# CS 370: OPERATING SYSTEMS
# [PROCESSES]

**A process in action**
Processes and programs are betrothed
A program's static dormant even
But get it to *execute* and a process materializes

Many a process, have you?
Take turns running
An illusion of *concurrency*

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## Frequently asked questions from the previous class survey

- Privileged instructions
- Interrupts?
- What is a clock? How does it work?
- Traps? Triggered by hardware or software
  - Kernel mode transitions
- User-kernel mode transitions: how expensive? What if they don't occur for some reason? Are there kernel-user mode transitions?
- Why are clock cycles important?
- If files from the OS are in the RAM, when there is a power loss will the files be gone forever?
- What is disk latency? Quantum?

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## Topics covered in this lecture

- Processes
- A process in memory
- Process Control Blocks
- Interrupts & Context switches
- Operations on processes
  - Creation



## Processor exceptions

- A processor exception is a **hardware event** caused by *user program behavior* that causes a transfer of control to the kernel
- A processor exception occurs whenever a process
  - Attempts to perform a privileged instruction
  - Accesses memory outside of its own memory region
  - Causes an arithmetic overflow. E.g., divide-by-zero
  - Accesses a word of memory with a non-aligned address
  - Attempts to write to read-only memory

## User processes can also transition into the kernel voluntarily

- To request that the kernel perform an operation on the user's behalf
- A **system call** is any procedure provided by the kernel that can be called from the user level
  - Examples include system calls to establish a connection to a web server, to send or receive packets over the network, to create or delete files, to read or write data into files, and to create a new user process



## To protect the kernel from misbehaving user programs

- It is key that the hardware transfers control on a system call to a pre-defined address
  - User processes cannot be allowed to jump to arbitrary places in the kernel
- The kernel handles the details of:
  - Checking and copying arguments
  - Performing the operation, and
  - Copying return values back into the process's memory

## System calls provide the illusion that the kernel is simply a set of library routines available to users

- Implementing system calls requires the operating system to define a **calling convention**
- Once the arguments are in the correct format, the user-level program can issue a system call by executing the trap instruction to transfer control to the kernel
- The kernel implement its system calls in a way that **protects itself** from all errors and attacks that might be launched
  - Extreme version of defensive programming: *always* assume that system call parameters are intentionally designed to be as malicious as possible!



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You say, "Goodbye" and I say, "Hello, hello, hello"
I don't know why you say, "Goodbye", I say, "Hello, hello, hello"
I don't know why you say, "Goodbye", I say, "Hello"
Hello, Goodbye: *The Beatles*

## INTERRUPT VECTOR TABLE



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## When an interrupt, processor exception or system call trap occurs …

- How does the processor know what code to run?
- The processor has a special register that points to an area of kernel memory called the **interrupt vector table**
- The hardware determines which device caused the interrupt, if the trap instruction was executed, or what exception condition occurred
  - Thus, the hardware can select the right entry from the interrupt vector table and invoke the appropriate handler
- The format of the interrupt vector table is processor-specific



## The interrupt vector table on the x86

- Entries 0 – 31: are for different types of processor exceptions
  - anything related to arithmetic overflow (e.g.: divide-by-zero, bound ranges, floating point exceptions etc.) and faults (page and segment)
- Entries 32 – 255 are for different types of interrupts
  - Timer, keyboard, etc.
- By convention, entry-**64 points to the system call trap handler**

## What about kernel to user mode transitions? When do these happen?

- New process
- **Resume** after an interrupt, processor exception, or system call
- Switch to a different process
- User-level upcall
  - Most OS provide user programs with the ability to receive *asynchronous* notification of events



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## There are two approaches to improving performance

- Determine component **bottlenecks**
  - Replicate:  Horizontal scaling
  - Improve: Vertical scaling



