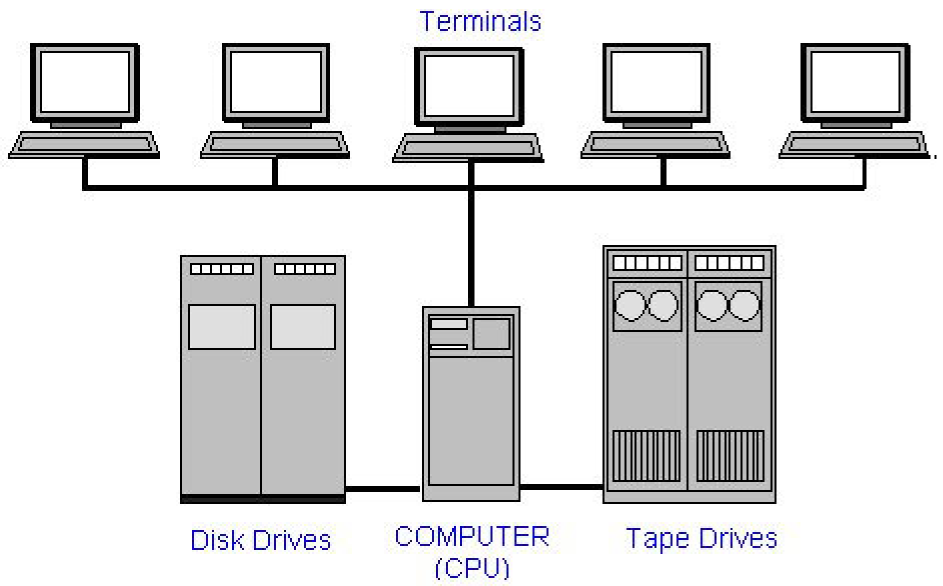
Interactive Processing

- OS with remote terminals



Interactive Processing (cont.)

- Terminals



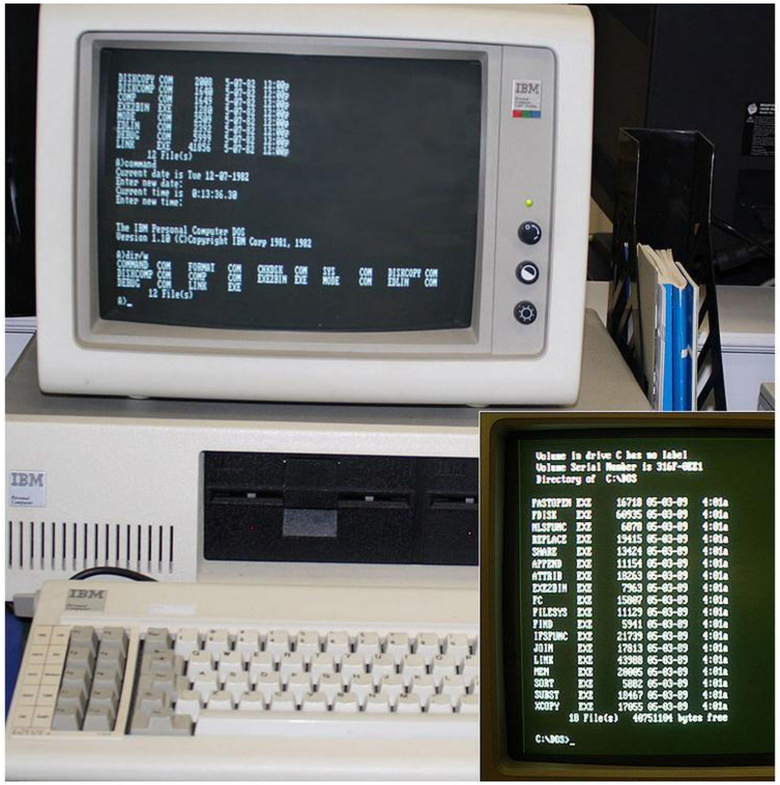
Real-Time Processing

- Real-time OS has well-defined fixed time constraints
  - **Hard real-time system**
    - Processing **must** be done within the constraint
    - Correct operation only if constraints met
  - **Soft real-time system**
    - Missing a timing is serious but does not necessarily result in failure (ex: multimedia)

- Real-time means **on time**! (not fast)

Multi-Tasking

- Before multi-tasking, one job at a time
- Example: MS DOS



```
DISKCOPY COM     2008   5-07-82  12:00p
DISKCOMP COM     1640   5-07-82  12:00p
COMP     COM     1649   5-07-82  12:00p
EXE2BIN  EXE     1280   5-07-82  12:00p
MODE     COM     2509   5-07-82  12:00p
EDLIN    COM     2392   5-07-82  12:00p
DEBUG    COM     5999   5-07-82  12:00p
LINK     EXE    41856   5-07-82  12:00p
       12 File(s)
A>command
Current date is Tue 12-07-1982
Enter new date:
Current time is  0:13:36.30
Enter new time:


The IBM Personal Computer DOS
Version 1.10 (C)Copyright IBM Corp 1981, 1982

A>dir/w
COMMAND  COM    FORMAT   COM    CHKDSK   COM    SYS      COM    DISKCOPY COM
DISKCOMP COM    COMP     COM    EXE2BIN  EXE    MODE     COM    EDLIN    COM
DEBUG    COM    LINK     EXE
       12 File(s)
A>_
```

```
Volume in drive C has no label
Volume Serial Number is 316F-0EE1
Directory of  C:\DOS

FASTOPEN EXE     16718 05-03-89   4:01a
FDISK    EXE     60935 05-03-89   4:01a
NLSFUNC  EXE      6878 05-03-89   4:01a
REPLACE  EXE     19415 05-03-89   4:01a
SHARE    EXE     13424 05-03-89   4:01a
APPEND   EXE     11154 05-03-89   4:01a
ATTRIB   EXE     18263 05-03-89   4:01a
EXE2BIN  EXE      7963 05-03-89   4:01a
FC       EXE     15807 05-03-89   4:01a
FILESYS  EXE     11129 05-03-89   4:01a
FIND     EXE      5941 05-03-89   4:01a
IFSFUNC  EXE     21739 05-03-89   4:01a
JOIN     EXE     17813 05-03-89   4:01a
LINK     EXE     43988 05-03-89   4:01a
MEM      EXE     20005 05-03-89   4:01a
SORT     EXE      5882 05-03-89   4:01a
SUBST    EXE     18467 05-03-89   4:01a
XCOPY    EXE     17055 05-03-89   4:01a
       18 File(s)   40751104 bytes free

C:\DOS>_
```

Multi-Tasking (cont.)

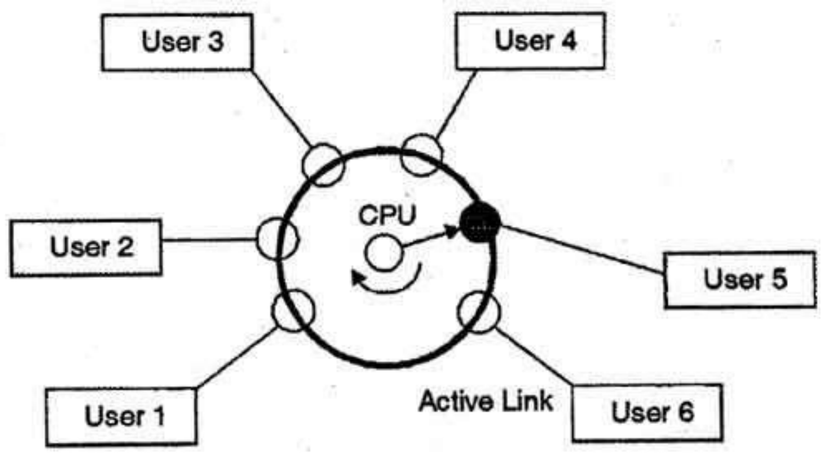
- A single user cannot always keep CPU and I/O devices busy
  - E.g., humans and disk I/O are too slow compared to CPU and memory
- Put multiple programs in memory
- OS organizes jobs so that the CPU always has one to execute
  - When a job has to wait (e.g., for I/O), OS **switches to another job**

➡ Increase CPU utilization

➡ Need job and CPU scheduling

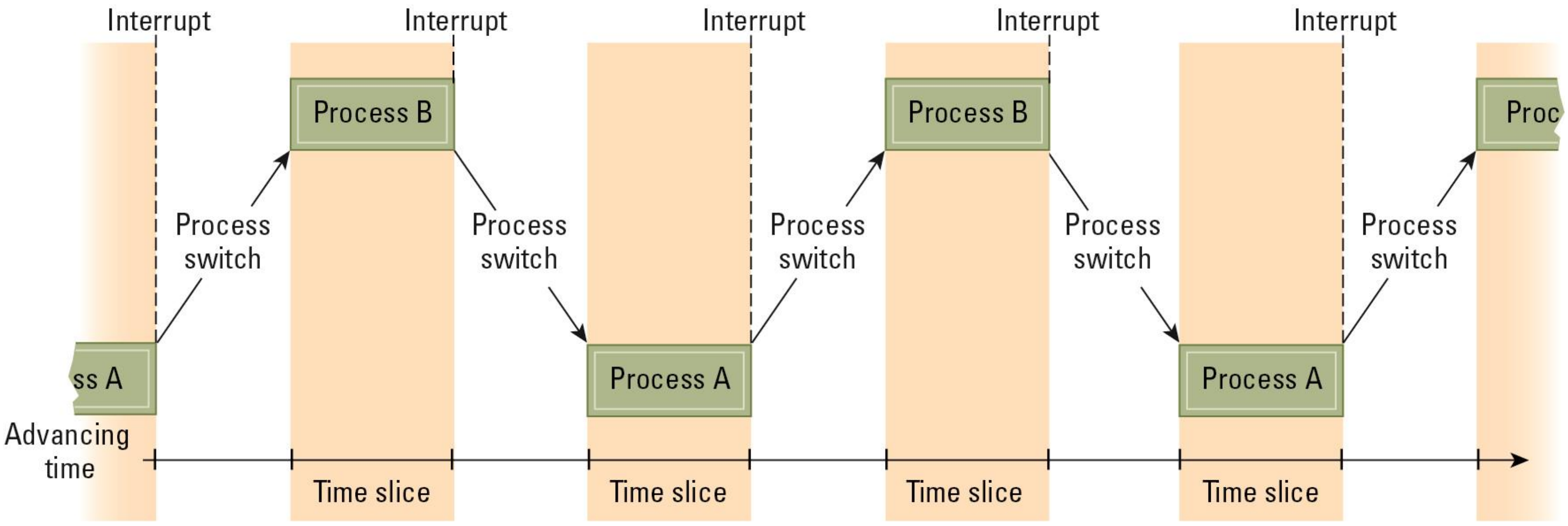
Multi-Tasking with Time-Sharing

- CPU switches jobs frequently so that users can interact with each job while it is running
  - Only **one** (per core) task is being executed at any given time
  - A logical extension of multi-tasking
  - **Interactivity**!
    - Response time should be less than 1 sec.



