CS 370: OPERATING SYSTEMS
[INTER PROCESS COMMUNICATIONS]

IPC: Looking to communicate?
Work alongside the kernel
lower those guardrails so
other processes may join the fray

Use shared memory with its intricate setup
for the fastest speed but heed the call for clean up

Message passing is seamless with ease
But duplication causes speed to decrease
IPC: Choose speed or ease but not both

Shrideep Pallickara
Computer Science
Colorado State University

1

Frequently asked questions from the previous class survey

- fork()
  - Where all does it occur? Do parent-child run concurrently?
  - Do children "see" other children?
  - Can fork() return a non-zero id even if a child wasn't created?
  - Is this used only by the OS? Why isn't there something better?
  - What does it mean to be short on resources?
- exec():
  - Why? What if you didn't do it? How does exec() know what to execute?
  - Why wait() for a child? Zombie processes, are these bad? After exec() do the child and parent still share resources?
- Windows
  - Is process creation less efficient?

2

`fork()`: An example output

```
int child_pid = fork();

 if (child_pid == 0) {    // I'm the child process.
     printf("I am process #%d\n", getpid());
     return 0;
 } else {                 // I'm the parent process.
     printf("I am the parent of process #%d\n", child_pid);
     return 0;
 }
```

Possible output:
I am the parent of process 495
I am process 495

Another less likely but still possible output:
I am process 456
I am the parent of process 456

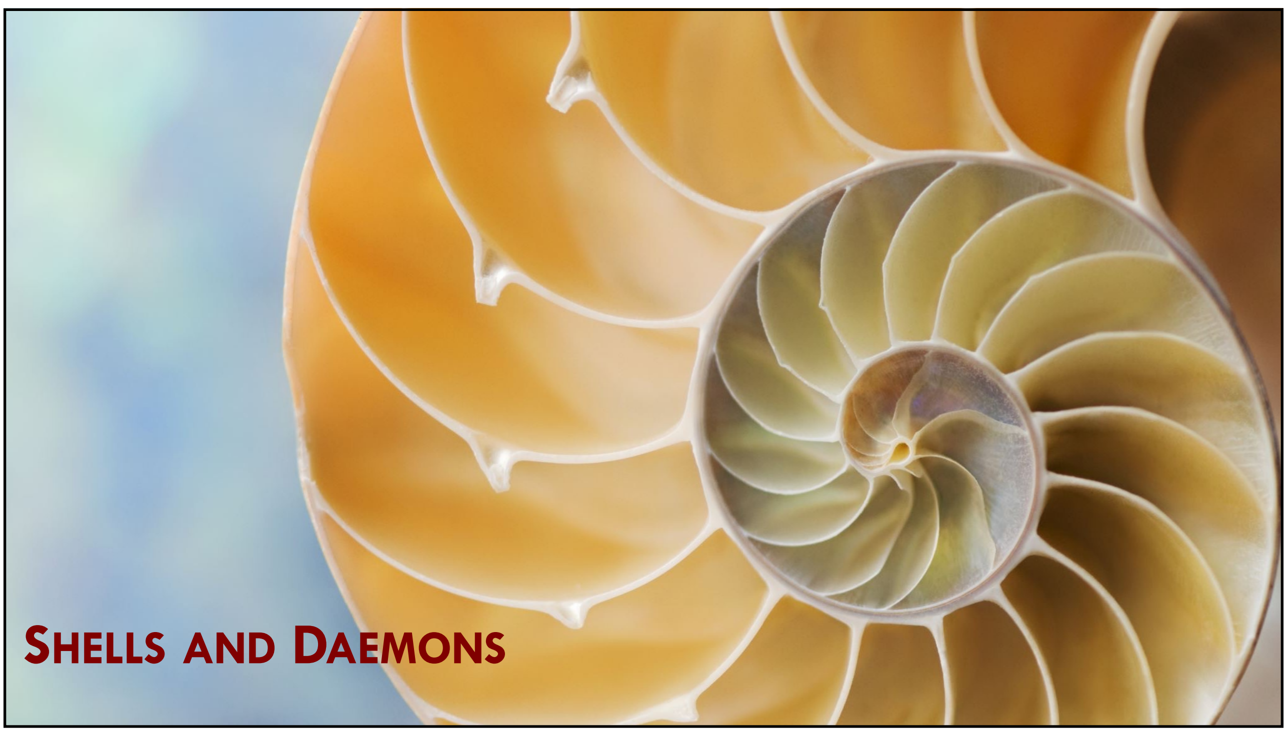
Topics covered in this lecture

- Shells and Daemons
- POSIX
- Inter Process Communications

Nota Bene: Regarding Unix I/O

- The commands to read and write to an open **file descriptor** are the same whether the file descriptor represents a
  - Keyboard
  - Screen
  - File
  - Device
  - Pipe
- UNIX programs do not need to be aware of where their input is coming from, or where their output is going