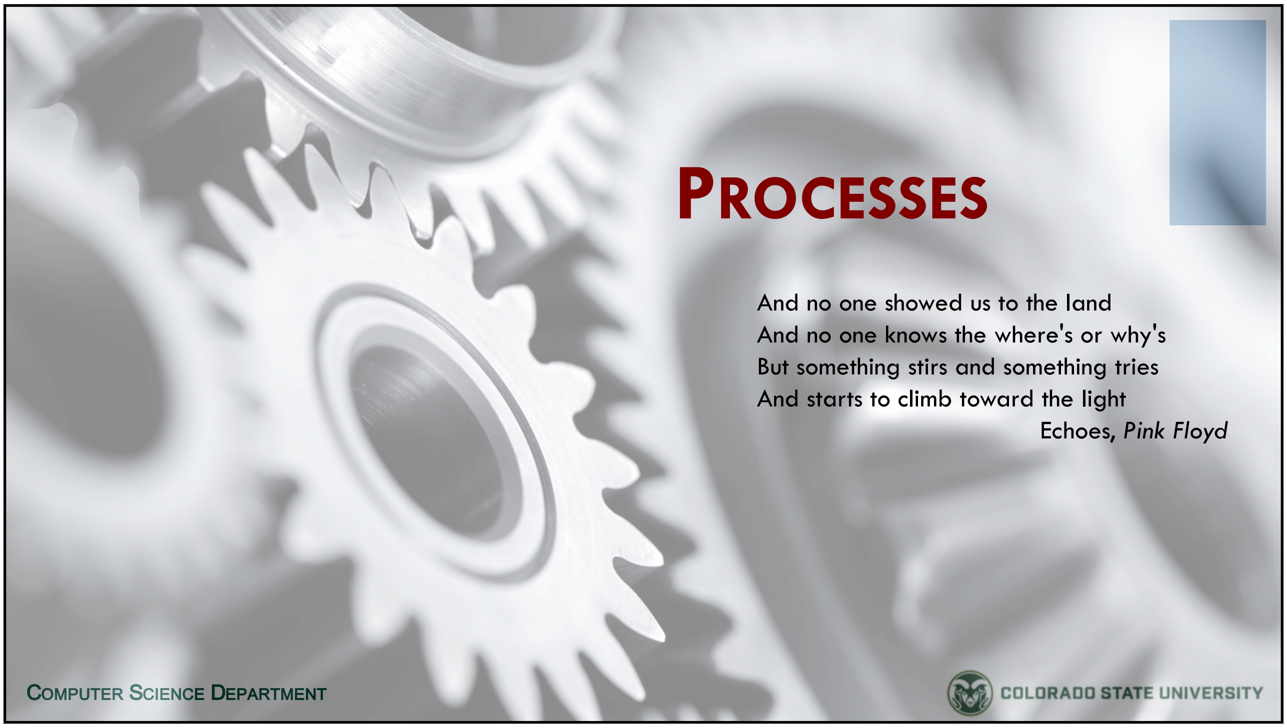
## To replicate or improve?

"*If one ox could not do the job, they* [pioneers] *did not grow a bigger ox, but used two oxen.*"

– Admiral Grace Murray Hopper
Computer Software pioneer

"*If you were plowing a field, which would you rather use? Two strong oxen or 1024 chickens?*"

— Seymour Cray
Computer Hardware pioneer

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## Process

- The oldest and most important abstraction that an operating system provides
- Supports the ability to have (*psuedo*) **concurrent** operation
  - Even if there is only 1 CPU

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## What is a process?

