Introduction

CS 571: Operating Systems (Spring 2021)

Lecture 1

Yue Cheng

Some material taken/derived from:

- Wisconsin CS-537 materials created by Remzi Arpaci-Dusseau.

Introduction

- Instructor
  - Dr. Yue Cheng (web: cs.gmu.edu/~yuecheng)
  - Email: yuecheng@gmu.edu
  - Office hours: Wednesday 1:30pm-2:30pm
  - Research interests: Distributed and storage systems, serverless and cloud computing, operating systems

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  - Dr. Yue Cheng (web: cs.gmu.edu/~yuecheng)
  - Email: yuecheng@gmu.edu
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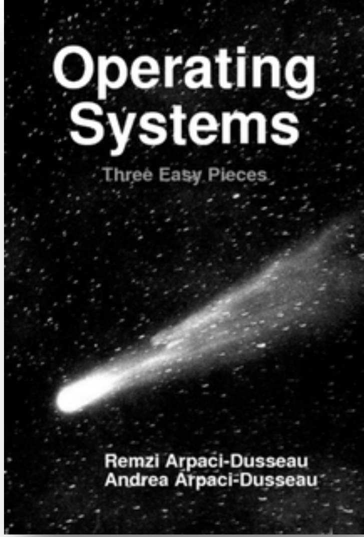
  - Research interests: Distributed and storage systems, serverless and cloud computing, operating systems

- Graduate teaching assistant
  - Michael Crawshaw
  - Email: mcrawsha@masonlive.gmu.edu
  - Office hours:
    - Monday 1:30 – 2:30 pm + Thursday 2:30 – 3:30 pm

Administrivia



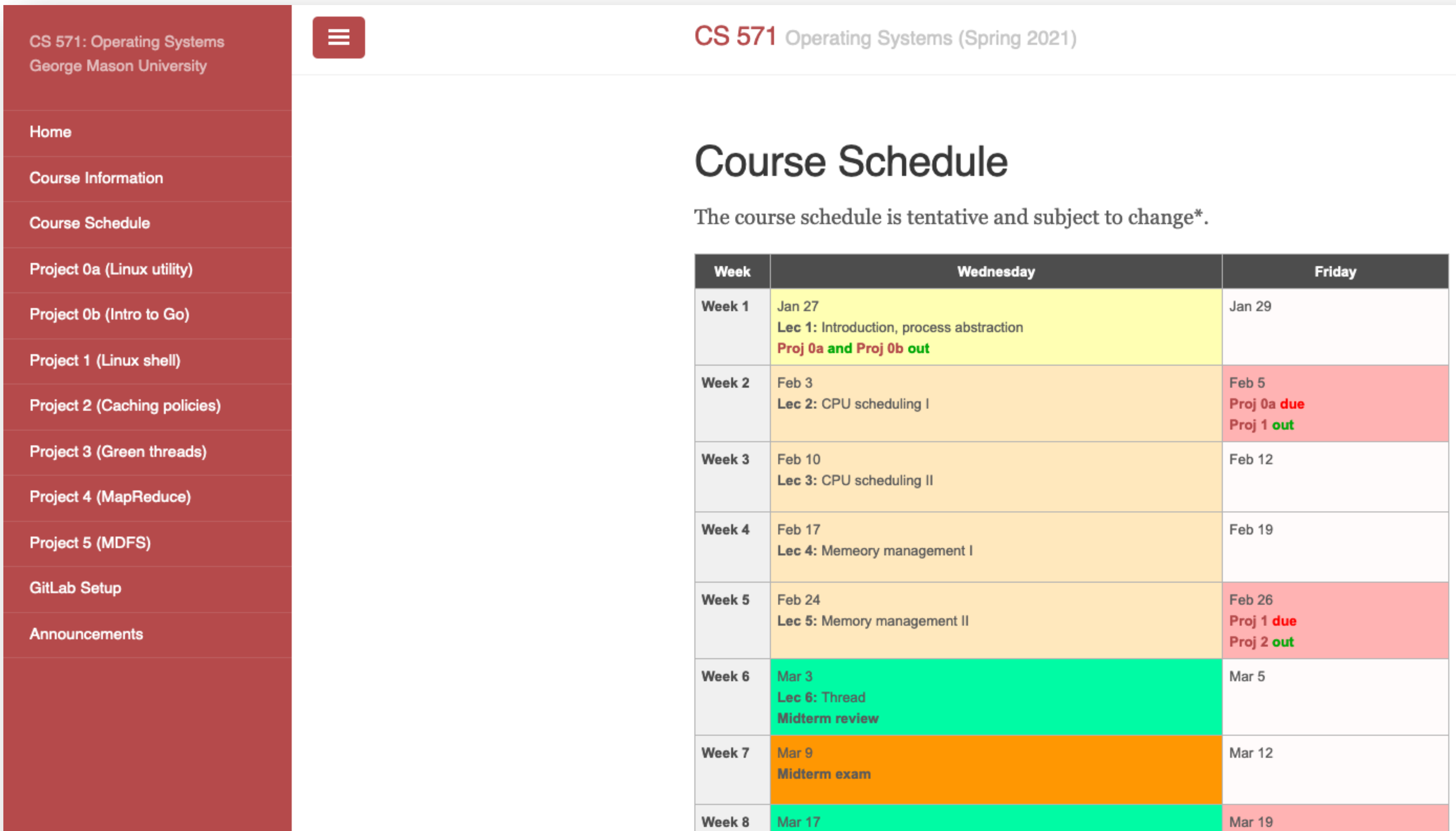
- Required textbook
  - Operating Systems: Three Easy Pieces,
    By Remzi H. Arpaci-Dusseau, Andrea C. Arpaci-Dusseau
- Recommended textbook
  - Operating Systems Principles & Practices
    By T. Anderson and M. Dahlin
- Prerequisites are enforced!!
  - CS 310 Data Structures
  - CS 367 Computer Systems & Programming
  - CS 465 Computer Systems Architecture
  - Be comfortable with C programming language
- Class web page
  - https://tddg.github.io/cs571-spring21/
  - Class materials will all be available on the class web page

Administrivia (cont.)

- Syllabus
  - https://cs.gmu.edu/media/syllabi/Spring2021/CS_571ChengY.html
- Grading
  - 50% projects
  - 10% homework
  - 20% midterm exam
  - 20% final exam
- Reminders
  - Honor code
  - Late policy: 15% deducted each day. No credit after 3 days

Course schedule

- Materials, assignments, due dates



CS 571: Operating Systems
George Mason University

- Home
- Course Information
- Course Schedule
- Project 0a (Linux utility)
- Project 0b (Intro to Go)
- Project 1 (Linux shell)
- Project 2 (Caching policies)
- Project 3 (Green threads)
- Project 4 (MapReduce)
- Project 5 (MDFS)
- GitLab Setup
- Announcements

CS 571 Operating Systems (Spring 2021)

Course Schedule

The course schedule is tentative and subject to change*.

