CS4410

Operating Systems

Lecture 4:
Abstractions I: Threads
Abstractions II: Processes
Abstractions III: IPC

Rachit Agarwal

Goal of Today’s Lecture

- Wrap up discussion on the first abstraction: thread
- Deeper dive into the second abstraction: process
- Introduction to the third abstraction: IPC abstractions

Recall: Four Fundamental OS Concepts

- **Thread: Execution Context**
  - A virtual core: a single, sequential execution context
- **Address space** (with **translation**)
  - Program's view of memory is distinct from physical memory
- **Process: an instance of a running program**
  - Address Space + One or more Threads + …
- **Protection/Isolation**
  - Only the “system” can access certain resources
  - Combined with translation, isolates programs from each other

Recall: Threads

- **Virtual cores: illusion of infinite processors**
  - Each thread executes a sequence of instructions, in order, on a physical core

- **Why threads?**
  - *Statistical multiplexing:* improved utilization of physical cores

- **Challenges:**
  - synchronization (correctness), scheduling (performance)

Recall: Address space

- **Virtual address space: illusion of infinite memory**

- **Why virtual address space?**
    - *Statistical multiplexing*: improved utilization of physical memory
    - *Protection/Isolation* (not yet covered)
    - ….

- **Challenges?**
    - Efficient address translation

Recall: Process

- **Execution environment with restricted rights: Illusion of a machine**
    - One or more threads
    - Execution state: everything that can affect, or be affected by, a thread
        - Code, data, registers, call stack, files, sockets, etc.
    - Part of the process state is “owned” by individual threads
    - Part is shared among all threads in the process

- **Why processes?**
    - *Statistical multiplexing*: improved utilization of physical resources

- **Challenges?**
    - Protection/isolation/sharing

Recall: Protection/Isolation

- **Virtualization (address space, in particular)**

- **Dual mode operations**
    - Hardware provides at least two modes of operations:
        - Kernel mode (or “supervisor” / “protected” mode)
        - User mode
            - Processes execute in user mode
    - “Controlled” transitions between user mode and kernel mode
        - System calls, interrupts, exceptions

Recall: Need for Threads

- Consider the following program:

```
main() {
    ComputePI();
    PrintClassList("classlist.txt");
}
```

- The program would never print out class list:
    - **`ComputePI`** would never finish

Recall: With Threads

- Version of program with threads (loose syntax):

```
main() {
    create_thread(ComputePI());
    create_thread(PrintClassList("classlist.txt"));
}
```

- Now, you would actually see the class list
  - But only "now and then"
  - **Illusion: infinite number of processors (potentially varying speeds)**

- **`create_thread`**: Spawns a new thread running the given procedure
  - Should behave as if another CPU is running the given procedure