5



6

Shell: Command interpreter

- Prompts for commands
- Reads commands from standard input
- `fork`s children to execute commands
- Waits for children to finish
- When standard `I/O` comes from terminal
  - Terminate command with the interrupt character
    - Default `Ctrl-C`

? Background processes?

7

Simple Shell

```
main() {
    char *prog = NULL;
    char **args = NULL;

    // Read the input a line at a time, and parse each line into the program
    // name and its arguments. End loop if we've reached the end of the input.
    while (readAndParseCmdLine(&prog, &args)) {

        // Create a child process to run the command.
        int child_pid = fork();

        if (child_pid == 0) {
            // I'm the child process.
            // Run program with the parent's input and output.
            exec(prog, args);
            // NOT REACHED
        } else {
            // I'm the parent; wait for the child to complete.
            wait(child_pid);
            return 0;
        }
    }
}
```

8

Background processes and daemons

- Shell interprets commands ending with **&** as a background process
  - **No waiting** for process to complete
  - Issue prompt immediately
    - Accept new commands
  - `Ctrl-C` has no effect
- **Daemon** is a background process
  - Runs indefinitely

? Servers?

9

POSIX

10

Portable Operating Systems Interface for UNIX (POSIX)

- 2 **distinct**, **incompatible** flavors of UNIX existed
  - System V from AT&T
  - BSD UNIX from Berkeley
- Programs written for one type of UNIX
  - Did not run correctly (sometimes even compile) on UNIX from another vendor
- Pronounced *pahz-icks*

IEEE attempt to develop a standard for UNIX libraries

- **POSIX.1** published in 1988
  - Covered a small subset of UNIX
- In 1994, X/Open Foundation had a much more comprehensive effort
  - Called **Spec 1170**
  - Based on System V
- Inconsistencies between POSIX.1 and Spec 1170

The path to the final POSIX standard

- **1998**
  - Another version of the X/Open standard
  - Many additions to POSIX.1
  - **Austin Group** formed
    - Open Group, IEEE POSIX, and ISO/IEC tech committee
      - International Standards Organization (ISO)
      - International Electrotechnical Commission (IEC)
    - Revise, combine and update standards

The path to the final POSIX standard: Joint document

- Approved by IEEE & Open Group
  - End of 2001
- ISO/IEC approved it in November 2002
- Single UNIX spec
  - Version 3, IEEE Standard 1003.1-2001
  - **POSIX**

If you write for POSIX-compliant systems

- No need to contend with small, but critical variations in library functions
  - Across platforms

COLORADO STATE UNIVERSITY Professor: SHRIDEEP PALLICKARA COMPUTER SCIENCE DEPARTMENT INTER-PROCESS COMMUNICATIONS L5.15

15

16

Independent and Cooperating processes

- Independent: **CANNOT** *affect* or *be affected* by other processes
- Cooperating: **CAN** *affect* or *be affected* by other processes

Why have cooperating processes?

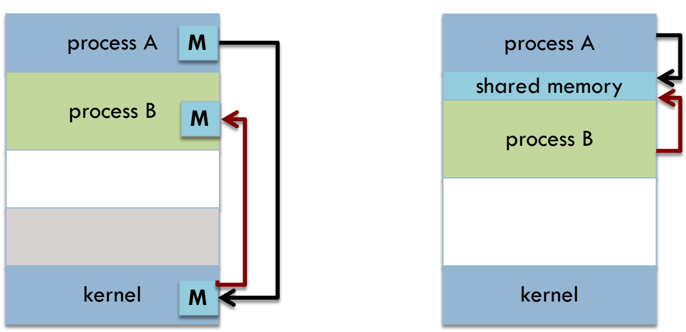
- Information sharing
- Computational speedup
  - Sub tasks for concurrency
- Modularity
- Convenience: Do multiple things in parallel
- Privilege separation

Cooperating processes need IPC to exchange data and information

- **Shared memory**
  - Establish memory region to be shared
  - Read and write to the shared region
- **Message passing**
  - Communications through message exchange

? Which is faster?

