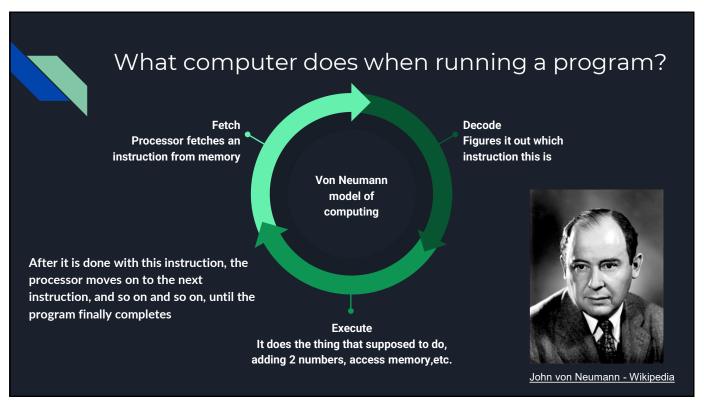


Operating System

- 03603332 Operating System (First semester of 2022)
- Credits: 3 (3 hrs. In class-0 hr in Labs-6 hrs self-study)
- Prerequisites: 03603223 Computer Architecture and Organization
- Course description: Concepts of operating systems. Processes and concurrency.
 Process management and scheduling. Input/output management. Memory management. File systems. Computer systems security.
- Duration : 15 weeks
- Location & date time: 17301 Mon. 16.30-19.30
- MSTEAM code: tml9h8o (This team is the channel for communication between instruction and students, assignments, relevant files, and online meeting.
- Scoring: in-class activities 10%, assignments 20%, project 20%, midterm exam 20%, final exam 20%, class attend 10%
- Grading: A: > 80, B+ to D: based on group of students, F: <40
- Contact: 23617 or korawit@eng.src.ku.ac.th or facebook
- Material: mostly based on <u>Operating Systems: Three Easy Pieces</u> (wisc.edu)







Primary goal of OS (1)

- Sound Simple, right? But in this class we will be learning that while a program runs, a lot of other wild things are going on with the primary goal of making the system **easy to use.**
- There is a body of software that responsible for making it easy to run programs (allowing you to seemingly run many at same time), allowing programs to share memory, enabling programs to interact with devices, and others.
- The body of software is called <u>operating system (OS)</u>, it is in charge of making sure that system operates correctly and efficiently in an easy-to-use manner.

Primary goal of OS (2)

- OS does through a general technique called <u>virtualization</u>,
 OS takes a physical resource (processor, or memory, or a disk) and transforms it into a more general, powerful, and easy-to-use <u>virtual</u> form of itself. Thus we sometimes refer OS as a virtual machine.
- In order to allow users to tell OS what to do and make use of the features of the virtual machine (running a program, or allocation memory, or accessing file), OS provides some interfaces (APIs) you can call. A few hundred system calls, are available to applications, we also sometimes called standard library to applications.

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Primary goal of OS (3)

- Finally because Virtualization allows
 - Many programs to run (CPU sharing)
 - Many programs to concurrently access their own instruction and data (memory sharing)
 - Many programs to access devices (disk sharing and so forth)
- OS sometimes known as a resource manager. CPU, memory, disk is a resource of the system, OS's role to manage those resources efficiently or fairly or indeed with many other possible goals in mind.

Virtualizing CPU (1)

```
#include <stdio.h>
   #include <stdlib.h>
   #include <sys/time.h>
   #include <assert.h>
   #include "common.h"
   main(int argc, char *argv[])
       if (argc != 2) {
10
           fprintf(stderr, "usage: cpu <string>\n");
           exit(1);
12
13
       char *str = argv[1];
       while (1) {
           Spin(1);
           printf("%s\n", str);
17
19
       return 0;
20
```

Figure 2.1: Simple Example: Code That Loops And Prints (cpu.c)

```
prompt> gcc -o cpu cpu.c -Wall
prompt> ./cpu "A"
A
A
^C
prompt>
```

spin(), a function that repeatedly checks the time and return once it has run for a second

ostep-code/intro at master · remziarpacidusseau/ostep-code · GitHub

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Virtualizing CPU (2)

```
prompt> ./cpu A & ./cpu B & ./cpu C & ./cpu D &
[1] 7353
[2] 7354
[3] 7355
[4] 7356
A
В
D
C
A
В
D
C
A
```

Figure 2.2: Running Many Programs At Once

Let's run many different instances of this same program. Even though we have only one processor, somehow all four of these programs seem to be running at the same time! How does this magic happen?