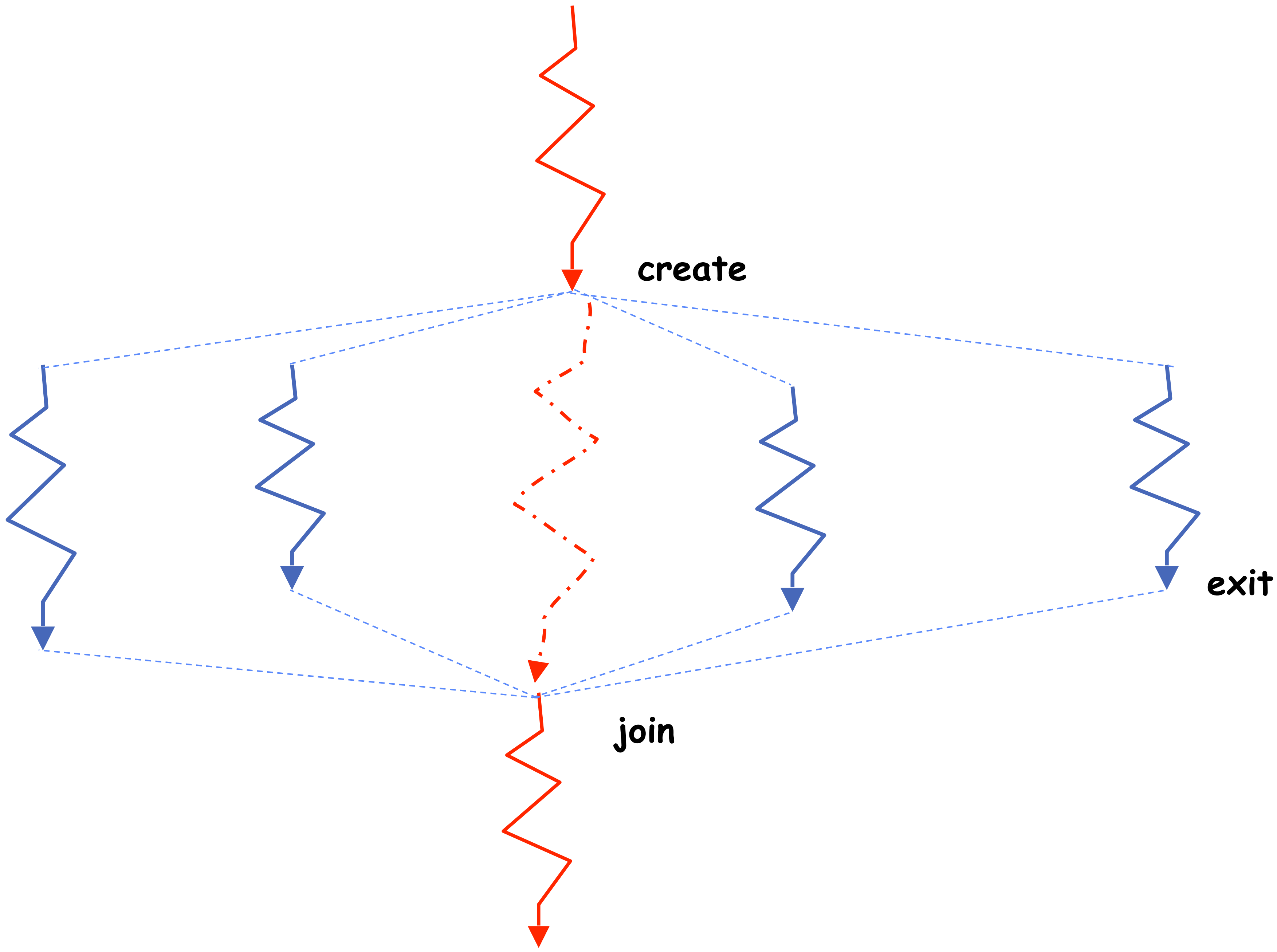
Questions?

Wrapping up Abstraction I: Threads

Multithreaded Programs

- When you compile a C program and run the executable
  - It creates a process that is executing that program
- Initially, this new process has *one thread* in its own address space
  - With code, globals, etc. as specified in the executable
- How can we make a multithreaded process?
  - A process can issues *syscalls* to create new threads
  - These new threads are part of the process:
    - They share its address space

