

CS 7172

Parallel and Distributed Computing

Process

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<https://kevinsuo.github.io/>

Outline

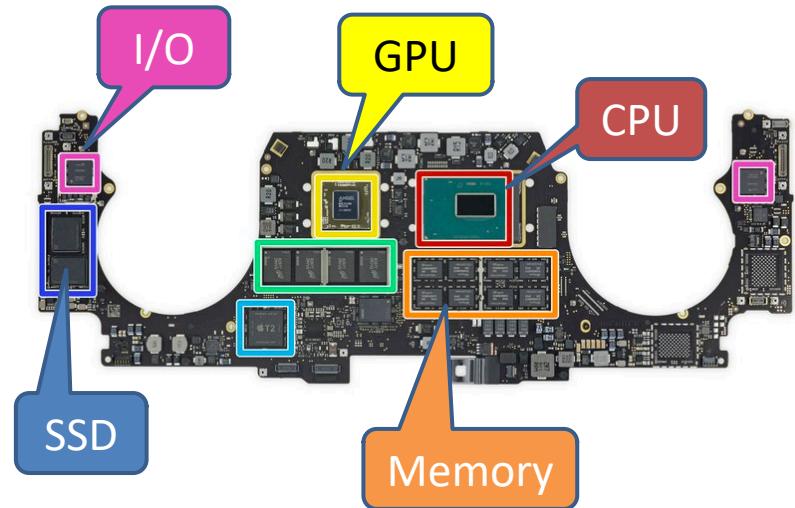
- Hardware review
- What is process?
 - Process vs Program
 - Linux Process Control Block
- Process related System calls
 - Fork
- Process on Distributed OSes



Computer Hardware Review

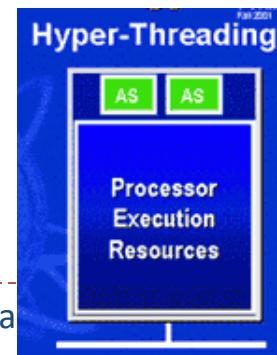
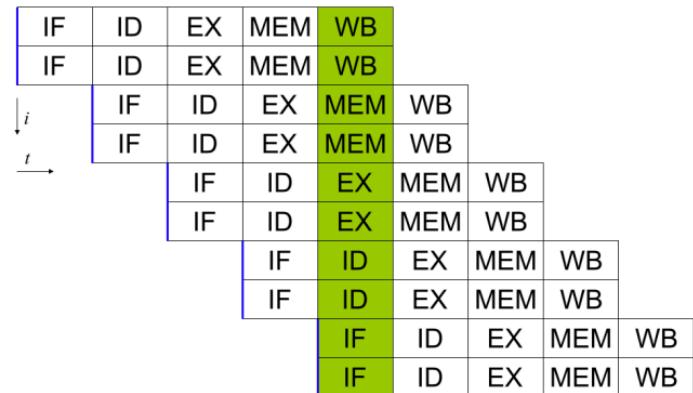
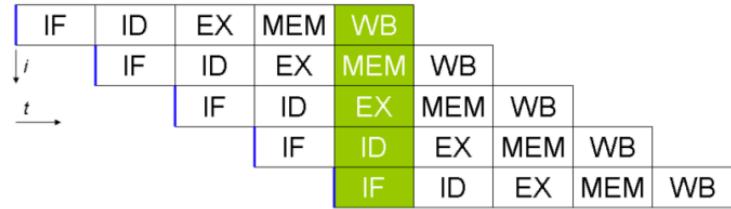


Computer Hardware Review



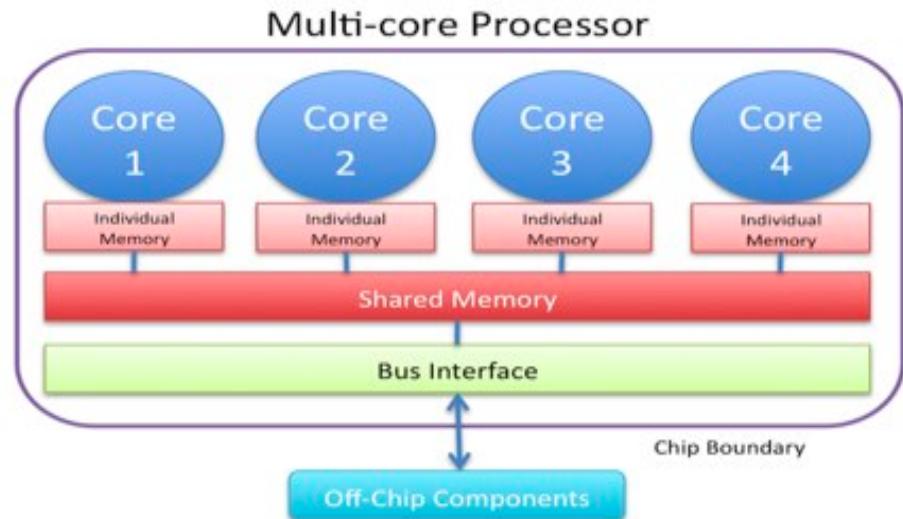
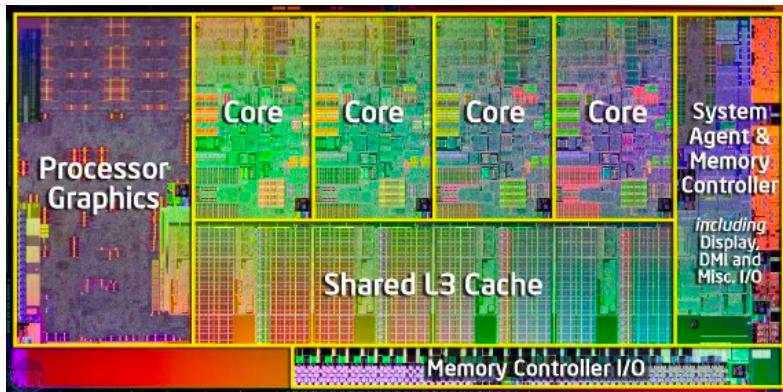
Central Processing Unit (CPU)

- Components
 - Arithmetic Logic Unit (ALU) -> Compute and data
 - Control Unit (CU) -> control device and system
- Clock rate
 - The speed at which a CPU is running
- Data storage
 - General-purpose registers: EAX, EBX ...
 - Special-purpose registers: PC (program counter), SP (stack), IR (instruction register) ...
- Parallelism
 - Instruction-level parallelism
 - Thread-level parallelism
 - ▶ Hyper-threading: duplicate units that store architectural states
 - ▶ Replicated: registers. Partitioned: ROB, load buffer... Shared: reservation station, caches



Multi-Core Processors (SMP)

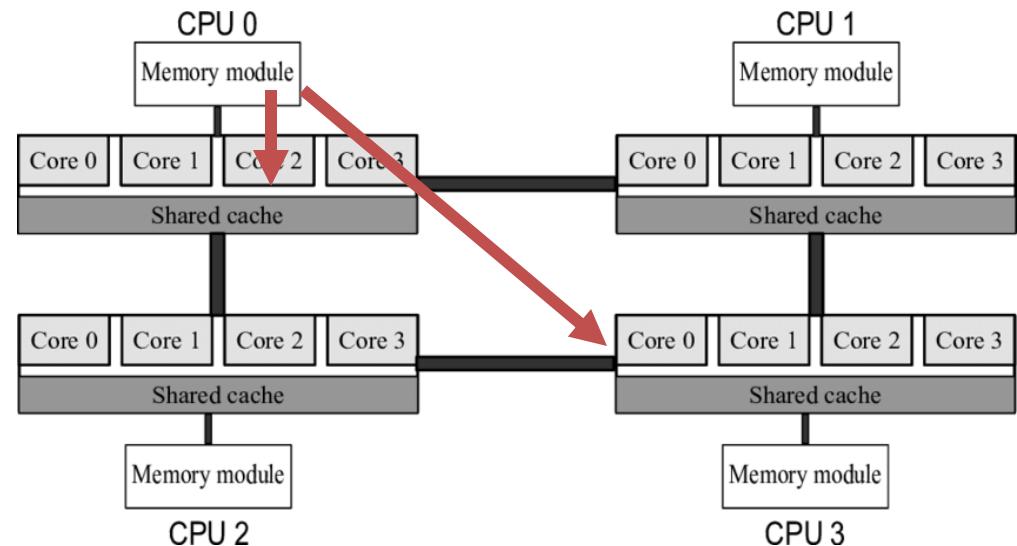
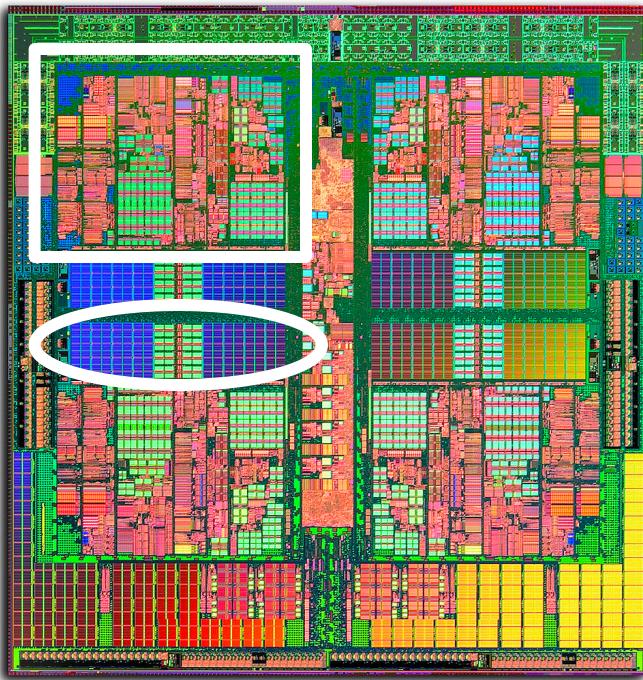
- Multiple CPUs on a single chip



Symmetric multiprocessing (**SMP**)

Multi-Core Processors (NUMA)

