[03] PROCESSES

OUTLINE

- Process Concept
  - Relationship to a Program
  - What is a Process?
- Process Lifecycle
  - Creation
  - Termination
  - Blocking
- Process Management
  - Process Control Blocks
  - Context Switching
  - Threads
- Inter-Process Communication
  - Requirements
  - Concept
  - Mechanisms

PROCESS CONCEPTS

- **Process Concept**
  - **Relationship to a Program**
  - **What is a Process?**
- Process Lifecycle
- Process Management
- Inter-Process Communication

WHAT IS A PROCESS?

The computer is there to execute programs, not the operating system!

Process ≠ Program

- A program is **static**, on-disk
- A process is **dynamic**, a program *in execution*

On a batch system, might refer to *jobs* instead of processes

WHAT IS A PROCESS?

Unit of protection and resource allocation

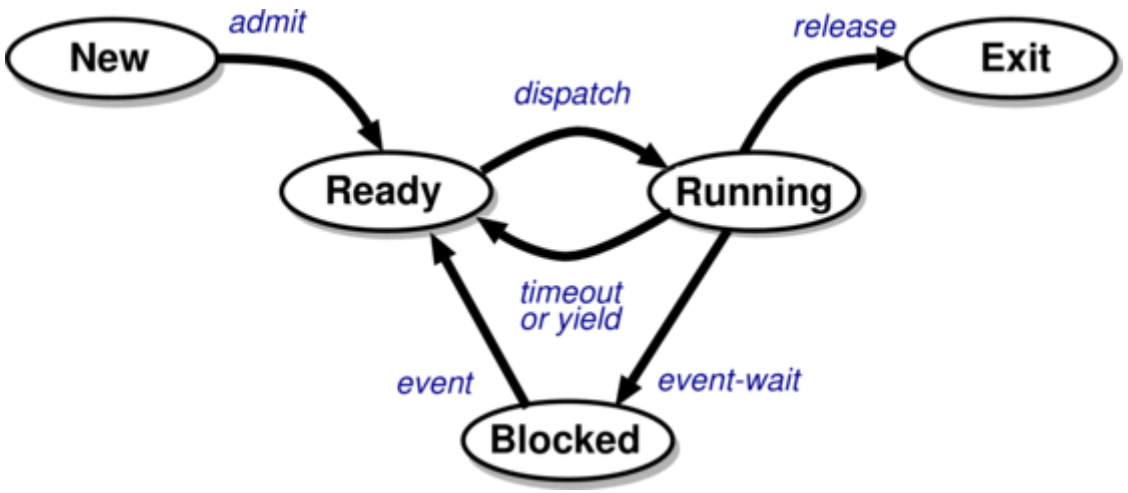
- So you may have multiple copies of a process running
- Each process executed on a *virtual processor*

Has a virtual address space (later)

Has one or more threads, each of which has

1. **Program Counter**: which instruction is executing
2. **Stack**: temporary variables, parameters, return addresses, etc.
3. **Data Section**: global variables shared among threads

PROCESS STATES



- **New**: being created
- **Running**: instructions are being executed
- **Ready**: waiting for the CPU, ready to run
- **Blocked**: stopped, waiting for an event to occur
- **Exit**: has finished execution

PROCESS LIFECYCLE

- Process Concept
- **Process Lifecycle**
  - **Creation**
  - **Termination**
  - **Blocking**
- Process Management
- Inter-Process Communication

PROCESS CREATION

Nearly all systems are hierarchical:
parent processes create child processes

- Resource sharing:
  - Parent and children share all resources
  - Children share subset of parent's resources
  - Parent and child share no resources

PROCESS CREATION

Nearly all systems are hierarchical:
parent processes create child processes

- Resource sharing
- Execution:
  - Parent and children execute concurrently
  - Parent waits until children terminate

PROCESS CREATION

Nearly all systems are hierarchical:
parent processes create child processes

- Resource sharing
- Execution
- Address space:
  - Child duplicate of parent
  - Child has a program loaded into it

EXAMPLES

Unix:

- `fork()` system call creates a child process, cloned from parent; then
- `execve()` system call used to replace the process' memory space with a new program

NT/2K/XP:

- `CreateProcess()` system call includes name of program to be executed

PROCESS TERMINATION

Occurs under three circumstances

1. Process executes last statement and asks the OS to delete it (`exit`):
    - Output data from child to parent (`wait`)
    - Process' resources are deallocated by the OS

PROCESS TERMINATION

Occurs under three circumstances

1. Process executes last statement and asks the OS to delete it
2. Process performs an illegal operation, e.g.,
    - Makes an attempt to access memory to which it is not authorised
    - Attempts to execute a privileged instruction

