Creating and managing processes

Syscall	Description
fork()	Create a child process as a clone of the current process. Return to both parent and child. Return child's pid to parent process; return 0 to child
exec (prog, args)	Run application prog in the current process with the specified args (replacing any code and data that was present in process)
wait (&status)	Pause until a child process has exited
exit (status)	Current process is complete and should be garbage collected.
kill (pid, type)	Send an interrupt (signal) of a specified type to a process (a bit of an overdramatic misnomer...)

[Unix]

Fork in action

Process 13
Program A

PC

pid
?

```
pid = fork();
if (pid==0)
   exec(B);
else
wait(&status);
```

Fork in action

Process 13
Program A

PC

pid
?

```
pid = fork();
if (pid==0)
   exec(B);
else
wait(&status);
```

Process 13
Program A

PC

pid
14

```
pid = fork();
if (pid==0)
   exec(B);
else
wait(&status);
```

Process 14
Program B

PC

pid
0

```
pid = fork();
if (pid==0)
   exec(B);
else
wait(&status);
```

```
main() {
   ...
   return;
}
```

Fork in action

Process 13
Program A

PC

pid
?

```
pid = fork();
if (pid==0)
   exec(B);
else
wait(&status);
```

Process 13
Program A

PC

pid
14

```
pid = fork();
if (pid==0)
   exec(B);
else
wait(&status);
```

Status
0

Process 14
Program B

PC

```
main() {
   ...
  return;
}
```

calls exit(0)