Virtualization CPU (3)

- In turns out that OS and some help from hardware, is in charge of this illusion, system has a very large number of virtual CPUs.
- Turning a single CPU into a seemingly infinite number of CPUs and thus allowing many programs to seemingly run at once in what we call **virtualizing the CPU**, the focus of the first major part of this course.
- Run programs, stop them, otherwise tell the OS which programs to run, there need some interfaces (APIs) that you can use to communicate your desires to OS.
- You might notice the ability to run multiple programs at once raises all sorts of new questions.
 - If two programs want to run at a particular time, which should run? Policy of the OS
 - O We will study them as we learn about the basic mechanisms that OS implement (a resource manager)

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Virtualizing Memory (1)

```
#include <unistd.h>
   #include <stdio.h>
   #include <stdlib.h>
   #include "common.h"
   main(int argc, char *argv[])
       int *p = malloc(sizeof(int));
                                                          // a1
       assert (p != NULL);
       printf("(%d) address pointed to by p: %p\n",
11
              getpid(), p);
                                                          // a2
                                                         // a3
       *p = 0;
13
       while (1) {
14
           Spin(1);
           *p = *p + 1;
           printf("(%d) p: %d\n", getpid(), *p);
                                                         // a4
17
19
       return 0;
20
   }
```

Figure 2.3: A Program That Accesses Memory (mem.c)

```
prompt> ./mem
(2134) address pointed to by p: 0x200000
(2134) p: 1
(2134) p: 2
(2134) p: 3
(2134) p: 4
(2134) p: 5
C
```

Physical memory is just an array of bytes, to read memory, one must specify an address to access the data stored there, to write memory, one must also specify the data to be written to the given address. malloc() is a function to allocate memory.

Virtualizing Memory (2)

```
prompt> ./mem &; ./mem &
[1] 24113
[2] 24114
(24113) address pointed to by p: 0x200000
(24114) address pointed to by p: 0x200000
(24113) p: 1
(24114) p: 1
(24114) p: 2
(24113) p: 2
(24113) p: 3
(24113) p: 3
(24114) p: 3
(24114) p: 4
...

Figure 2.4: Running The Memory Program Multiple Times
```

The result shows that it allocated memory at the same address(0x200000) but each seems to be updating the value independently. Each running program has its own private memory, instead of sharing the same physical memory with other running programs. OS is virtualizing memory (Virtual address space) OS somehow maps onto the physical memory of the machine. Why? who know, I have a reward for

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Concurrency(1)

```
#include <stdio.h>
   #include <stdlib.h>
   #include "common.h"
   #include "common_threads.h"
   volatile int counter = 0;
   int loops;
   void *worker(void *arg) {
       int i;
       for (i = 0; i < loops; i++) {
12
            counter++;
13
14
       return NULL;
15
16
   int main(int argc, char *argv[]) {
18
       if (argc != 2) {
           fprintf(stderr, "usage: threads <value>\n");
19
            exit(1);
21
       loops = atoi(argv[1]);
22
       pthread_t p1, p2;
23
       printf("Initial value : %d\n", counter);
24
25
       Pthread_create(&p1, NULL, worker, NULL);
26
27
       Pthread_create(&p2, NULL, worker, NULL);
       Pthread_join(p1, NULL);
28
       Pthread_join(p2, NULL);
29
30
       printf("Final value
                              : %d\n", counter);
       return 0;
31
  }
32
           Figure 2.5: A Multi-threaded Program (threads.c)
```

Concurrency(2)

```
prompt> gcc -o thread thread.c -Wall -pthread
```

prompt> ./thread 1000
Initial value : 0
Final value : 2000

prompt> ./thread 100000

Initial value : 0

Final value : 143012 // huh??

prompt> ./thread 100000

Initial value: 0

Final value : 137298 // what the??