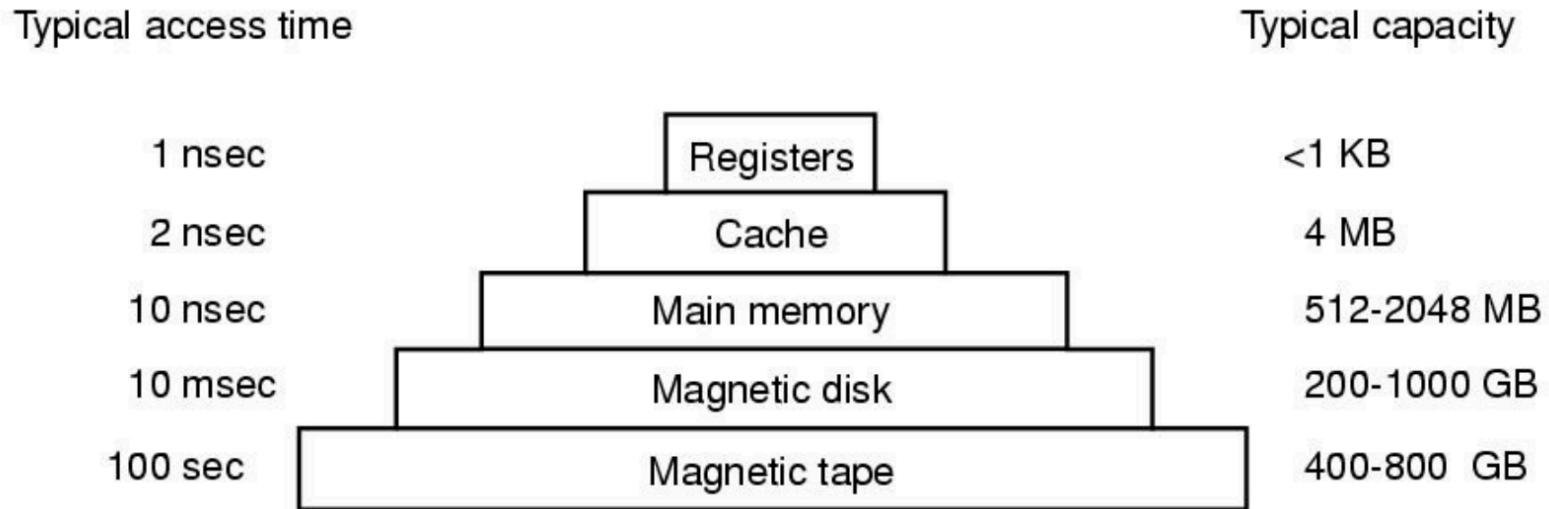
- Multiple CPUs on a single chip



Non-uniform memory access (**NUMA**)

Memory

- A typical memory hierarchy

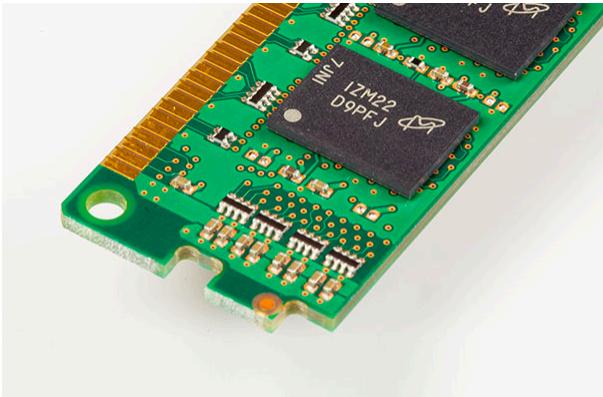
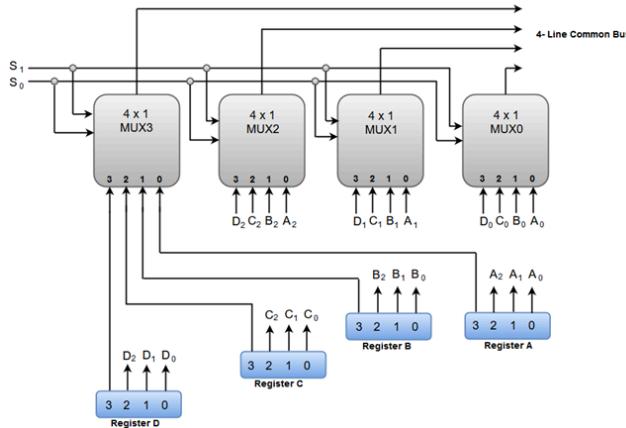


Minimize the access time vs. Cost

Memory

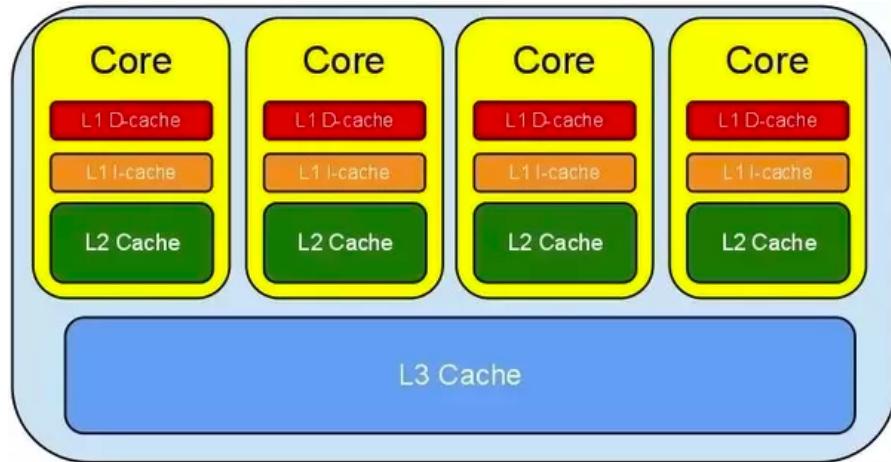
- A typical memory hierarchy

Bus System for 4 Registers:

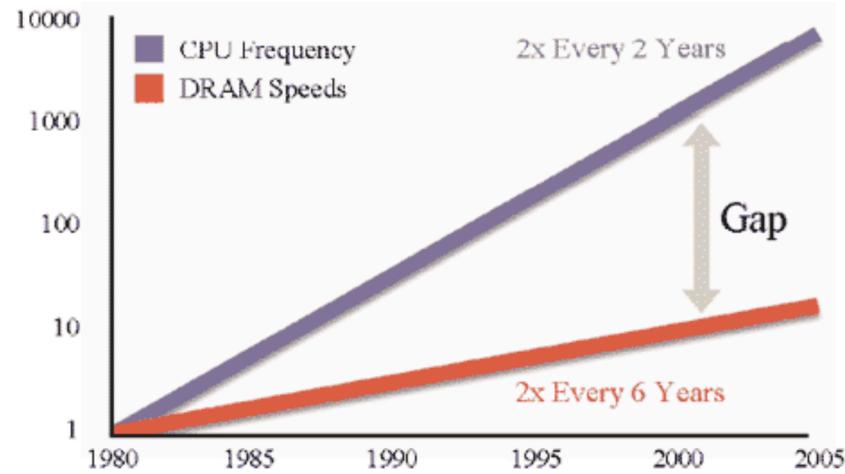


Cache

- Why Cache is important?



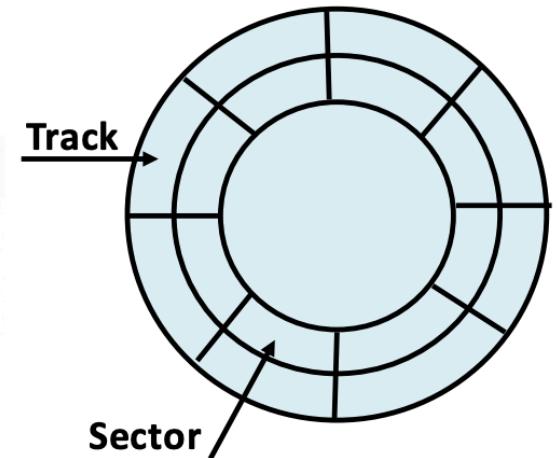
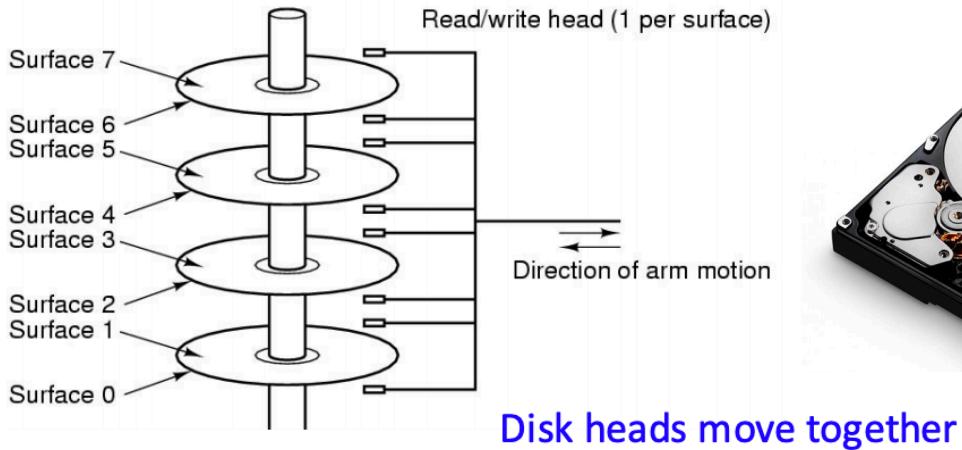
A larger size than registers
A much faster speed than memory
Tradeoff between performance and cost



MacBook Pro	
Hardware Overview:	
Model Name:	MacBook Pro
Model Identifier:	MacBookPro15,1
Processor Name:	Intel Core i9
Processor Speed:	2.3 GHz
Number of Processors:	1
Total Number of Cores:	8
L2 Cache (per Core):	256 KB
L3 Cache:	16 MB
Hyper-Threading Technology:	Enabled
Memory:	16 GB
Boot ROM Version:	220.270.99.0.0 (iBridge: 16.16.6568.0.0,0)
Serial Number (system):	C02YR4JHLVCJ
Hardware UUID:	DCC2D30A-9630-57B5-89A2-5F2B85254DC1

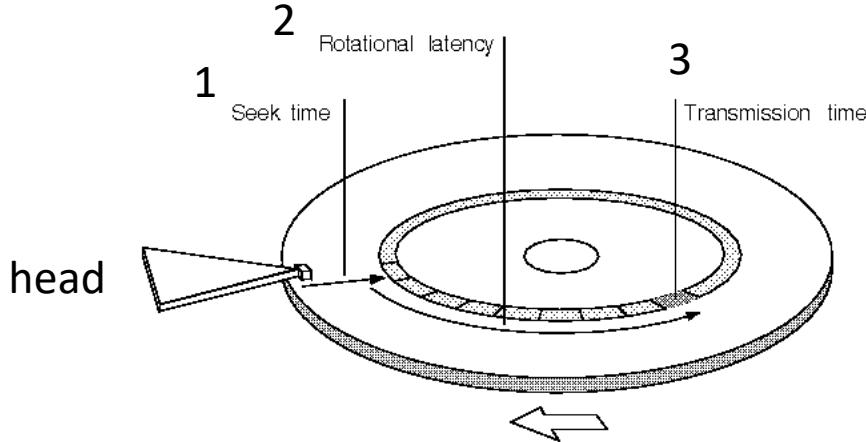


Disk



- A stack of platters, a surface with a magnetic coating
- Typical numbers (depending on the disk size):
 - 500 to 2,000 tracks per surface
 - 32 to 128 sectors per track
 - ▶ A sector is the smallest unit that can be read or written
- Originally, all tracks have the same number of sectors

Disk



- Disk head: each side of a platter has separate disk head
- Read/write data is a three-stage process:
 - Seek time: position the arm over the proper track
 - Rotational latency: wait for the desired sector to rotate under the read/write head
 - Transfer time: transfer a block of bits (sector) under the read-write head
- Average seek time as reported by the industry:
 - Typically in the range of 8 ms to 15 ms