Fork in action

```
#include <stdio.h>
#include <unistd.h>

int main() {

   int child_pid = fork();

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

Possible outputs?

Signals (Virtualized Interrupts)

Just
a
taste...

Asynchronous notifications in user space

ID	Name	Default Action	Corresponding Event
2	SIGINT	Terminate	Interrupt (e.g., CTRL-C from keyboard)
9	SIGKILL	Terminate	Kill program (cannot override or ignore)
14	SIGALRM	Terminate	Timer signal
17	SIGCHLD	Ignore	Child stopped or terminated
20	SIGSTP	Stop until SIGCONT	Stop signal from terminal (e.g., CTRL-Z from keyboard)

Sending a Signal

- Kernel delivers a signal to a destination process, for a variety of reasons
  - kernel detected a system event (e.g., division by zero (SIGFPE) or termination of a child (SIGCHLD) or…
  - a process invoked the kill systems call requesting kernel to send another process a signal
    - debugging
    - suspension
    - resumption
    - timer expiration

Receiving a Signal

- Each signal prompts one of these default actions
  - terminate the process
  - ignore the signal
  - terminate the process and dump core
  - stop the process
  - continue process if stopped
- Signal can be caught by executing a user-level function called signal handler
  - similar to exception handler invoked in response to an asynchronous interrupt
- Process can also be suspended waiting for a signal to be caught (synchronously)

More stack magic!

- When process receives a signal
  - crosses to the kernel: current process context is copied to the process' kernel stack
  - kernel handler copies the process context to the bottom of the signal's stack (yet another stack!) maintained in user space