PROCESS TERMINATION

Occurs under three circumstances

1. Process executes last statement and asks the OS to delete it
2. Process performs an illegal operation
3. Parent may terminate execution of child processes (`abort`, `kill`), e.g. because
    - Child has exceeded allocated resources
    - Task assigned to child is no longer required
    - Parent is exiting ("cascading termination")

EXAMPLES

Unix: `wait()`, `exit()` and `kill()`

NT/2K/XP: `ExitProcess()` for self, `TerminateProcess()` for others

BLOCKING

- In general a process blocks on an event, e.g.,
  - An IO device completes an operation
  - Another process sends a message
- Assume OS provides some kind of general-purpose blocking primitive, e.g., `await()`
- Need care handling concurrency issues, e.g.,

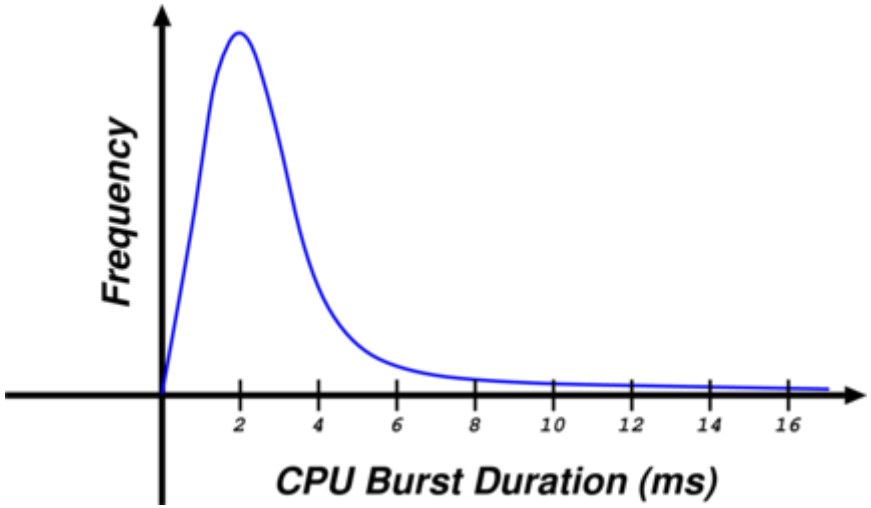
```
if(no key being pressed) {
  await(keypress);
  print("Key has been pressed!\n");
}
// handle keyboard input
```

  - What happens if a key is pressed at the first `{`?
  - Complicated! For next year... :)

CPU IO BURST CYCLE

- Process execution consists of a cycle of CPU execution and IO wait
- Processes can be described as either:
  1. **IO-bound**:
     - spends more time doing IO than computation
     - many short CPU bursts
  2. **CPU-bound**:
     - spends more time doing computations
     - a few, very long, CPU bursts

CPU IO BURST CYCLE



Observe that most processes execute for at most a few milliseconds before blocking

We need multiprogramming to obtain decent overall CPU utilisation

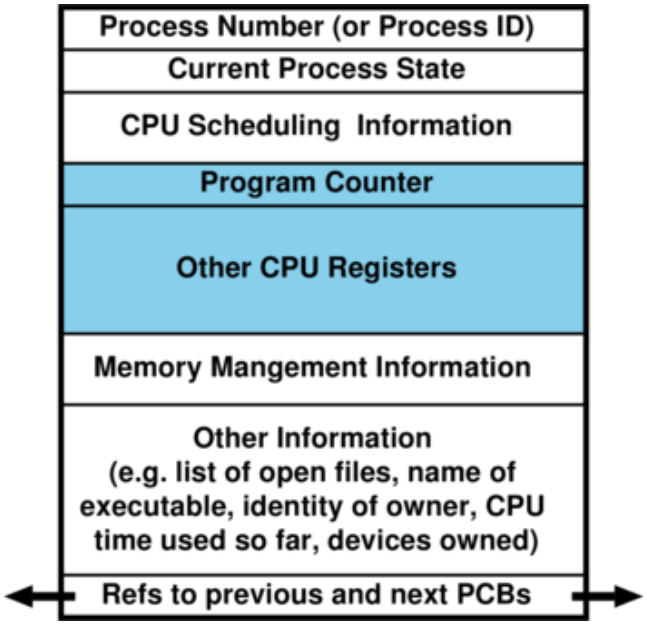
PROCESS MANAGEMENT

- Process Concept
- Process Lifecycle
- **Process Management**
  - **Process Control Blocks**
  - **Context Switching**
  - **Threads**
- Inter-Process Communication