Week	Wednesday	Friday
Week 1	Jan 27 **Lec 1:** Introduction, process abstraction **Proj 0a and Proj 0b out**	Jan 29
Week 2	Feb 3 **Lec 2:** CPU scheduling I	Feb 5 **Proj 0a due** **Proj 1 out**
Week 3	Feb 10 **Lec 3:** CPU scheduling II	Feb 12
Week 4	Feb 17 **Lec 4:** Memeory management I	Feb 19
Week 5	Feb 24 **Lec 5:** Memory management II	Feb 26 **Proj 1 due** **Proj 2 out**
Week 6	Mar 3 **Lec 6:** Thread **Midterm review**	Mar 5
Week 7	Mar 9 **Midterm exam**	Mar 12
Week 8	Mar 17	Mar 19

Course format

- (Review) + lecture + (*worksheets* and/or *demos*)
  - A short overview of the previous lecture to make sure the old content is not completely forgotten
  - Worksheet practices to make sure the lecture is well understood
  - Demos to help you gain a better understanding of the materials taught
    - e.g., OSTEP demos/simulators, tools
  - We will also cover a few seminal research papers on the way
    - ARC, MapReduce

Course projects

- Goals:
  1. To gain hands-on systems programming experience with C
  2. To gain experience building practical distributed systems using Go

Course projects

- Goals:
  1. To gain hands-on systems programming experience with C
  2. To gain experience building practical distributed systems using Go

- Five + one coding projects
  - Project 0a (C warm-up): Linux utilities
  - Project 0b: Intro to Go
  - Project 1: Implement a Linux shell
  - Project 2: Implement and analyze a suite of caching policies
  - Project 3: Implement a user-level green thread library
  - Project 4: Implement a MapReduce framework using Go
  - Project 5 (*extra credits*): Implement a Mason Distributed File System (MDFS) using Go

Course projects

- Goals:
  1. To gain hands-on systems programming experience
  2. To gain experience hacking a moderately sized system codebase (OS/161)

- Five + one coding projects (50%+3%+7%)
  - Project 0a (C warm-up): Linux utilities – 5%
  - Project 0b: Intro to Go – 5%
  - Project 1: Implement a Linux shell – 10%
  - Project 2: Implement and analyze a suite of caching policies – 10%+3%
  - Project 3: Implement a user-level green thread library – 10%
  - Project 4: Implement a MapReduce framework using Go – 10%
  - Project 5 (*extra credits*): Implement a Mason Distributed File System (MDFS) using Go – 7%

Homework assignments

- Three written homework assignments
  - Assignment 0 (getting you prepared: 0%)
  - Assignment 1 before the midterm (5%)
  - Assignment 2 after the midterm (5%)

Getting help

- My office hours
  - Wednesday 1:30 pm – 2:30 pm, on Zoom
- Michael's office hours
  - Monday 1:30 – 2:30 pm + Thursday 2:30 – 3:30 pm
- Piazza
  - Good place to ask and answer questions
    - About project and materials from lectures
  - No anonymous posts or questions
  - You are highly encouraged to answer questions posted by your classmates
  - Setting expectation: Michael and I will monitor/respond to Piazza 1-2 times per day in a burst of activity

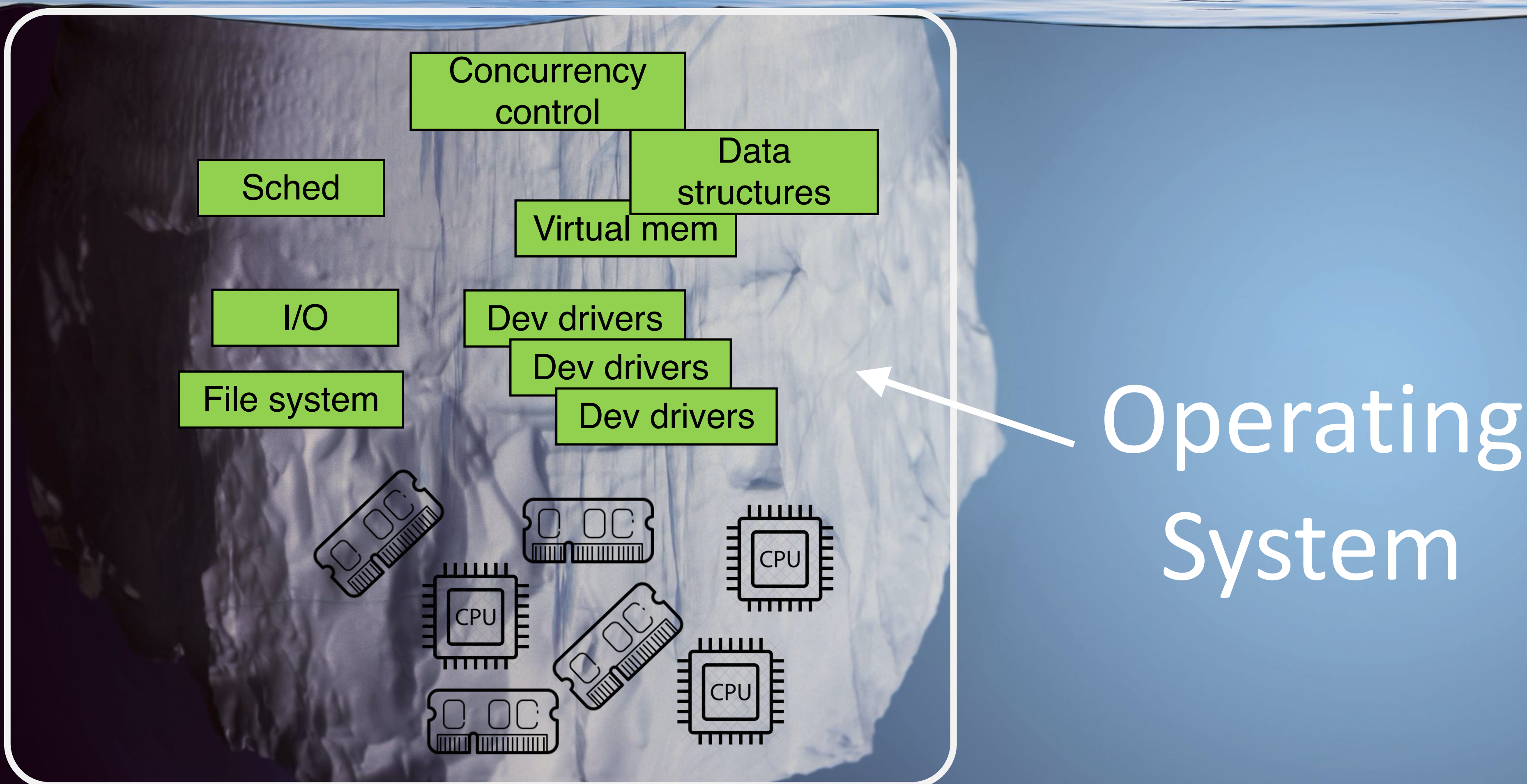
What is an OS?

What is an OS?