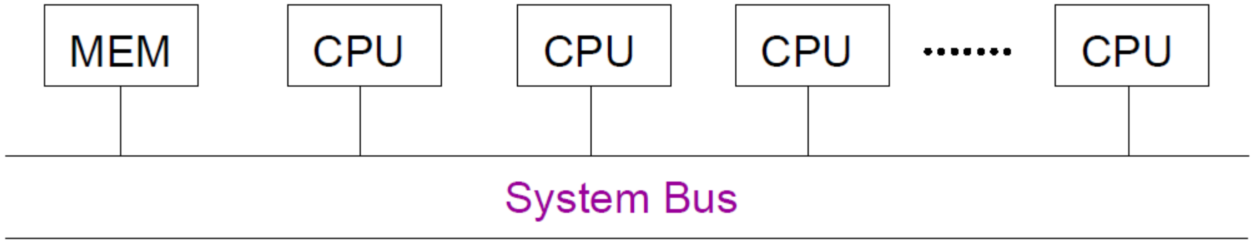
Context Switch

- Kernel saves the state of the old process and loads the saved state for the new process
- Context switch time is **purely overhead**
- Switch time (about 1 ~ 1000 ms) depends on hardware

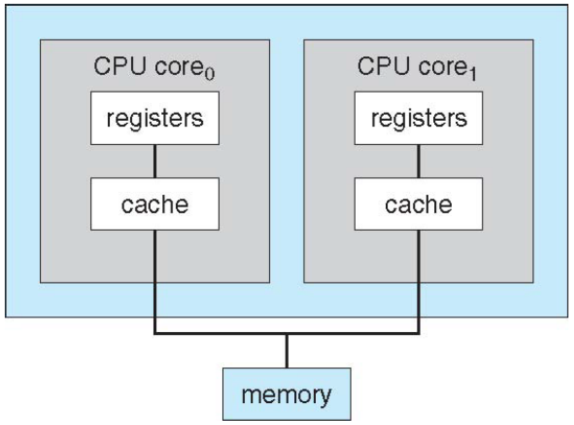


Multiprocessor

- More than one processor in close communication sharing bus, memory, and peripheral devices



- The recent trend: from a fast single processor to lots of processors
  - **Multiple cores** over a single chip



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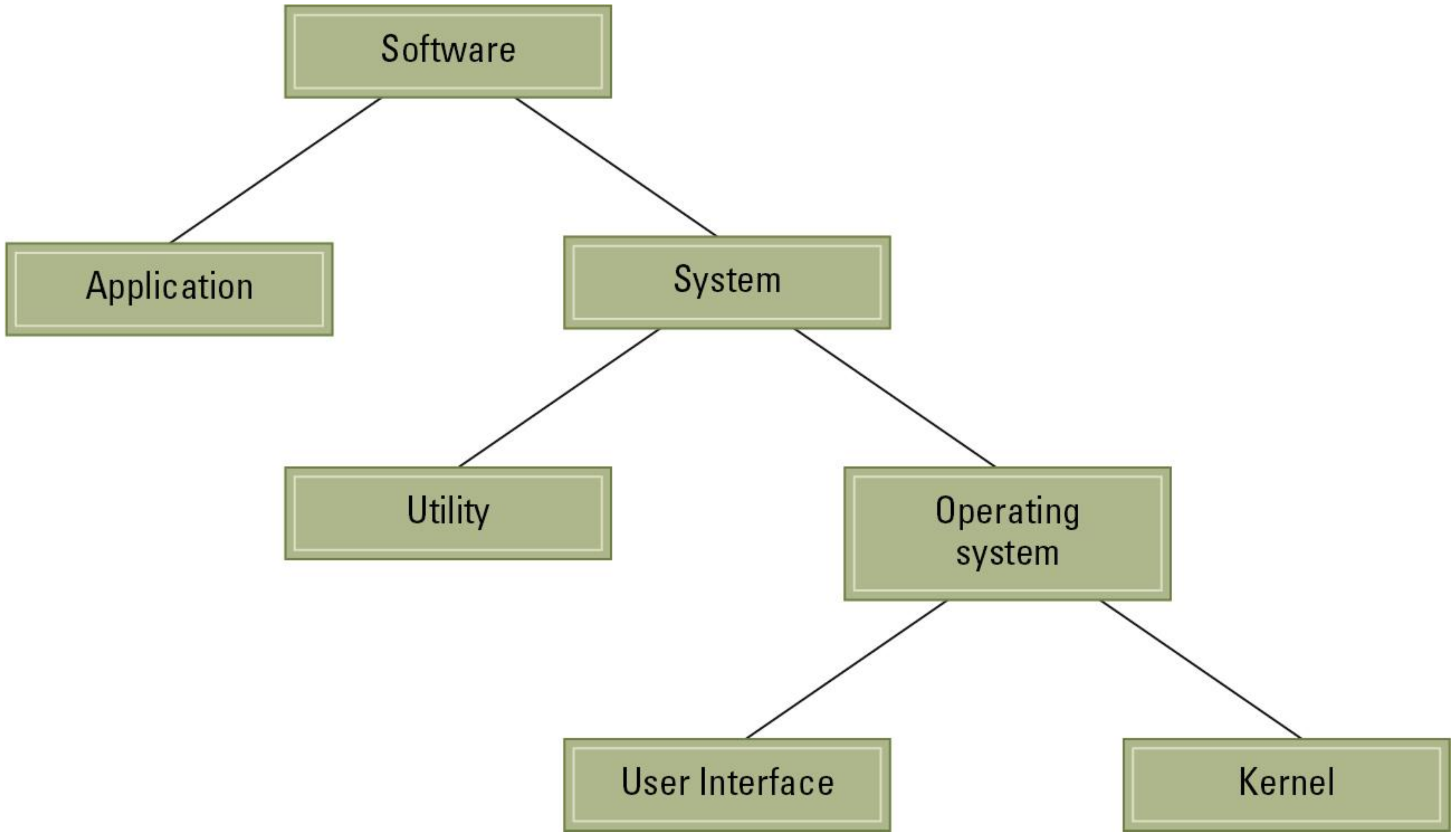
Software Classification

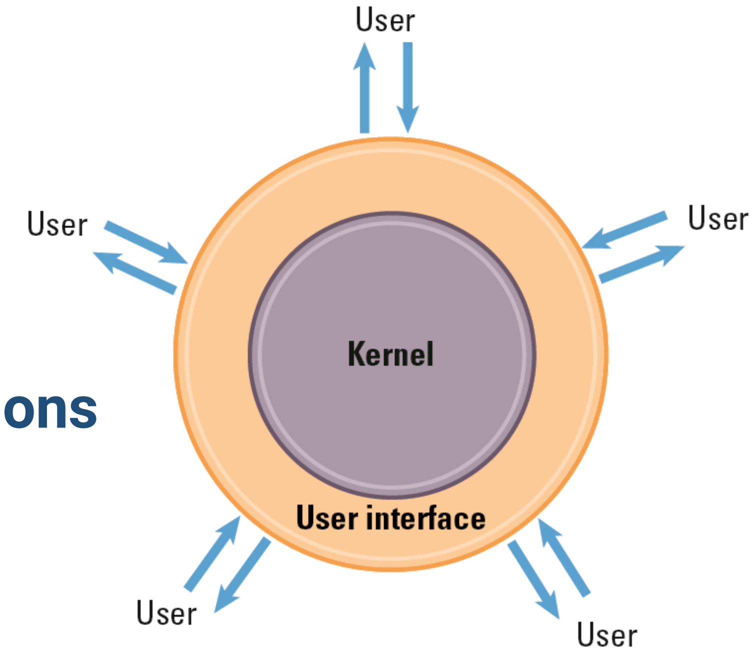
- **Application software**
  - Performs specific tasks for users (productivity, games, software development)
- **System software**
  - Provides infrastructure for application software
  - Consists of operating system and utility software

Software Classification (cont.)

