The Hardware/Software Interface

CSE351 Winter 2013

Processes

Roadmap

C:

```
car *c = malloc(sizeof(car));
c->miles = 100;
c->gals = 17;
float mpg = get_mpg(c);
free(c);
```

Java:

```
Car c = new Car();
c.setMiles(100);
c.setGals(17);
float mpg =
    c.getMPG();
```

Assembly language:

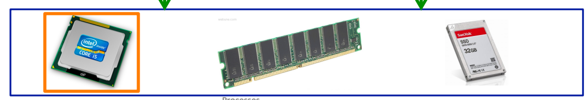
```
get_mpg:
    pushq   %rbp
    movq    %rsp, %rbp
    ...
    popq    %rbp
    ret
```

Machine code:

```
0111010000011000
100011010000010000000010
1000100111000010
110000011111101000011111
```

OS:

Computer system:



Data & addressing
Integers & floats
Machine code & C
x86 assembly programming
Procedures & stacks
Arrays & structs
Memory & caches
Exceptions & processes
Virtual memory
Memory allocation
Java vs. C

What is a process?

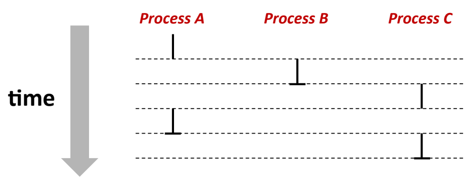
- Why are we learning about processes?
  - Processes are another *abstraction* in our computer system – the process abstraction provides an *interface* between the program and the underlying CPU + memory.
- What do processes have to do with exceptional control flow (previous lecture)?
  - Exceptional control flow is the mechanism that the OS uses to enable multiple processes to run on the same system.
- What is a program? A processor? A process?

Processes

- **Definition: A *process* is an instance of a running program**
  - One of the most important ideas in computer science
  - Not the same as “program” or “processor”
- **Process provides each program with two key abstractions:**
  - Logical control flow
    - Each process seems to have exclusive use of the CPU
  - Private virtual address space
    - Each process seems to have exclusive use of main memory
- **Why are these illusions important?**
- **How are these illusions maintained?**
  - Process executions interleaved (multi-tasking)
  - Address spaces managed by virtual memory system – next course topic

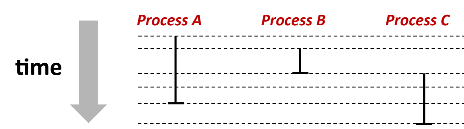
Concurrent Processes

- **Two processes *run concurrently* (are concurrent) if their instruction executions (flows) overlap in time**
- **Otherwise, they are *sequential***
- **Examples:**
  - Concurrent: A & B, A & C
  - Sequential: B & C



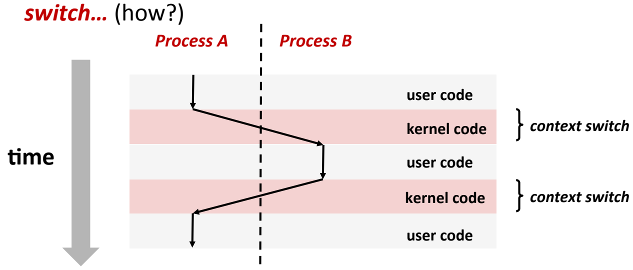
User View of Concurrent Processes

- **Control flows for concurrent processes are physically disjoint in time**
  - CPU only executes instructions for one process at a time
- **However, we can think of concurrent processes as executing in parallel**



Context Switching

- **Processes are managed by a shared chunk of OS code called the *kernel***
  - Important: the kernel is not a separate process, but rather runs as part of a user process
- **Control flow passes from one process to another via a *context switch…*** (how?)