Disk R/W Process



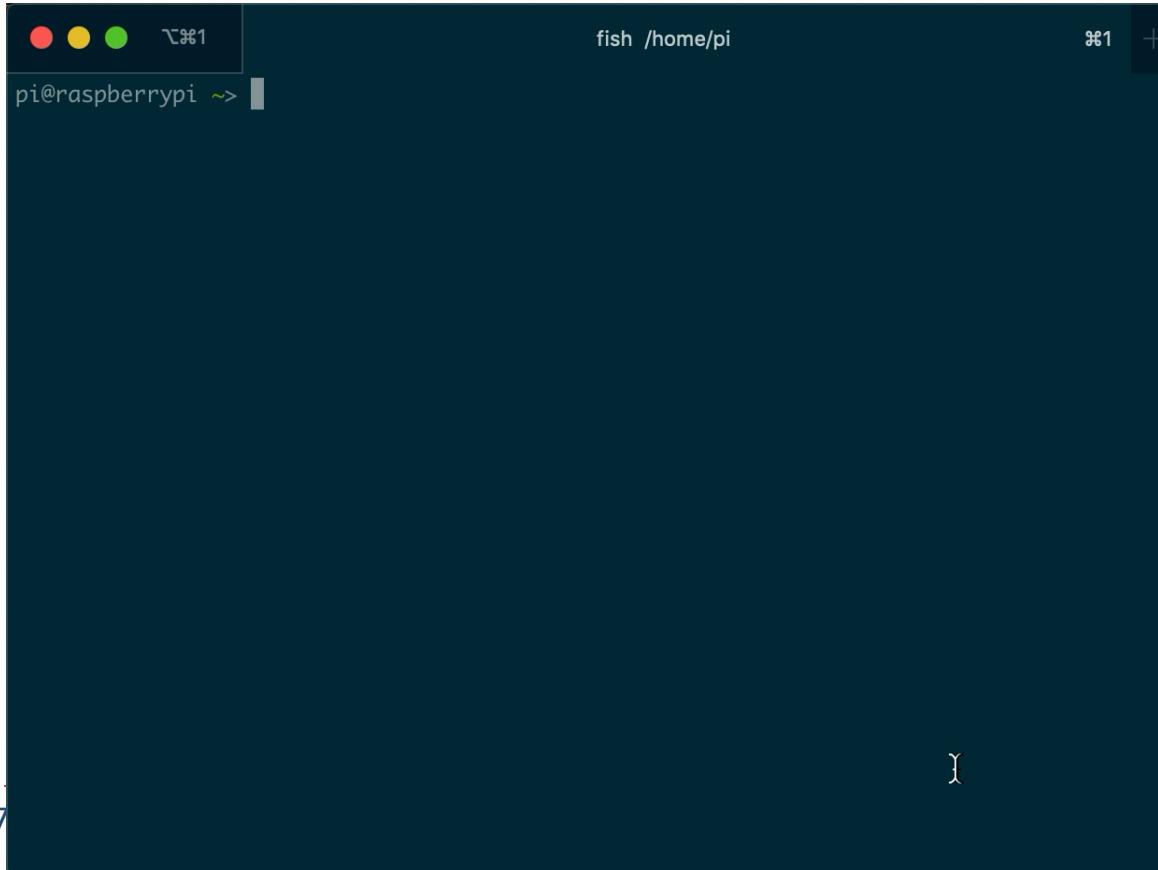
An interesting video introducing hardware



<https://www.youtube.com/watch?v=ExxFxD4OSZ0>

How to get my machine spec?

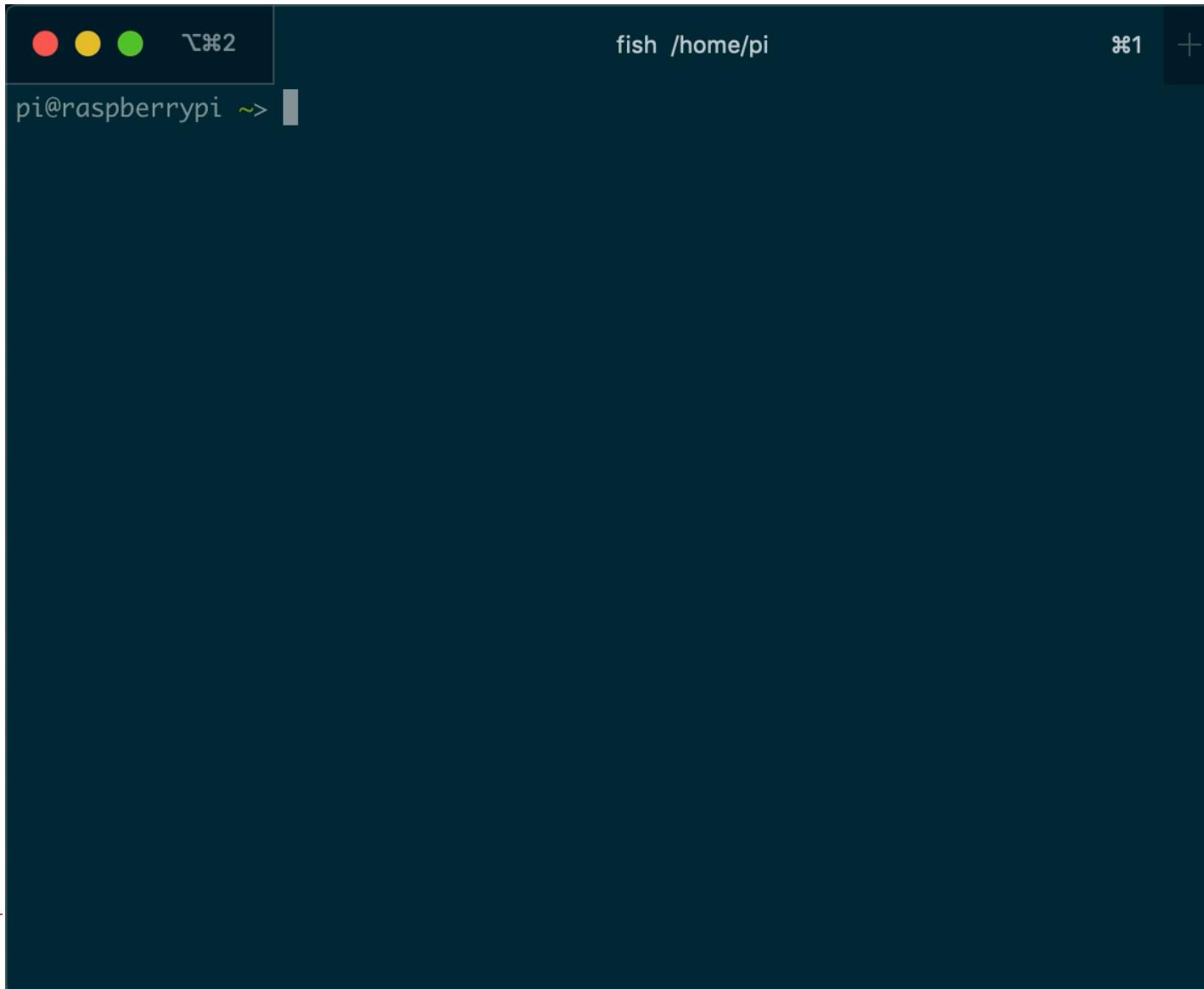
- Inxi: <https://www.tecmint.com/inxi-command-to-find-linux-system-information/>



A screenshot of a terminal window on a Raspberry Pi. The window title bar shows three colored dots (red, yellow, green) and the text 'fish /home/pi'. The status bar at the bottom right shows '⌘1 +'. The terminal prompt is 'pi@raspberrypi ~>'. The main area of the terminal is completely black, indicating no output from the command.



How to get my machine spec? One command for All!



Outline

- Hardware review
- What is process?
 - Process vs Program
 - Linux Process Control Block
- Process related System calls
 - Fork
- Process on Distributed OSes



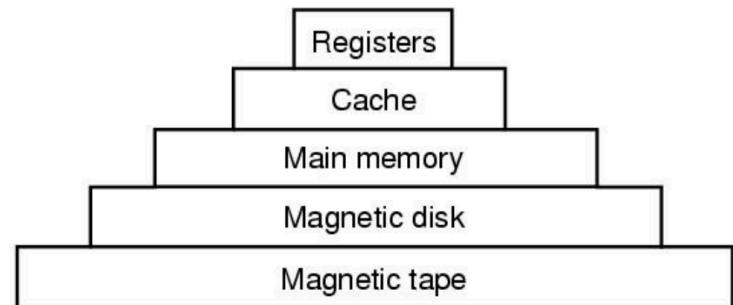
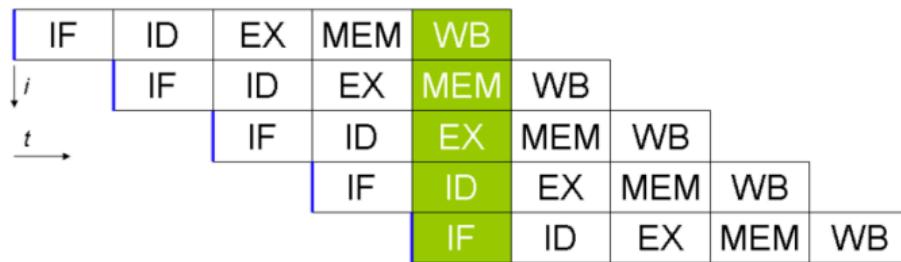
Process

- Definition
 - An instance of a *program* running on a computer
 - An *abstraction* that supports running programs - -> cpu virtualization
 - An *execution stream* in the context of a particular *process state* - -> dynamic unit
 - A *sequential* stream of execution in its *own address space* - -> execution code line by line



Process

- Two parts of a process
 - Sequential execution of instructions
 - Process state
 - ▶ registers: PC (program counter), SP (stack pointer), ...
 - ▶ Memory: address space, code, data, stack, heap ...
 - ▶ I/O status: open files ...



Program vs. Process

- Program \neq Process
 - Program = static code + data
 - Process = dynamic instantiation of code + data + files ...
- No 1:1 mapping
 - Program : process = 1:N
 - ▶ A program can invoke many processes



Program vs. Process

The diagram illustrates the relationship between a program and its processes. On the left, a screenshot of the Mac OS X Applications folder shows the application "Google Chrome" selected. A blue callout bubble labeled "Program: An executable file in long-term storage" points to it. On the right, a screenshot of the Activity Monitor shows multiple processes running under the name "Google Chrome Helper". A red dashed box highlights these processes. A blue callout bubble labeled "Process: The running instantiation of a program, stored in RAM" points to them. Below the processes, a summary table provides system statistics.

Program:
An executable file in
long-term storage

Process:
The running instantiation of
a program, stored in RAM

Item	Value
CPU Usage	3.65% 6.11% 90.24%
CPU LOAD	[Graph]
Threads:	1246
Processes:	350

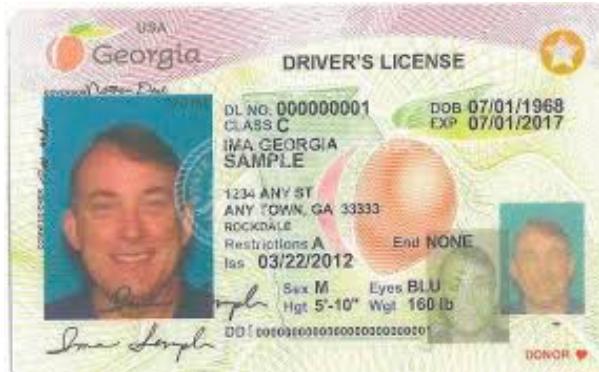


Program vs. Process

BASIS FOR COMPARISON	PROGRAM	PROCESS
Basic	Program is a set of instruction.	When a program is executed, it is known as process.
Nature	Passive	Active
Lifespan	Longer	Limited
Required resources	Program is stored on disk in some file and does not require any other resources.	Process holds resources such as CPU, memory address, disk, I/O etc.



