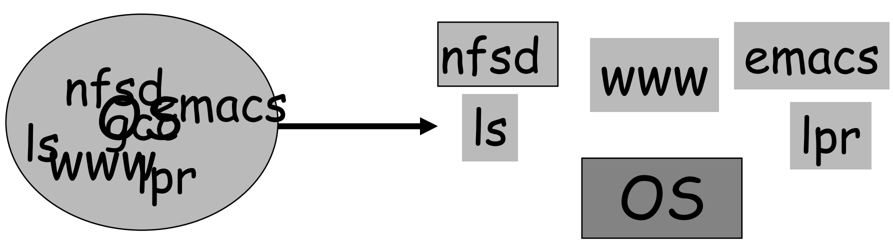
CS 316:
Processes and Synchronization

Slides modified from CS 414

Processes

- Hundreds of things going on in the system: how to manage?



- How to make things simple?
  - Decompose computation into separate *processes*
- How to make things reliable?
  - Isolate processes from each other to protect from each others' faults
- How to speed up?
  - Overlap I/O bursts of one process with CPU bursts of another

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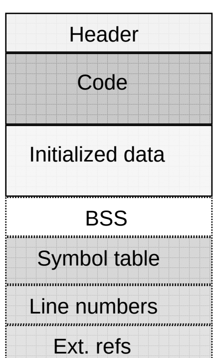
What is a process?

- A program being executed
  - Sequential, one instruction at a time.
- An operating system abstraction: a thread of execution running in a restricted virtual environment – a virtual CPU and virtual memory environment, interfacing with the OS via system calls.
  - The unit of execution
  - The unit of scheduling
  - Thread of execution + address space

The same as “job” or “task” or “sequential process”. Closely related to “thread”.

Process != Program

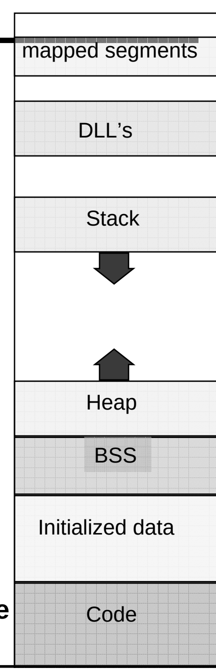


Executable

Program is passive
• Code + static data

Process is running program
• stack, registers, heap, pc

Example:
We both run Firefox on one machine.
• same program
• separate processes
• same virtual address space
• different physical memory



Process address space

Context Switch

- Context Switch
  - Process of switching CPU from one process to another
- State of a running process must be saved and restored:
  - Program Counter, Stack Pointer, General Purpose Registers
- Suspending a process: OS saves state
  - Saves register values
- To execute another process, the OS restores state
  - Loads register values

Details of Context Switching

– Context switching code is architecture-dependent
  - Depends on registers
- Very tricky to implement
  - OS must save state without changing state
  - Must run without changing any user program registers
    - CISC: single instruction saves all state
    - RISC: reserve registers for kernel
      - Or way to save a register and then continue
- Overheads: CPU is idle during a context switch
  - Explicit:
    - direct cost of loading/storing registers to/from main memory
  - Implicit:
    - Opportunity cost of flushing useful caches (cache, TLB, etc.)
    - Waiting for pipeline to drain in pipelined processors

How to create a process?

- Double click on a icon?
- After boot OS starts the first process
  - e.g. **`init`** for Linux, **`ntoskrnl.exe`** for XP
- The first process creates other processes:
  - the creator is called the parent process
  - the created is called the child process
  - the parent/child relationships creates a process tree

Processes Under UNIX

- New *child* process is created by the **`fork()`** system call:

  `int fork()`

  - creates a new address space
  - copies the parent's address space into the child's
    - uses copy-on-write to avoid copying memory that is only read
  - starts a new thread of control in the child's address space
  - parent and child are *almost* identical
    - in parent, **`fork()`** returns a non-zero integer
    - in child, **`fork()`** returns a zero.
    - difference allows parent and child to distinguish themselves
  - **`fork()`** returns TWICE!