- A process is the **execution** of an application program with restricted rights
  - It is the abstraction for protected execution provided by the kernel



## All modern computers do several things at a time

- Browsing while e-mail client is fetching data
- Printing files while burning a Blu-Ray disc

## Multiprogramming

- CPU **switches** from process-to-process quickly
- Runs each process for a few milliseconds



## Multiprogramming and parallelism

- At any instant of time, the CPU is running **only one** process
- In the course of 1 second, it is working on **several** of them
- Gives the **illusion** of parallelism
  - Psuedoparallelism

## A process is the unit of work in most systems

- Arose out of a need to **compartmentalize** and control *concurrent* program executions
- A process is a program in execution
- Essentially an **activity** of some kind
  - Has a program, input, output, and a state

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## A process is just an instance of a program [1/2]

- In much the same way that an object is an instance of a class in object-oriented programming
- Each program can have zero, one or more processes executing it
- For each instance of a program, there is a process with its *own* copy of the program **in memory**

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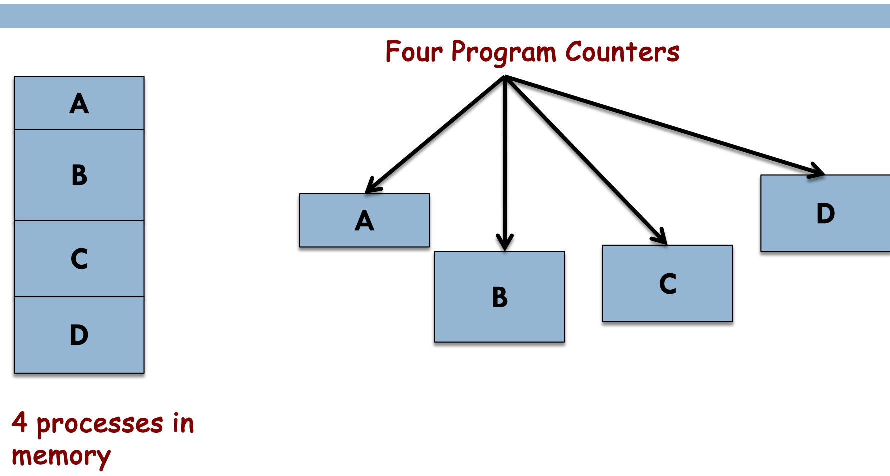
## A process is just an instance of a program [2/2]

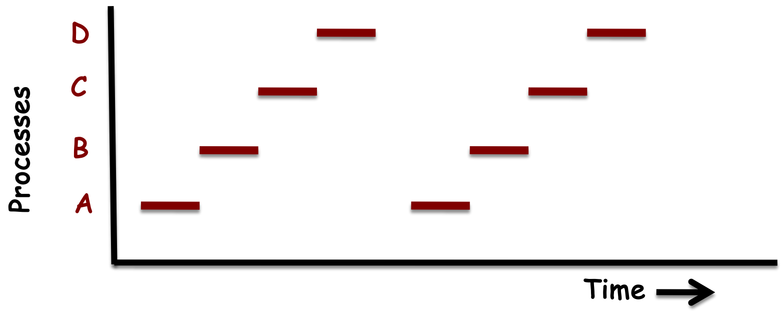
- Conceptually each process has its own **virtual CPU**
- In reality, the CPU switches back-and-forth from process to process
- Processes are <u>not affected</u> by the multiprogramming
  - Or *relative speeds* of different processes



## An example scenario: 4 processes



## Example scenario: 4 processes




- At any instant <u>only one</u> process executes
- *Viewed over a long time*, all processes have made **progress**

