Processes

Today
- Process concept
- Process model
- Implementing processes
- Multiprocessing once again

Next Time
- Scheduling processes
The process model

- Most computers can do more than one thing at a time
  - Hard to keep track of multiple tasks
  - How do you call each of them?
- Process – the OS’s abstraction for execution
  - A program in execution a.k.a. job, task
- Simplest (classic) case – a sequential process
  - An address space – abstraction of memory
  - A single thread of execution – abstraction of CPU
The process model

- Conceptually, every process has its own CPU
  - OS creates the illusion by virtualizing the CPU

- In reality, CPU switches back & forth among processes
  - Pseudo-parallelism

- Multiprogramming on a single CPU
  - At any instant of time one CPU means one executing task, but over time …

- Process rate of execution – not reproducible
What’s in a process

• A process consists of (at least)…
  – An address space
    • Running program code
    • Its’ data
  – A thread state
    • Execution stack and stack pointer
    • Program counter
    • General purpose registers
  – A set of OS resources
    • Including open files, network connections, …
  – Other process metadata (e.g. signal handlers)

• i.e. all you need to run or restart a program if interrupted
Process identifiers

- Every process has a unique ID
  - The PID namespace is global to the system
  - Operations that create processes return a PID (e.g., fork)
  - Operations on processes take a PID as argument (e.g., kill)

- Creating process in Unix – fork
  - `pid_t fork(void);`
  - Call once, returns twice
  - Returns 0 in child, pid in parent, -1 on error

- Special process IDs: 0 – swapper, 1 – init

- Since it’s unique sometimes used to guarantee uniqueness of other identifiers (`tmpnam/tmpfile`)
Process execution states

- Possible process states (in Unix run `ps`)
  - New – being created
  - Ready – waiting to get the processor
  - Running – being executed *(how many at once?)*
  - Waiting – waiting for some event to occur
  - Terminated – finished executing

- Transitions between states

Which state is a process in most of the time?
Implementing processes

- OS uses a data struct to keep track of process state
  - The Process Control Block
- PCB: information associated with each process
  - Process state: ready, waiting, ...
  - Program counter
  - CPU registers
  - CPU scheduling information: e.g. priority
  - Memory-management information
  - Accounting information
  - I/O status information
  - ...

- In Linux: defined in task_struct (include/linux/sched.h)
Processes in xv6 (~x86-port of Unix v6)

code:

enum procstate {UNUSED, EMBRYO, SLEEPING, RUNNABLE, RUNNING, ZOMBIE};

// Per-process state
struct proc {
    char *mem; // Start of process memory (kernel address)
    uint sz; // Size of process memory (bytes)
    char *kstack; // Bottom of kernel stack for this process
    enum procstate state; // Process state
    volatile int pid; // Process ID
    struct proc *parent; // Parent process
    struct trapframe *tf; // Trap frame for current syscall
    struct context *context; // Switch here to run process
    void *chan; // If non-zero, sleeping on chan
    int killed; // If non-zero, have been killed
    struct file *ofile[Nofile]; // Open files
    struct inode *cwd; // Current directory
    char name[16]; // Process name (debugging)
};

...
Processes in xv6 (~x86-port of Unix v6)

// The registers xv6 will save and restore
// to stop and subsequently restart a process
struct context {
    int eip;            // program counter
    int esp;            // stack pointer
    int ebx;            // Base index
    int ecx;            // Counter
    int edx;            // Extend the precision of the accumulator
    int esi;            // Source index for string ops
    int edi;            // Destination index for string ops
    int ebp;            // Stack base pointer to current stack frame
}

struct {
    struct spinlock lock;
    struct proc proc[NPROC];
} ptable;
PCBs and CPU state

- When a process is running, hardware state is loaded on CPU and registers
- When process is waiting, state is saved in the PCB
- Switching a CPU between process: context switch
  - ~5 microseconds in 1996, now is sub-microsecs

Choosing which process to run next – scheduling (Next lectures!)

![Diagram showing context switch process]
Context switching in xv6

# Context switch
# void swtch(struct context **old, struct context *new);
# Save current register context in old
# and then load register context from new.