Creating New Processes & Programs

- **fork-exec model:**
  - `fork()` creates a copy of the current process
  - `execve()` replaces the current process' code & address space with the code for a different program
- **`fork()` and `execve()` are *system calls***
  - Note: process creation in Windows is slightly different from Linux's fork-exec model
- **Other system calls for process management:**
  - `getpid()`
  - `exit()`
  - `wait()` / `waitpid()`

fork: Creating New Processes

- **`pid_t fork(void)`**
  - creates a new process (child process) that is identical to the calling process (parent process)
  - returns 0 to the child process
  - returns child's process ID (**`pid`**) to the parent process

```
pid_t pid = fork();
if (pid == 0) {
   printf("hello from child\n");
} else {
   printf("hello from parent\n");
}
```

- **`fork` is unique (and often confusing) because it is called *once* but returns *twice***

Understanding fork

Process n

```
pid_t pid = fork();
if (pid == 0) {
   printf("hello from child\n");
} else {
   printf("hello from parent\n");
}
```

pid = m

```
pid_t pid = fork();
if (pid == 0) {
   printf("hello from child\n");
} else {
   printf("hello from parent\n");
}
```

```
pid_t pid = fork();
if (pid == 0) {
   printf("hello from child\n");
} else {
   printf("hello from parent\n");
}
```

Child Process m

```
pid_t pid = fork();
if (pid == 0) {
   printf("hello from child\n");
} else {
   printf("hello from parent\n");
}
```

pid = 0

```
pid_t pid = fork();
if (pid == 0) {
   printf("hello from child\n");
} else {
   printf("hello from parent\n");
}
```

```
pid_t pid = fork();
if (pid == 0) {
   printf("hello from child\n");
} else {
   printf("hello from parent\n");
}
```

`hello from parent` ***Which one is first?*** `hello from child`

Fork Example

- **Parent and child both run the same code**
  - Distinguish parent from child by return value from **`fork()`**
  - Which runs first after the **`fork()`** is undefined
- **Start with same state, but each has a *private* copy**
  - Same variables, same call stack, same file descriptors…

```
void fork1()
{
    int x = 1;
    pid_t pid = fork();
    if (pid == 0) {
       printf("Child has x = %d\n", ++x);
    } else {
       printf("Parent has x = %d\n", --x);
    }
    printf("Bye from process %d with x = %d\n", getpid(), x);
}
```

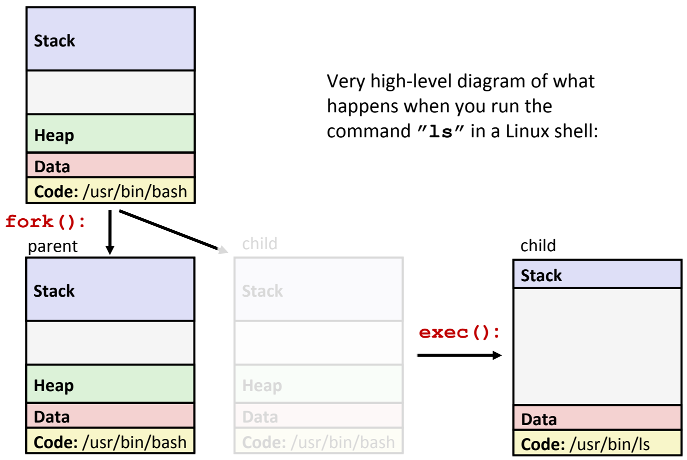

Fork-Exec

- **fork-exec model:**
  - **`fork()`** creates a copy of the current process
  - **`execve()`** replaces the current process' code & address space with the code for a different program
    - There is a whole family of **`exec`** calls – see **exec(3)** and **execve(2)**

```
// Example arguments: path="/usr/bin/ls",
//     argv[0]="/usr/bin/ls", argv[1]="-ahl", argv[2]=NULL
void fork_exec(char *path, char *argv[])
{
    pid_t pid = fork();
    if (pid != 0) {
        printf("Parent: created a child %d\n", pid);
    } else {
        printf("Child: exec-ing new program now\n");
        execv(path, argv);
    }
    printf("This line printed by parent only!\n");
}
```