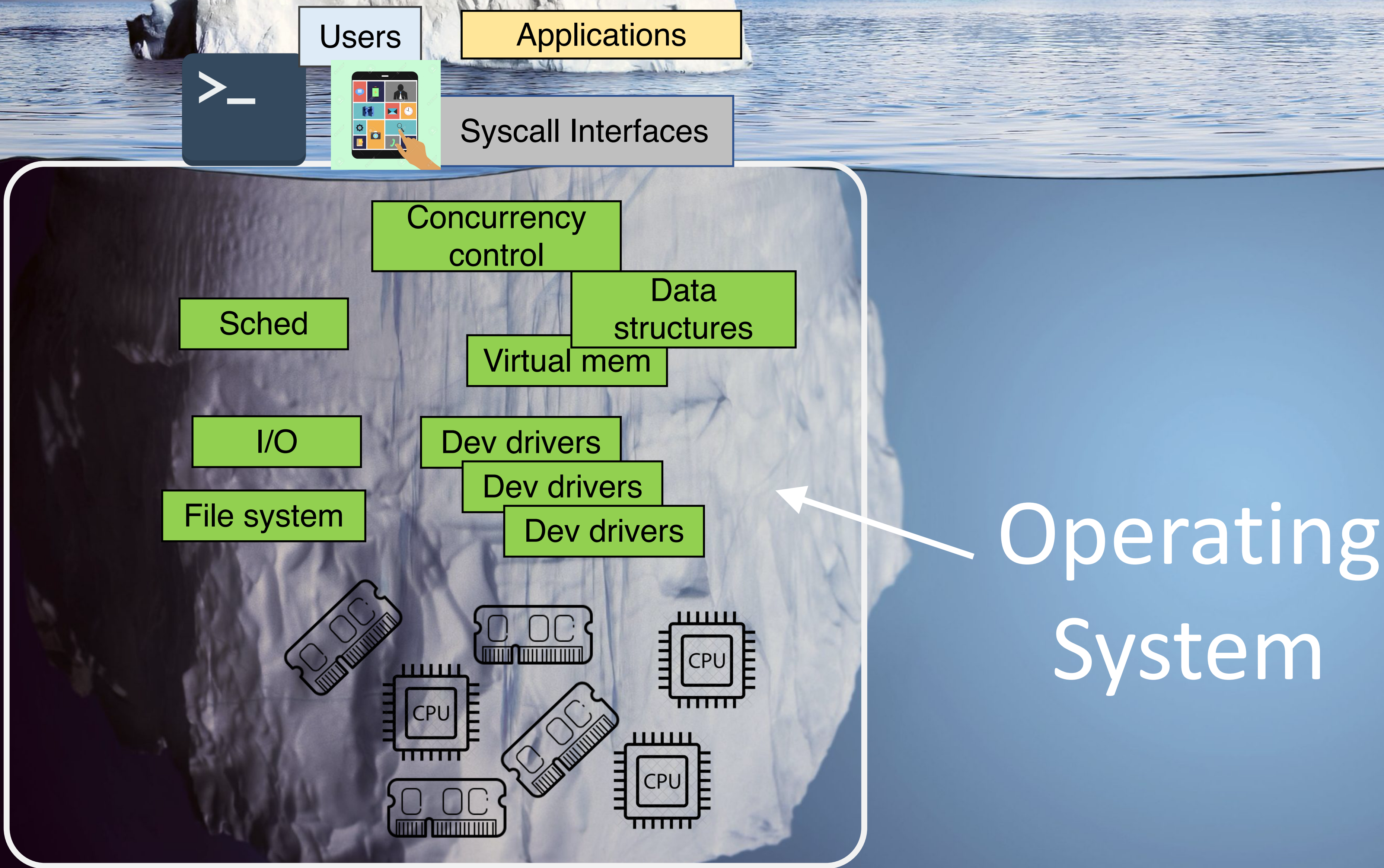
- OS manages resources
  - Memory, CPU, storage, network
  - Data (file systems, I/O)
- Provides low-level abstractions to applications
  - Files
  - Processes, threads
  - Virtual machines (VMs), containers
  - …