  - kernel resets context saved on the kernel stack so that PC and SP point to the user space signal handler and signal stack
  - kernel exits — and user process starts executing signal handler
  - when the handler finishes, it invokes a syscall, and the sequence is reversed
    - handler's context copied on kernel stack; kernel handler resets original process context copying it from handler's stack and returns from interrupt

Booting an OS

- ``pull oneself over a fence by one's bootstraps"
- Steps in booting an O.S.:
  - CPU starts at fixed address
    - in supervisor mode, with interrupts disabled
  - BIOS (in ROM) loads "boot loader" code from specified storage or network device into memory and runs it
  - Boot loader loads OS kernel code into memory and runs it

O.S. initialization

- Determine location/size of physical memory
- Set up initial MMU/page tables
- Initialize the interrupt vector
- Determine which devices the computer has
  - invoke device driver initialization code for each
- Initialize file system code
- Load first process from file system
- Start first process

Review

- A process is an abstraction of a running program
- The process' context captures its running state:
  - registers (including PC, SP, PSW)
  - memory (including the code, heap, stack)
- The implementation uses two contexts:
  - user context
  - kernel (supervisor) context
- A Process Control Block (PCB) points to both contexts and has other information about the process

Review

- Processes can be in one of the following states:
  - Initializing
  - Running
  - Ready (aka "runnable" on the "ready" queue)
  - Waiting (aka Sleeping or Blocked)
  - Zombie

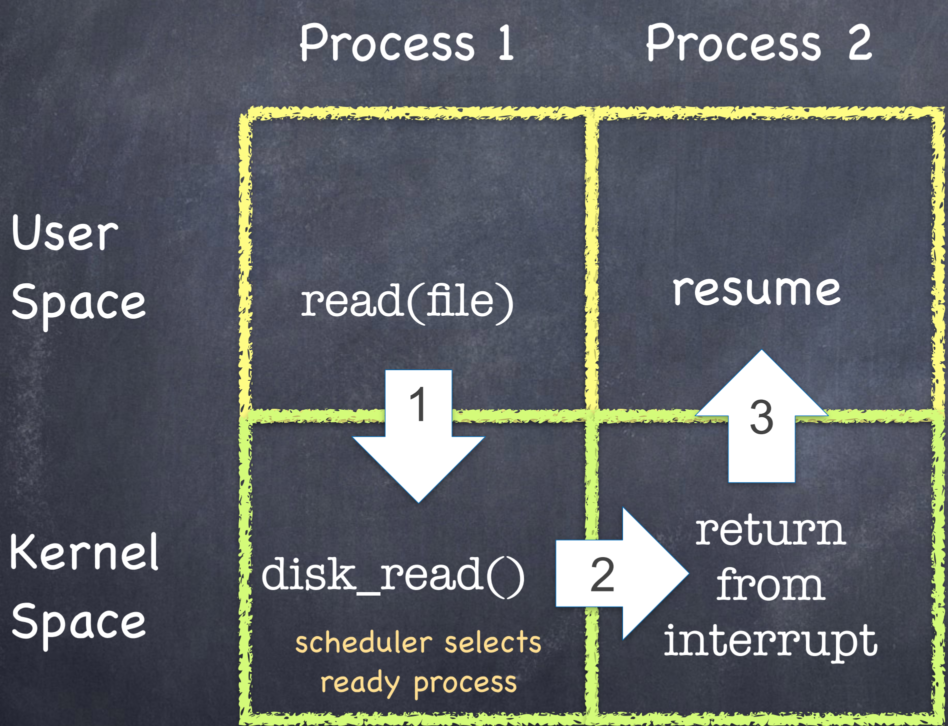
More Processes than Processors

- Solution: time multiplexing