.globl swtch
swtch:
    movl 4(%esp), %eax
    movl 8(%esp), %edx

    # Save old callee-save registers
    pushl %ebp
    pushl %ebx
    pushl %esi
    pushl %edi

    # Switch stacks
    movl %esp, (%eax)
    movl %edx, %esp

    # Load new callee-save registers
    popl %edi
    popl %esi
    popl %ebx
    popl %ebp
    ret

    Loads arguments off the stack into %eax and %edx before changing stack pointer

    Pushes register state creating a context structure on the current stack;
    %esp is save implicitly to *old;
    %eip was saved by call instruction that invoked swtch and is above %ebp

    Switch stacks

    New stack has same format, so just undo;
    ret has the %eip at the top
State queues

- OS maintains a collection of queues that represent the state of processes in the system
  - Typically one queue for each state
  - PCBs are queued onto/move between state queues according to current/new state of the associated process

- There may be many wait queues, one for each type of wait (devices, timer, message, ...)

```
Ready queue

head

Thunderbird
(9764)

…

Wait queue

head

evince
(10012)

…

term
(9089)

…

Firefox
(28918)

…

pdigin
(20309)

…
```
PCB and state queues

- PCB are data structures
  - Dynamically allocated inside OS memory
- When a process is created
  - OS allocates and initializes a PCB for it
  - OS places it on the correct queue
- As process computes
  - OS moves its PCB from queue to queue
- When process terminates
  - PCB may hang around for a while (exit code …)
  - Eventually OS frees its PCB
Process creation

- Principal events that cause process creation
  - System initialization
  - Execution of a process creation system
  - User request to create a new process
  - Initiation of a batch job

- In all cases – a process creates another one
  - Running user process, system process or batch manager process

- Process hierarchy
  - UNIX calls this a "process group"
  - No hierarchies in Windows - all created equal (parent does get a handle to child, but this can be transferred)

*Chicken and egg – What creates the first process and when?*
Process creation

- Resource sharing
  - Parent and children share all resources, a subset or none

- Execution
  - Parent and children execute concurrently or parent waits

- Address space
  - Child duplicate of parent or one of its own from the start

- Unix example
  - `fork()` system call creates new process; a clone of parent
  - Both continue execution at the instruction after the fork
  - `execve` replaces process’ memory space with new one

*Why two steps?*

*Can you think of an everyday example where `fork` is enough?*
Hierarchy of processes in Solaris

- **sched** is first process
- Its children pageout, fsflush, init …
- **csh** *(pid = 7778)*, user logged using telnet
- …
Process creation in UNIX

- Processes are created by existing processes
- UNIX creation through `fork()`
  - Creates and initializes a new PCB
  - Creates a new address space and initializes it with content of parent’s
  - Initializes kernel resources with those of the parent
  - Places PCB in ready queue
- the `fork()` call once, returns twice
  - Once into the parent, and once into the child
    - Returns child’s PID to the parent
    - And 0 to the child
- `fork()` ~ clone me
Process creation in UNIX

#include <stdio.h>
#include <sys/types.h>

int main (int argc, char* argv[])
{
    int pid; int ppid = getpid();

    if ((pid = fork()) < 0){
        perror("fork failed");
        return 1;
    } else {
        if (pid == 0){  /* Return 0 to the child */
            printf("I am %d the child of %d\n", getpid(), ppid);
            return 0;
        } else {  /* And the child PID to the parent */
            printf("I am %d, the parent of %d\n", ppid, pid);
            return 0;
        }
    }
}

Where does the newly created process start?
Testing `fork()` - output

[fabianb@eleuthera tmp]$ gcc -o creatone createone.c
[fabianb@eleuthera tmp]$ ./creatone
I am 6647, the parent of 6648
I am 6648 the child of 6647
Process creation in UNIX

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

int main (void)
{
    pid_t childpid, mypid;

    mypid = getpid();
    childpid = fork();
    if (childpid == -1) {
        perror("Failed to fork\n");
        return 1;
    }
    if (childpid == 0) /* child */
        printf("Child %d, ID = %d\n", getpid(), mypid);
    else /* parent */
        printf("Parent %d, ID = %d\n", getpid(), mypid);
    return 0;
}
```

Both IDs should be the same
The dangers with sharing ...

[fabianb@eleuthera tmp]$ ./badpid
Child 3948, ID = 3947
Parent 3947, ID = 3947

...  
mypid = getpid();
childpid = fork();
if (childpid == -1) {
    perror("Failed to fork\n");
    return 1;
}
if (childpid == 0) /* child */
    printf("Child %d, ID = %d\n", getpid(), mypid);
else /* parent */
    printf("Parent %d, ID = %d\n", getpid(), mypid);
return 0;
}
Process creation in UNIX + exec(

- Beyond cloning – first fork, then exec
- `int execv(char *prog, char *argv[])`
  - (a family of functions, front-ends for execve)
  - Stops current process
  - Loads prog into the address space (overwriting what’s there)
  - Initializes hardware content, args for new program
  - Places PCB onto ready queue

- To run a new program, then
  - `fork` to create a child
  - Child does an `exec`
  - Parent can wait for child to complete or not
Process creation in UNIX

... 