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Concurrency (3)

- As it turns out, the reason for these odd and unusual outcomes relate to how instructions are executed, which is one at a time.
 Unfortunately, a key part of the program above, where the shared counter is incremented, takes three instructions:
- one to load the value of the counter from memory into a register, one to increment it, and one to store it back into memory.
- Because these three instructions do not execute atomically (all at once), strange things can happen. It is this problem of concurrency that we will address in great detail in the second part of this course

Persistence(1)

- In system memory, data can be easily lost, as devices such as DRAM store values in a volatile manner; when power goes away or the system crashes, any data in memory is lost. Thus, we need hardware and software to be able to store data persistently; such storage is thus critical to any system as users care a great deal about their data.
- The hardware comes in the form of some kind of input/output or I/O device; in modern systems, a hard drive is a common repository for long lived information, although solid-state drives (SSDs) are making headway in this arena as well.
- The software in the operating system that usually manages the disk is called the file system; it is thus responsible for storing any files the user creates in a reliable and efficient manner on the disks of the system.

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Persistence(2)

```
#include <stdio.h>
  #include <unistd.h>
   #include <assert.h>
   #include <fcntl.h>
   #include <sys/types.h>
   int main(int argc, char *argv[]) {
       int fd = open("/tmp/file", O_WRONLY|O_CREAT|O_TRUNC,
8
                       S_IRWXU);
       assert (fd > -1);
       int rc = write(fd, "hello world\n", 13);
11
       assert (rc == 13);
12
       close (fd);
13
       return 0;
14
15
              Figure 2.6: A Program That Does I/O (io.c)
```

Persistence(3)

- To understand this better, let's look at some code. Figure 2.6 presents code to create a file (/tmp/file) that contains the string "hello world".
- To accomplish this task, the program makes three calls into the operating system.
 - The first, a call to open(), opens the file and creates it;
 - the second, write(), writes some data to the file;
 - o the third, close(), simply closes the file thus indicating the program won't be writing any more data to it.
- These system calls are routed to the part of the operating system called the file system, which then handles the requests and returns some kind of error code to the user.

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Persistence(4)

- The file system has to do a fair bit of work: first figuring out where on disk this new data will reside, and then keeping track of it in various structures the file system maintains.
- Doing so requires issuing I/O requests to the underlying storage device, to either read existing structures or update (write) them.
- As anyone who has written a device driver knows, getting a device to do something on your behalf is an intricate and detailed process.
- It requires a deep knowledge of the low-level device interface and its exact semantics. Fortunately, the OS provides a standard and simple way to access devices through its system calls. Thus, the OS is sometimes seen as <u>a standard library</u>.

Design Goal(1)

- basic goals is to build up some abstractions in order to make the system convenient and easy to use.
- Abstractions are fundamental to everything we do in computer science. Abstraction makes it possible to write a large program by dividing it into small and understandable pieces, to write such a program in a high-level language like C without thinking about assembly, to write code in assembly without thinking about logic gates, and to build a processor out of gates without thinking too much about transistors.
- Abstraction is so fundamental that sometimes we forget its importance, but we won't here; thus, in each section, we'll discuss some of the major abstractions that have developed over time, giving you a way to think about pieces of the OS.

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Design Goal(2)

- One goal in designing and implementing an operating system is to provide high performance;
- another way to say this is our goal is to minimize the overheads of the OS. Virtualization and making the system easy to use are well worth it, but not at any cost; thus, we must strive to provide virtualization and other OS features without excessive overhead.
- These overheads arise in a number of forms: extra time (more instructions) and extra space (in memory or on disk).
- We'll seek solutions that minimize one or the other or both, if possible. Perfection, however, is not always attainable, something we will learn to notice and (where appropriate) tolerate.