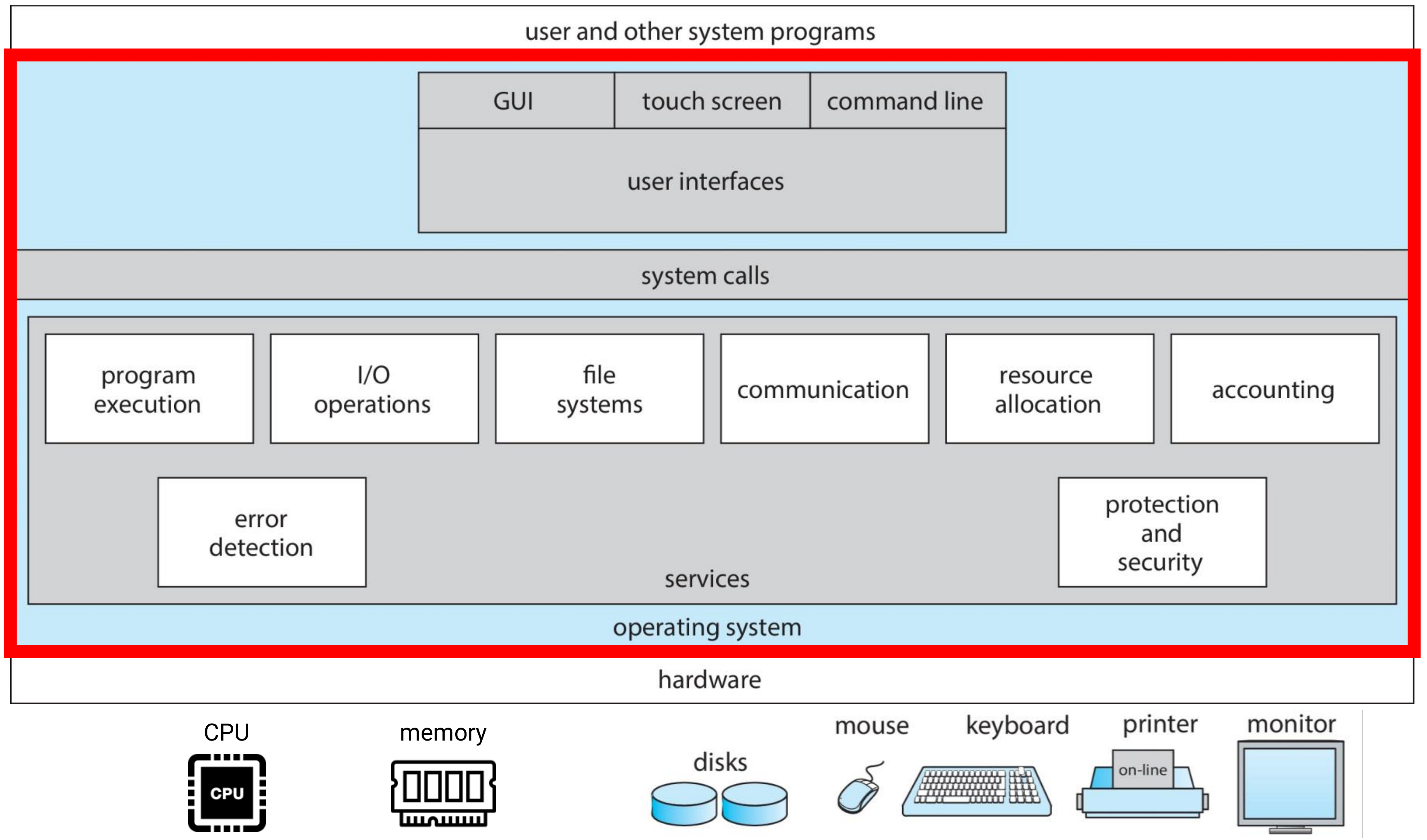


Operating System Components

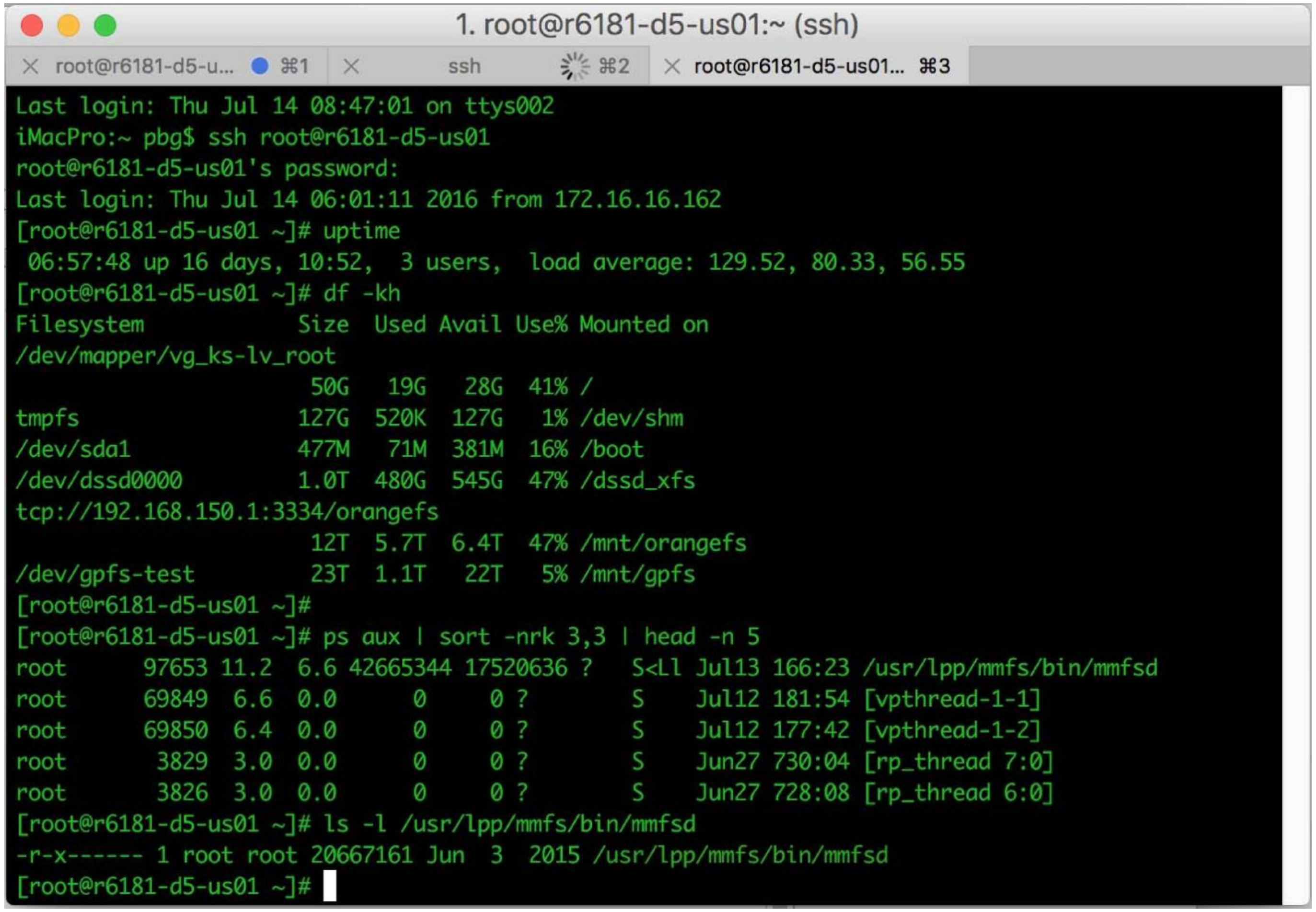
- **User interface:**
  - **Communicates with users**
    - Text-based (Shell)
    - Graphical user interface (GUI)
- **Kernel:**
  - **Performs basic required functions**
    - File manager
    - Device drivers
    - Memory manager
    - Scheduler
    - Dispatcher



Operating System Components (cont.)



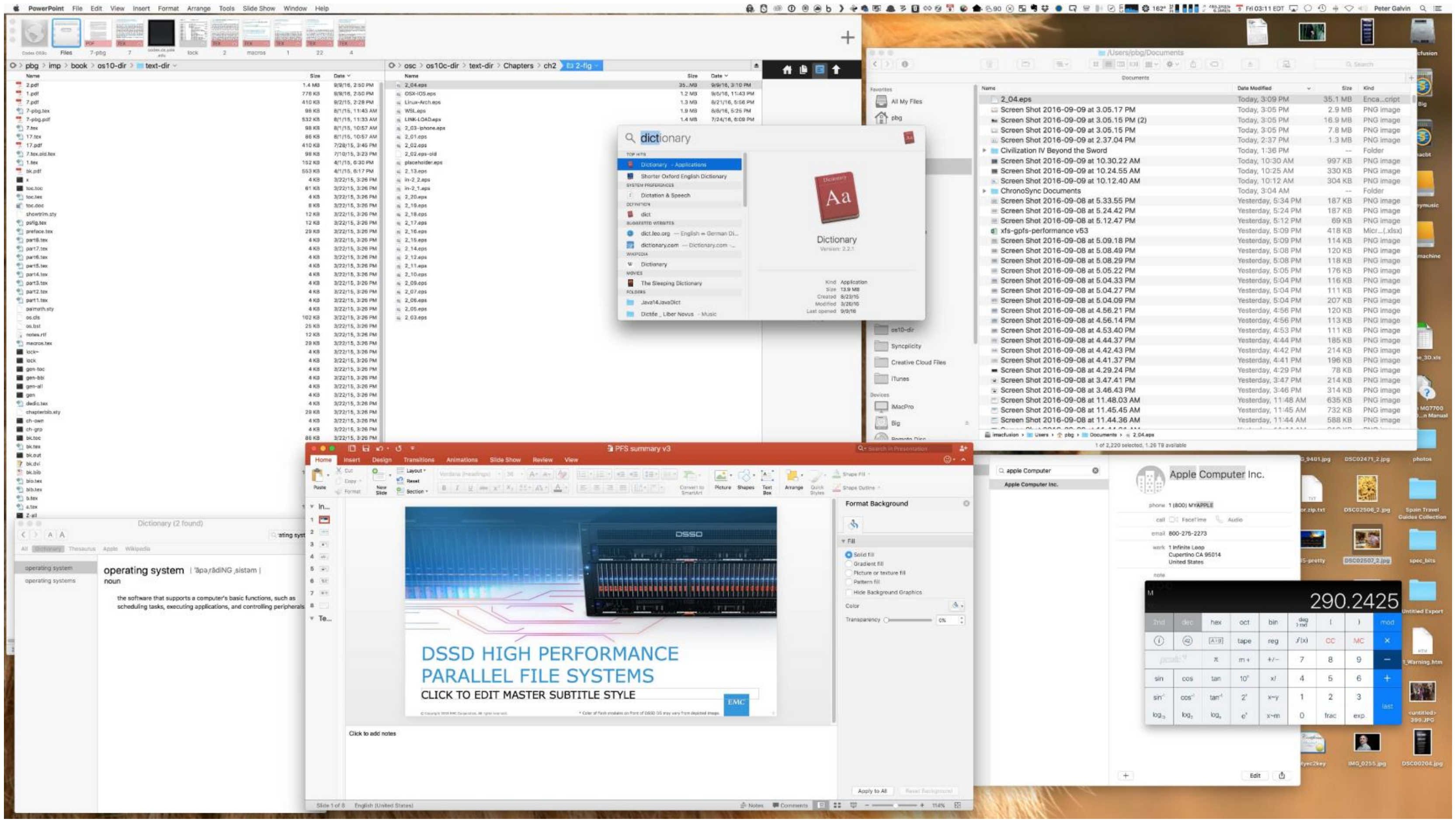
User Interface: Shell



```
Last login: Thu Jul 14 08:47:01 on ttys002
iMacPro:~ pbg$ ssh root@r6181-d5-us01
root@r6181-d5-us01's password:
Last login: Thu Jul 14 06:01:11 2016 from 172.16.16.162
[root@r6181-d5-us01 ~]# uptime
 06:57:48 up 16 days, 10:52,  3 users,  load average: 129.52, 80.33, 56.55
[root@r6181-d5-us01 ~]# df -kh
Filesystem            Size  Used Avail Use% Mounted on
/dev/mapper/vg_ks-lv_root
                       50G   19G   28G  41% /
tmpfs                 127G  520K  127G   1% /dev/shm
/dev/sda1             477M   71M  381M  16% /boot
/dev/dssd0000         1.0T  480G  545G  47% /dssd_xfs
tcp://192.168.150.1:3334/orangefs
                       12T  5.7T  6.4T  47% /mnt/orangefs
/dev/gpfs-test         23T  1.1T   22T   5% /mnt/gpfs
[root@r6181-d5-us01 ~]#
[root@r6181-d5-us01 ~]# ps aux | sort -nrk 3,3 | head -n 5
root     97653 11.2  6.6 42665344 17520636 ?   S<Ll Jul13 166:23 /usr/lpp/mmfs/bin/mmfsd
root     69849  6.6  0.0      0     0 ?        S    Jul12 181:54 [vpthread-1-1]
root     69850  6.4  0.0      0     0 ?        S    Jul12 177:42 [vpthread-1-2]
root      3829  3.0  0.0      0     0 ?        S    Jun27 730:04 [rp_thread 7:0]
root      3826  3.0  0.0      0     0 ?        S    Jun27 728:08 [rp_thread 6:0]
[root@r6181-d5-us01 ~]# ls -l /usr/lpp/mmfs/bin/mmfsd
-r-x------ 1 root root 20667161 Jun  3  2015 /usr/lpp/mmfs/bin/mmfsd
[root@r6181-d5-us01 ~]#
```