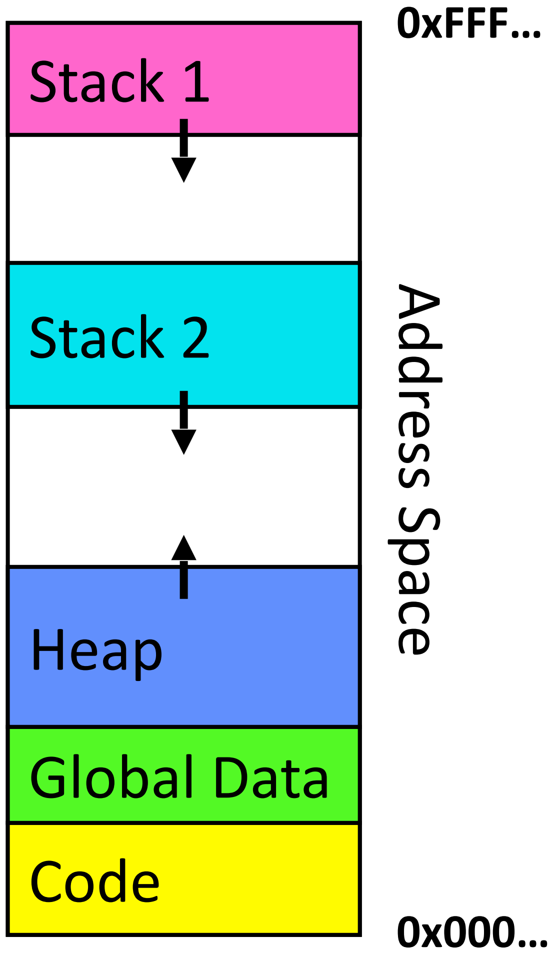
New Idea: Fork-Join Pattern



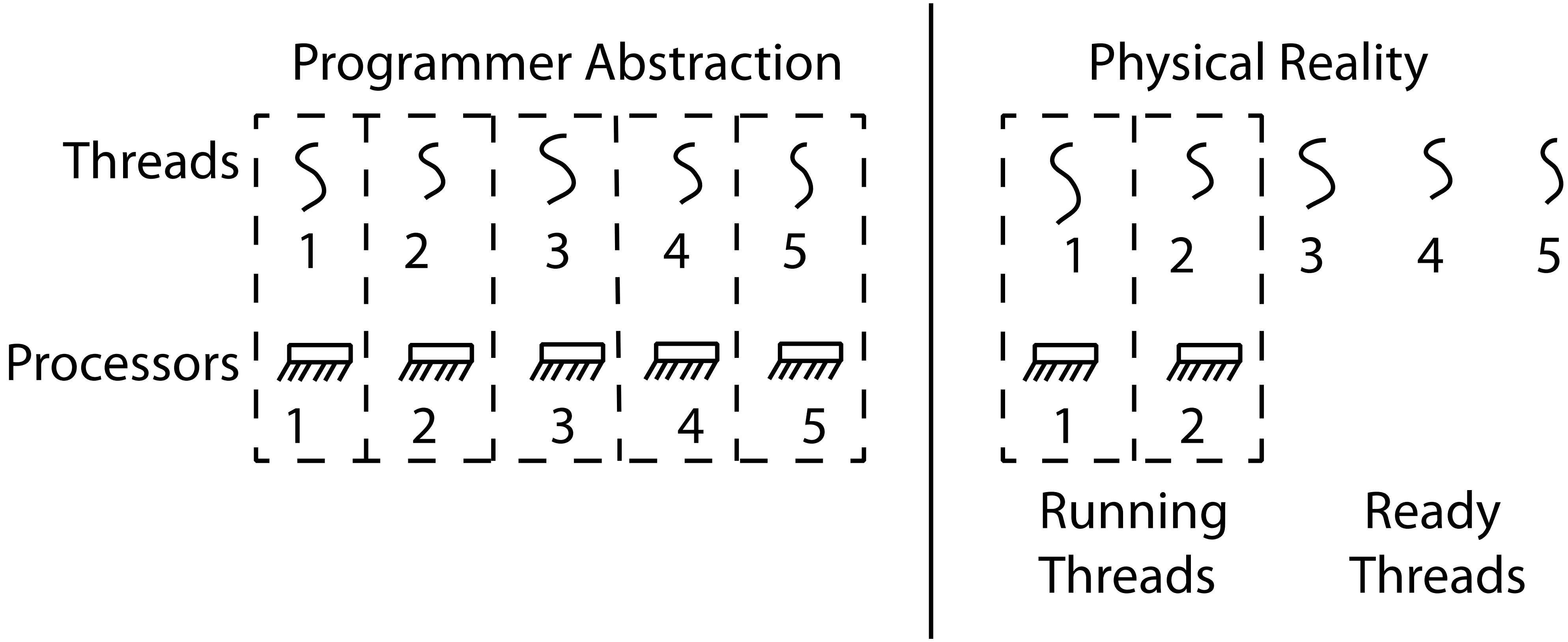
- Main thread *creates* (forks) collection of sub-threads passing them args to work on…
- … and then *joins* with them, collecting results.