Design Goal(3)

- Another goal will be to provide <u>protection</u> between applications, as well as between the OS and applications.
- Because we wish to allow many programs to run at the same time, we want to make sure that the malicious or accidental bad behavior of one does not harm others; we certainly don't want an application to be able to harm the OS itself (as that would affect all programs running on the system).
- Protection is at the heart of one of the main principles underlying an operating system, which is that of isolation; isolating processes from one another is the key to protection and thus underlies much of what an OS must do

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Design Goal(4)

- The operating system must also run non-stop; when it fails, all applications running on the system fail as well. Because of this dependence, operating systems often strive to provide a high degree of **reliability**.
- As operating systems grow evermore complex (sometimes containing millions of lines of code), building a reliable operating system is quite a challenge — and indeed, much of the on-going research in the field

Design Goal(5)

- Other goals make sense: <u>energy-efficiency</u> is important in our increasingly green world;
- <u>security</u> (an extension of protection, really) against malicious applications is critical, especially in these highly-networked times; mobility is increasingly important as OSes are run on smaller and smaller devices.
- Depending on how the system is used, the OS will have different goals and thus likely be implemented in at least slightly different ways. However, as we will see, many of the principles we will present on how to build an OS are useful on a range of different devices.

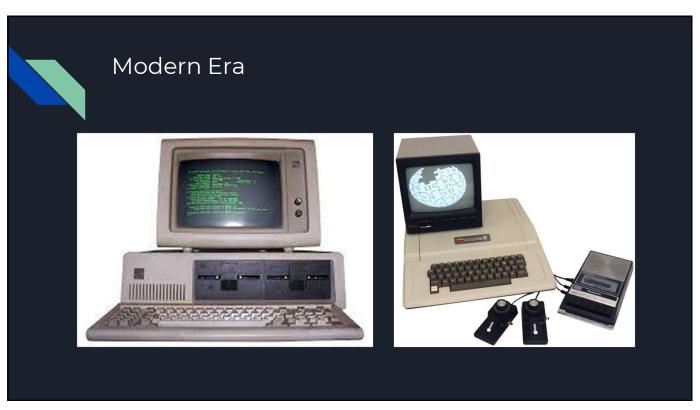
25

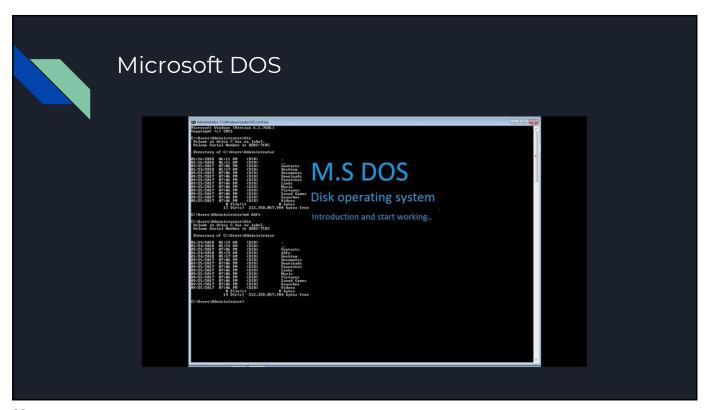
History of OS

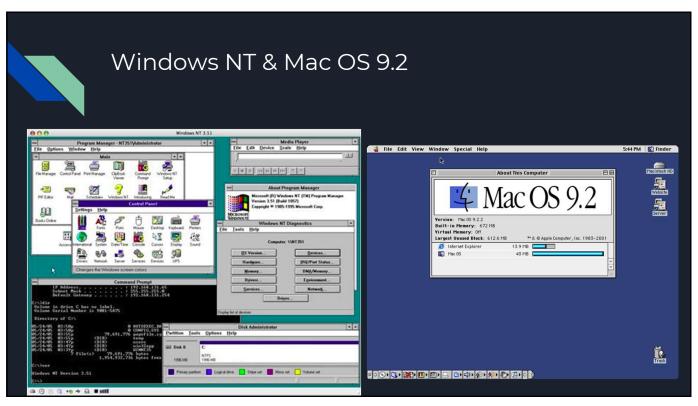
One of the major practical advances of the time was the introduction of the UNIX operating system, primarily thanks to **Ken Thompson** (and Dennis Ritchie) at **Bell Labs** (yes, the phone company). UNIX took many good ideas from different operating systems (particularly from Multics, and some from systems like TENEX and the Berkeley TimeSharing System), but made them simpler and easier to use. Soon this team was shipping tapes containing UNIX source code to people around the world, many of whom then got

involved and added to the system







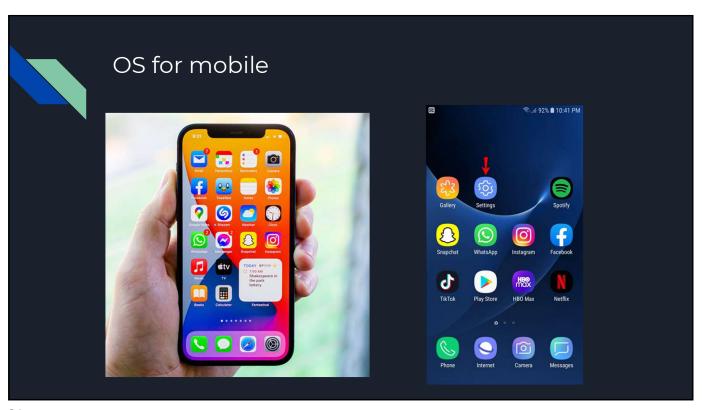


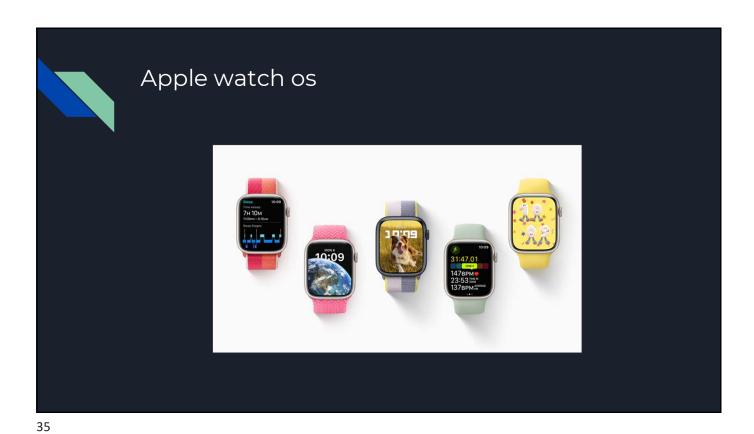












WSL & install Ubuntu on Windows II

Install Ubuntu on WSL2 on Windows 10 | Ubuntu

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Lab notes: install git & git clone

```
korawit@DESKTOP-80IT9FH:~$ git clone https://github.com/remzi-arpacidusseau/ostep-code.git
Cloning into 'ostep-code'...
remote: Enumerating objects: 312, done.
remote: Counting objects: 100% (72/72), done.
remote: Compressing objects: 100% (21/21), done.
remote: Total 312 (delta 57), reused 51 (delta 51), pack-reused 240
Receiving objects: 100% (312/312), 54.28 KiB | 1.70 MiB/s, done.
Resolving deltas: 100% (143/143), done.
korawit@DESKTOP-80IT9FH:~$ dir
ostep-code
korawit@DESKTOP-80IT9FH:~$ cd ostep-code/
korawit@DESKTOP-80IT9FH:~/ostep-code$ cd intro
korawit@DESKTOP-80IT9FH:~/ostep-code/intro$ ls
Makefile README.md common.h common_threads.h cpu.c io.c mem.c threads.c
```