OS abstracts away low-level details

OS abstracts away low-level details



OS abstracts away low-level details



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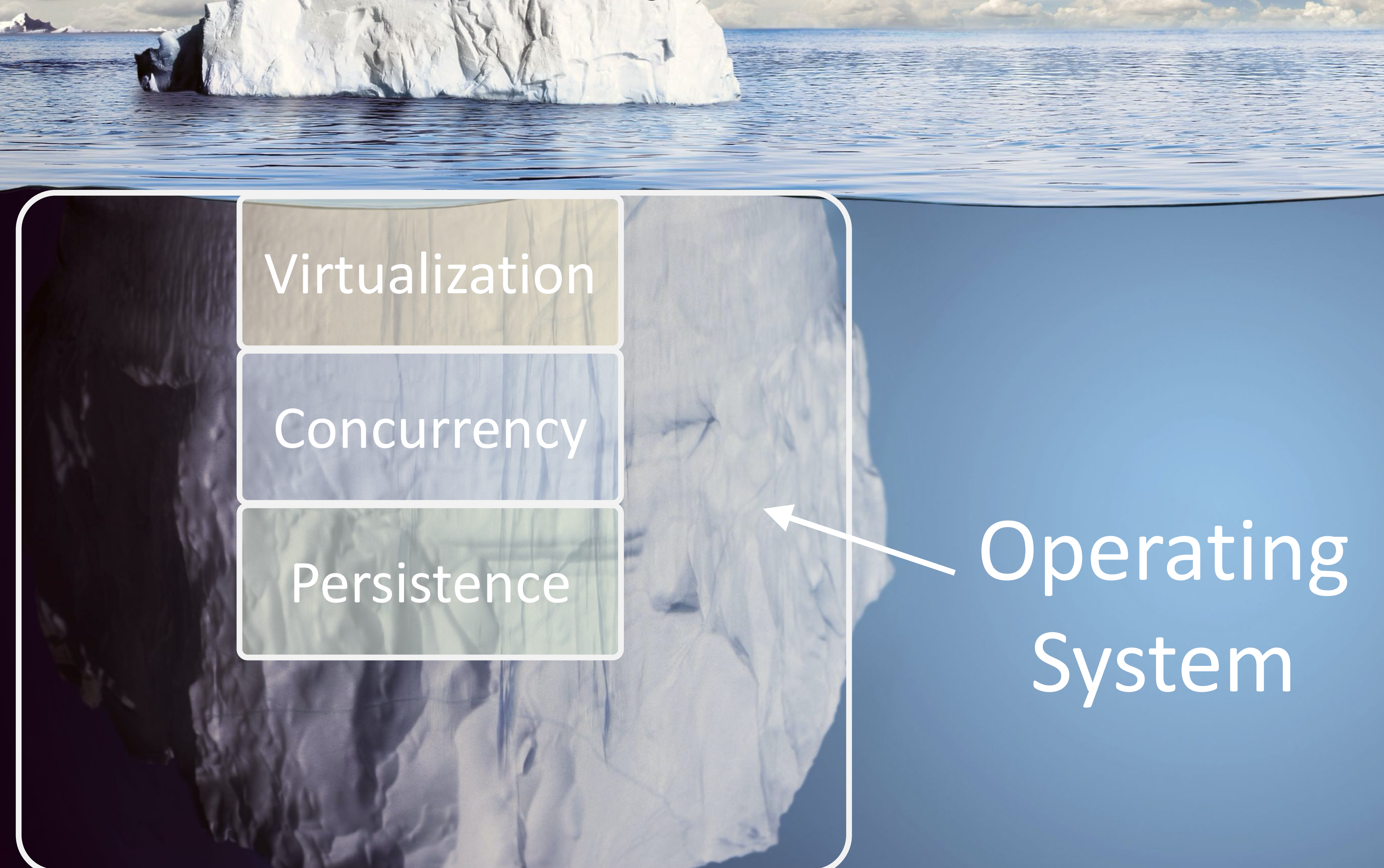
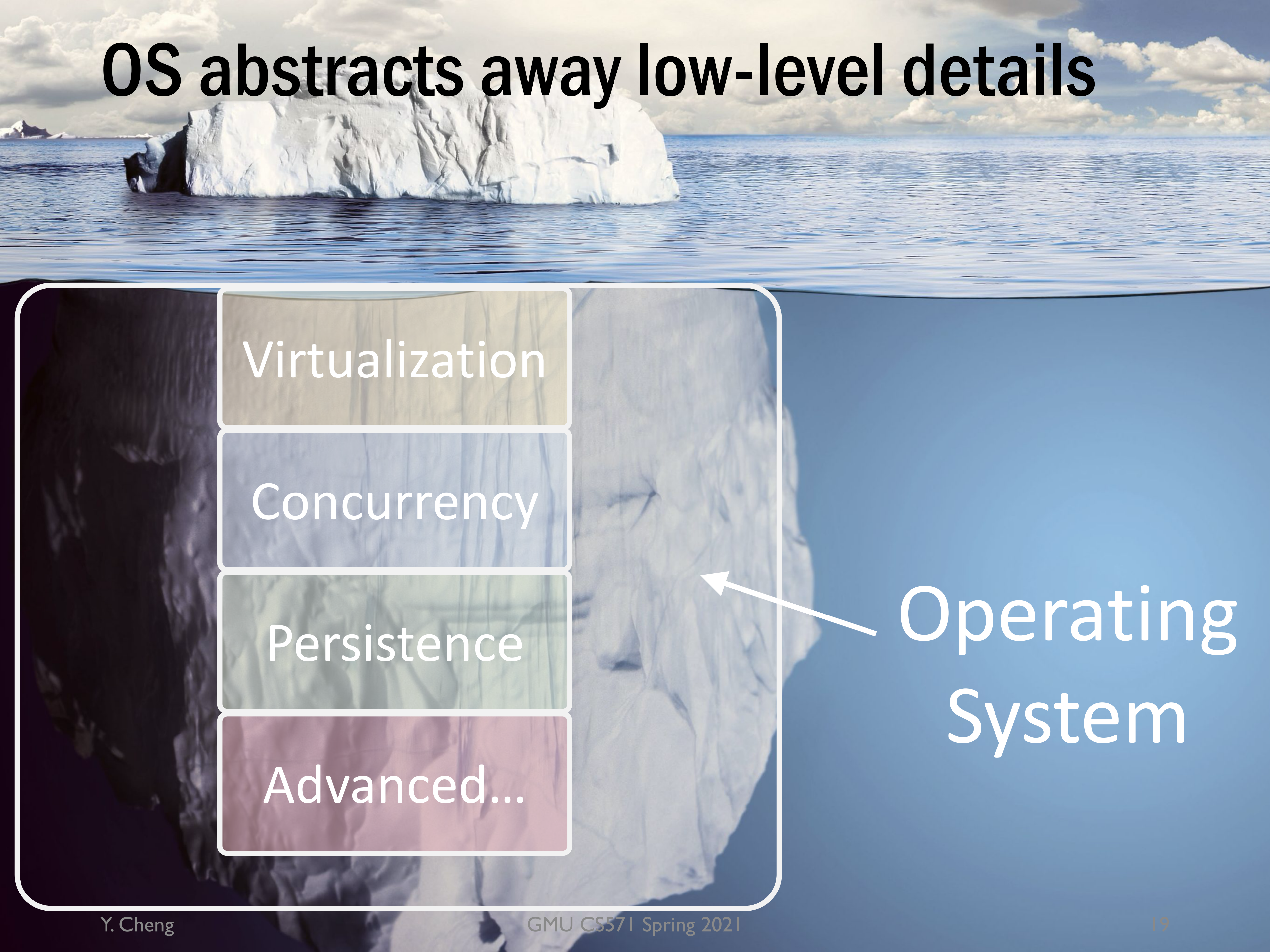


OS abstracts away low-level details



What happens when a program runs?

- A running program executes instructions
    1. The processor **fetches** an instruction from memory
    2. **Decode**: Understand which instruction it is
    3. **Execute**
    4. The processor moves on to **the next instruction** and so on

How does a running program interact with the OS?

- System calls allow a user application to tell the OS what to do
  - OS provides interfaces (APIs)
  - Hundreds of system calls (for Linux)
    - Run programs
    - Access memory
    - Access devices

Virtualization

- OS virtualizes physical resources
  - Gives illusion of private resources

Virtualizing the CPU

- OS creates and manages many virtual CPUs
  - Turning a single CPU into seemingly infinite number of CPUs
  - Allowing many programs to seemingly run at once (concurrently)

Demo

Virtualizing memory

- The physical memory is an array of bytes
- A program keeps (most of) its data in memory
  - Read memory (load): Access an address to fetch the data
  - Write memory (store): Store the data to a given address

Demo

Virtualizing memory (cont.)

- Each process access its own private **virtual address space**
  - OS maps address space onto the physical memory
  - A memory reference from a running program **does not affect** the address space of other processes
  - Physical memory is a **shared resource** managed by OS