Bourne Shell (default shell of UNIX ver. 7)

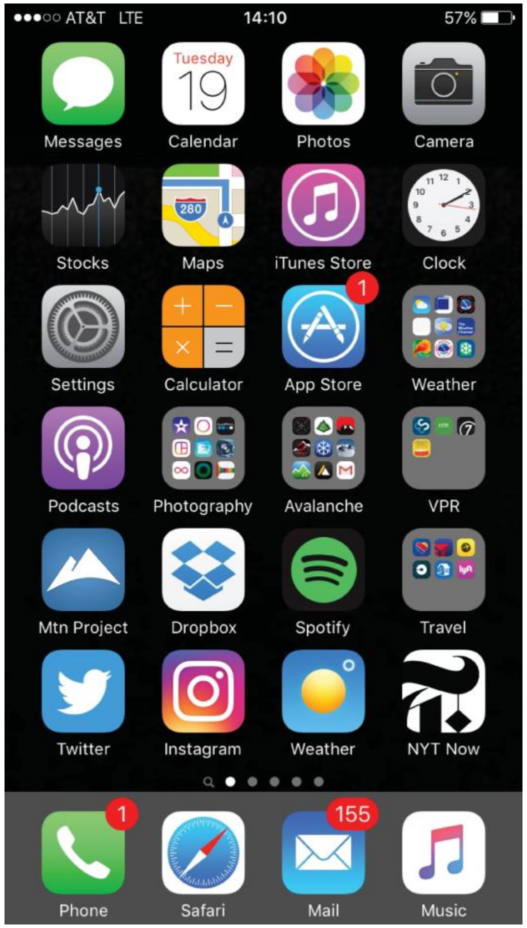
User Interface: GUI

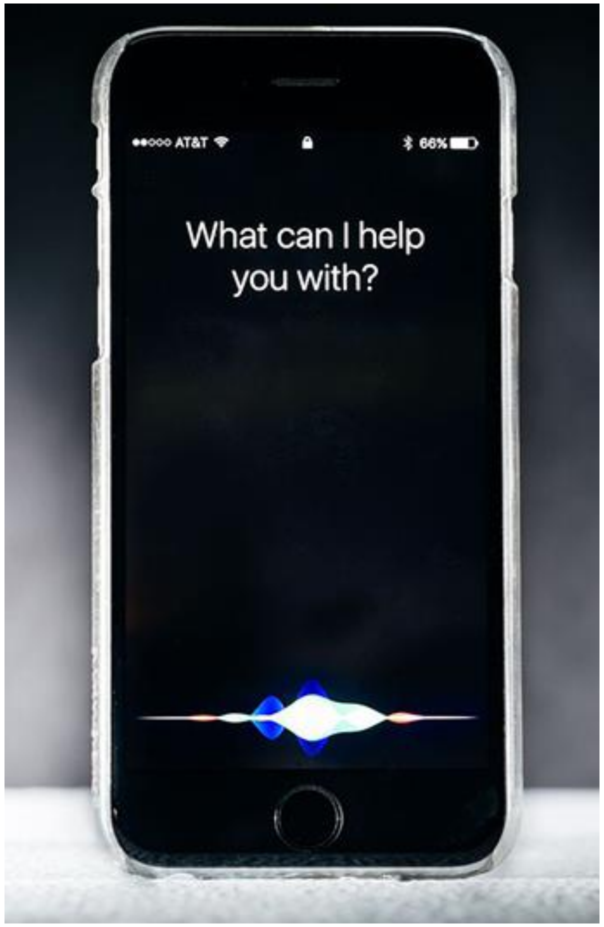


Mac OS X GUI

User Interface: Others

- Touch-screen
- Voice control





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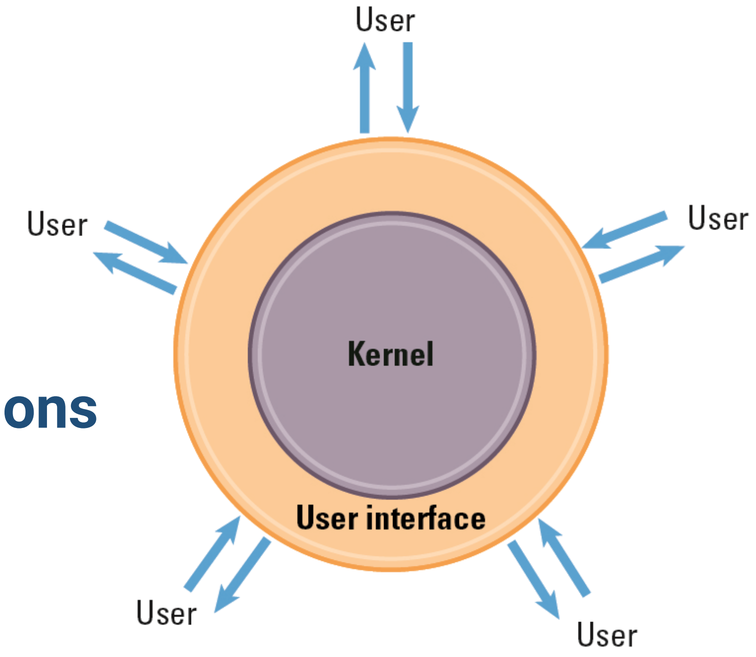
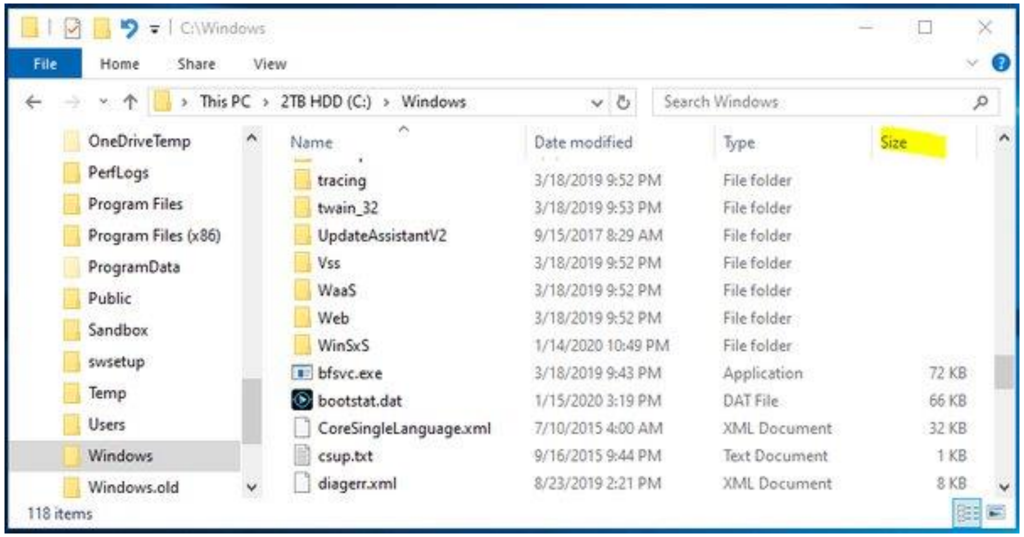


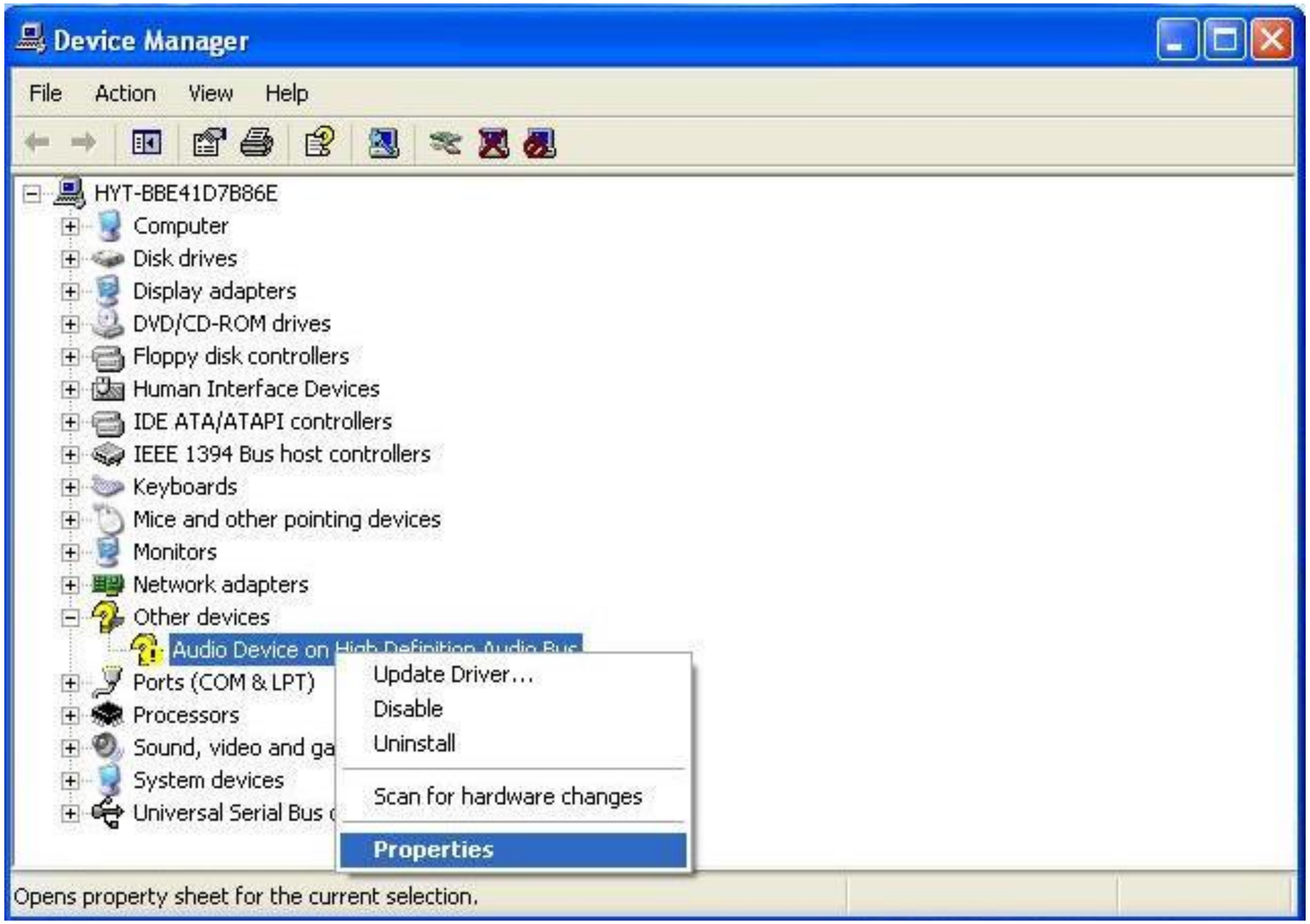
Kernel: File Manager

- Directory (or folder)
  - A user-created bundle of files and other directories (subdirectories)
- Directory path
  - A sequence of directories within directories