Install Git | Atlassian Git Tutorial

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Install make (1)

```
korawit@DESKTOP-80IT9FH:~/ostep-code/intro$ make

Command 'make' not found, but can be installed with:

sudo apt install make # version 4.2.1-1.2, or
sudo apt install make-guile # version 4.2.1-1.2
```

Install make (2)

```
korawit@DESKTOP-80IT9FH:~/ostep-code/intro$ sudo apt install make
[sudo] password for korawit:
Reading package lists... Done
Building dependency tree
Reading state information... Done
Suggested packages:
 make-doc
The following NEW packages will be installed:
\theta upgraded, 1 newly installed, \theta to remove and \theta not upgraded.
Need to get 162 kB of archives.
After this operation, 393 kB of additional disk space will be used.
Get:1 http://archive.ubuntu.com/ubuntu focal/main amd64 make amd64 4.2.1-1.2 [162 kB]
Fetched 162 kB in 1s (123 kB/s)
Selecting previously unselected package make.
(Reading database ... 31836 files and directories currently installed.)
Preparing to unpack .../make_4.2.1-1.2_amd64.deb ...
Unpacking make (4.2.1-1.2) ...
Setting up make (4.2.1-1.2) ...
Processing triggers for man-db (2.9.1-1) ...
korawit@DESKTOP-80IT9FH:~/ostep-code/intro$
```