Memory Layout with Two Threads

- Two sets of CPU registers
- Two sets of stacks
- Issues:
  - How do we position stacks relative to each other?
  - What maximum size should we choose for the stacks?
  - What happens if threads violate this?
  - How might you catch violations?



Thread Abstraction



- **Illusion: infinite number of processors, potentially varying speeds**
- Reality: threads execute with variable "speed"
  - Why?
  - Depends on scheduling policies
- Programs must be designed to work with any schedule

Programmer vs. Processor View

Programmer's View

.
.
.
x = x + 1;
y = y + x;
z = x +5y;
.
.
.

Possible Execution #1

.
.
.
x = x + 1;
y = y + x;
z = x + 5y;
.
.
.

Possible Execution #2

.
.
.
x = x + 1
....
thread is suspended
other thread(s) run
thread is resumed
....
y = y + x
z = x + 5y

Possible Execution #3

.
.
.
x = x + 1
y = y + x
....
thread is suspended
other thread(s) run
thread is resumed
....
z = x + 5y

Correctness with Concurrent Threads

- Goal: Correctness by Design
  - What makes this a challenging goal?
- Non-determinism:
  - Scheduler can run threads in any (non-deterministic) order
    - Why?
  - Scheduler can switch threads at any time
    - Why?
- Independent Threads
  - No state shared with other threads
  - Deterministic, reproducible conditions
- Cooperating Threads
  - Shared state between multiple threads

Race Conditions

- Initially x == 0 and y == 0

Thread A	Thread B
`x = 1;`	`y = 2;`

- What are the possible values of x below after all threads finish?
- Must be **1**. Thread B does not interfere with Thread A.

Race Conditions

- Initially x == 0 and y == 0

Thread A

```
x = y + 1;
```

Thread B

```
y = 2;
y = y * 2;
```

- What are the possible values of x below?
- 1 or 3 or 5 (non-deterministic)
- Race Condition: Thread A "races" against Thread B!

Abstraction II: Processes

Recall: Process

- **Definition: execution environment with restricted rights**
    - One or more threads
    - Execution state: everything that can affect, or be affected by, a thread
        - Code, data, registers, call stack, files, sockets, etc.
    - Part of the process state is “owned” by individual threads
    - Part is shared among all threads in the process

Process control block (PCB)

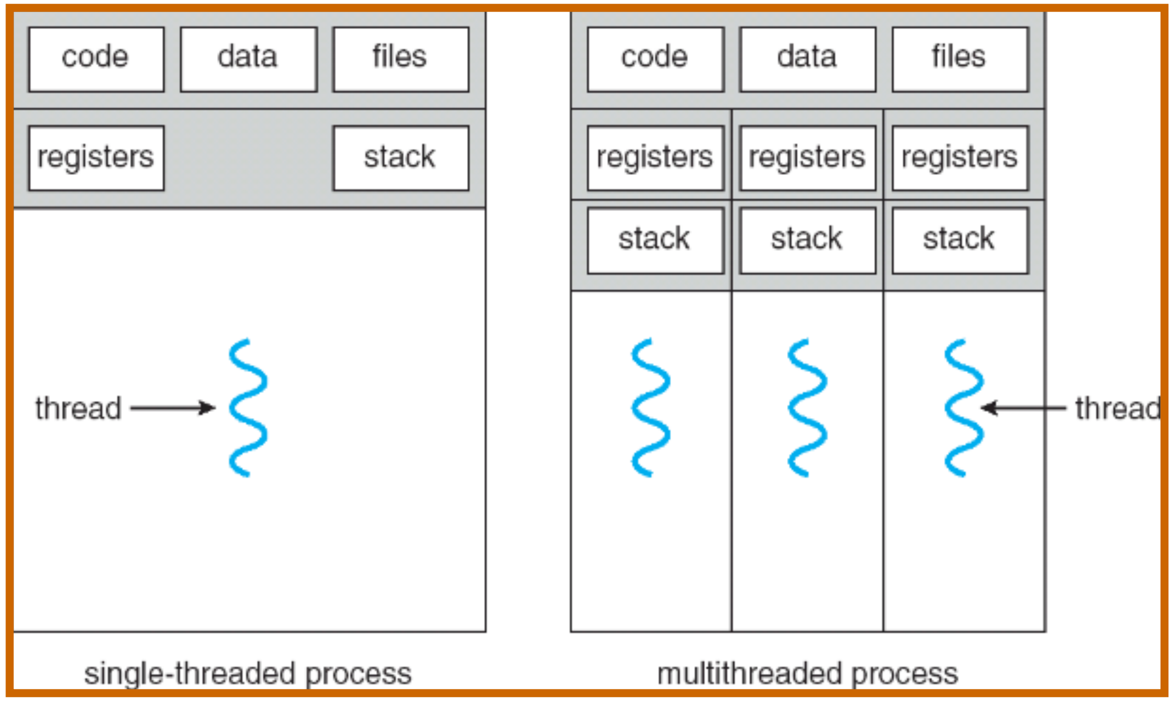
- **Each process has a “state”—Process control block (PCB)**
    - Execution state for each thread
    - Scheduling information
    - Information about memory used by the process
    - Information about files, sockets, etc.
    - ….