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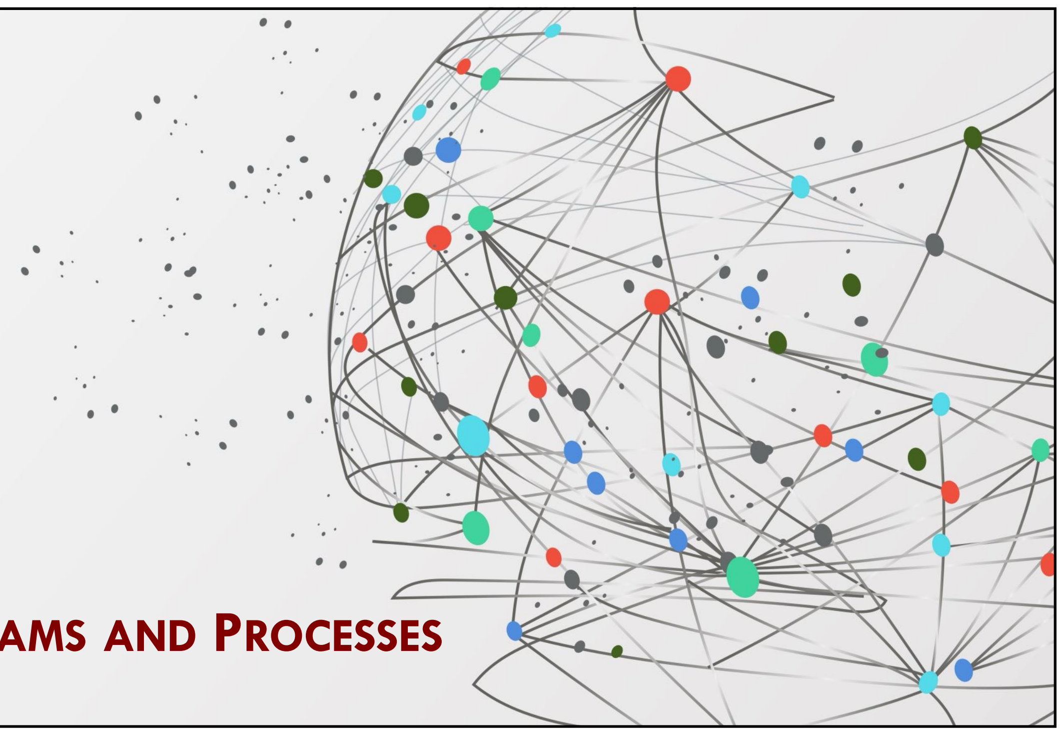

# PROGRAMS AND PROCESSES

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## Programs and processes

- Programs are **passive**, processes are **active**
- The difference between a program and a process is subtle, but crucial





## Analogy of a culinary-minded computer scientist baking cake for his daughter

| Analogy | Mapping to real settings |
|---|---|
| Birthday cake recipe | Program (algorithm expressed in a suitable notation) |
| Well-stocked kitchen: flour, eggs, sugar, vanilla extract, etc | Input Data |
| Computer scientist | Processor (CPU) |

- **Process is the activity of**
  1. Baker reading the recipe
  2. Fetching the ingredients
  3. Baking the cake

## Scientist's son comes in screaming about a bee sting

- Scientist records *where he was* in the recipe
  - State of current process is saved
- Gets out a first aid book, follows directions in it





## In our example, the scientist has switched to a higher priority process …

- FROM Baking
  - Program is the cake recipe
- TO administering medical care
  - Program is the first-aid book
- When the bee sting is taken care of
  - Scientist **goes back to where he was** in the baking

## Key concepts

- Process is an **activity** of some kind; it has a
  - Program
  - Input and Output
  - State
- Single processor may be shared among several processes
  - **Scheduling algorithm** decides when to stop work on one process, and start work on another process



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## HOW A PROGRAM BECOMES A PROCESS



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## The journey from code to a becoming a process [1/2]