  - Abstractly each processor runs:
    - for ever:
      - NextProcess = scheduler()
      - Copy NextProcess->registers to registers
      - Run for a while
      - Copy registers to NextProcess->registers
  - Scheduler selects some process on the ready queue

Three Flavors of Context Switching

- Interrupt: from user to kernel space
  - on system call, exception, or interrupt
  - Stack switch: P_x user stack $\rightarrow$ P_x interrupt stack
- Yield: between two processes, inside kernel
  - from one PCB/interrupt stack to another
  - Stack switch P_x interrupt stack $\rightarrow$ P_y interrupt stack
- Return from interrupt: from kernel to user space
  - with the homonymous instruction
  - Stack switch: P_x interrupt stack $\rightarrow$ P_x user stack

Switching between Processes



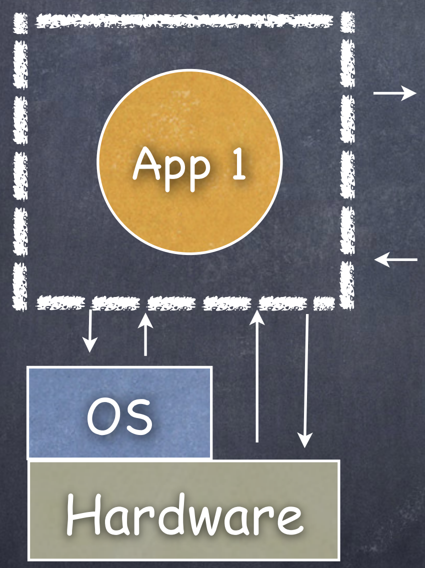
1. Save Process 1 user registers (including SP and PC)
2. Save Process 1 kernel registers; switch SP; restore Process 2 kernel registers
3. Restore Process 2 user registers

Threads

An abstraction for concurrency

(Chapters 25-27)

Rethinking the Process Abstraction



- Processes serve two key purposes:
  - defines the granularity at which the OS offers isolation
    - address space identifies what can be touched by the program
  - define the granularity at which the OS offers scheduling and can express concurrency
    - a stream of instructions executed sequentially

Threads: a New Abstraction for Concurrency

- Decouple the two functionalities in two distinct abstractions:
- A process is an abstraction of a computer
    - its state comprises CPU, memory, devices
- A thread is an abstraction of a core
    - its state consists only of registers (including PC and SP)