Process Descriptor

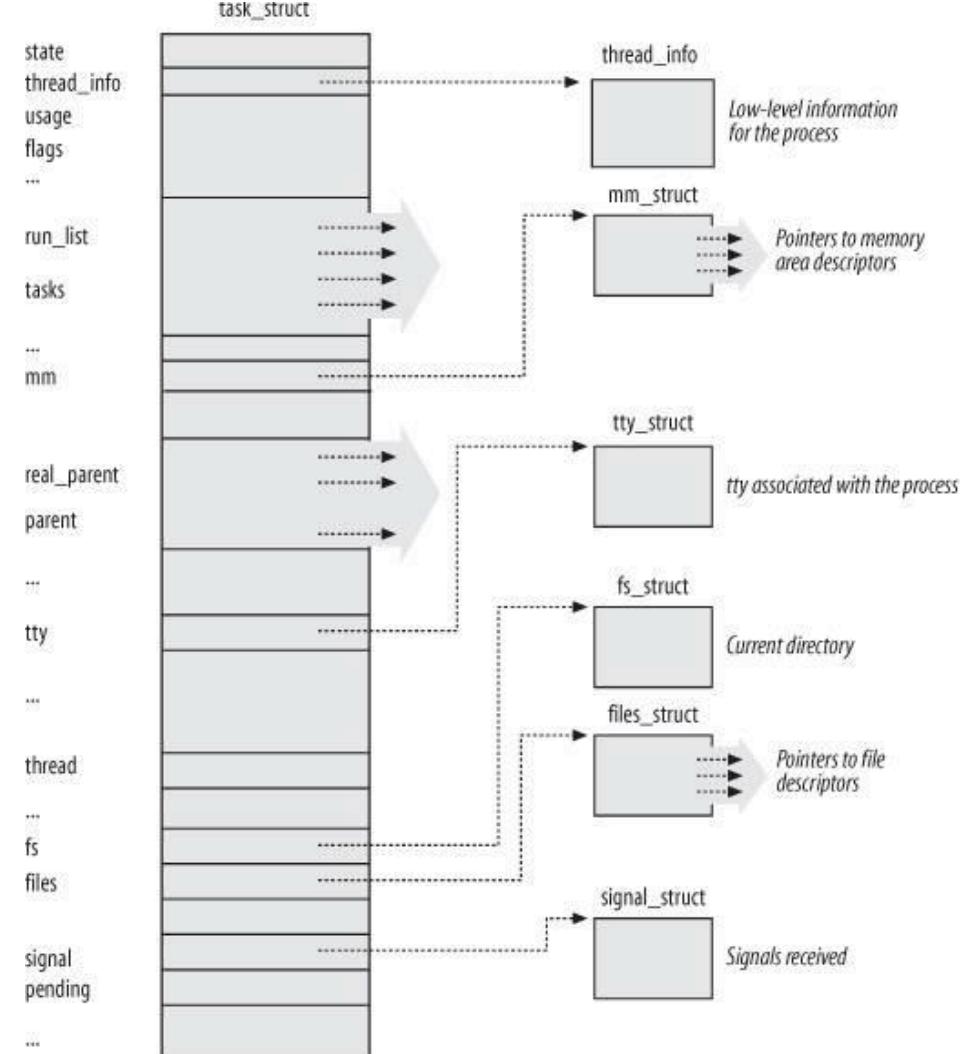


- Driving license
 - ID
 - Name
 - Address
 - Birth
 - Time
 - ...
- Process control block (PCB)
 - State
 - Identifiers
 - Scheduling info
 - File system
 - Virtual memory
 - Process specific context
 - ...

Process in Linux

<https://elixir.bootlin.com/linux/latest/source/include/linux/sched.h#L584>

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Process in Linux

- Process control block (PCB)

- State 

- Identifiers

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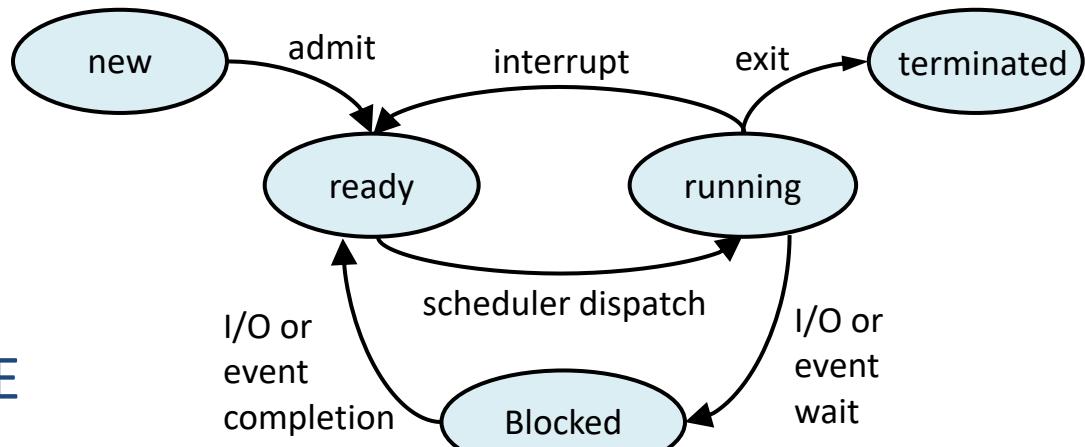
- ...



Linux PCB (5-state model to describe lifecycle of one process)

- State

- **TASK_RUNNING**
 - ▶ Running, ready
- **TASK_INTERRUPTABLE**
 - ▶ Blocked
- **EXIT_ZOMBIE**
 - ▶ Terminated by not deallocated
- **EXIT_DEAD**
 - ▶ Completely terminated



\$ ps -lf : process information

```
pi@raspberrypi ~> ps
  PID TTY          TIME CMD
  947 pts/0        00:00:00 bash
  966 pts/0        00:00:03 fish
 1256 pts/0        00:00:00 ps
pi@raspberrypi ~> ps -lf 947
 F S UID          PID  PPID C PRI  NI ADDR SZ WCHAN  STIME TTY          TIME CMD
 0 S pi          947   944  0  80    0 - 1523 wait    07:03 pts/0        0:00 -bash
pi@raspberrypi ~>
```

Bash is a UNIX OS
shell program

The state of the
process

- R : The process is running
- S : The process is sleeping/idle
- T : The process is terminated
- Z : The process is in zombie state

Process in Linux

- Process control block (PCB)

- State
- Identifiers 
- Scheduling info
- File system
- Virtual memory
- Process specific context
- ...



Linux Process Control Block (cont')

- Identifiers
 - pid: ID of the process

```
pi@raspberrypi ~> ps -lf
F S UID      PID  PPID   C PRI  NI ADDR SZ WCHAN  STIME TTY          TIME CMD
0 S pi        4408  4405   2 80    0 - 1523 wait    19:48 pts/0    00:00:00 -bash
0 S pi        4428  4408   6 80    0 - 6635 wait    19:48 pts/0    00:00:00 fish
0 R pi        4459  4428   0 80    0 - 1935 -       19:48 pts/0    00:00:00 ps -lf
pi@raspberrypi ~>
```

ID for this process

Parent process ID

Process in Linux

- Process control block (PCB)

- State
- Identifiers
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- ...



Linux Process Control Block (cont')

- Scheduling information
 - prio, static_prio, normal_prio
 - rt_priority
 - sched_class



Linux Process Control Block (cont')

- Scheduling information
 - prio, static_prio, normal_prio



- (1) Static priority: $P_1 > P_2 = P_3 = P_4$, P_1 can execute whenever it needs;
- (2) Normal priority: $P_1 = P_2 = P_3 = P_4$, P_1 execute depending on the scheduling algorithm;
- (3) Prio: dynamic priority, will change over the time

Linux Process Control Block (cont')

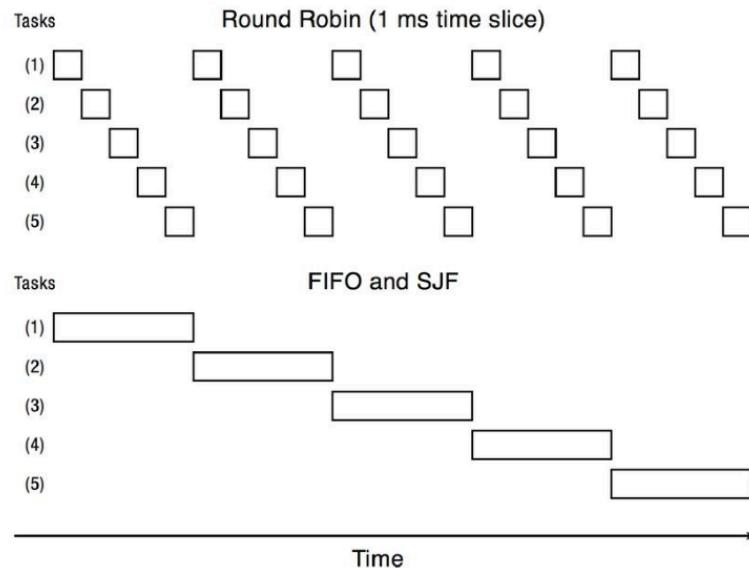
- Scheduling information
 - rt_priority



Rt_priority process is always higher than other priority of processes and will be scheduled immediately when it needs

Linux Process Control Block (cont')

- Scheduling information
 - `sched_class`: different scheduling policy implementations, e.g., FIFO, SJF, RR...
 - ▶ `Task->sched_class->pick_next_task(runqueue)`



`pick_next_task` of RR:
pick based on time cycle

`pick_next_task` of FIFO:
pick based on order

\$ ps -lf : process information

```
pi@raspberrypi ~> ps
  PID TTY          TIME CMD
  947 pts/0        00:00:00 bash
  966 pts/0        00:00:03 fish
 1256 pts/0        00:00:00 ps
pi@raspberrypi ~> ps -lf 947
F S UID          PID  PPID C PRI  NI ADDR SZ WCHAN  STIME TTY          TIME CMD
0 S pi           947   944  0  80    0 - 1523 wait    07:03 pts/0        0:00 -bash
pi@raspberrypi ~>
```

Bash is a UNIX OS shell program

How many cpus it consumes

Nice value: default is 0, could be modified to adjust the priority

Process priority value

\$ chrt: process scheduling info

```
pi@raspberrypi ~> sudo chrt -p 4408
pid 4408's current scheduling policy: SCHED_OTHER
pid 4408's current scheduling priority: 0
pi@raspberrypi ~>
```

scheduling policy

scheduling priority

SCHED_OTHER
SCHED_FIFO
SCHED_RR
SCHED_BATCH

min/max priority : 0/0
min/max priority : 1/99
min/max priority : 1/99
min/max priority : 0/0