Contrasting the two IPC approaches



Easier to implement
Best for **small** amounts of data
Kernel intervention for communications

Maximum **speed**
System calls to **establish** shared memory

Shared memory systems

- Shared memory resides **in** the address space of process creating it
- Other processes must **attach** segment to their address space

Using shared memory

- But the OS typically ***prevents*** processes from accessing each other's memory, so …
  1. Processes must agree to **remove** this ***restriction***
  2. Processes also ***coordinate*** access to this region

Let's look a little closer at cooperating processes

- **Producer-consumer** problem is a good exemplar of such cooperation
- Producer process *produces* information
- Consumer process *consumes* this information

One solution to the producer-consumer problem uses *shared-memory*

- Buffer is a shared-memory region for the 2 processes
- Buffer needed to allow producer & consumer to run **concurrently**
  - Producer fills it
  - Consumer empties it

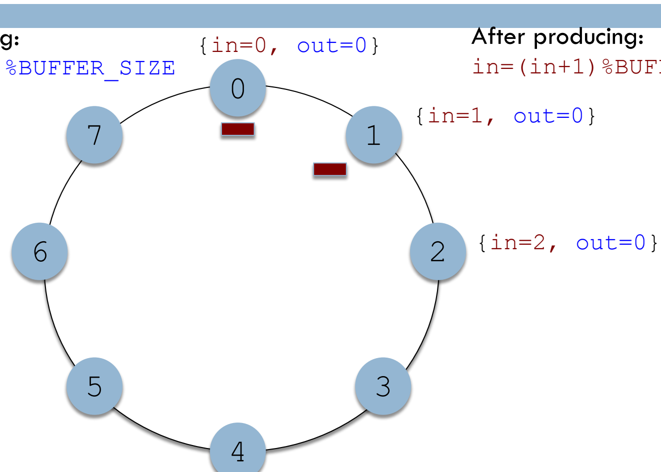
Buffers and sizes

- Bounded: Assume **fixed** size
  - Consumer waits if buffer is empty
  - Producer waits if buffer is full
- Unbounded: **Unlimited** number of entries
  - Only the consumer waits WHEN buffer is empty

Circular buffer: Bounded

After consuming:
`out=(out+1)%BUFFER_SIZE`

After producing:
`in=(in+1)%BUFFER_SIZE`

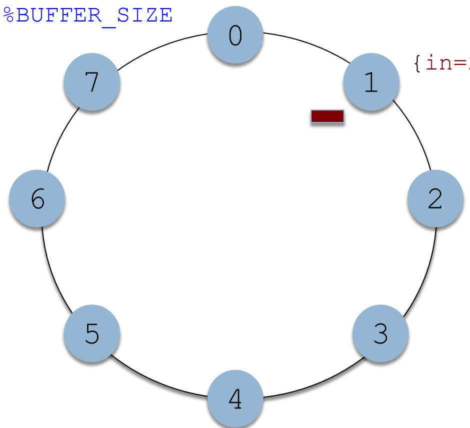


`in`: next free position (producer)
`out`: first full position (consumer)

Circular buffer: Bounded

After consuming:
`out=(out+1)%BUFFER_SIZE`

After producing:
`in=(in+1)%BUFFER_SIZE`



`{in=2, out=1}`

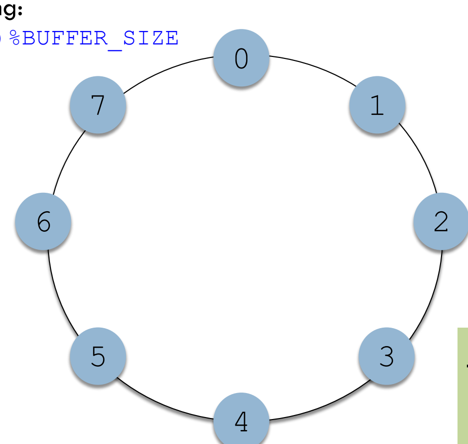
`in`: next free position (producer)
`out`: first full position (consumer)