```c
if ((pid = fork()) < 0) {
    perror("fork failed");
    return 1;
} else {
    if (pid == 0) {
        printf("Child before exec ... now the ls output\n");
        execlp("/bin/ls", "ls", NULL);
    } else {
        wait(NULL); /* block parent until child terminates */
        printf("Child completed\n");
        return 0;
    }
}
```
fork() + exec() – output

[fabianb@eleuthera tmp]$ ./creattwo
Child before exec ... now the ls output

    copy_shell          creatone.c~  p3id    skeleton
    copy_shell.tar      creattwo      p3id.c   uwhich.tar
    creatone            creattwo.c    p3id.c~
    creatone.c          creattwo.c~

Child completed
Faster creation

- The semantics of fork() says that the child’s address space is a copy of the parent’s
- Expensive (i.e. slow) implementation
  - Allocate physical memory for the new address space
  - Copy one into the other
  - Set up child’s page tables to map to new address space
- To make it faster …
Faster creation – version 1

- Vfork() – oldest approach, redefine the problem
  - “child address space is a copy of the parent’s” ➞ “child address space *is* the parent’s”
  - Parent suspended until child exits or calls execve
  - Child promises not to modify the address space before that
  - Not enforced, use at your own peril
  - Saves the effort of duplicating parent’s address space when child is going to exec anyway
  - Uncommon today
Faster creation – version 2

- Keep old semantic, but implement it differently
  - Copy only what you need, on demand

- COW – copy on write
  - Create new address space
  - Initialize page tables to the same mappings as parent’s and set both parents and child page tables to read-only
  - If either parent or child tries to write – page fault
  - When a page fault occurs
    - Allocate new physical page for child
    - Copy content
    - Mark entries as writable
    - Restart process

- *Page are copied only as needed*
UNIX shells

```c
int main(int argc, char **argv)
{
    while (1) {
        printf("% ");
        char *cmd = get_next_cmd();
        int pid = fork();
        if (pid == 0) {
            exec(cmd);
            panic("exec failed!");
        } else {
            wait(pid);
        }
    }
}
```
... Read and run input commands.
while(getcmd(buf, sizeof(buf)) >= 0){
    if(buf[0] == 'c' && buf[1] == 'd' && buf[2] == ' '){
        // Clumsy but will have to do for now.
        // Chdir has no effect on the parent if run in the child.
        buf[strlen(buf)-1] = 0; // chop 
        if(chdir(buf+3) < 0)
            printf(2, "cannot cd %s\n", buf+3);
        continue;
    }
    if(fork1() == 0)
        runcmd(parsecmd(buf));
    wait();
}
...
Fork and Linux’ clone

- Clone is replacing fork (and vfork)

```c
#include <sched.h>
int clone (int (*fn) (void *), void *child_stack, int flags, void *arg);
```

- Starting at a different point, with a given stack, and after inheriting something from the parent
- Not typically called directly
exec and company

- exec is not a system call

  ```c
  int execl(const char *path, const char *arg, ...);
  int execlp(const char *file, const char *arg, ...);
  int execl(const char *path, const char *arg,
             ..., char * const envp[]);
  int execv(const char *path, char *const argv[]);
  int execvp(const char *file, char *const argv[]);
  int execve(const char *file, char *const argv[],
             char *const envp[]);
  ```

- execve is the only “exec-like” system call
  - The rest are front-ends to it
  - execve knows whether you have done a fork or a vfork by a flag in the PCB
Summary

• Today
  – The process abstraction
  – Its implementation
    • How they are represented
    • How the CPU is scheduled across processes
    • ...
  – Processes in Unix
  – Perhaps the most important part of the class

• Coming up
  – Scheduling ...