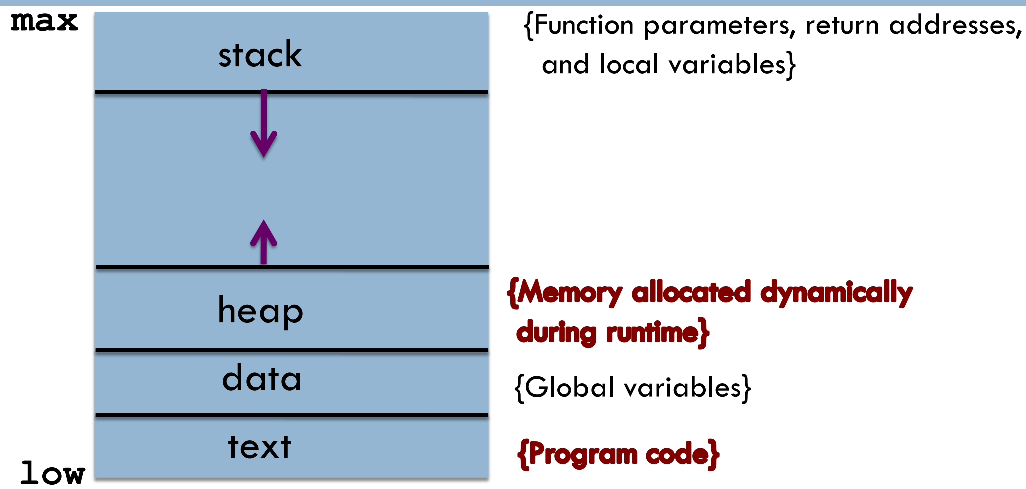
- Programmer types code in some high-level language
- A compiler converts that code into a sequence of machine instructions and stores those instructions in a file
  - Called the program's **executable image**
  - Compiler also defines any static data the program needs, along with its initial values, and includes them in the executable image



## The journey from code to a becoming a process [2/2]

- To run the program, the kernel copies the instructions and data from the executable image into physical memory
- The kernel sets aside memory regions
  - The execution **stack**, to hold local variables during procedure calls
  - The **heap**, for any dynamically allocated data structures the program might need
- Of course, to copy the program into memory, the kernel itself must already be in memory, with its own stack and heap

## A process in memory






## Memory conservation

- Most operating systems reuse memory wherever possible
- The OS stores only a single copy of a program's instructions
  - Even when multiple copies of the program are executed at the same time
- Even so, a **separate copy** of the program's data, heap, and stack are needed

## How a program becomes a process

- Allocation of memory is *not enough* to make a program into a process
- Must have a process ID
- OS tracks IDs and process **state**s to orchestrate system resources



## Program in memory [1/2]

- Program image *appears* to occupy **contiguous** blocks of memory
- OS **maps** programs into non-contiguous blocks

## Program in memory [2/2]

- Mapping divides the program into equal-sized pieces: **pages**
- OS loads pages into memory
- When processor references memory on page
  - OS looks up page in table, and loads into memory



## Advantages of the mapping process

- Allows **large** logical address space for stack and heap
  - **No physical memory used** unless actually needed
- OS hides the mapping process
  - Programmer views program image as **logically contiguous**
  - Some pages may not reside in memory

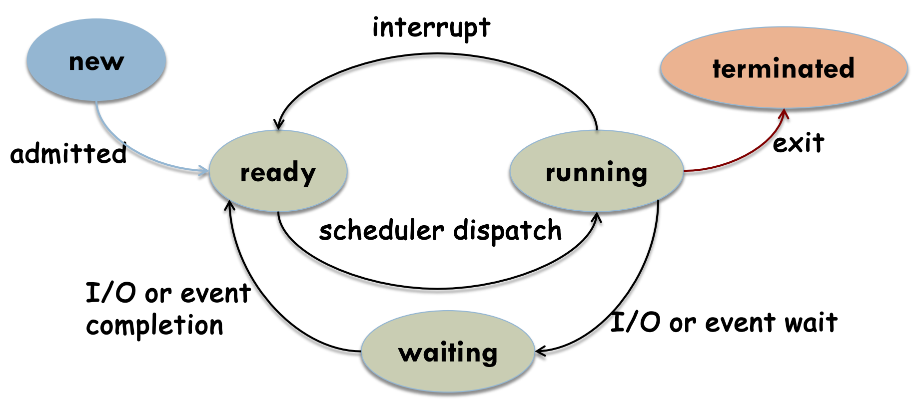
## Finite State Machine

- An initial **state**
- A set of possible **input** events
- A finite number of states
- **Transitions** between these states
- Actions