Process in Linux

- Process control block (PCB)

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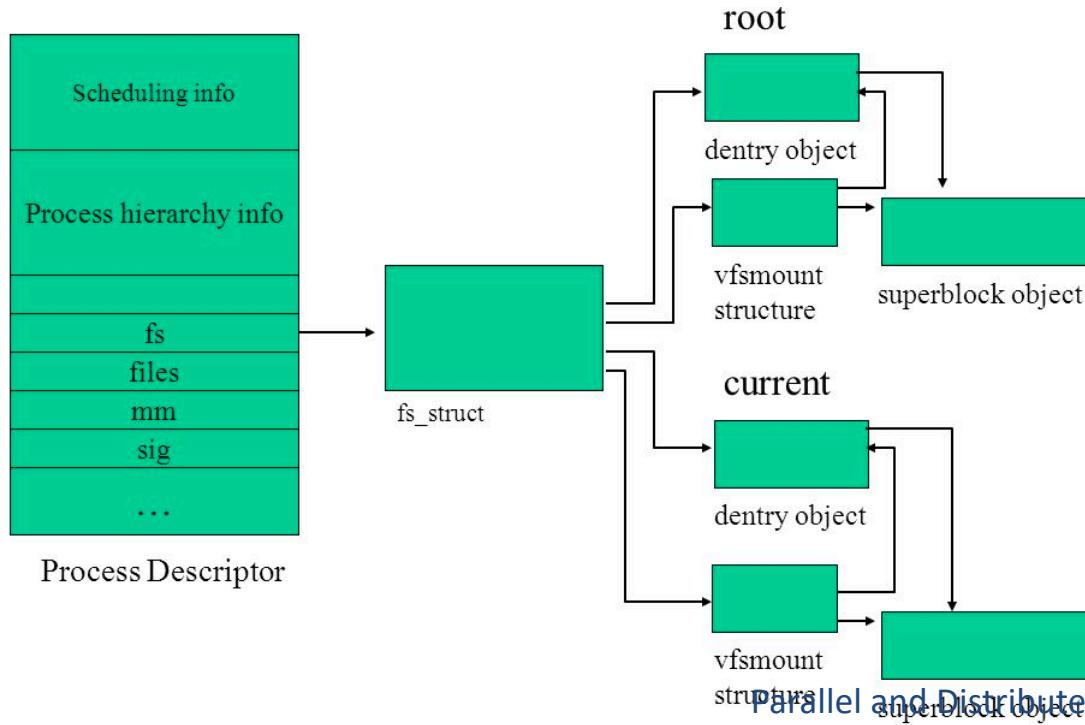
Linux Process Control Block (cont')

- Files

- **fs_struct**

<https://elixir.bootlin.com/linux/v4.2/source/include/linux/sched.h#L1525>

- ▶ file system information: root directory, current directory



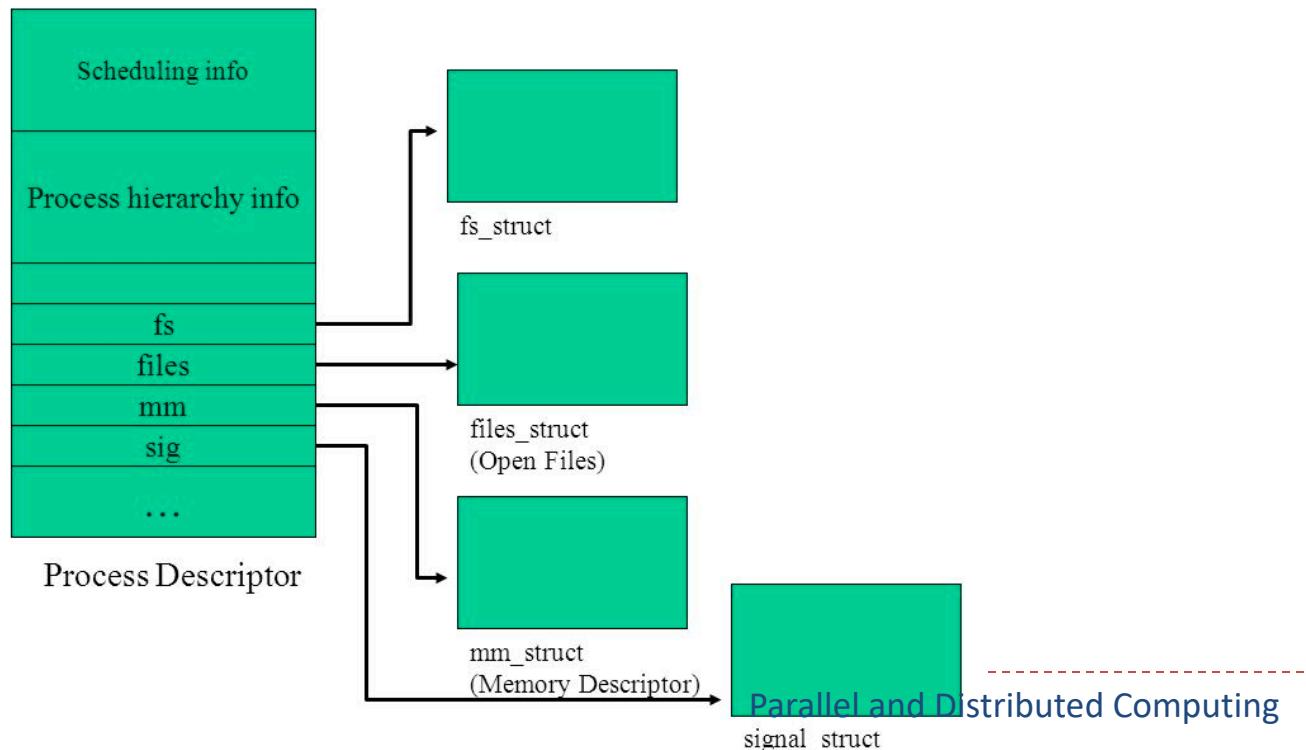
Linux Process Control Block (cont')

- Files

- `files_struct`

<https://elixir.bootlin.com/linux/v4.2/source/include/linux/sched.h#L1528>

- ▶ Information on opened files



\$lsof: list all open files

The screenshot shows a terminal window with the following content:

```
pi@raspberrypi ~> ps
  PID TTY      TIME CMD
 947 pts/0    00:00:00 bash
 966 pts/0    00:00:02 fish
1209 pts/0    00:00:00 ps
pi@raspberrypi ~> lsof -p 947
COMMAND PID USER   FD   TYPE DEVICE SIZE/OFF NODE NAME
bash    947  pi cwd   DIR  179,7     4096 1572867 /home/pi
bash    947  pi rtd   DIR  179,7     4096      2 /
bash    947  pi txt   REG  179,7  912712  524329 /bin/bash
bash    947  pi mem   REG  179,7   38560 1445488 /lib/arm-linux-gnueabihf/libnss_files-2.24.so
bash    947  pi mem   REG  179,7   38588 1445507 /lib/arm-linux-gnueabihf/libnss_nis-2.24.so
bash    947  pi mem   REG  179,7   71604 1445594 /lib/arm-linux-gnueabihf/libnsl-2.24.so
bash    947  pi mem   REG  179,7   26456 1445612 /lib/arm-linux-gnueabihf/libnss_compat-2.24.so
bash    947  pi mem   REG  179,7  1679776 670175 /usr/lib/locale/locale-archive
bash    947  pi mem   REG  179,7 1234700 1445500 /lib/arm-linux-gnueabihf/libc-2.24.so
bash    947  pi mem   REG  179,7   9800 1445460 /lib/arm-linux-gnueabihf/libdl-2.24.so
bash    947  pi mem   REG  179,7 124808 1445519 /lib/arm-linux-gnueabihf/libtinfo.so.5.9
bash    947  pi mem   REG  179,7   21868 144001 /usr/lib/arm-linux-gnueabihf/libarmmem.so
bash    947  pi mem   REG  179,7 138576 1445547 /lib/arm-linux-gnueabihf/ld-2.24.so
bash    947  pi mem   REG  179,7   26262 145746 /usr/lib/arm-linux-gnueabihf/gconv/gconv-modules.cache
bash    947  pi  0u  CHR  136,0     0t0      3 /dev/pts/0
bash    947  pi  1u  CHR  136,0     0t0      3 /dev/pts/0
bash    947  pi  2u  CHR  136,0     0t0      3 /dev/pts/0
bash    947  pi 255u  CHR  136,0     0t0      3 /dev/pts/0
```

The terminal window has a dark blue background with light blue text. It includes standard Linux navigation icons (red, yellow, green circles) and a status bar at the top right showing "fish /home/pi".

A blue speech bubble points from the terminal output to the command "lsof -p 947" with the text "All files opened by bash". Another blue speech bubble points from the same output to the column headers with the text "File descriptor, size, name, location, ...".

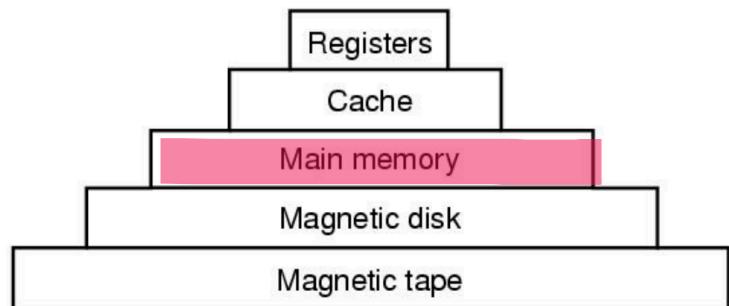
Process in Linux

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 - ...