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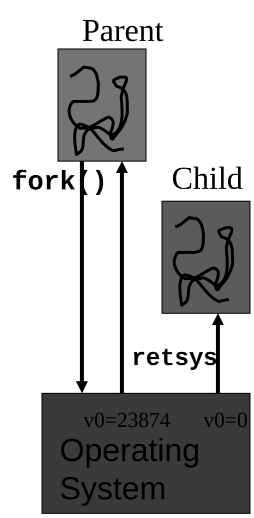
Example

```
int main(int argc, char **argv)
{
   char *myName = argv[1];
   int cpid = fork();
   if (cpid == 0) {
      printf("The child of %s is %d\n", myName, getpid());
      exit(0);
   } else {
      printf("My child is %d\n", cpid);
      exit(0);
   }
}
```

What does this program print?

Bizarre But Real

```
$ gcc a.c
$ ./a.out foobar
The child of foobar is 23874
My child is 23874
```



Parallel Programming and Synchronization

Cooperating Processes

- Processes can be independent or can work cooperatively
  - Cooperating processes exploit *parallelism=concurrency*
- Cooperating processes can be used for:
  - speedup by spreading computation over multiple processors/cores
  - speedup and improving interactivity: one process can work while others are stopped waiting for I/O.
  - better structuring of an application into separate concerns
    - e.g., a pipeline of processes processing data
- But: cooperating processes need ways to
  - Communicate information
  - Coordinate (synchronize) activities

Shared memory

- By default processes have disjoint physical memory -- complete isolation prevents communication
- Processes can set up a segment of memory as *shared* with other process(es)
  - Typically part of the memory of the process creating the shared memory. Other processes attach this to their memory space.
- Allows high-bandwidth communication between processes by just writing into memory

Example

```
#include <stdio.h>
#include <sys/shm.h>
#include <sys/stat.h>

int main(int argc, char
   char* shared_memory;
   const int size = 4096;
   int segment_id = shmget(IP                                SR);
   int cpid = fork();
   if (cpid == 0) {
      shared_memory = (char*) shmat(segment_id, NULL, 0);
      sprintf(shared_memory, "Hi from process %d",getpid());

                     (char*) shmat(segment_id, NULL, 0);
                  %d read: %s\n", getpid(), shared_memory);
      shmdt(shared_memory);
      shmctl(segment_id, IPC_RMID, NULL);
} }
```

Allocate shared memory, return handle

Attach shared memory to address space

Wait for forked process to finish

Detach shared memory from address space and deallocate

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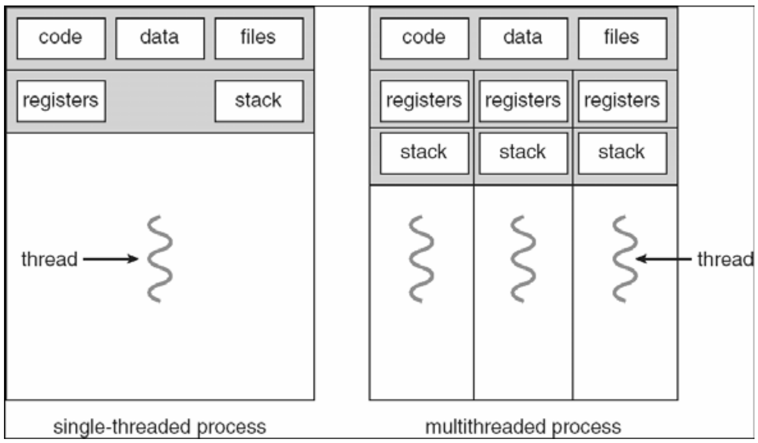
Processes are heavyweight

- Parallel programming with processes:
  - They share almost everything
  - They all share the same code and any data in shared memory (process isolation is not useful)
  - They all share the same privileges
- What don't they share?
  - Each has its own PC, registers, and stack
- Idea: why don't we separate the idea of process (address space, accounting, etc.) from that of the minimal "thread of control" (PC, SP, registers)?