Concurrency

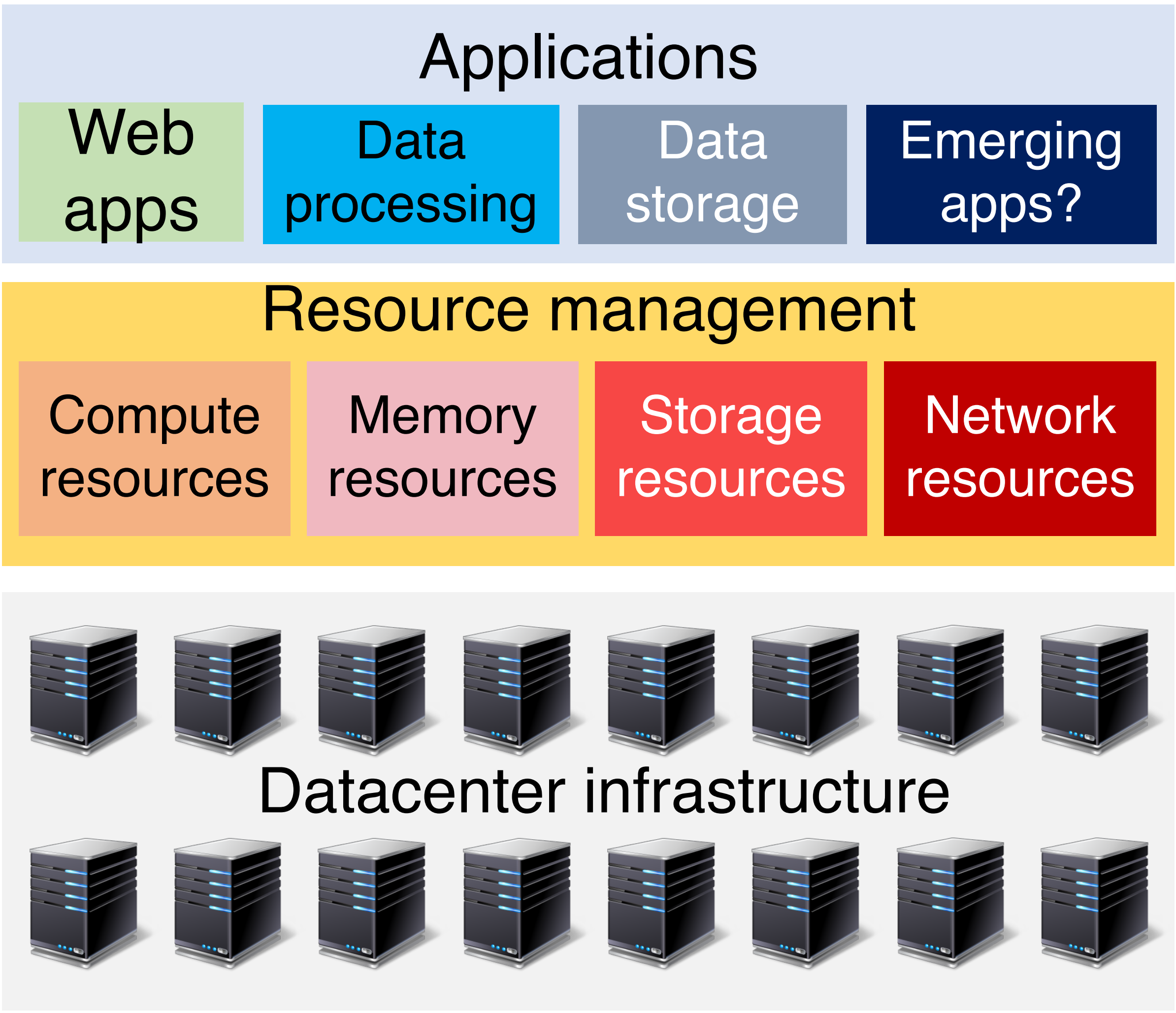
- OS is juggling many things at once
  - First running one process, then another, and so forth
- Multi-threaded programs also have concurrency problem

Demo

Persistence

- Main memory (DRAM) is volatile
- How to persist data?
  - Hardware: I/O devices such as hard disk drives (HDDs)
  - Software: File systems

Advanced topics – Distributed systems



Design goals

- Build up **abstraction**
  - Make the system easy to use
- Provide high **performance**
  - Minimize the overhead of OS
  - Virtualization **w/o excessive overhead**
- **Protection** between applications
  - **Isolation**: Bad behavior of one does not harm others and the OS itself

Why do you take this course?

General learning goals

1. Grasp basic knowledge about Operating Systems and Computer Systems software
2. Learn important systems concepts in general
   - Multi-processing/threading
   - Concurrency and synchronization
   - Scheduling
   - Caching, memory, storage
   - RPC, MapReduce
   - And more…
3. Gain hands-on experience in writing/hacking/designing moderately large systems software

Why do you take this course?

- The OS concepts are everywhere
  - Fundamental OS techniques broadly generalize to widely-used systems technique
    - Scheduling
    - Concurrency
    - Memory management
    - Caching
    - …

What is a process?

What is a process?

- Programs are code (static entity)
- Processes are running programs

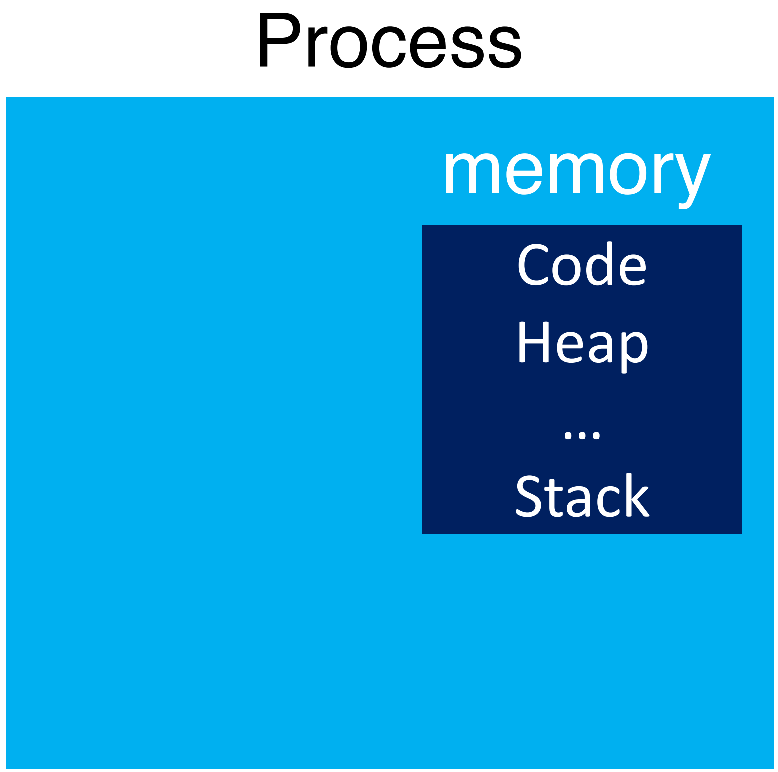
- Java analogy
  - class -> “program”
  - object -> “process”

What is in a process?

Process

What things change as a program runs?

What is in a process?



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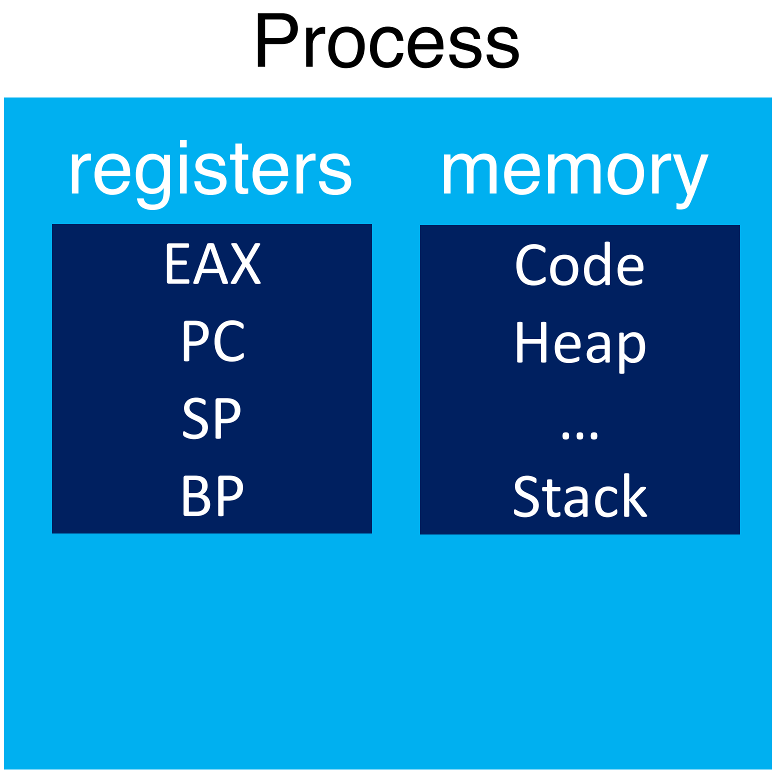