Processes

- How to manage process state?
    - How to create a process?
    - How to manage process state?
    - How to exit from a process?

- Remember: Everything outside of the kernel is running in a process!

- Processes are created and managed… by processes!



Processes

- **Processes are created and managed by ….**
  - processes!
  - Hhhmm. How does the first process start?
    - By the kernel
    - Often configured as an argument to the kernel
      - Before the kernel boots
      - Often called the “init” process
  - After this, all processes are created by other processes

Process Management

- **`exit`** — terminate a process
- **`fork`** — copy the current process
- **`exec`** — change the *program* being run by the current process
- **`wait`** — wait for a process to finish
- **`kill`** — send a *signal* (interrupt-like notification) to another process
- **`sigaction`** — set handlers for signals

Process Management

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exit ()

- **Called after process terminates**
    - Deallocates memory
    - Destructs most OS data structures
    - Closes open files

exit()

```
#include <stdlib.h>
#include <stdio.h>
#include <string.h>
#include <unistd.h>
#include <sys/types.h>
int main(int argc, char *argv[])
{
  /* get current processes PID */
  pid_t pid = getpid();
  printf("My pid: %d\n", pid);

  exit(0);
}
```

Q: What if we let main return without ever calling exit?

- The OS Library calls exit() for us!
- The entry point of the executable is in the OS library
- OS library calls main
- If main returns, OS library calls exit

Process Management

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fork ()

- **Used to create processes—**copy the current process
- New “child” process has a different process ID (pid) AND a single thread
- New “child” process is a clone:
  - State of original process **duplicated** in both parent and child process
- Returns twice (!), to both the parent and the child process
  - Sets pid to different values (return value from fork(): pid)
  - When > 0
    - Running in original **(parent)** process
    - Return value is child’s process pid
  - When = 0
    - Running in new **child** process
  - When < 0
    - Error (must handle somehow)
    - Running in parent process