Linux Process Control Block (cont')

- Virtual memory
 - `mm_struct`: describes the content of a process's virtual memory
 - ▶ The pointer to the page table and the virtual memory areas



\$pmap: memory mapping

Memory address

size

Read/write/
execution
permission

Lib/execut
ion file

All memory accessed by bash

memory used by
process bash

PID	TTY	TIME	CMD
947	pts/0	00:00:00	bash
966	pts/0	00:00:01	fish
1026	pts/0	00:00:00	ps
pi@raspberrypi ~> pmap 947			
947: -bash			
00010000	872K	r-x--	bash
000f9000	4K	r----	bash
000fa000	20K	rw---	bash
000ff000	36K	rw---	[anon]
00533000	1088K	rw---	[anon]
76bac000	36K	r-x--	libnss_files-2.24.so
76bb5000	60K	----	libnss_files-2.24.so
76bc4000	4K	r----	libnss_files-2.24.so
76bc5000	4K	rw---	libnss_files-2.24.so
76bc6000	24K	rw---	[anon]
76bcc000	36K	r-x--	libnss_nis-2.24.so
76bd5000	60K	----	libnss_nis-2.24.so
76be4000	4K	r----	libnss_nis-2.24.so
76be5000	4K	rw---	libnss_nis-2.24.so
76bf6000	68K	r-x--	libnsl-2.24.so
76bt7000	60K	----	libnsl-2.24.so
76c06000	4K	r----	libnsl-2.24.so
76c07000	4K	rw---	libnsl-2.24.so
76c08000	8K	rw---	[anon]
76c0a000	24K	r-x--	libnss_compat-2.24.so
76c0b000	60K	----	libnss_compat-2.24.so
76c1f000	4K	r----	libnss_compat-2.24.so

\$pmap: memory mapping

Memory address

size

Read/write/
execution
permission

Lib/execut
ion file

Code loaded by bash

Constant/static variable
loaded by bash

Data loaded by bash

```
pi@raspberrypi ~> ps
  PID TTY      TIME CMD
 947 pts/0    00:00:00 bash
 966 pts/0    00:00:01 fish
1026 pts/0    00:00:00 ps
pi@raspberrypi ~> pmap 947
947: -bash
00010000  872K r-x-- bash
000f9000     4K r---- bash
000fa000   20K rw--- bash
000ff000    36K rw--- [ anon ]
00533000 1088K rw--- [ anon ]
76bac000   36K r-x-- libnss_files-2.24.so
76bb5000   60K ----- libnss_files-2.24.so
76bc4000    4K r---- libnss_files-2.24.so
76bc5000    4K rw--- libnss_files-2.24.so
76bc6000    24K rw--- [ anon ]
76bcc000   36K r-x-- libnss_nis-2.24.so
76bd5000   60K ----- libnss_nis-2.24.so
76be4000    4K r---- libnss_nis-2.24.so
76be5000    4K rw--- libnss_nis-2.24.so
76bf6000   68K r-x-- libnsl-2.24.so
76b77000   60K ----- libnsl-2.24.so
76c06000    4K r---- libnsl-2.24.so
76c07000    4K rw--- libnsl-2.24.so
76c08000    8K rw--- [ anon ]
76c0a000  24K r-x-- libnss_compat-2.24.so
76c1b000   60K ----- libnss_compat-2.24.so
76c1f000    4K r---- libnss_compat-2.24.so
```

Bash in memory

\$pmap: memory mapping

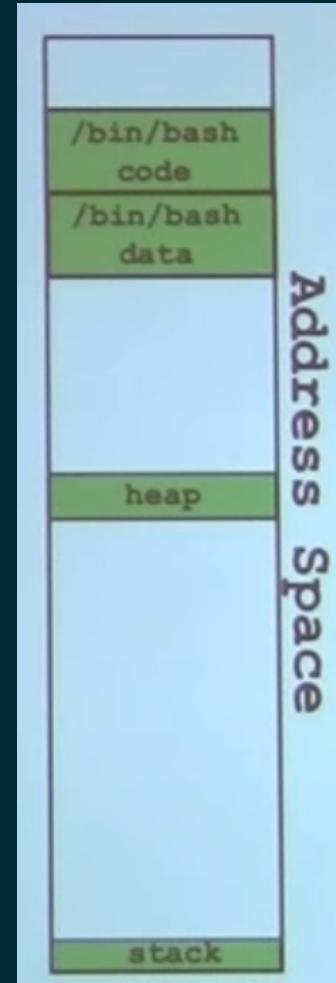
Memory address

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1026 pts/0    00:00:00 ps
pi@raspberrypi ~> pmap 947
947: -bash
00010000  872K r-x-- bash
000f9000     4K r---- bash
000fa000   20K rw--- bash
000ff000    36K rw--- [ anon ]
00533000 1088K rw--- [ anon ]
76bac000   36K r-x-- libnss_files-2.24.so
76bb5000   60K ----- libnss_files-2.24.so
76bc4000    4K r---- libnss_files-2.24.so
76bc5000    4K rw--- libnss_files-2.24.so
76bc6000   24K rw--- [ anon ]
76bcc000   36K r-x-- libnss_nis-2.24.so
76bd5000   60K ----- libnss_nis-2.24.so
76be4000    4K r---- libnss_nis-2.24.so
76be5000    4K rw--- libnss_nis-2.24.so
76c0000   68K r-x-- libnsl-2.24.so
76b17000   60K ----- libnsl-2.24.so
76c06000    4K r---- libnsl-2.24.so
76c07000    4K rw--- libnsl-2.24.so
76c08000    8K rw--- [ anon ]
76c0a000 24K r-x-- libnss_compat-2.24.so
76c0b000   60K ----- libnss_compat-2.24.so
76c1f000    4K r---- libnss_compat-2.24.so
```



The diagram illustrates the memory space for the bash process. It shows a vertical stack of memory regions. From top to bottom, the regions are: /bin/bash code (green), /bin/bash data (green), heap (green), and stack (green). The 'Address Space' is labeled vertically along the right side of the diagram.

Outline

- Hardware review
- What is process?
 - Process vs Program
 - Linux Process Control Block
- Process related System calls
 - Fork
- Process on Distributed OSes



Where do processes come from?

- Process creation always uses fork() system call

```
pi@raspberrypi ~> pstree -p
systemd(1)─avahi-daemon(304)─avahi-daemon(307)
                  └─bluealsa(674)─{bactl}(683)
                                ├─{gdbus}(685)
                                └─{gmain}(684)
                └─bluetoothd(659)
                └─cron(328)
                └─dbus-daemon(305)
                └─dhcpcd(351)
                └─docker(1853)─{docker}(1854)
                                ├─{docker}(1855)
                                ├─{docker}(1856)
                                ├─{docker}(1860)
                                └─{docker}(1869)
                └─hciattach(649)
                └─lightdm(458)─Xorg(476)─{InputThread}(488)
                                ├─{llvmpipe-0}(482)
                                ├─{llvmpipe-1}(483)
                                ├─{llvmpipe-2}(484)
                                └─{llvmpipe-3}(485)
                └─lightdm(491)─lxsession(510)─lxpanel(595)─sh(727)
                                ├─{gdbus}(633)
                                ├─{gmain}(632)
                                └─{menu-cache-io}(762)
                └─lxpolkit(593)─{gdbus}(610)
                                └─{gmain}(609)
```

Where do processes come from? First process in the kernel

```
asmlinkage __visible void __init start_kernel(void)
{
    char *command_line;
    char *after_dashes;

    set_task_stack_end_magic(&init_task);
    smp_setup_processor_id();
    debug_objects_early_init();

    cgroup_init_early();

    local_irq_disable();
    early_boot_irqs_disabled = true;

    /*
     * Interrupts are still disabled. Do necessary setups, then
     * enable them.
     */
    boot_cpu_init();
    page_address_init();
    pr_notice("%s", linux_banner);
    setup_arch(&command_line);
}
```

<https://elixir.bootlin.com/linux/latest/source/init/main.c#L551>

- The start of linux kernel begins from `start_kernel()` function, it is equal to the main function of kernel
- `set_task_stack_end_magic()` creates the first process in the OS
- The first process is the only one which is not created by `fork` function



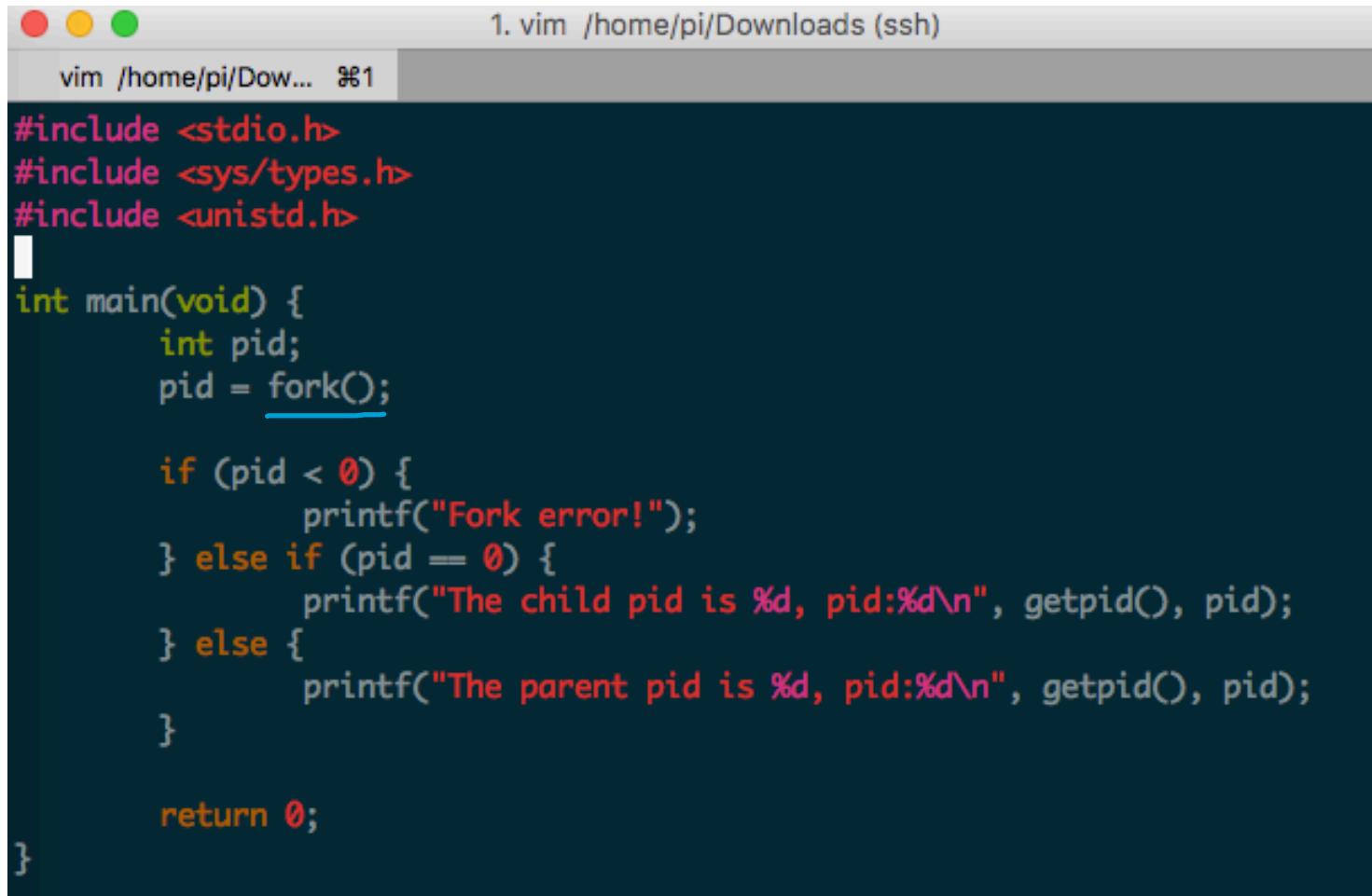
Fork() system call

- Process creation always uses fork() system call
- When?
 - User runs a program at command line
 - ▶ `./test.o`
 - OS creates a process to provide a service
 - ▶ Timer, networking, load-balance, daemon, etc.
 - One process starts another process
 - ▶ Parents and child process



Fork() system call

<https://github.com/kevinsuo/CS7172/blob/master/fork.c>