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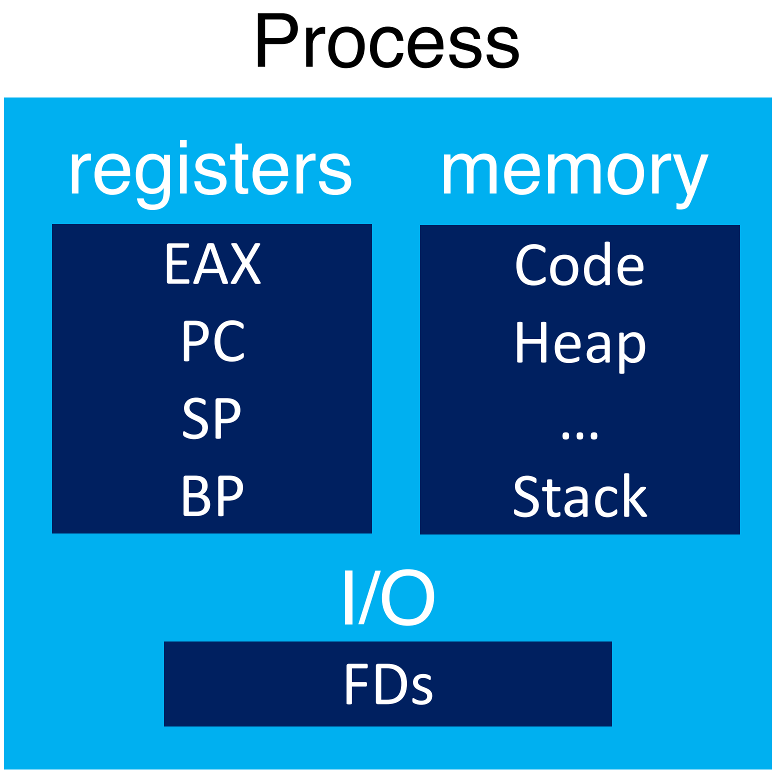


What things change as a program runs?

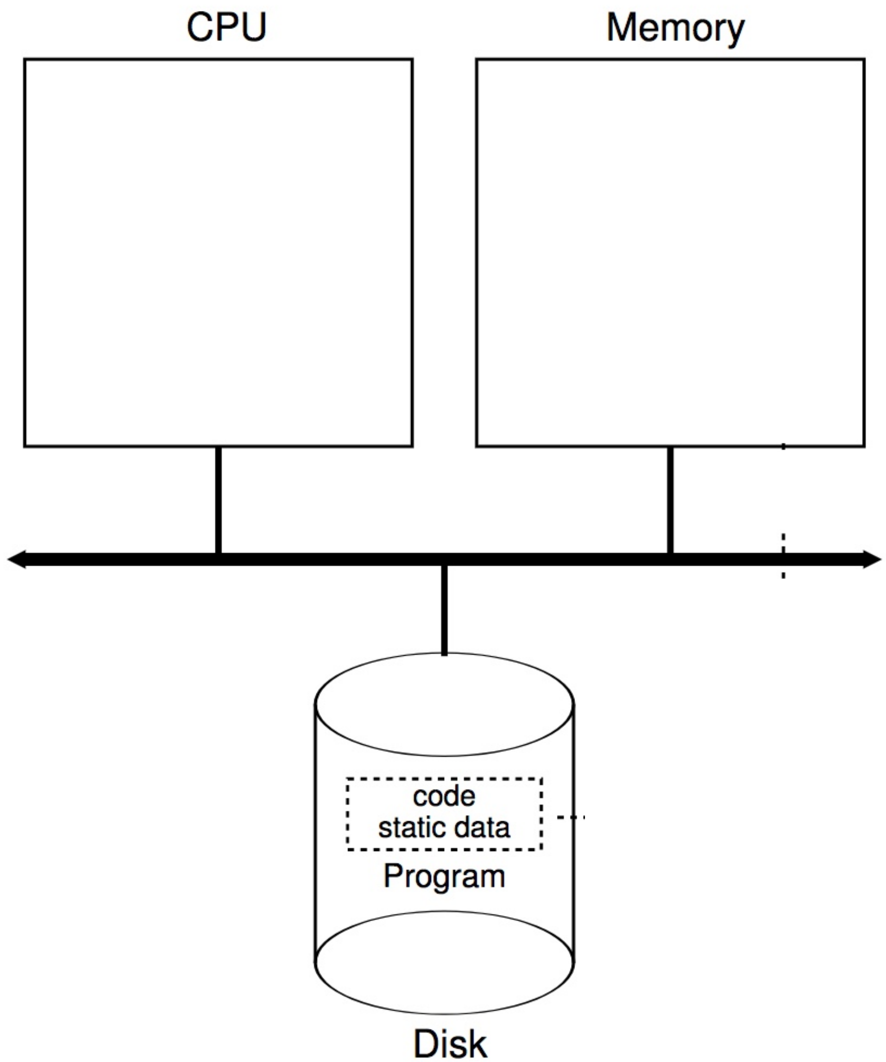
Peeking inside

- Processes share code, but each has its own "context"
- CPU
  - Instruction pointer (Program Counter)
  - Stack pointer
- Memory
  - Set of memory addresses ("address space")
  - `cat /proc/<PID>/maps`
- Disk
  - Set of file descriptors
  - `cat /proc/<PID>/fdinfo/*`