    - it is independently schedulable by the OS
    - it lives inside some host address space

The Power of Abstractions

Infinite machines![†]

Infinite cores![†]

[†]on a single CPU (?!?)

Processes and Threads

- As previously described, processes have one sequential thread of execution
- Many OSs offers the ability to have multiple concurrent threads execute in a process
  - Individual threads perform one instruction at a time
  - Multiple threads in a process allow multiple task to be performed concurrently, at the same time (at least, logically)
- Resources are managed differently:
  - CPU state managed on a per-thread basis
  - All other resources on a per-process basis

Why Threads?

- To express a natural program structure
  - updating the screen, fetching new data, receiving user input — different tasks within the same address space
- To exploit multiple processors
  - different threads may be mapped to distinct processors
- To maintain responsiveness
  - slow, long running task performed by background threads
  - foreground threads respond immediately to user interactions
- Masking long I/O device latency in blocking syscalls
  - do useful work while waiting

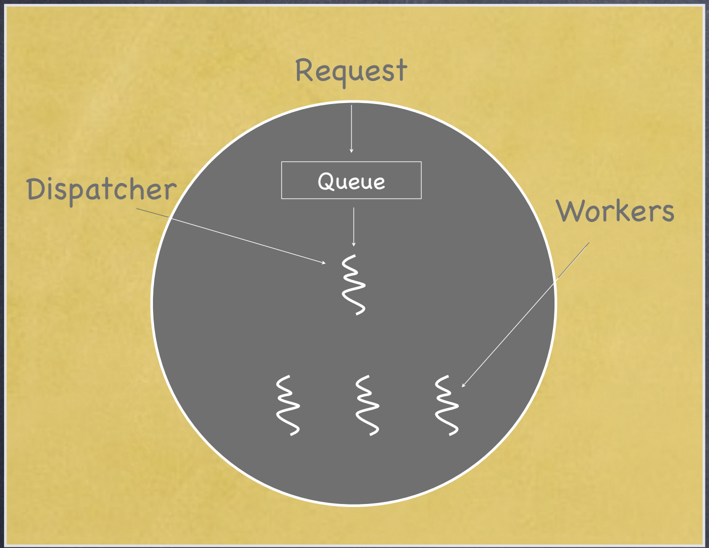
Multithreading: Responsiveness

- Common web browser pattern:
  - UI thread draws web page, handles mouse clicks
  - Pool of background threads downloads web pages from remote web servers
- Does this require multiple CPUs to yield a benefit?
  - NO!
  - BG threads will usually be blocked on I/O
  - Ditto for UI thread
- Even with a single processor, multithreading can greatly improve application responsiveness
  - especially when tasks are I/O bound

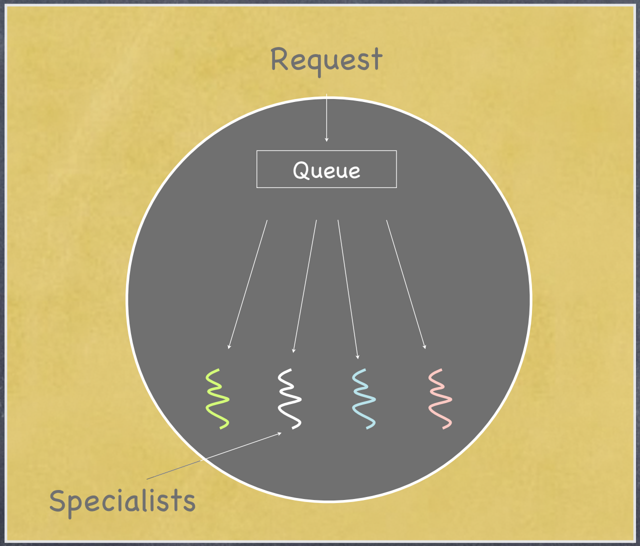