Name	Date modified	Type	Size
tracing	3/18/2019 9:52 PM	File folder	
twain_32	3/18/2019 9:53 PM	File folder	
UpdateAssistantV2	9/15/2017 8:29 AM	File folder	
Vss	3/18/2019 9:52 PM	File folder	
WaaS	3/18/2019 9:52 PM	File folder	
Web	3/18/2019 9:52 PM	File folder	
WinSxS	1/14/2020 10:49 PM	File folder	
bfsvc.exe	3/18/2019 9:43 PM	Application	72 KB
bootstat.dat	1/15/2020 3:19 PM	DAT File	66 KB
CoreSingleLanguage.xml	7/10/2015 4:00 AM	XML Document	32 KB
csup.txt	9/16/2015 9:44 PM	Text Document	1 KB
diagerr.xml	8/23/2019 2:21 PM	XML Document	8 KB

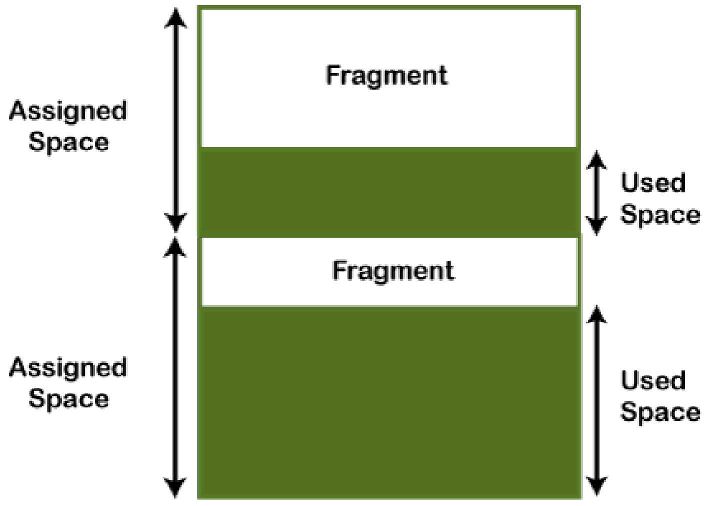
Kernel: Device Drivers



Opens property sheet for the current selection.

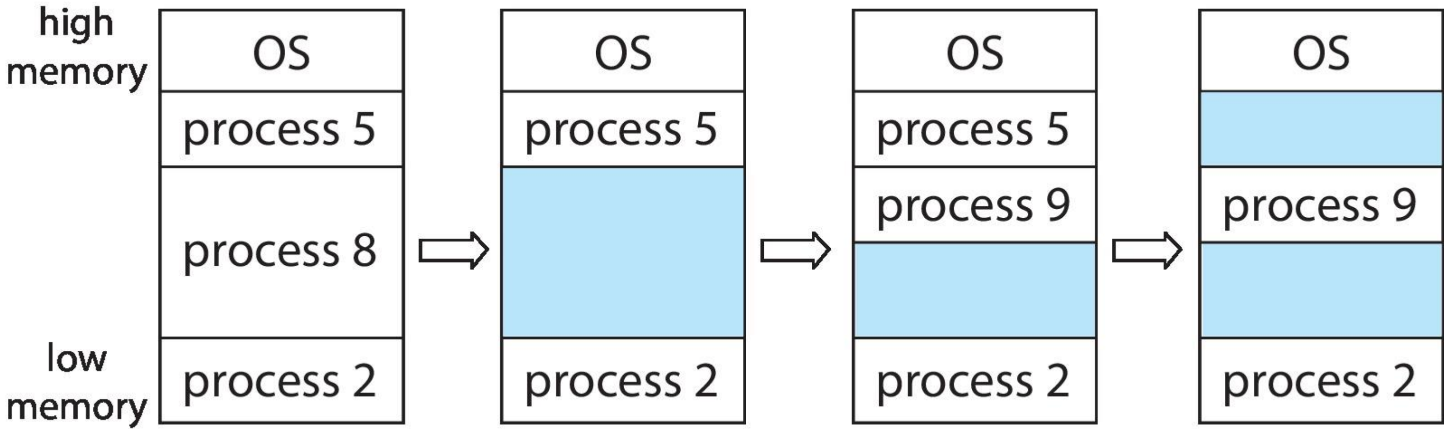
Kernel: Memory Manager

- Allocating space in the main memory
- **Contiguous allocation: fixed-partition allocation**
  - Each process loads into one partition of fixed-size
  - **Degree of multi-programming** is bounded by the number of partitions
  - Result in **internal fragmentation**
    - Memory that is internal to a partition but is not being used



Kernel: Memory Manager (cont.)

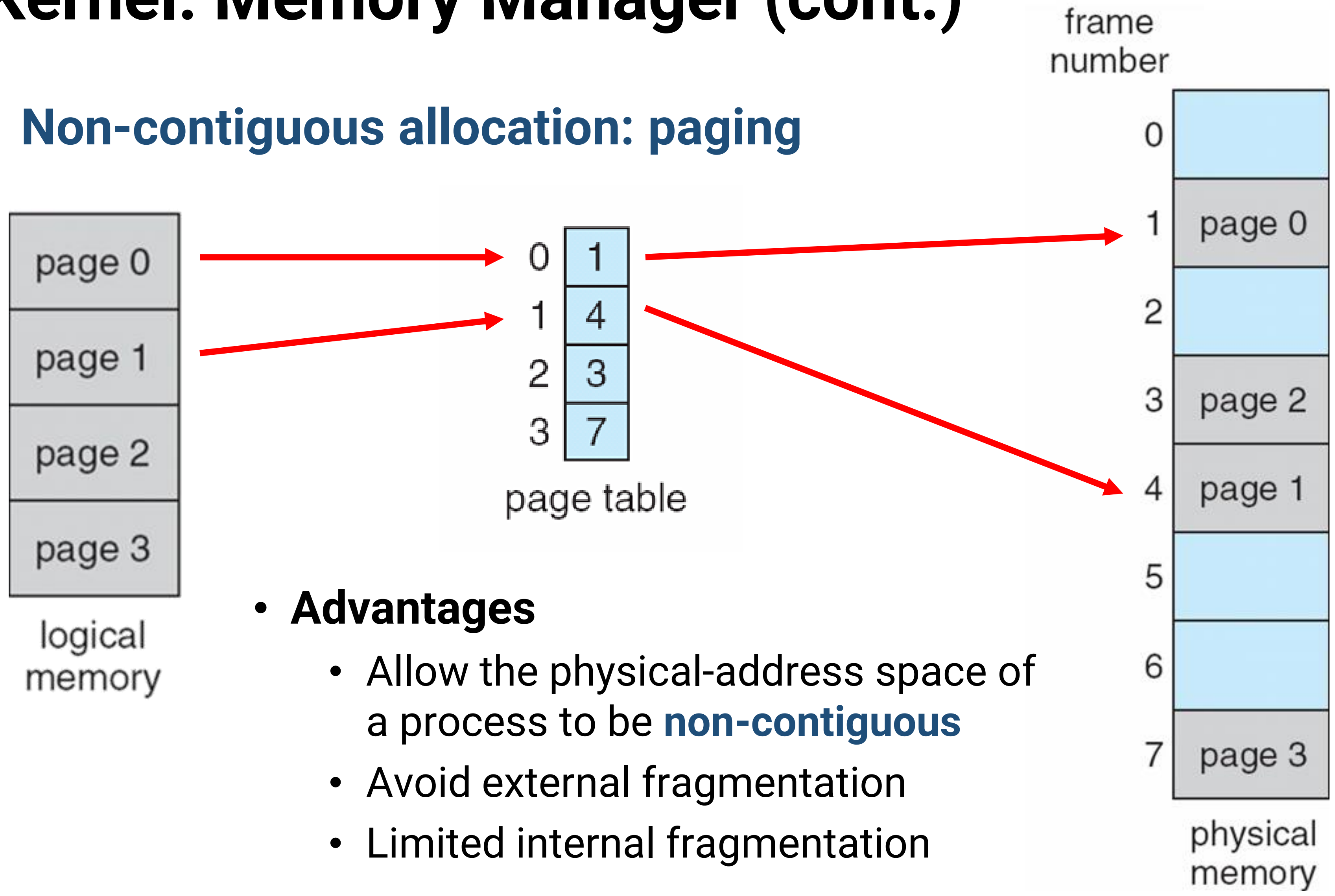
- Allocating space in the main memory
- **Contiguous allocation: variable-size partition**



  - When a process arrives, it is allocated a hole **large enough** to accommodate it
  - Result in **external fragmentation**

Kernel: Memory Manager (cont.)