Threads vs. processes

- Most operating systems therefore support two entities:
  - the process,
    - which defines the address space and general process attributes
  - the thread,
    - which defines a sequential execution stream within a process
- A thread is bound to a single process.
  - For each process, however, there may be many threads.
- Threads are the unit of scheduling
- Processes are *containers* in which threads execute

Multithreaded Processes



Two threads, one counter

Web servers use concurrency:

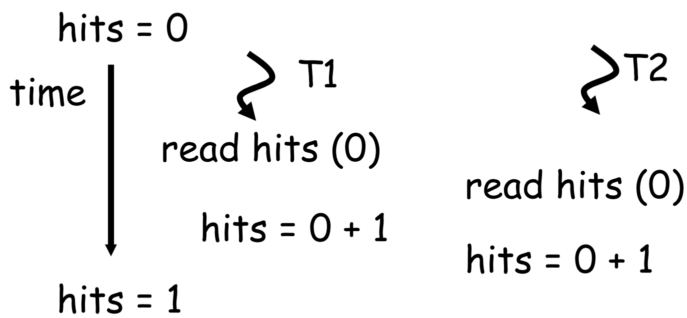
- Multiple threads handle client requests in parallel.
- Some shared state, e.g. hit counts:
  - each thread increments a shared counter to track number of hits

```
…
hits = hits + 1;
…
```

- What happens when two threads execute concurrently?

Shared counters

- Usual result: works fine.
- Possible result: lost update!



- Occasional timing-dependent failure ⇒ Difficult to debug
- Called a *race condition*

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Race conditions

- Def: a timing-dependent error involving shared state
  - Whether it happens depends on how threads scheduled: who wins “races” to instructions that update state
  - Races are intermittent, may occur rarely
    - Timing dependent = small changes can hide bug
  - A program is correct *only* if *all possible* schedules are safe
    - Number of possible schedule permutations is huge
    - Need to imagine an adversary who switches contexts at the worst possible time

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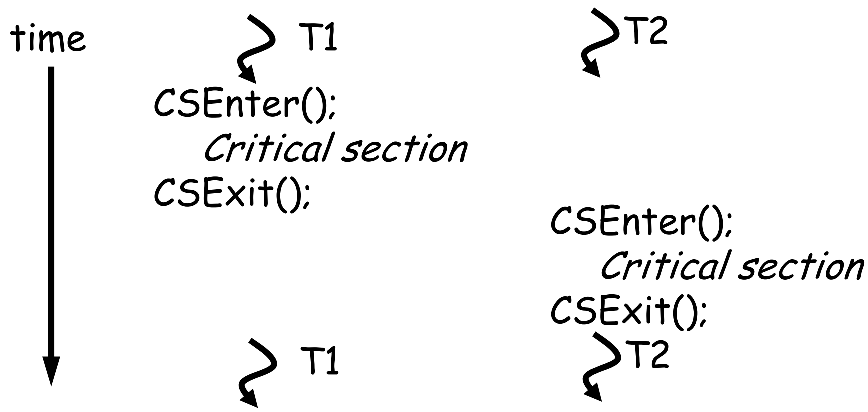
Critical Sections

- Basic way to eliminate races: use *critical sections* that only one thread can be in
  - Contending threads must wait to enter



Mutexes

- Critical sections typically associated with mutual exclusion locks (*mutexes*)
- Only one thread can hold a given mutex at a time
- Acquire/Lock mutex on entry to critical section
  - Or block if another thread already holds it
- Release/Unlock mutex on exit
  - One waiting thread (if any) can acquire & proceed

```
                pthread_mutex_init(m);
pthread_mutex_lock(m);     pthread_mutex_lock(m);
    hits = hits+1;             hits = hits+1;
pthread_mutex_unlock(m);   pthread_mutex_unlock(m);
```

T1 T2

Using atomic hardware primitives

- Mutex implementations usually rely on special hardware instructions that atomically do a read and a write.
- Requires special memory system support on multiprocessors

Mutex init: lock = false;

```
while (test_and_set(&lock));

Critical Section

lock = false;
```

test_and_set uses a special hardware instruction that sets the lock and returns the OLD value (true: locked; false: unlocked)
- Alternative instruction: compare & swap