fork() example

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

int main(int argc, char *argv[]) {
  pid_t cpid, mypid;
  pid_t pid = getpid();              /* get current processes PID */
  printf("Parent pid: %d\n", pid);
  cpid = fork();
  if (cpid > 0) {                    /* Parent Process */
    mypid = getpid();
    printf("[%d] parent of [%d]\n", mypid, cpid);
  } else if (cpid == 0) {            /* Child Process */
    mypid = getpid();
    printf("[%d] child\n", mypid);
  } else {
    perror("Fork failed");
  }
}
```

Process Management

- **`exit`** — terminate a process
- **`fork`** — copy the current process
- **`exec`** — change the *program* being run by the current process
- **`wait`** — wait for a process to finish
- **`kill`** — send a *signal* (interrupt-like notification) to another process
- **`sigaction`** — set handlers for signals

exec (program, arguments)

- Used to run **program** in the *current process* with specified **arguments**
  - Load **program** into address space
  - Copy **arguments** into address space's memory
  - Start execution at ``start''

Process Management

- **`exit`** — terminate a process
- **`fork`** — copy the current process
- **`exec`** — change the *program* being run by the current process
- **`wait`** — wait for a process to finish
- **`kill`** — send a *signal* (interrupt-like notification) to another process
- **`sigaction`** — set handlers for signals

wait ()

- Causes the parent process to wait until the child process terminates
    - Parent gets return value from child
    - If no children alive, wait() returns immediately

- Different from exit()
    - exit() called after process terminates

Abstraction III: I/O

Everything is a “File”

- **A radical idea**
  - Proposed by Dennis Ritchie and Ken Thompson in 1974
  - In their seminal paper on UNIX called “The UNIX Time-Sharing System”

- **Core idea: we should have identical interfaces for:**
  - Files on disk
  - Networking (sockets)
  - Devices (terminals, printers, etc.)
  - Local interprocess communication (pipes, sockets)

- Based on the system calls **open()**, **read()**, **write()**, and **close()**

Key Design Ideas

- **Uniformity:** everything is a file
- **open() before use:** Provides opportunity for access control and arbitration
- **Byte-oriented:** Least common denominator
  - OS hides underlying details:
    - Block-based data transfers? Sure.
    - Stream data transfers? Sure.
- **Kernel buffered read() and write()**
  - Helpful to make everything byte-oriented
  - Process is **blocked** while waiting for return
  - Complete in background
    - Writes return immediately
  - Enables a "global" buffer management (eg., taking caches into account)
- **Explicit close()**

Interprocess Communication

- **What if two processes wish to communication with one another?**
  - What are the possible options?

- **One option: shared memory address space**
  - But the OS enforces protection…
  - Possible, but can be catastrophic

- **Another option: use a file**
  - Producer (writer) writes to a file; consumer (reader) reads.
  - Better; OS even provides a way:
    - file descriptors are shared between parent & child processes
  - Problem?
    - High overheads

- Other options: IPC and RPC

Interprocess Communication

- **A crazy idea: Create an *in-memory* queue**
  - Data written by producer process is written to the queue
  - Consumer processes can read from the queue
  - Use a file interface to enable reads and writes
    - Recall: file descriptors are shared between parent & child processes
  - Done!?!
- Allowing the processes to access the queue as and when they want leads to..
  - Potential protection violation (it is shared memory after all)
  - What could we do?
    - Suppose we ask the Kernel to help…
    - Use syscalls! Allow accessing the queue via system calls
- **Challenge?**
  - What if A generates data faster than B can consume it?
  - What if B consumes data faster than A generates it?

"Pipe" for Interprocess Communication

- **A crazy idea: Create an *in-memory* queue**
  - Data written by producer process is written to the queue
  - Consumer processes can read from the queue
  - Use a file interface to enable reads and writes
    - Recall: file descriptors are shared between parent & child processes
  - Enable accessing the queue via syscalls!

- **Challenge?**
  - What if A generates data faster than B can consume it?
  - What if B consumes data faster than A generates it?

- **Solution:** blocked reads and writes!

- **This queue is called a "pipe"**
  - Has two file descriptors, one for executing each of read and write

“Sockets” for *Remote* Interprocess Communication

- **What if the two processes are running on two different physical servers?**
  - With a network sitting in the middle?
  - What could we do?

- **Sockets!**
  - Create an in-memory queue at each process
  - Exactly the same semantics as a file
  - Ensure the correct “semantics” between the two queues
    - Data read at the consumer has exactly the same ordering as the data written by the producer

- **The correctness is enabled by the OS**
  - Using a reliable, in-order, delivery protocol for data transfer over the network