PROCESS CONTROL BLOCK

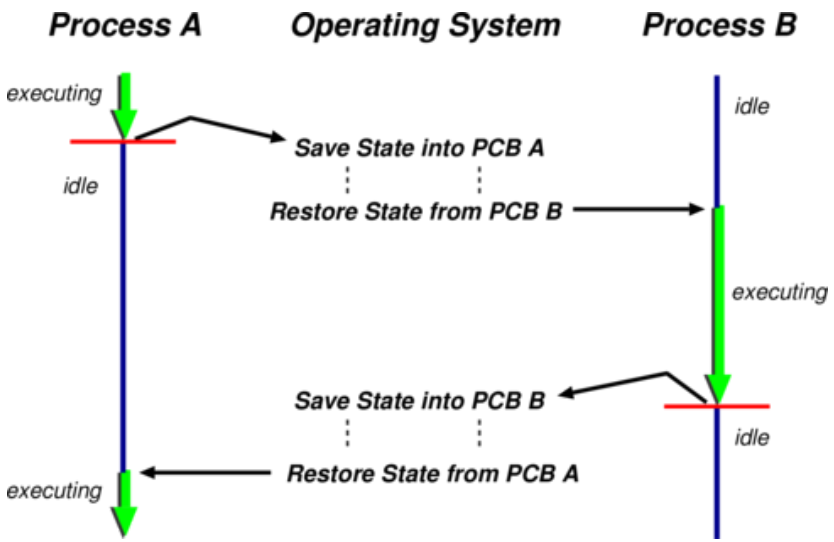
OS maintains information about every process in a data structure called a *process control block* (PCB). The *Process Context* (highlighted) is the machine environment during the time the process is actively using the CPU:

- Program counter
- General purpose registers
- Processor status register
- [Caches, TLBs, Page tables, ...]



CONTEXT SWITCHING

- To switch between processes, the OS must:
  - Save the context of the currently executing process (if any), and
  - Restore the context of that being resumed.
- Note this is *wasted time* — no useful work is carried out while switching
- Time taken depends on hardware support
  - From nothing, to
  - Save/load multiple registers to/from memory, to
  - Complete hardware "task switch"



THREADS

A **thread** represents an individual execution context

Threads are managed by a **scheduler** that determines which thread to run

Each thread has an associated **Thread Control Block** (TCB) with metadata about the thread: saved context (registers, including stack pointer), scheduler info, etc.

Context switches occur when the OS saves the state of one thread and restores the state of another. If between threads in different processes, process state also switches

Threads visible to the OS are **kernel threads** — may execute in kernel or address user space

INTER-PROCESS COMMUNICATION

- Process Concept
- Process Lifecycle
- Process Management
- **Inter-Process Communication**
  - **Requirements**
  - **Concept**
  - **Mechanisms**

REQUIREMENTS

For meaningful communication to take place, two or more parties have to exchange information according to a **protocol**:

- Data transferred must be in a commonly-understood format (**syntax**)
- Data transferred must have mutually-agreed meaning (**semantics**)
- Data must be transferred according to mutually understood rules (**synchronisation**)

In computer communications, the parties in question come in a range of forms, typically:

- Threads
- Processes
- Hosts

Ignore problems of discovery, identification, errors, etc. for now

INTER-PROCESS COMMUNICATION

In the context of this course, we are concerned with **Inter-Process Communication** (IPC)

- What it says on the tin — communication between processes on the same host
- Key point — it is possible to *share memory* between those processes

Given the protection boundaries imposed by the OS, by design, the OS must be involved in any communication between processes

- Otherwise it would be tantamount to allowing one process to write over another's address space
- We'll focus on POSIX mechanisms

INTER-THREAD COMMUNICATION

It is a common requirement for two running threads to need to communicate

- E.g., to coordinate around access to a shared variable

If coordination is not implemented, then all sorts of problems can occur. Range of mechanisms to manage this:

- Mutexes
- Semaphores
- Monitors
- Lock-Free Data Structures
- ...

Not discussed here!

- You'll get into the details next year in **Concurrent and Distributed Systems**
- (Particularly the first half, on *Concurrency*)

INTER-HOST COMMUNICATION

Passing data between different hosts:

- Traditionally different physical hosts
- Nowadays often virtual hosts

Key distinction is that there is now no shared memory, so some form of transmission medium must be used — **networking**

Also not discussed here!

- In some sense it is "harder" than IPC because real networks are inherently:
  - **Unreliable**: data can be lost
  - **Asynchronous**: even if data is not lost, no guarantees can be given about when it arrived
- You'll see a lot more of this next year in **Computer Networking**

CONCEPT

For IPC to be a thing, first you need multiple processes

- Initially created by running processes from a shell
- Subsequently may be created by those processes, ad infinitum
- (...until your machine dies from your fork bomb...)