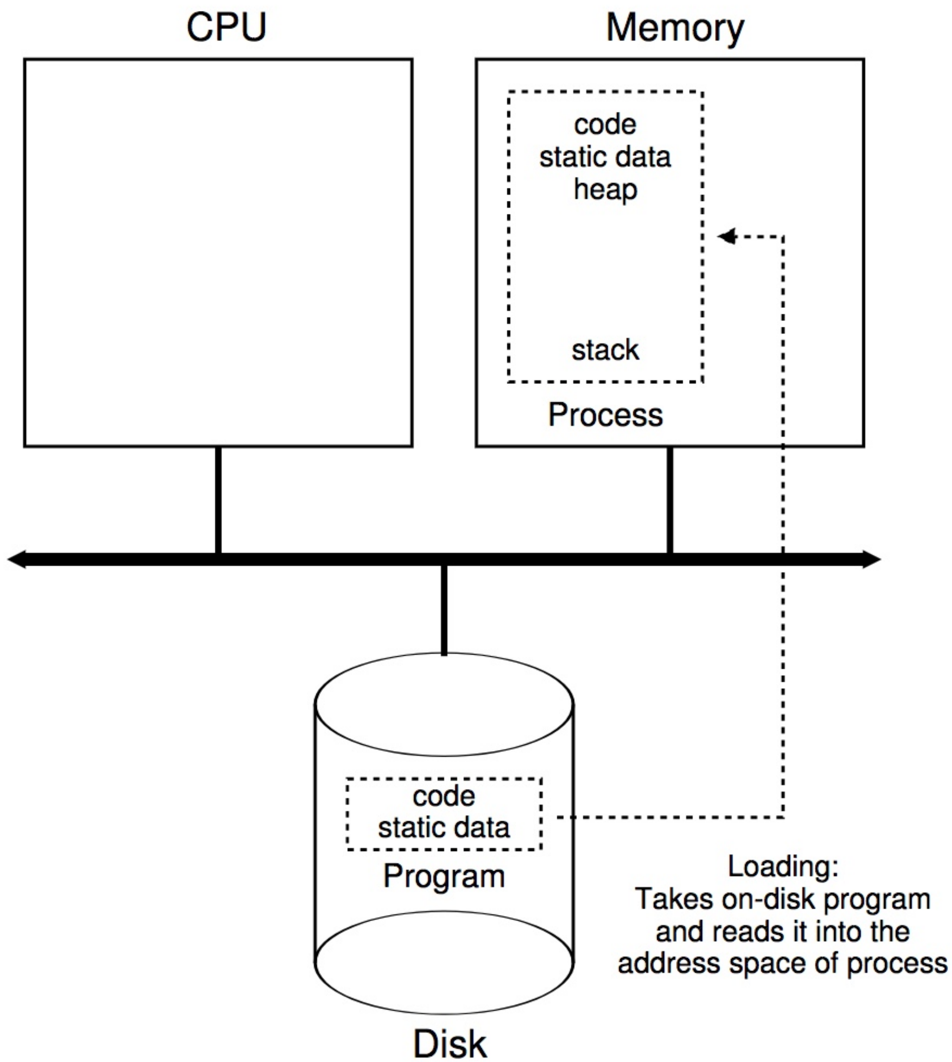
Process creation

- Principal events that cause process creation
  - System initialization
  - Execution of a process creation system call by a running process
  - User request to create a process