- **Non-contiguous allocation: paging**



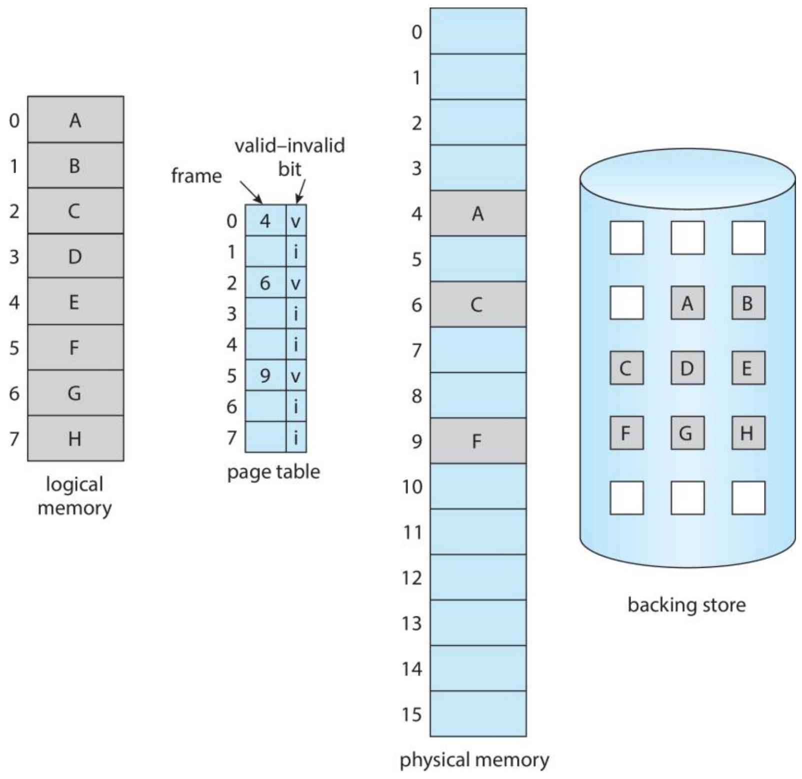
- **Advantages**
  - Allow the physical-address space of a process to be **non-contiguous**
  - Avoid external fragmentation
  - Limited internal fragmentation

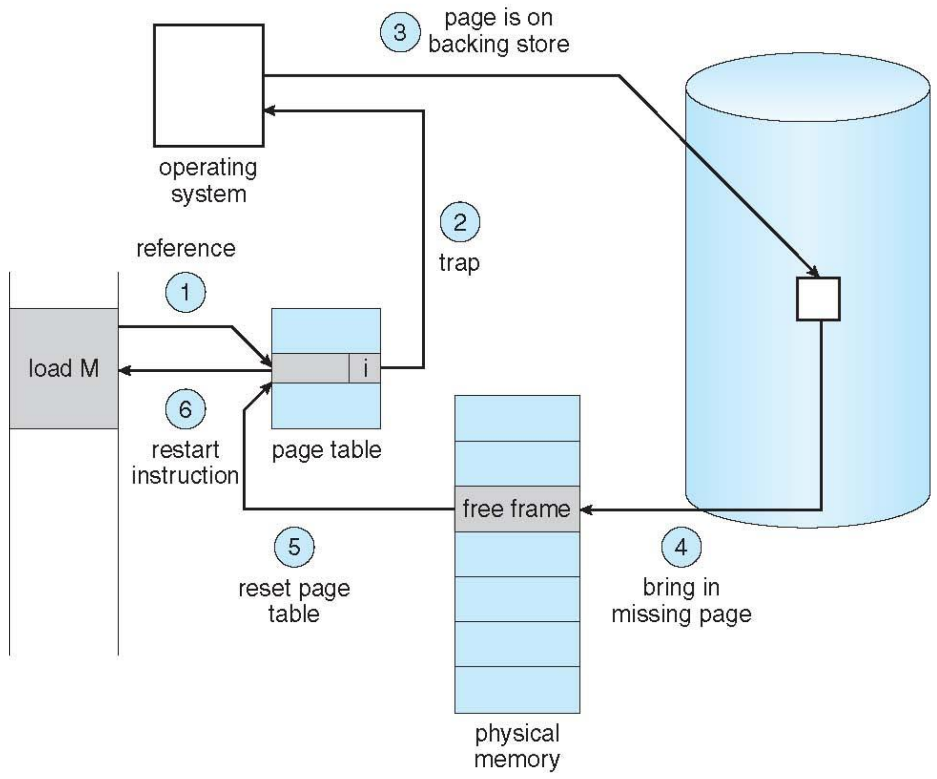
Kernel: Memory Manager (cont.)

- **Paging**
  - Divide **physical memory** into fixed-size blocks called **frames**
  - Divide **logical address** space into blocks of the **same size** called **pages**
  - To run a program of *n* pages, need to find *n* free frames and load the program
  - **Must keep track of free frames**
  - Set up a **page table** to translate logical to physical addresses

Kernel: Memory Manager

- **Virtual memory**
  - A process can be swapped out of memory to a **backing store**, and later brought back into memory for continuous execution



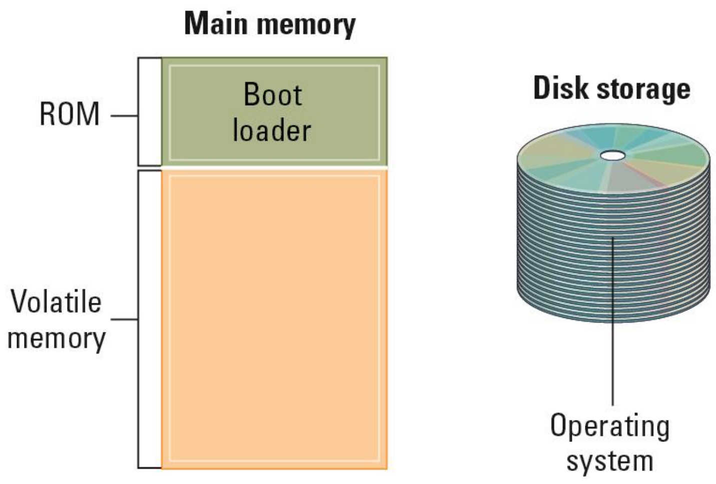


Kernel: Memory Manager

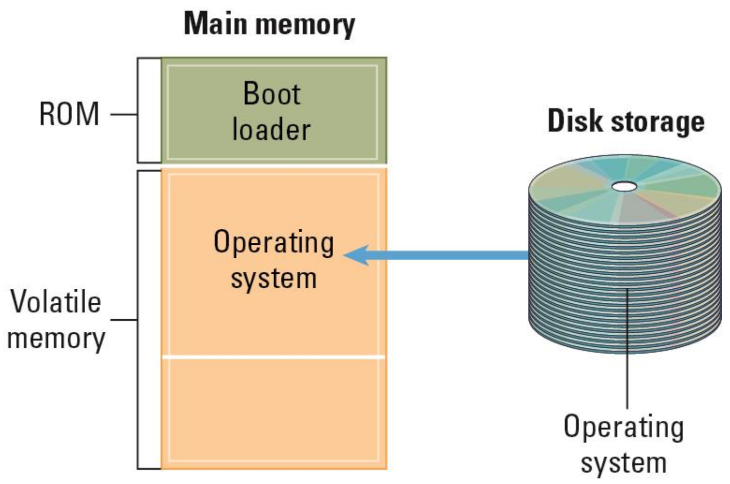
- **Virtual memory**
  - To run an **extremely large process**
    - Logical address space can be much larger than physical address space
  - To increase **CPU/resource utilization**
    - Higher degree of multi-tasking
    - Avoid putting rarely used data and codes in memory
  - To **launch** programs **faster**
    - Less I/O would be needed to load or swap

Bootstrapping / Booting

- **Boot loader:** program in ROM (read-only memory)
  - Run by the CPU when power is turned on
  - Transfers operating system from mass storage to main memory
  - Executes jump to the operating system

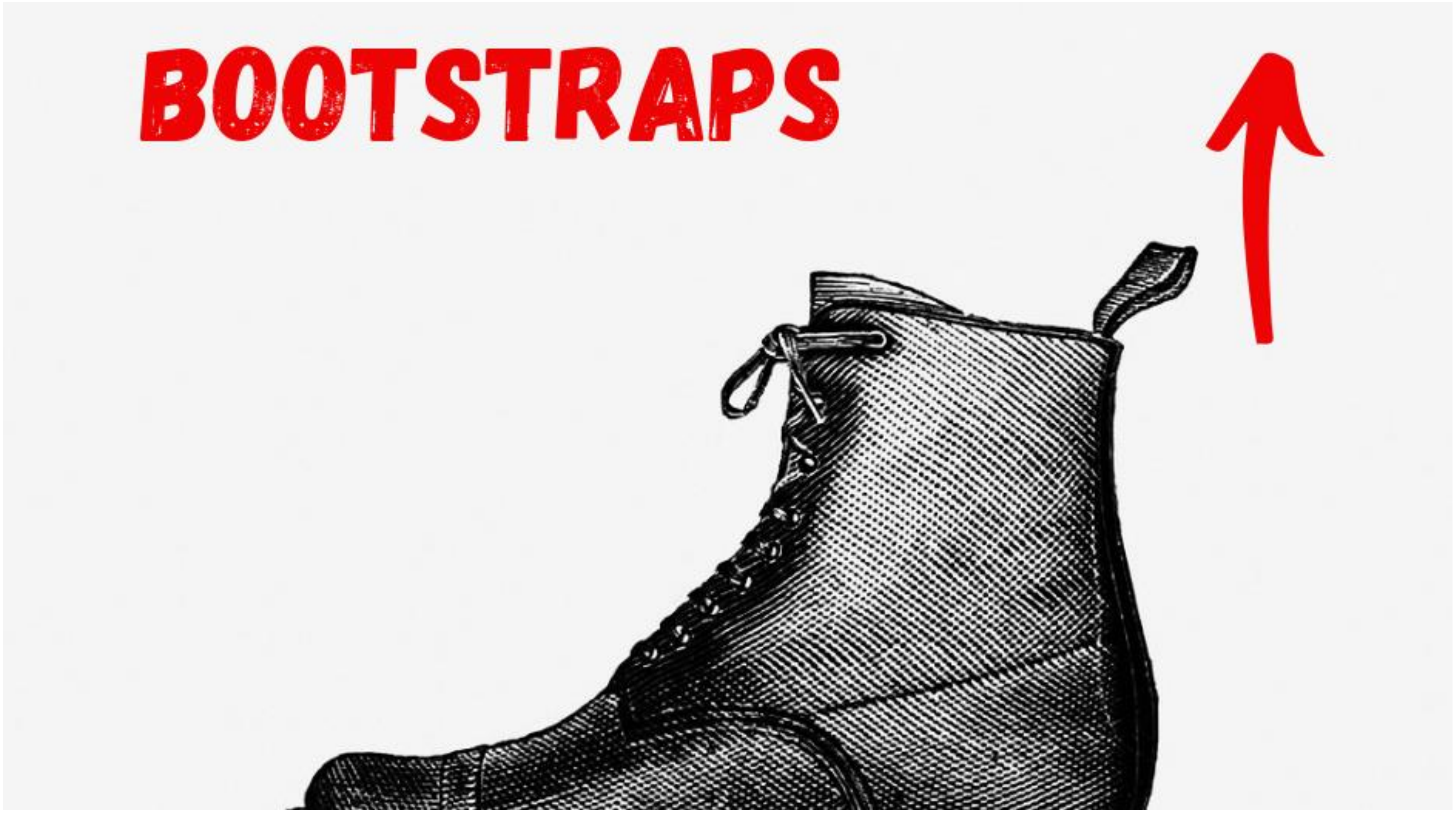


Step 1: Machine starts by executing the boot loader program already in memory. Operating system is stored in mass storage.