27

Circular buffer: Bounded

After consuming:
`out=(out+1)%BUFFER_SIZE`

After producing:
`in=(in+1)%BUFFER_SIZE`



`{in=2, out=2}`

<u>After consuming</u>
`in == out`
Buffer is EMPTY

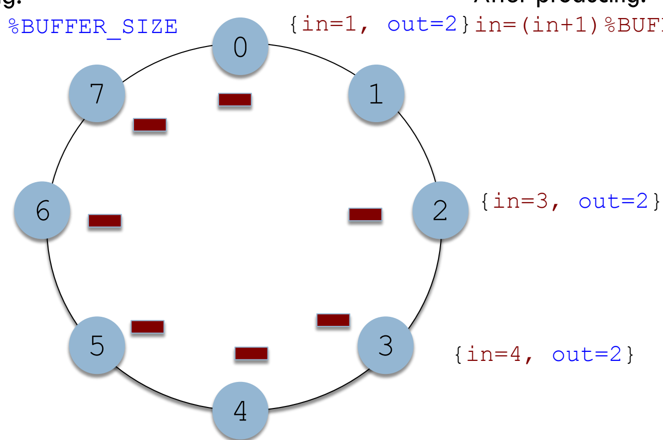
`in`: next free position (producer)
`out`: first full position (consumer)

28

Circular buffer: Bounded

After consuming:
`out=(out+1)%BUFFER_SIZE`

After producing:
`in=(in+1)%BUFFER_SIZE`



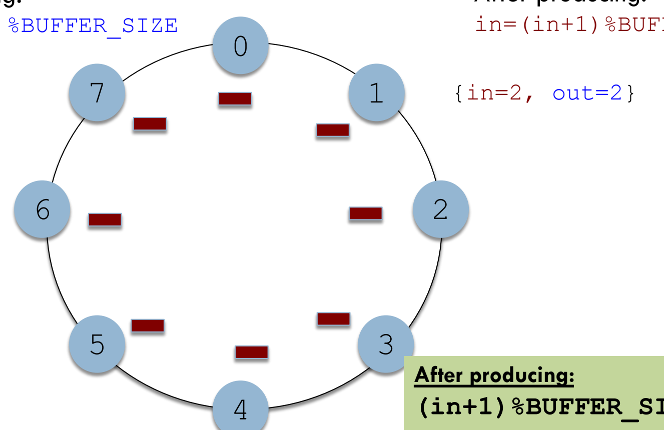
`in`: next free position (producer)
`out`: first full position (consumer)

29

Circular buffer: Bounded

After consuming:
`out=(out+1)%BUFFER_SIZE`

After producing:
`in=(in+1)%BUFFER_SIZE`



After producing:
`(in+1)%BUFFER_SIZE==out`
Buffer is FULL

`in`: next free position (producer)
`out`: first full position (consumer)

30

We'll travel south cross land
Put out the fire
And don't look past my shoulder
The exodus is here
The happy worlds are near
Let's get together
Baba O'Riley, Pete Townsend; The Who

INTER PROCESS COMMUNICATIONS

SHARED MEMORY

31

POSIX IPC: Shared Memory
Creating a memory segment to share

- First **create** shared memory segment `shmget()`
  `shmget(IPC_PRIVATE, size, S_IRUSR | S_IWUSR)`
  - `IPC_PRIVATE`: key for the segment
  - `size`: size of the shared memory
  - `S_IRUSR|S_IWUSR`: Mode of access (read, write)
- Successful invocation of `shmget()`
  - Returns integer ID of shared segment
    - Needed by other processes that want to use region

32

Processes wishing to use shared memory must first attach it to their address space

- Done using `shmat()`: SHared Memory ATtach
  - Returns pointer to beginning location in memory
- **`(void *) shmat(id, asmP, mode)`**
  - `id`: Integer ID of memory segment being attached
  - `asmP`: Pointer location to attach shared memory
    - `NULL` allows OS to *select* location for you
  - Mode indicating read-only or read-write
    - `0`: reads and writes to shared memory

IPC: Use of the created shared memory

- Once shared memory is attached to the process's address space
  - Routine memory accesses using * from `shmat()`
    - Write to it
      - `sprintf(`**`shared_memory`**`, "Hello");`
    - Print string from memory
      - `printf("*%s\n", `**`shared_memory`**`);`
- **RULE:** First attach, and then access

IPC Shared Memory: What to do when you are done

① **Detach** from the address space.