```
1. vim /home/pi/Downloads (ssh)
vim /home/pi/Dow... %1
#include <stdio.h>
#include <sys/types.h>
#include <unistd.h>

int main(void) {
    int pid;
    pid = fork();

    if (pid < 0) {
        printf("Fork error!");
    } else if (pid == 0) {
        printf("The child pid is %d, pid:%d\n", getpid(), pid);
    } else {
        printf("The parent pid is %d, pid:%d\n", getpid(), pid);
    }

    return 0;
}
```



Fork() system call

- fork() is called once. But it returns twice!!
 - Once in the parent (return child id)
 - Once in the child (return 0)



Fork() system call

<https://github.com/kevinsuo/CS7172/blob/master/fork.c>

```
#include <stdio.h>
#include <sys/types.h>
#include <unistd.h>

int main(void) {
    int pid;
    pid = fork();

    if (pid < 0) {
        printf("Fork error!");
    } else if (pid == 0) {
        printf("The child pid is %d, pid:%d\n", getpid(), pid);
    } else {
        printf("The parent pid is %d, pid:%d\n", getpid(), pid);
    }

    return 0;
}
```

```
pi@raspberrypi ~/Downloads> ./test.o
The parent pid is 2510, pid:2511
The child pid is 2511, pid:0
```

ting

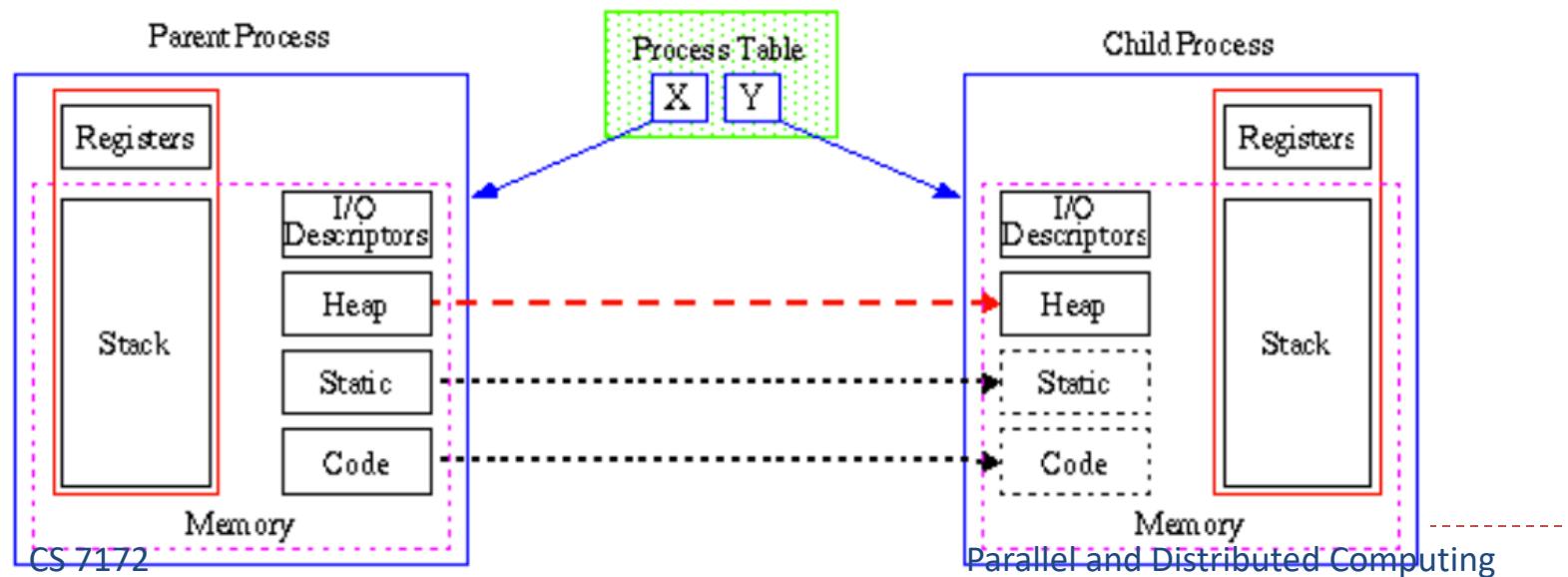
Fork() system call

- fork() is the UNIX system call that creates a new process.
- fork () creates a new process that is a **copy** of the calling process.
- After fork () we refer to the caller as the **parent** and the newly-created process as the **child**. They have a special relationship and special responsibilities.



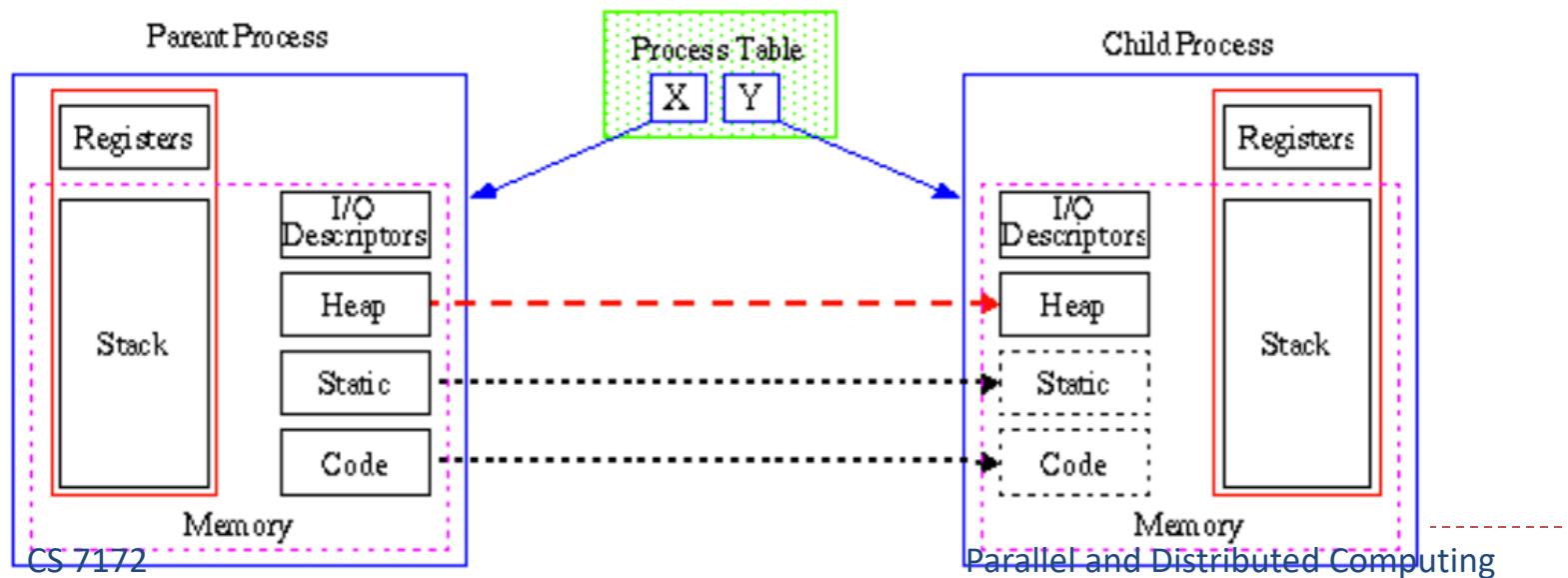
Parent process and child process

- When a parent process uses `fork()` to create a child process, the two processes have
 - the **same** program text.
 - but **separate** copies of the data, stack, and heap segments.



Parent process and child process

- The child's stack, data, and heap segments are **initially exact duplicates** of the corresponding parts the parent's memory.
- After the fork(), each process can modify the variables in its **own** data, stack, and heap segments without affecting the other process.



Fork() example

A screenshot of a terminal window titled "vim /home/pi/Downloads 1". The code in the editor is:

```
#include <stdio.h>
#include <sys/types.h>
#include <unistd.h>
int main()
{
    fork();
    printf("Hello world!\n");
    return 0;
}
```

Two arrows point from the original "fork();" statement to two separate "fork();" statements in the code. A blue arrow points to the first child's "fork();" and a red arrow points to the second child's "fork();". Below the code, a blue speech bubble labeled "Parent" and a red speech bubble labeled "Child" are positioned.

```
pi@raspberrypi ~/Downloads> ./a.o
Hello world!
Hello world!
```

A screenshot of a terminal window titled "vim /home/pi/Downloads 1". The code in the editor is:

```
#include <stdio.h>
#include <sys/types.h>
#include <unistd.h>
int main()
{
    fork();
    fork();
    fork();
    printf("Hello world!\n");
    return 0;
}
```

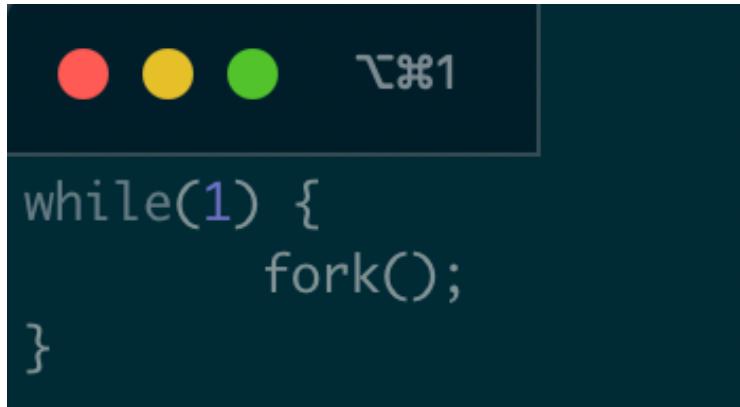
The code contains three nested "fork();" statements. A blue arrow points to the first child's "fork();", a red arrow points to the second child's "fork();", and another blue arrow points to the third child's "fork();". To the right of the code, a diagram shows a tree structure where the root node branches into three children, each of which further branches into two grandchildren, illustrating the recursive nature of the fork operation.