Step 2: Boot loader program directs the transfer of the operating system into main memory and then transfers control to it.

Bootstrapping / Booting (cont.)



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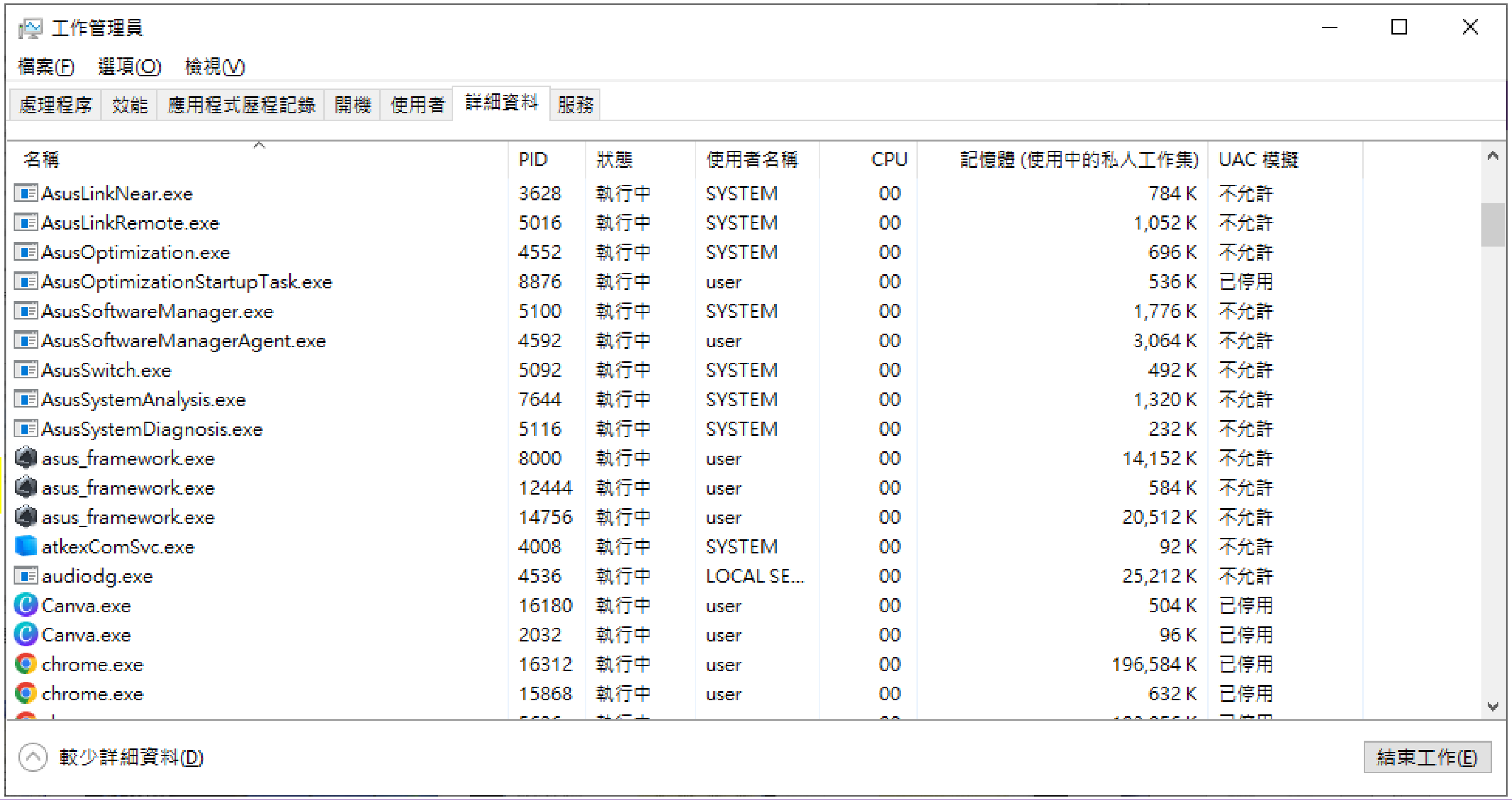
Coordinating the Machine’s Activities

- An operating system coordinates the execution of application software, utility software, and units within the operating system itself

Processes



工作管理員

檔案(F) 選項(O) 檢視(V)

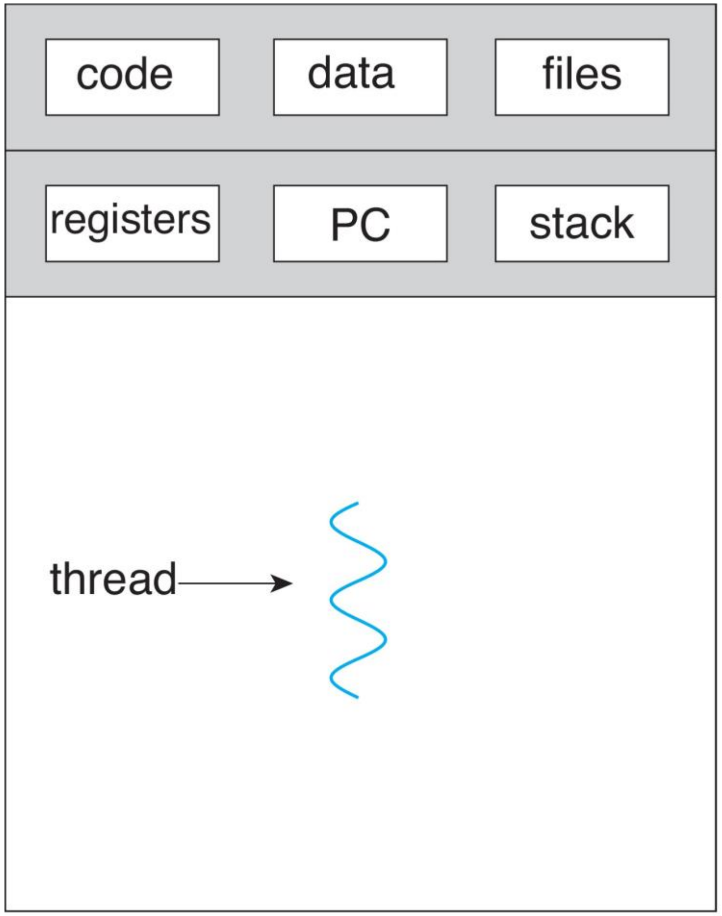
處理程序 | 效能 | 應用程式歷程記錄 | 開機 | 使用者 | 詳細資料 | 服務

名稱	PID	狀態	使用者名稱	CPU	記憶體 (使用中的私人工作集)	UAC 模擬
AsusLinkNear.exe	3628	執行中	SYSTEM	00	784 K	不允許
AsusLinkRemote.exe	5016	執行中	SYSTEM	00	1,052 K	不允許
AsusOptimization.exe	4552	執行中	SYSTEM	00	696 K	不允許
AsusOptimizationStartupTask.exe	8876	執行中	user	00	536 K	已停用
AsusSoftwareManager.exe	5100	執行中	SYSTEM	00	1,776 K	不允許
AsusSoftwareManagerAgent.exe	4592	執行中	user	00	3,064 K	不允許
AsusSwitch.exe	5092	執行中	SYSTEM	00	492 K	不允許
AsusSystemAnalysis.exe	7644	執行中	SYSTEM	00	1,320 K	不允許
AsusSystemDiagnosis.exe	5116	執行中	SYSTEM	00	232 K	不允許
asus_framework.exe	8000	執行中	user	00	14,152 K	不允許
asus_framework.exe	12444	執行中	user	00	584 K	不允許
asus_framework.exe	14756	執行中	user	00	20,512 K	不允許
atkexComSvc.exe	4008	執行中	SYSTEM	00	92 K	不允許
audiodg.exe	4536	執行中	LOCAL SE...	00	25,212 K	不允許
Canva.exe	16180	執行中	user	00	504 K	已停用
Canva.exe	2032	執行中	user	00	96 K	已停用
chrome.exe	16312	執行中	user	00	196,584 K	已停用
chrome.exe	15868	執行中	user	00	632 K	已停用

較少詳細資料(D) 結束工作(E)

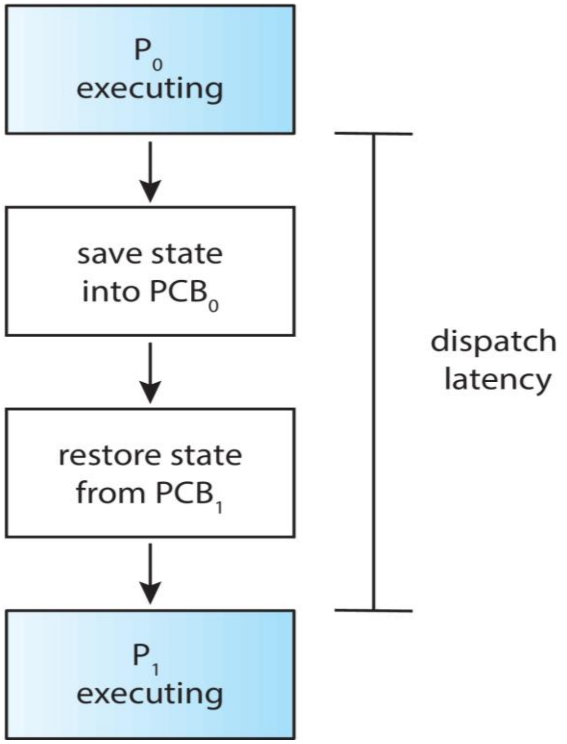
The Concept of a Process

- **Process**
  - The activity of executing a program
- **Process state**
  - Current status of the activity
    - Program counter
    - General purpose registers
    - Related portion of main memory
  - Managed by a process table (**Process Control Block, PCB**)
  - Save/load during a **context switch**