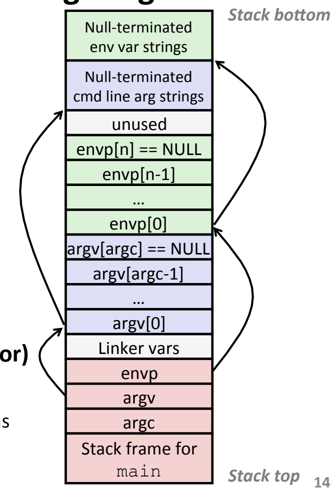
Exec-ing a new program

Very high-level diagram of what happens when you run the command "`ls`" in a Linux shell:



`execve`: Loading and Running Programs

- `int execve(`
  `char *filename,`
  `char *argv[],`
  `char *envp[]`
  `)`
- **Loads and runs in current process:**
  - Executable **`filename`**
  - With argument list **`argv`**
  - And environment variable list **`envp`**
    - Env. vars: "name=value" strings (e.g. "`PWD=/homes/iws/pjh`")
- **`execve` *does not return* (unless error)**
- **Overwrites code, data, and stack**
  - Keeps pid, open files, a few other items



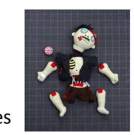
`exit`: Ending a process

- **`void exit(int status)`**
  - Exits a process
    - Status code: 0 is used for a normal exit, nonzero for abnormal exit
  - **`atexit()`** registers functions to be executed upon exit

```
void cleanup(void) {
   printf("cleaning up\n");
}

void fork6() {
   atexit(cleanup);
   fork();
   exit(0);
}
```


Zombies



- **Idea**
  - When process terminates, it still consumes system resources
    - Various tables maintained by OS
  - Called a "zombie"
    - A living corpse, half alive and half dead
- **Reaping**
  - Performed by parent on terminated child
  - Parent is given exit status information
  - Kernel discards process
- **What if parent doesn't reap?**
  - If any parent terminates without reaping a child, then child will be reaped by **`init`** process (pid == 1)
  - But in long-running processes we need *explicit* reaping
    - e.g., shells and servers

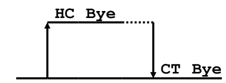
`wait`: Synchronizing with Children

- **`int wait(int *child_status)`**
  - Suspends current process (i.e. the parent) until one of its children terminates
  - Return value is the **`pid`** of the child process that terminated
    - On successful return, the child process is reaped
  - If **`child_status != NULL`**, then the int that it points to will be set to a status indicating why the child process terminated
    - There are special macros for interpreting this status – see **wait(2)**
- If parent process has multiple children, **`wait()`** will return when *any* of the children terminates
  - **`waitpid()`** can be used to wait on a specific child process

`wait` Example

```
void fork_wait() {
   int child_status;
   pid_t child_pid;

   if (fork() == 0) {
      printf("HC: hello from child\n");
   } else {
      child_pid = wait(&child_status);
      printf("CT: child %d has terminated\n",
          child_pid);
   }
   printf("Bye\n");
   exit();
}
```



Process management summary

- **`fork` gets us two copies of the same process (but `fork()` returns different values to the two processes)**
- **`execve` has a new process substitute itself for the one that called it**
  - Two-process program:
    - First **`fork()`**
    - if (pid == 0) { //child code } else { //parent code }
  - Two different programs:
    - First **`fork()`**
    - if (pid == 0) { **`execve()`** } else { //parent code }
    - Now running two completely different programs
- **`wait` / `waitpid` used to synchronize parent/child execution and to reap child process**

Summary

- **Processes**
  - At any given time, system has multiple active processes
  - Only one can execute at a time, but each process appears to have total control of the processor
  - OS periodically "context switches" between active processes
    - Implemented using *exceptional control flow*
- **Process management**
  - fork-exec model