```
pi@raspberrypi ~/Downloads> ./a.o
Hello world!
```



A fork() bomb

- What does this code do?



A screenshot of a terminal window with a dark background. At the top left are three colored circles (red, yellow, green) and a small icon. To their right is the text '✉⌘1'. Below this, the code for a fork() bomb is displayed:

```
while(1) {  
    fork();  
}
```



Agent smith

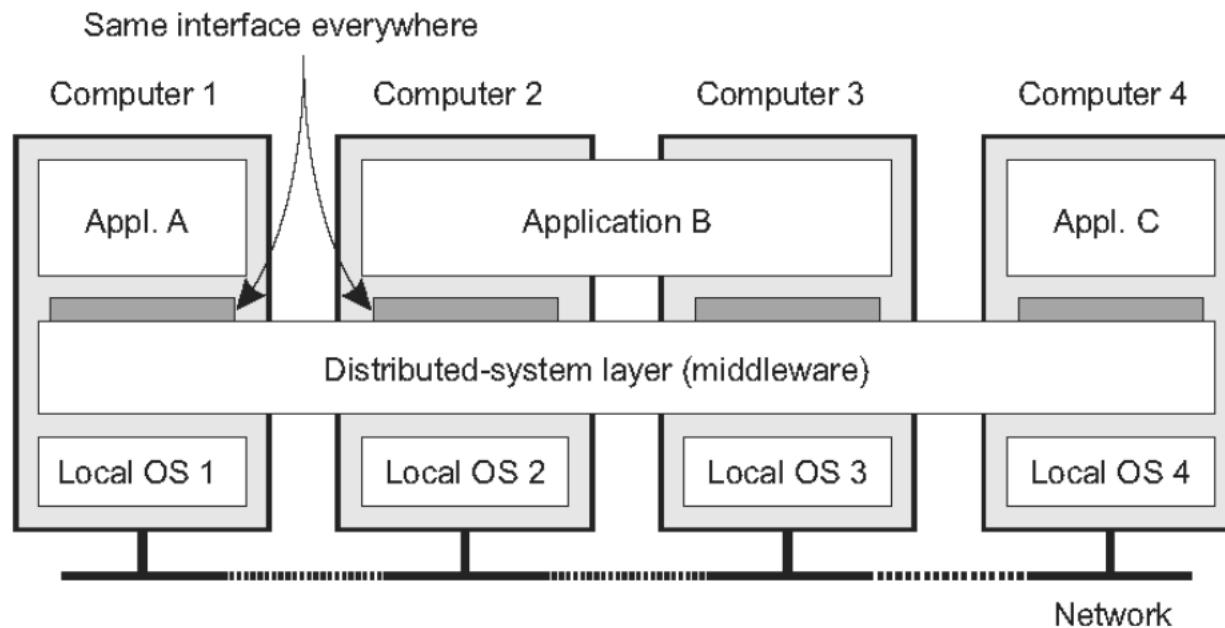
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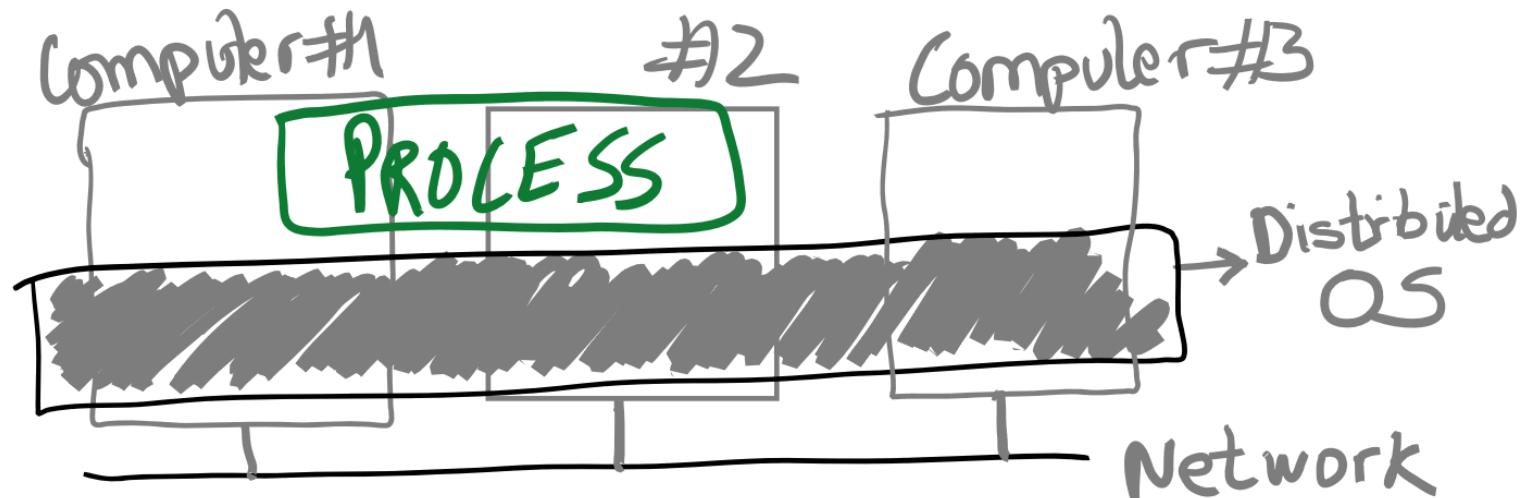
The OS of Distributed Systems

- Commonly used components and functions for distributed applications



The OS of Distributed Systems

- An OS that spans multiple computers
- Same OS services, functionality, and abstractions as single-machine OS



Distributed OS Challenges

- Providing the process abstraction and resource virtualization is hard
- Resource virtualization must be transparent
 - But in distributed settings, there's always a distinction between local and remote resources
- In a single-machine OS, processes don't care where their resources are coming from:
 - Which CPU cores, when they are scheduled, which physical memory pages they use, etc.
- In fact, providing abstract, virtual resources is one of the main OS services



Processes In Distributed OS

PROCESS

Process state:

- Code segment
- Memory pages
- Files
- Sockets
- Security permissions

Distributed OS

2-Computer

6-Computer



Transparency Issues In Distributed OS

PROCESS

Process state:

- Code segment
- Memory pages
- Files
- Sockets
- Security permissions

- Where does code run?
- Which memory is used?
Local vs. remote
- How are files accessed?

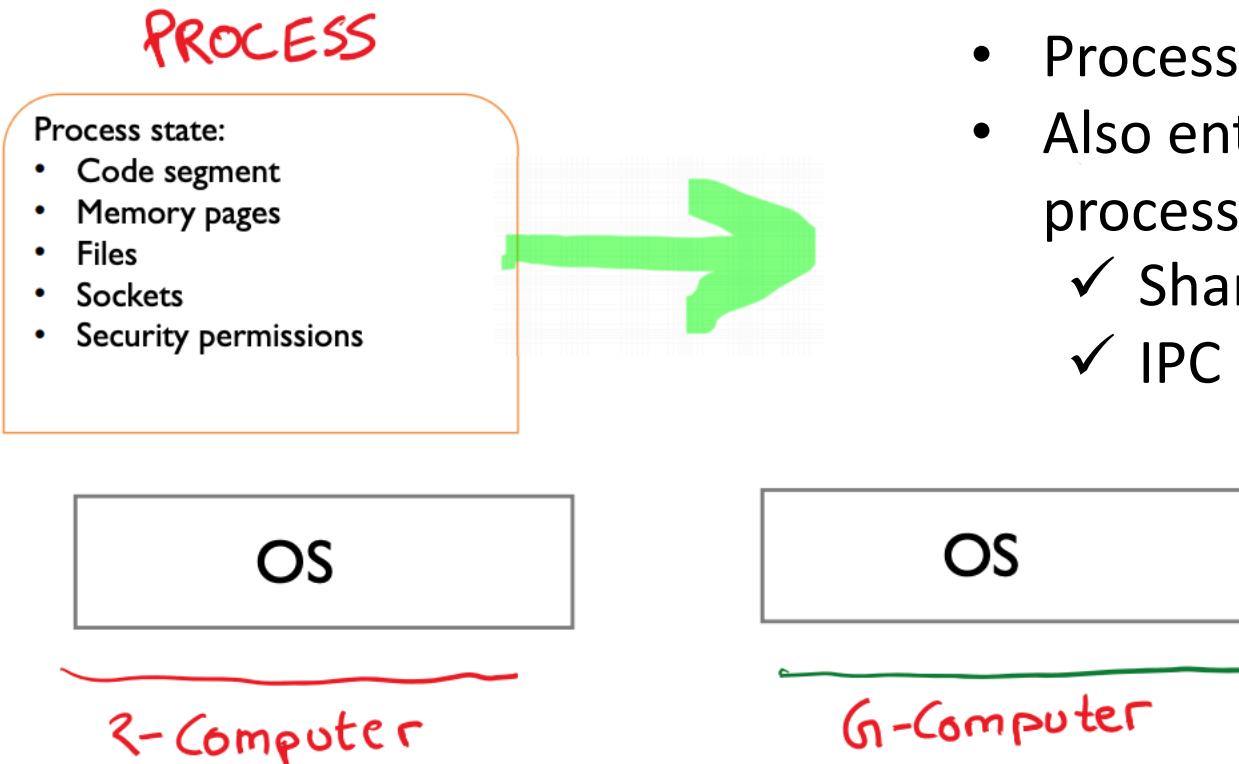
Distributed OS

R-Computer

G-Computer



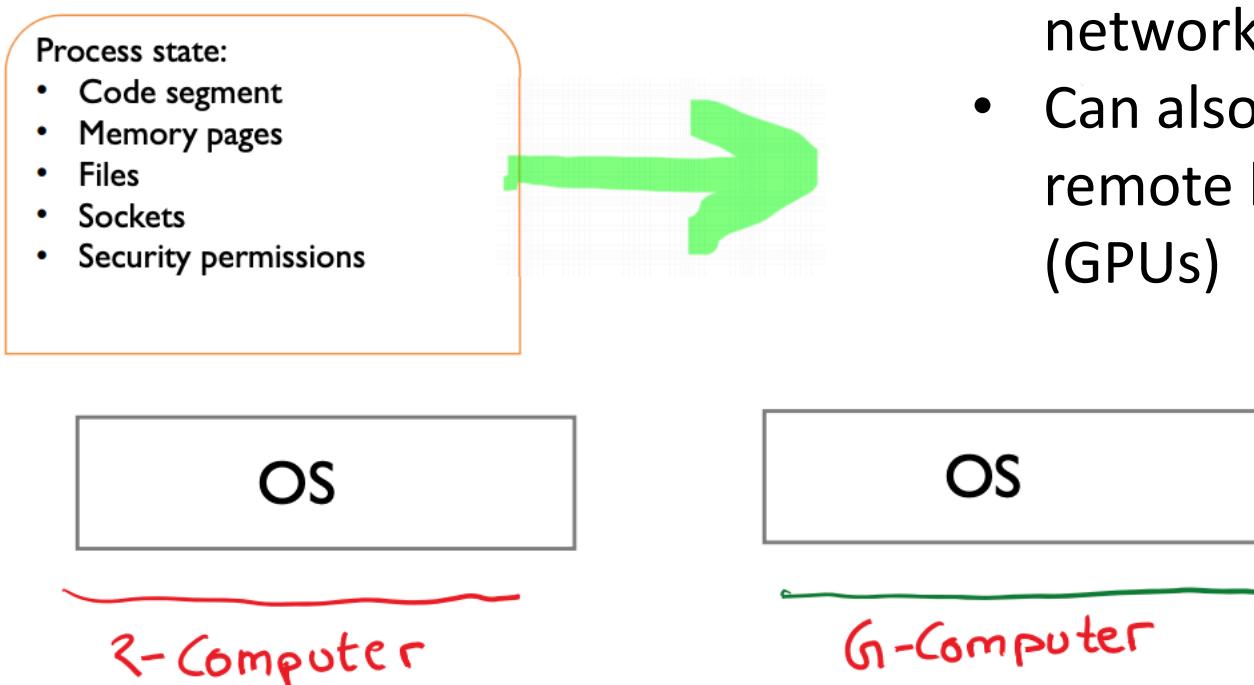
Process Migration



- Move all process state from one computer to another
- Process state can be vast
- Also entangled with other process states
 - ✓ Shared files?
 - ✓ IPC (pipes etc)

Process Migration

- Migrate some state
- Other state, if required, is accessed over the network
- Example: migrate only fraction of pages. Other pages are copied over the network on access.
- Can also be used to access remote hardware devices (GPUs)



Conclusion

- Hardware review
- What is process?
 - Process vs Program
 - Linux Process Control Block
- Process related System calls
 - Fork
- Process on Distributed OSes