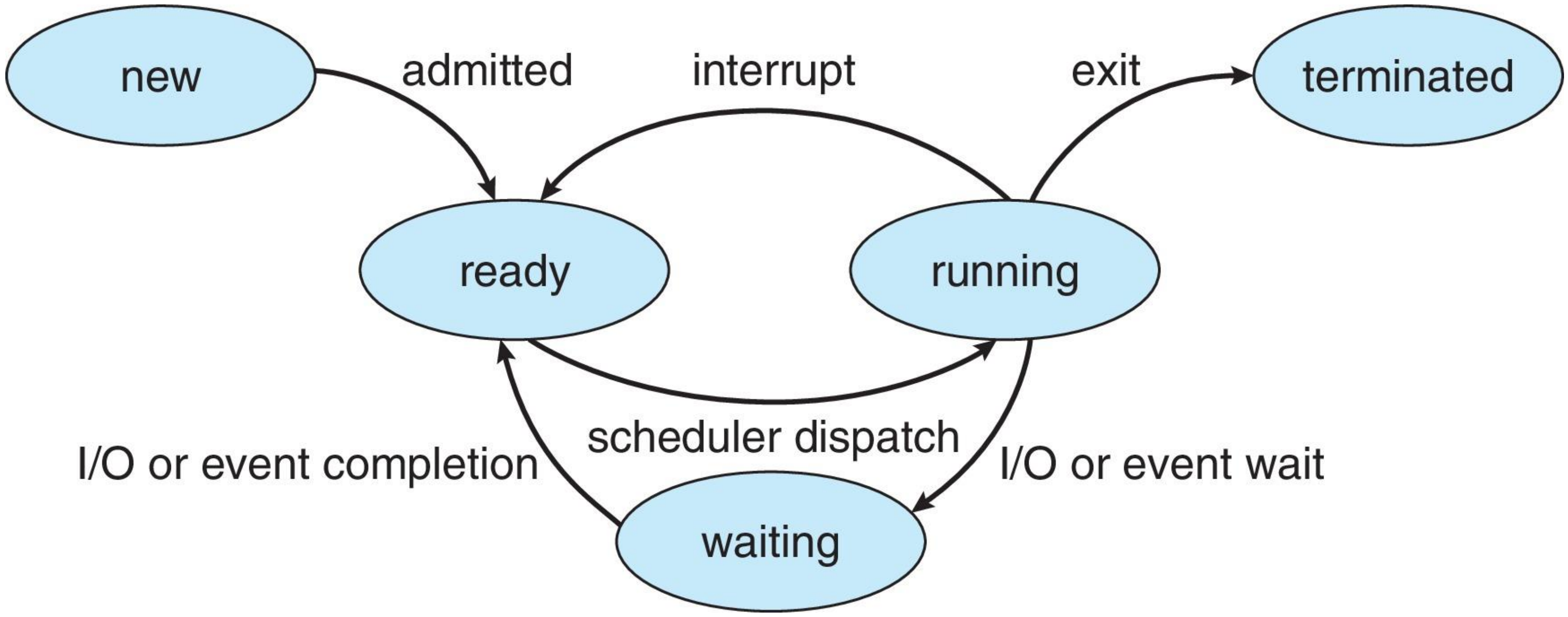


Process Administration

- **Scheduler**
  - Maintain the process table
    - Introduce new processes
    - Remove completed processes
    - Decide whether a process is ready or waiting
- **Dispatcher**
  - Really execute the program
    - Control the allocation of time slices to the processes
    - Switch processes (**context switch**)



Process State



Only one process is running on any processor at any instant

However, many processes may be ready or waiting (put into a queue)

Scheduling Criteria

- **CPU utilization**
  - Theoretically 0% ~ 100%
  - Real systems: 40% (light) ~ 90% (heavy)
- **Throughput** — system view
  - Number of completed processes per time unit
- **Turnaround time**
  - Submission ~ completion
- **Waiting time**
  - Total waiting time in the ready queue
- **Response time**
  - Submission ~ the first response is produced

single job view

Scheduling Criteria (cont.)

- **Max** CPU utilization
- **Max** Throughput
- **Min** Turnaround time
- **Min** Waiting time
- **Min** Response time

Scheduling Algorithms

- First-Come, First-Served (FCFS) scheduling
- Shortest-Job-First (SJF) scheduling
- Priority scheduling
- Round-Robin scheduling
- Multi-level queue scheduling
- Multi-level feedback queue scheduling

Outline

- What is an operating system
- The history of operating systems
- Operating system architecture
- Coordinating the machine’s activities
- Handling competition among processes
- Security

Data Consistency

- **Concurrent access** to **shared data** may result in **data inconsistency**

- Maintaining data consistency requires a mechanism to ensure the **orderly execution** of cooperating processes

Example: Consumer & Producer Problem

- **Producer** process produces information that is consumed by a **Consumer** process, both operating on a fixed-size buffer

```
/* Producer */
while (true) {
    // produce an item in next produced.
    while (counter == BUFFER_SIZE);
        // do nothing.
    buffer[in] = next_produced;
    in = (in + 1) % BUFFER_SIZE;
    counter++;
}
```

```
/* Consumer */
while (true) {
    while (counter == 0);
        // do nothing.
    next_consumed = buffer[out];
    out = (out + 1) % BUFFER_SIZE;
    counter--;
    // consume the item in next consumed.
}
```

Concurrent Operations on Counter

- The statement “counter++” may be implemented in machine language as

```
move R1, counter
add R1, 1
move counter, R1
```

- The statement “counter--” may be implemented as

```
move R2, counter
sub R2, 1
move counter, R2
```

Instruction Interleaving

- Assume the counter is initially 5. One interleaving of statement is

producer: move R1, counter	➔ R1 = 5
producer: add R1, 1	➔ R1 = 6
context switch	
consumer: move R2, counter	➔ R2 = 5
consumer: sub R2, 1	➔ R2 = 4
context switch	
producer: move counter, R1	➔ counter = 6
context switch	
consumer: move counter, R2	➔ counter = 4

Handling Competition among Processes

- **Critical Region**
  - A **protocol** for processes to cooperate
  - A group of instructions that should be executed by only one process at a time
- **Mutual exclusion**
  - Requirement that **only one** process at a time be allowed to execute a critical region

```
do {
    entry section       →  get entry permission
        critical section    →  modified shared data
    exit section        →  release entry permission
        remainder section
} while (1);
```

Semaphore

- A tool to generalize the synchronization problem
  - Can be achieved by hardware or software solutions
- Hardware support: **atomic instructions** (uninterruptible)

```
bool TestAndSet (bool &lock) {
        bool value = lock;
        lock = true;
        return value;
}
```

execute atomically:
return the value of “lock” and **set** “lock” to true

```
shared data: bool lock; // initially lock = false
```

```
// P0
do {
        while (TestAndSet (lock));
        critical section
        lock = false;
        remainder section
} while (1);
```

```
// P1
do {
        while (TestAndSet (lock));
        critical section
        lock = false;
        remainder section
} while (1);
```

Deadlock

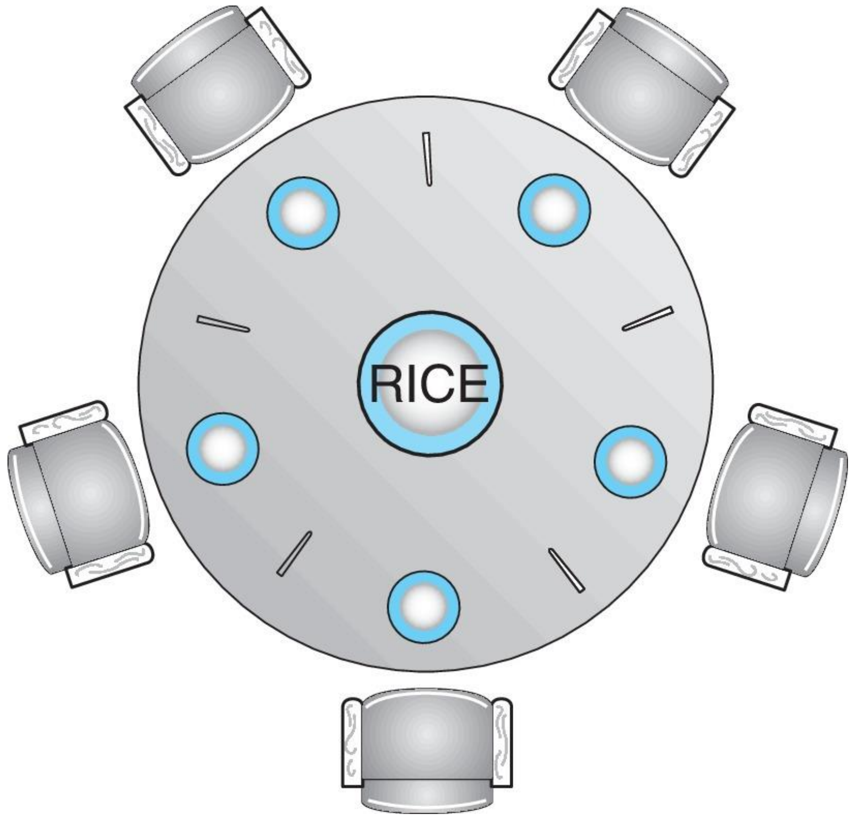
- Processes block each other from continuing because each is waiting for a resource that is allocated to another
- Example
  - 2 processes
    - P_1 holds resource B and waits for resource A
    - P_2 holds resource A and waits for resource B

Deadlock (cont.)

- Conditions required for deadlock
  - Competition for non-sharable resources (**mutual exclusion**)
    - Only one process at a time can use a resource
  - Resources requested on a partial basis (**hold and wait**)
    - A process holding some resources and is waiting for another resource
  - An allocated resource can not be forcibly retrieved (**no preemption**)
    - A resource can be only released by a process **voluntarily**
  - **Circular wait**
    - There exists a set $\{P_0, P_1, \ldots, P_n\}$ of waiting processes such that $P_0 \rightarrow P_1 \rightarrow P_2 \rightarrow \ldots \rightarrow P_n \rightarrow P_0$

Deadlock (cont.)

- Dining-philosophers problem



Handling Deadlocks

- Ensure the system will **never** enter a deadlock state
  - **Deadlock prevention**: ensure that at least one of the **four necessary conditions** cannot hold
  - **Deadlock avoidance**: **dynamically** examines the resource-allocation state before allocation
- Allow to **enter a deadlock state** and then **recover**
  - **Deadlock detection**
  - **Deadlock recovery**
- **Ignore the problem** and pretend that deadlocks never occur in the system
  - **Used by most operating systems, including UNIX**

Deadlock v.s. Starvation

- **Starvation**
  - Process cannot get the resources needed for a long time because the resources are being allocated to other processes
- **Aging**
  - Add an aging factor to the priority of each request

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Security

- **Goals**
  - Prevent error and misuse
  - Resources are only allowed to be accessed by authorized processes
- **Attacks from outside**
  - Problems
    - Insecure passwords and **bad habits**
    - Sniffing software
    - Virus, worms, Trojan horses
  - Counter measures
    - Auditing software (record and analyze activities)
    - Antivirus software

Security (cont.)

- **Attacks from within**
  - Problem
    - Process that gains access to memory outside its designated area
  - Counter measures
    - Control process activities via **privilege levels** and **privileged instructions**

Any Questions?