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Install gcc

```
korawit@DESKTOP-80IT9FH:~/ostep-code/intro$ sudo apt-get install gcc
Reading package lists... Done
Building dependency tree
Reading state information... Done
The following additional packages will be installed:
  binutils binutils-common binutils-x86-64-linux-gnu cpp cpp-9 gcc-9-gcc-9-base libasan5 libatomic1 libbinutils
libc-dev-bin libc6-dev libcc1-0 libcrypt-dev libctf-nobfd0 libctf0 libgcc-9-dev libgomp1 libisl22 libitm1 liblsan0
  libmpc3 libquadmath0 libtsan0 libubsan1 linux-libc-dev manpages-dev
Suggested packages:
  binutils-doc cpp-doc gcc-9-locales gcc-multilib autoconf automake libtool flex bison gdb gcc-doc gcc-9-multilib
  gcc-9-doc glibc-doc
The following NEW packages will be installed:
  binutils binutils-common binutils-x86-64-linux-gnu cpp cpp-9 gcc gcc-9 gcc-9-base libasan5 libatomic1 libbinutils
  libc-dev-bin libc6-dev libcc1-0 libcrypt-dev libctf-nobfd0 libctf0 libgcc-9-dev libgomp1 libisl22 libitm1 liblsan0
  libmpc3 libquadmath0 libtsan0 libubsan1 linux-libc-dev manpages-dev
0 upgraded, 28 newly installed, 0 to remove and 0 not upgraded.
Need to get 28.5 MB of archives.
After this operation, 123 MB of additional disk space will be used.
Do you want to continue? [Y/n] y
Get:1 http://archive.ubuntu.com/ubuntu focal/main amd64 binutils-common amd64 2.34-6ubuntu1 [207 kB] Get:2 http://archive.ubuntu.com/ubuntu focal/main amd64 libbinutils amd64 2.34-6ubuntu1 [474 kB]
Get:3 http://archive.ubuntu.com/ubuntu focal/main amd64 libctf-nobfd0 amd64 2.34-6ubuntu1 [47.0 kB]
```

```
korawit@DESKTOP-80IT9FH:~/ostep-code/intro$ make
gcc -o cpu cpu.c -Wall
gcc -o mem mem.c -Wall
gcc -o threads threads.c -Wall -pthread
gcc -o io io.c -Wall
korawit@DESKTOP-80IT9FH:~/ostep-code/intro$ dir
Makefile README.md common.h common_threads.h cpu cpu.c io io.c mem mem.c threads threads.c
korawit@DESKTOP-80IT9FH:~/ostep-code/intro$
```

```
korawit@DESKTOP-80IT9FH:~/ostep-code/intro$ ./cpu "A"
A
A
A
A
A
A
A
C
korawit@DESKTOP-80IT9FH:~/ostep-code/intro$
```

```
How to kill processes
korawit@DESKTOP-80IT9FH:~$ ps -ef
           PID PPID C STIME TTY
                                           TIME CMD
            1
                  0 0 08:10 ?
                                       00:00:00 /init
root
root
           143
                      0 08:10 ?
                                       00:00:00 /init
                                                                A
C
D
B
root
                                       00:00:00 /init
           144
                 143 0 08:10 ?
root
                 144
                      0 08:10 pts/0
                                       00:00:01 /mnt/wsl/do
           160
                 143
                                       00:00:00 /init
root
                      0 08:10 ?
korawit
           161
                 160
                      0 08:10 pts/1
                                       00:00:01 docker serv
                                                                ^C
[1]
root
          5086
                      0 15:16 ?
                                       00:00:00 /init
                                                                      Killed
                                                                                              ./cpu A
root
          5087
                5086
                      0 15:16 ?
                                       00:00:00 /init
                                                                [2]
                                                                      Killed
                                                                                              ./cpu B
                5087 0 15:16 pts/3
korawit
          5088
                                       00:00:00 -bash
                                                                [3]-
                                                                      Killed
                                                                                              ./cpu C
                5088 99 15:17 pts/3
                                       00:00:26 ./cpu A
korawit
          5109
                                                                [4]+ Killed
                                                                                              ./cpu D
         5110
                5088 99 15:17 pts/3
                                       00:00:26 ./cpu B
korawit
                                                                korawit@DESKTOP-80IT9FH:~/ostep-code/intro$
korawit
               5088 99 15:17 pts/3
          5111
                                       00:00:26 ./cpu C
                                       00:00:26 ./cpu D
00:00:00 /init
korawit
          5112
                5088 99 15:17 pts/3
root
          5113
                   1 0 15:17 ?
root
          5114
                5113 0 15:17 ?
                                       00:00:00 /init
          5115 5114 0 15:17 pts/2
korawit
                                       00:00:00 -bash
          5128
               5115 0 15:17 pts/2
                                       00:00:00 ps -ef
korawit@DESKTOP-80IT9FH:~$ kill -9 5109 5110 5111 5112
korawit@DESKTOP-80IT9FH:~$
```

```
korawit@DESKTOP-80IT9FH:~/ostep-code/intro$ ./mem 0
(5132) addr pointed to by p: 0x557b5231f2a0
(5132) value of p: 1
(5132) value of p: 2
(5132) value of p: 3
(5132) value of p: 4
(5132) value of p: 4
(5132) value of p: 5
(5132) value of p: 6
(5132) value of p: 7
^C
korawit@DESKTOP-80IT9FH:~/ostep-code/intro$
```

```
Run multiple mem.c
korawit@DESKTOP-80IT9FH:~/ostep-code/intro$ ./mem 0 & ./
  korawit@DESKTOP-80IT9FH:~/ostep-code/intro$ (5133) addr pointed to by p: 0x55675e5752a0
  (5134) addr pointed to by p: 0x55f6388002a0
  (5134) value of p: 1
 (5133) value of p: 1
(5134) value of p: 2
 (5133) value of p: 2
  (5134) value of p: 3
 (5133) value of p: 3
  (5133) value of p: 4
  (5134) value of p: 4
 (5134) value of p: 5
  (5133) value of p: 5
 (5133) value of p: 6
(5134) value of p: 6
(5134) value of p: 7
 (5133) value of p: 7
  (5134) value of p: 8
  (5133) value of p: 8
  ^C
```



```
io.c
           korawit@DESKTOP-80IT9FH:~/ostep-code/intro$ ./io
           korawit@DESKTOP-80IT9FH:~/ostep-code/intro$ cat /tmp/file
           hello world
          korawit@DESKTOP-80IT9FH:~/ostep-code/intro$
```