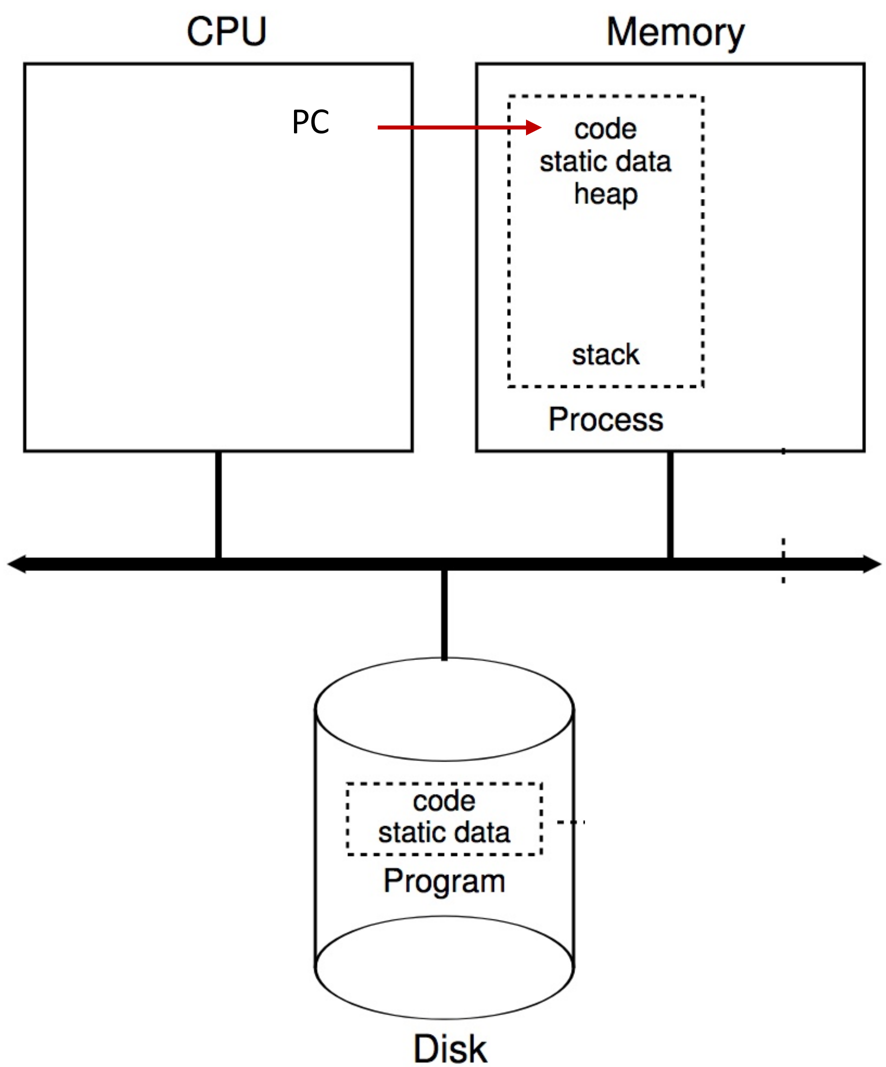
Process creation



Process creation



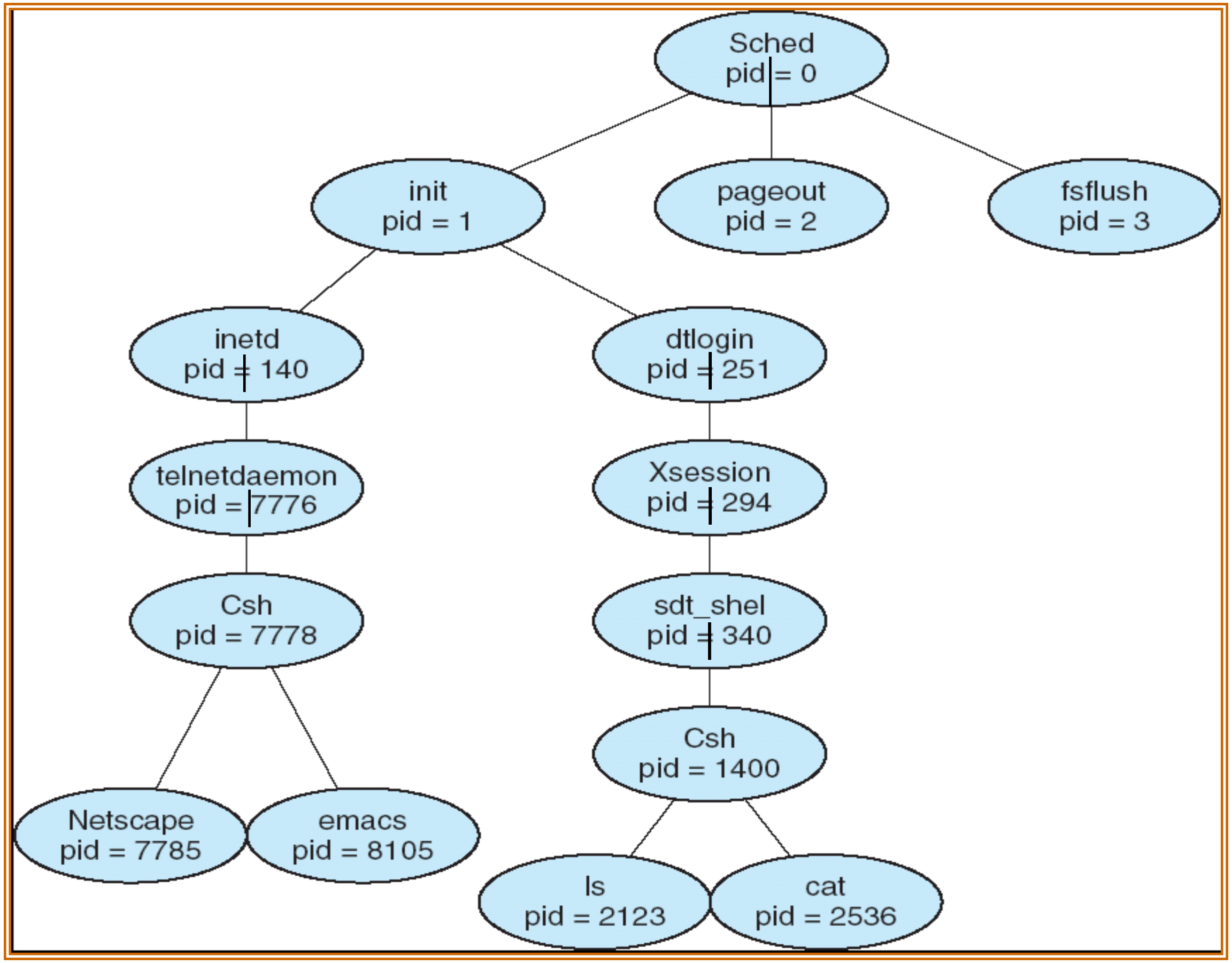
Process creation



Process creation (cont.)

- Parent process creates children processes, which, in turn create other processes, forming a tree (hierarchy) of processes

An example process tree



How to view process tree in Linux?

- `% ps auxf`
  - ‘`f`’ is the option to show the process tree

- `% pstree`

Process creation (cont.)

- Parent process creates children processes, which, in turn create other processes, forming a tree (hierarchy) of processes

- Questions:
  - Will the parent and child execute concurrently?
  - How will the address space of the child be related to that of the parent?
  - Will the parent and child share some resources?

Process creation in Linux

- Each process has a process identifier (pid)
- The parent executes `fork()` system call to spawn a child
- The child process has a separate copy of the parent's address space

  - Both the parent and the child continue execution at the instruction following the `fork()` system call
  - The return value for the `fork()` system call is
    - zero value for the new (child) process
    - non-zero pid for the parent process
  - Typically, a process can execute a system call like `execvp()` to load a binary file into memory

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Simply the return value of fork() in the context of the new child proc

This is the pid of the child process

The man page of fork()

http://man7.org/linux/man-pages/man2/fork.2.html

RETURN VALUE top

On success, the PID of the child process is returned in the parent, and 0 is returned in the child. On failure, -1 is returned in the parent, no child process is created, and *errno* is set appropriately.

ERRORS top

EAGAIN A system-imposed limit on the number of threads was encountered. There are a number of limits that may trigger this error:

* the **RLIMIT_NPROC** soft resource limit (set via setrlimit(2)), which limits the number of processes and threads for a real user ID, was reached;

* the kernel's system-wide limit on the number of processes and threads, */proc/sys/kernel/threads-max*, was reached (see proc(5));

* the maximum number of PIDs, */proc/sys/kernel/pid_max*, was reached (see proc(5)); or

* the PID limit (*pids.max*) imposed by the cgroup "process number" (PIDs) controller was reached.

A new system call: execvp()

- `execvp()` effectively reboots a process to run a different program from scratch
- `execvp()` has many variants (`execle`, `execlp`, and so forth. Type `man execvp` to see all of them)
- We generally use `execvp()` in this course

Example program with fork()

```
void main () {
  int pid;

  pid = fork();
  if  (pid < 0) {/* error_msg */}
  else if (pid == 0) {  /* child process */
          execl("/bin/ls", "ls", NULL); /* execute ls */
   } else {                    /* parent process */
          /* parent will wait for the child to complete */
          wait(NULL);
          exit(0);
   }
  return;
}
```

A Very simple shell using fork()

```
while (1) {
        type_prompt();
        read_command(cmd);
        pid = fork();
         if  (pid < 0) {/* error_msg */}
         else if (pid == 0) { /* child process */
             execute_command(cmd);
         } else {                /* parent process */
              wait(NULL);
         }
}
```

More example: fork 1

forkexample.c

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

int number = 7;

int main(void) {
    pid_t pid;
    printf("\nRunning the fork example\n");
    printf("The initial value of number is %d\n", number);

    pid = fork();
    printf("PID is %d\n", pid);

    if (pid == 0) {
        number *= number;
        printf("\tIn the child, the number is %d -- PID is %d\n", number, pid);
        return 0;
    } else if (pid > 0) {
        wait(NULL);
        printf("In  the parent, the number is %d\n", number);
    }

    return 0;
}

```

Results

```
./forkexample1

Running the fork example
The initial value of number is 7
 PID is 2137
 PID is 0
         In the child, the number is 49 -- PID is 0
In the parent, the number is 7
```

Further more example: fork 2

forkexample2.c

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

int number = 7;

int main(void) {
    pid_t pid;
    printf("\nRunning the fork example\n");
    printf("The initial value of number is %d\n", number);

    pid = fork();
    printf("PID is %d\n", pid);

    if (pid == 0) {
        number *= number;
        fork();
        printf("\tIn the child, the number is %d -- PID is %d\n", number, pid);
        return 0;
    } else if (pid > 0) {
        wait(NULL);
        printf("In  the parent, the number is %d\n", number);
    }

    return 0;
}
```

Results

./forkexample2

Running the fork example

The initial value of number is 7

PID is 2164

PID is 0

In the child, the number is 49 -- PID is 0

In the child, the number is 49 -- PID is 0

In the parent, the number is 7

execl (or execvp) vs. fork

execlexample.c

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

int number = 7;

int main(void) {
    pid_t pid;
    printf("\nRunning the execl example\n");
    pid = fork();
    printf("PID is %d\n", pid);

    if (pid == 0) {
        printf("\tIn the execl child, PID is %d\n", pid);
        execl("./forkexample2", "forkexample2", NULL);
        return 0;
    } else if (pid > 0) {
        wait(NULL);
        printf("In  the parent, done waiting\n");
    }

    return 0;
}
```

Results

./execlexample
Running the execl example
 PID is 2179
 PID is 0

In the execl child,   PID is 0

Running the fork example
The initial value of number is 7
 PID is 2180
 PID is 0

In the child, the number is 49 -- PID is 0
In the child, the number is 49 -- PID is 0
In the parent, the number is 7
In the parent, done waiting

forkexample2

Today's demo code

- You can fork it here: https://github.com/remzi-arpacidusseau/ostep-code
  - Three easy pieces: under `intro/`
  - Process-related: under `cpu-api/`

Assignment and project

- Assignment 0 (0%):
  - Please sign-up for aws educate
  - Please sign-up for Piazza
  - Please finish the go programming exercise by Week 11
- Project 0 (10%)
  - Project 0a due next Friday, 02/05, end of day
  - Project 0b due (tentatively) on 04/09 – to familiarize yourself with Go