Multithreading: Scalability

- A large scientific/mathematical computation:
  - instead of using a single thread, split in multiple concurrently executing threads
- Does this require multiple CPUs to yield a benefit?
  - YES!
  - Threads will be mostly CPU bound, not I/O bound
  - With only one CPU, multithreading will actually likely slow execution, not speed it up!
    - (context switches, synchronization overheads, etc)
- On the other hand... A single-threaded process cannot take advantage of multiple CPUs
  - need either multiple processes, or one process with multiple threads

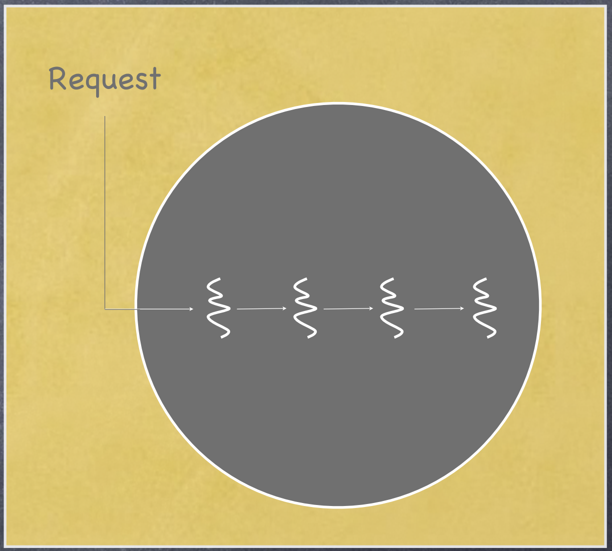
Multithreaded Processing Paradigms



Dispatcher/Workers

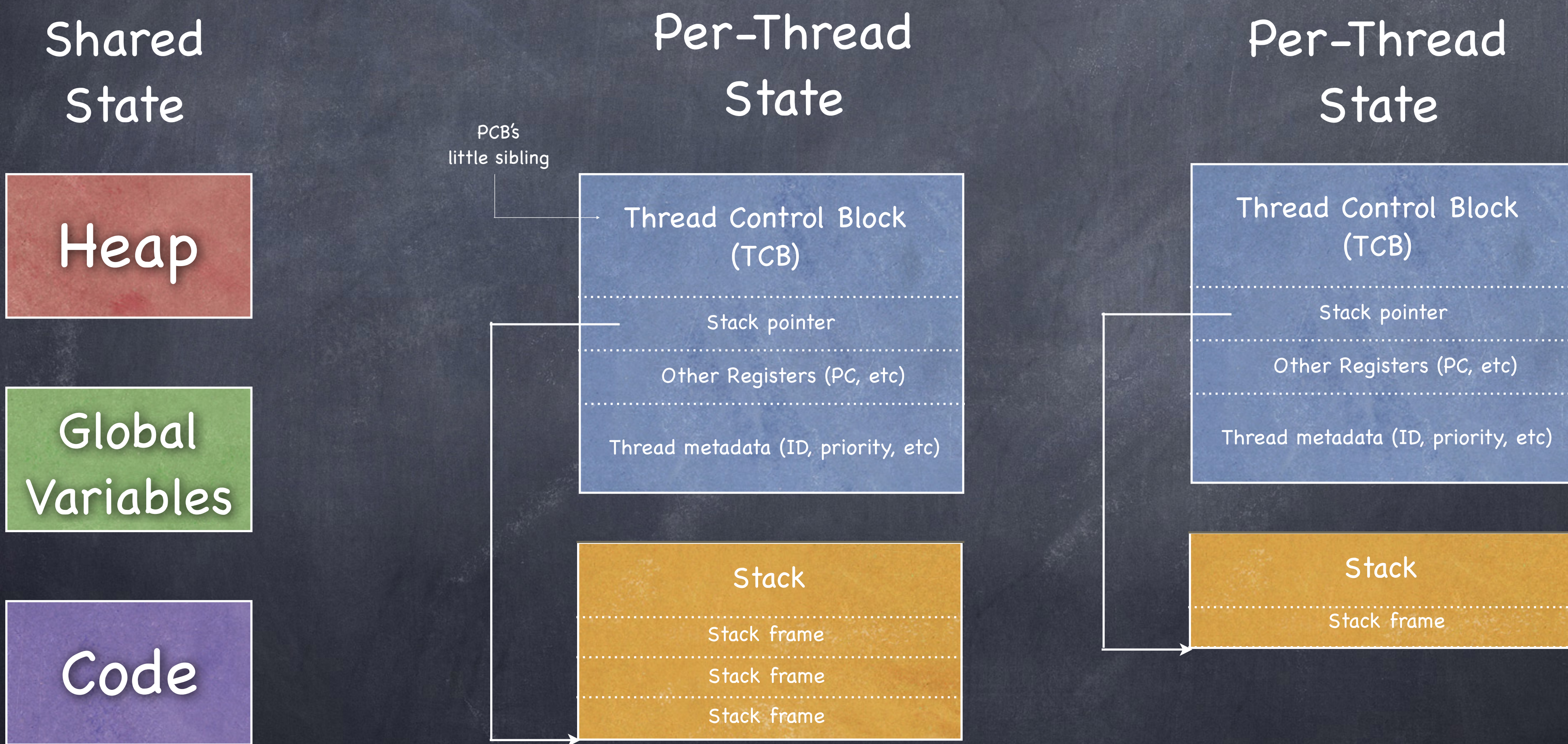


Specialists



Pipeline

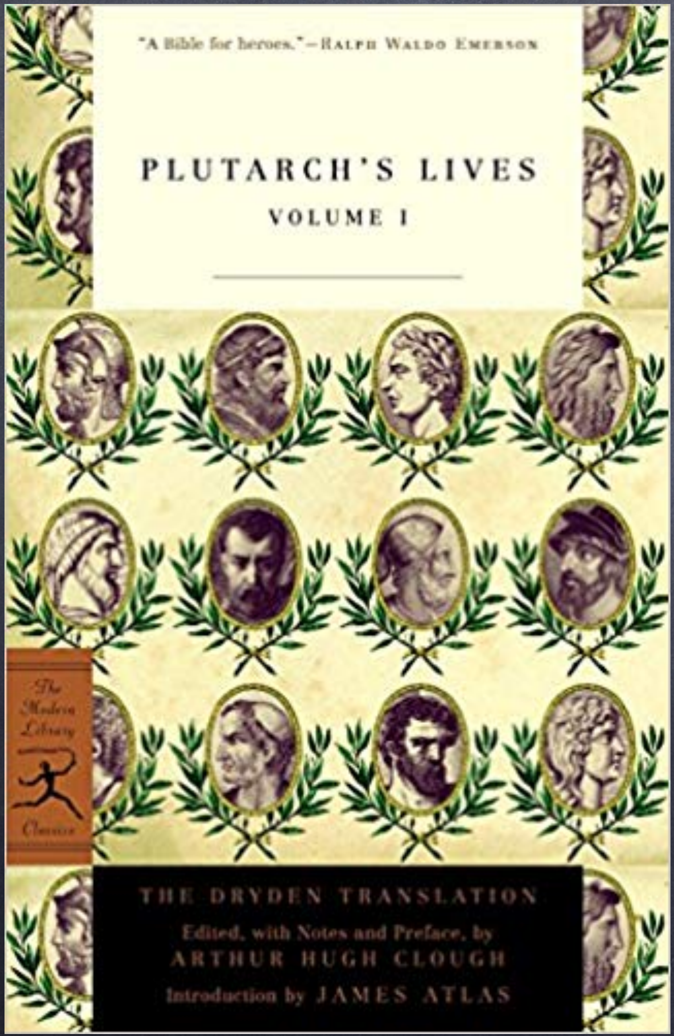
Implementing threads

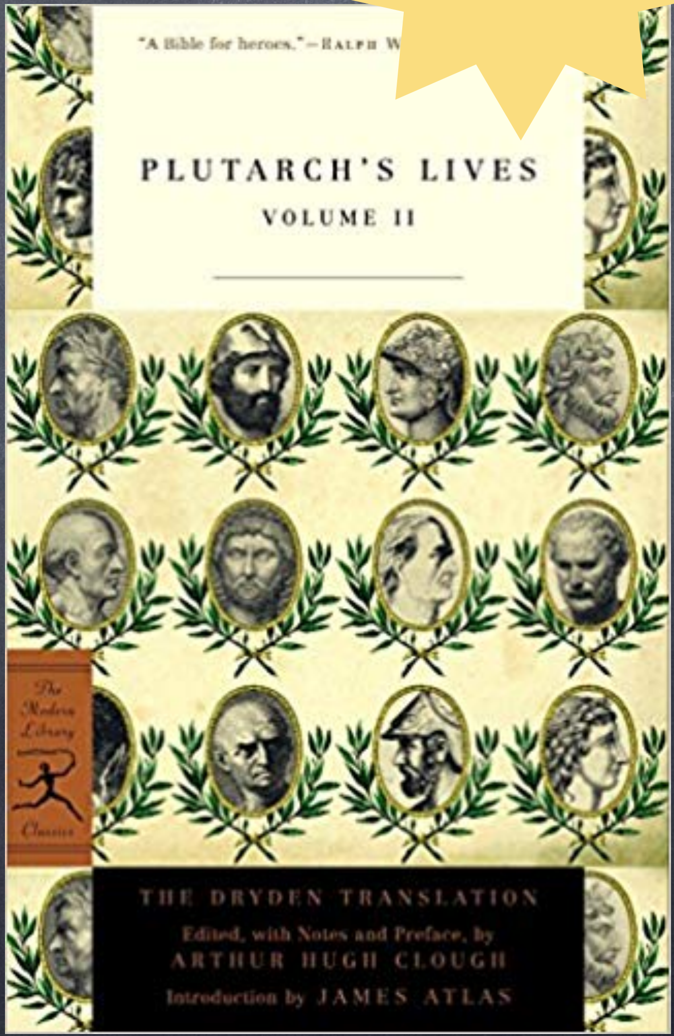


Note: No protection enforced at the thread level!

Processes vs. Threads: Parallel lives

More books!





Processes vs. Threads: Parallel lives

Processes

- Have data/code/heap and other segments
- Include at least one thread
- If a process dies, its resources are reclaimed and its threads die
- Interprocess communication via OS and data copying
- Have own address space, isolated from other processes'
- Each process can run on a different processor
- Expensive creation and context switch

Threads

- No data segment or heap
- Needs to live in a process
- More than one can be in a process. First calls main.
- If a thread dies, its stack is reclaimed
- Inter-thread communication via memory
- Have own stack and registers, but no isolation from other threads in the same process
- Each thread can run on a different processor
- Inexpensive creation and context switch