## Process state transition diagram: When a process executes it changes state

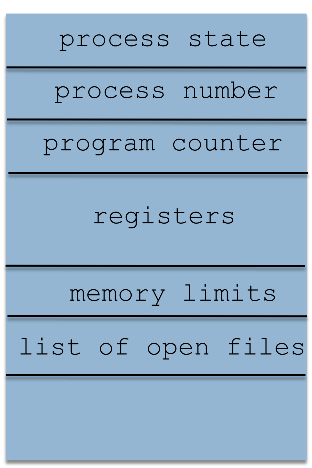


## How does the OS track processes?

- Via a data structure called the **process control block**, or **PCB**
- The PCB stores all the information the OS needs about a particular process
  - Where it is stored in memory, where its executable image resides on disk, which user asked it to execute, what privileges it has, etc.
- The set of the PCBs defines the current state of the OS



## Each process is represented by a process control block (PCB)




PCB is a **repository** for *any* information that *varies* from process to process.

## Where is the PCB stored?

- Since PCB contains the critical information for the process
  - It must be kept in an area of memory protected from normal user access
- Maintained in kernel memory



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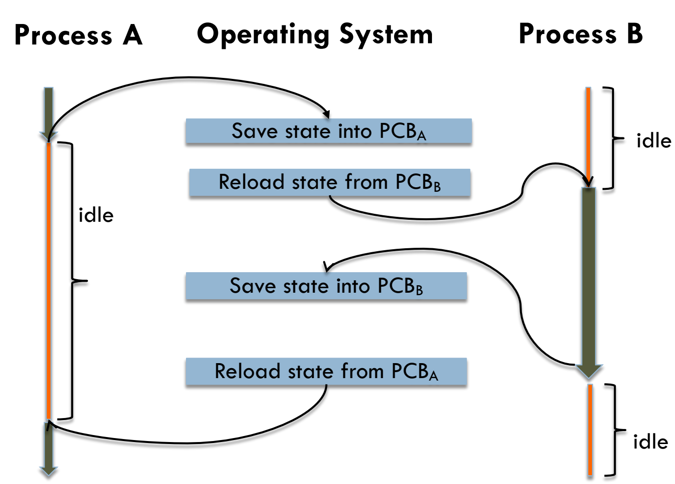
## An example of CPU switching between processes



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## THERE'S AN APP FOR THAT!

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## What can be at the user level, should be.

- Allow user programs to create and manage their own processes
- If creating a process is something a process can do, then anyone can build a new version of any of these applications
  - **Without recompiling the kernel** or forcing anyone else to use it
- Instead of a single program that does everything, we can create specialized programs for each task, and mix-and-match what we need
  - There's an app for that!

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# INTERRUPTS & CONTEXTS



## Interrupts and Contexts

- Interrupt causes the OS to **change** CPU from its current task to run a kernel routine
- Save current context so that ***suspend*** and ***resume*** are possible
- Context is represented in the **PCB**
  - Value of CPU registers
  - Process state
  - Memory management information

## Context switch refers to switching from one process to another

① **Save** state of current process

② **Restore** state of a different process

- Context switch time is pure **overhead**
  - No useful work done while switching





## Factors that impact the speed of the context switch

- Memory speed
- Number of registers to copy
- Special instructions for loading/storing registers
- Memory management: Preservation of address space

## The contents of this slide-set are based on the following references

- *Andrew S Tanenbaum and Herbert Bos. Modern Operating Systems. 4th Edition, 2014. Prentice Hall. ISBN: 013359162X/ 978-0133591620.* [Chapter 2].
- *Thomas Anderson and Michael Dahlin. Operating Systems: Principles and Practice, 2nd Edition. Recursive Books. ISBN: 0985673524/978-0985673529. [Chapters 1-2]*
- *Avi Silberschatz, Peter Galvin, Greg Gagne. Operating Systems Concepts, 9th edition. John Wiley & Sons, Inc. ISBN-13: 978-1118063330.* [Chapter 3]