Basic process mechanisms: `fork(2)` followed by `execve(2)` and/or `wait(2)`

Will look at that plus several other common POSIX mechanisms

`FORK(2)`,`WAIT(2)`

Simply put, `fork(2)` allows a process to clone itself:

- **Parent** process creates **child** process
- Child receives copy-on-write (COW) snapshot of parent's address space

Parent typically then either:

- Detaches from child — hands responsibility back to `init` process
- Waits for child — calling `wait(2)`, parent blocks until child exits

SIGNALS

Simple asynchronous notifications on another process

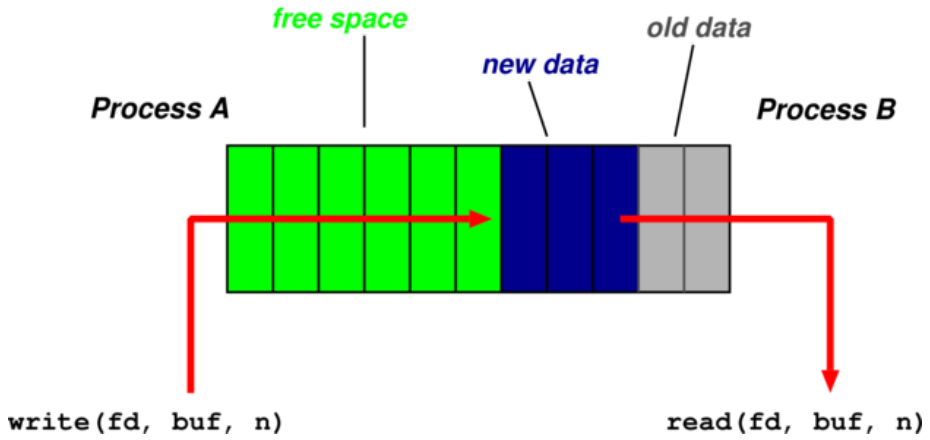
- A range of signals (28 at my last count), defined as numbers
- Mapped to standard `#defines`, a few of which have standard mappings to numbers

Among the more common ones:

- `SIGHUP`: hangup the terminal (1)
- `SIGINT`: terminal interrupt (2)
- `SIGKILL`: terminate the process [cannot be caught or ignored] (9)
- `SIGTERM`: terminate process (15)
- `SIGSEGV`: segmentation fault — process made an invalid memory reference
- `SIGUSR1/2`: two user signals [system defined numbers]

Use `sigaction(2)` to specify what function the signalled process should invoke on receipt of a given signal

PIPES



Simplest form of IPC: `pipe(2)` returns a pair of **file descriptors**

- (`fd[0]`, `fd[1]`) are the (read, write) fds

Coupled with `fork(2)`, can now communicate between processes:

- Invoke `pipe(2)` to get read/write fds
- `fork(2)` to create child process
- Parent and child then both have read/write fds available, and can communicate

NAMED PIPES / FIFOS

The same as `pipe(2)` — except that it has a name, and isn't just an array of two fds

- This means that the two parties can coordinate without needing to be in a parent/child relationship
- All they need is to share the (path)name of the FIFO

Then simply treat as a file:

- `open(2)`
- `read(2)`
- `write(2)`

`open(2)` will block by default, until some other process opens the FIFO for reading

- Can set non-blocking via `O_NDELAY`

SHARED MEMORY SEGMENTS

What it says on the tin — obtain a segment of memory that is shared between two (or more) processes

- `shmget(2)` to get a segment
- `shmat(2)` to attach to it

Then read and write simply via pointers — need to impose concurrency control to avoid collisions though

Finally:

- `shmdt(2)` to detach
- `shmctl(2)` to destroy once you know no-one still using it

FILES

Locking can be mandatory (enforced) or advisory (cooperative)

- Advisory is more widely available
- `fcntl(2)` sets, tests and clears the lock status
- Processes can then coordinate over access to files
- `read(2)`, `write(2)`, `seek(2)` to interact and navigate

Memory Mapped Files present a simpler — and often more efficient — API

- `mmap(2)` "maps" a file into memory so you interact with it via a pointer
- Still need to lock or use some other concurrency control mechanism

UNIX DOMAIN SOCKETS

Sockets are commonly used in network programming — but there is (effectively) a shared memory version for use between local processes, having the same API:

- `socket(2)` creates a socket, using `AF_UNIX`
- `bind(2)` attaches the socket to a file
- The interact as with any socket
  - `accept(2)`, `listen(2)`, `recv(2)`, `send(2)`
  - `sendto(2)`, `recvfrom(2)`

Finally, `socketpair(2)` uses sockets to create a full-duplex pipe

- Can read/write from both ends

SUMMARY

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