- `shmdt()` :SHared Memory DeTtach
- `shmdt(shared_memory)`

② To **remove** a shared memory segment

- `shmctl()` : SHared Memory ConTroL operation
  - Specify the segment ID to be removed
  - Specify operation to be performed: `IPC_RMID`
  - Pointer to the shared memory region

Communicate and synchronize actions without sharing the same address space

- Two main operations
  - `send(message)`
  - `receive(message)`
- Message sizes can be:
  - Fixed: Easy
  - Variable: Little more effort

Communications between processes

- There needs to be a communication link
- Underlying physical implementation
  - Shared memory
  - Hardware bus
  - Network

Aspects to consider for IPC

① **Communications**
- Direct or indirect

② **Synchronization**
- Synchronous or asynchronous

③ **Buffering**
- Automatic or explicit buffering

Communications: Naming allows processes to refer to each other

- Processes use each other's identity to communicate
- Communications can be
  - Direct
  - Indirect

Direct communications

- Explicitly name recipient or sender
- Link is established automatically
  - Exactly one link between the 2 processes
- Addressing
  - Symmetric
  - Asymmetric

41

Direct Communications: Addressing

- Symmetric addressing
  - `send(P, message)`
  - `receive(Q, message)`

Explicitly name recipient and sender of message

- Asymmetric addressing
  - `send(P, message)`
  - `receive(id, message)`
    - Variable `id` set to name of the sending process

Only sender names recipient
Recipient does not

42

Direct Communications: Disadvantages

- **Limited modularity** of process definitions
- **Cascading effects** of changing the identifier of process
  - Examine *all* other process identifiers

43

Indirect communications: Message sent and received from mailboxes (ports)

- Each **mailbox** has a unique identification & owner
  - POSIX message queues use `integers` to identify mailboxes
- Processes communicate *only* if they have **shared mailbox**
  - `send(A, message)`
  - `receive(A, message)`

44

Indirect communications: Link properties

- Link established only if both processes share mailbox
- Link may be associated with more than two processes

Indirect communications

- Processes `P1`, `P2` and `P3` share mailbox `A`
  - `P1` sends a message to `A`
  - `P2`, `P3` execute a `receive()` from `A`
- Possibilities? Allow …
  1. Link to be associated with at most 2 processes
  2. At most 1 process to execute `receive()` at a time
  3. System to arbitrarily select who gets message

Mailbox ownership issues

- Owned by process
- Owned by the OS

Mailbox ownership issues: Owned by process

- Mailbox is part of the **process's address space**
  - Owner: Can *only receive* messages on mailbox
  - User: Can *only send* messages to mailbox
- When process terminates?
  - Mailbox disappears

Mailbox ownership issues: Owned by OS

- Mailbox has its own existence
- Mailbox is **independent**
  - Not attached to any process
- OS must allow processes to
  - Create mailbox
  - Send and receive *through* the mailbox
  - Delete mailbox

Message passing: Synchronization issues Options for implementing primitives

- Blocking send
  - Block *until* received by process or mailbox
- Nonblocking send
  - Send and *promptly resume* other operations
- Blocking receive
  - Block *until* message available
- Nonblocking receive
  - Retrieve *valid* message or *null*
- Producer-Consumer problem: Easy with blocking

Message Passing: Buffering

- Messages exchanged by communicating processes reside in a **temporary** queue
- Implementation schemes for queues
  - ZERO Capacity
  - Bounded
  - Unbounded

? When does a consumer wait?

? When does a producer wait?

Message Passing Buffer: Consumer always has to wait for message

- ZERO capacity: No messages can reside in queue
  - Sender ***must block*** till recipient receives
- BOUNDED: At most n messages can reside in queue
  - Sender **blocks *only if* queue is *full***
- UNBOUNDED: Queue length potentially infinite
  - Sender ***never blocks***

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

- *Avi Silberschatz, Peter Galvin, Greg Gagne. Operating Systems Concepts, 9th edition. John Wiley & Sons, Inc. ISBN-13: 978-1118063330.* [Chapter 3]
- *Kay Robbins & Steve Robbins. Unix Systems Programming, 2nd edition, Prentice Hall ISBN-13: 978-0-13-042411-2.* [Chapter 2, 3]
- *Andrew S Tanenbaum. Modern Operating Systems. 4th Edition, 2014. Prentice Hall. ISBN: 013359162X/ 978-0133591620.* [Chapter 2]