W4118: Process and Address Space

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References: Modern Operating Systems (3rd edition), Operating Systems Concepts (8th edition), previous W4118, and OS at MIT, Stanford, and UWisc

Outline

- Process
- Address space
- Process dispatch
- Common process operations

What is a process

- Process: an execution stream in the context of a particular process state
  - "Program in execution" "virtual CPU"
- Execution stream: a stream of instructions
- Process state: determines effect of running code
  - Registers: general purpose, instruction pointer (program counter), floating point, …
  - Memory: everything a process can address, code, data, stack, heap, …
  - I/O status: file descriptor table, …

Program v.s. process

- Program != process
  - Program: static code + static data
  - Process: dynamic instantiation of code + data + more

- Program ⇔ process: no 1:1 mapping
  - Process > program: more than code and data
  - Program > process: one program runs many processes
  - Process > program: many processes of same program

Why use processes?

- Express concurrency
  - Systems have many concurrent jobs going on
    - E.g. Multiple users running multiple shells, I/O, …
  - OS must manage
- General principle of divide and conquer
  - Decompose a large problem into smaller ones → easier to think of well contained smaller problems
- Isolated from each other
  - Sequential with well defined interactions

Process management

- Process control block (PCB)
  - Process state (new, ready, running, waiting, finish …)
  - CPU registers (e.g., %eip, %eax)
  - Scheduling information
  - Memory-management information
  - Accounting information
  - I/O status information

- OS often puts PCBs on various queues
  - Queue of all processes
  - Ready queue
  - Wait queue

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System categorization

- Uniprogramming: one process at a time
  - Eg., early main frame systems, MSDOS
  - Good: simple
  - Bad: poor resource utilization, inconvenient for users

- Multiprogramming: multiple processes, when one waits, switch to another
  - E.g, modern OS
  - Good: increase resource utilization and user convenience
  - Bad: complex

  - Note: multiprogramming != multiprocessing

Multiprogramming

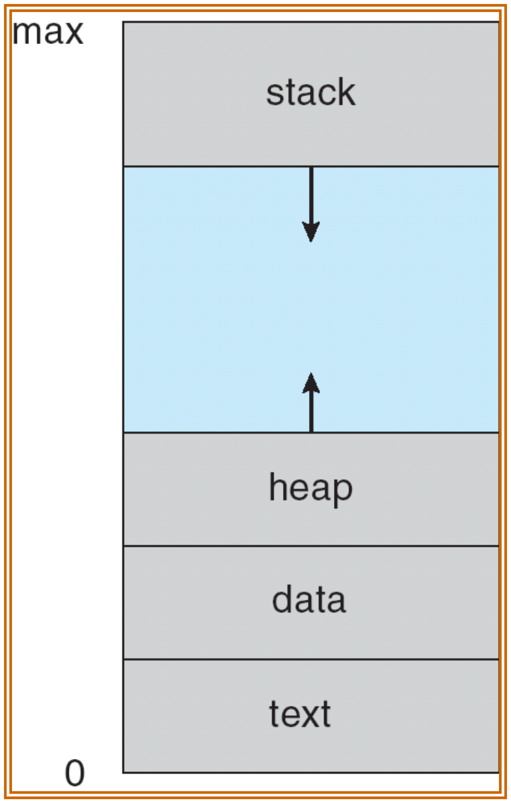
- OS requirements for multiprogramming
  - Scheduling: what process to run? (later)
  - Dispatching: how to switch? (today + later)
  - Memory protection: how to protect from one another? (today + later)

- Separation of policy and mechanism
  - Recurring theme in OS
  - Policy: decision making with some performance metric and workload (scheduling)
  - Mechanism: low-level code to implement decisions (dispatching, protection)

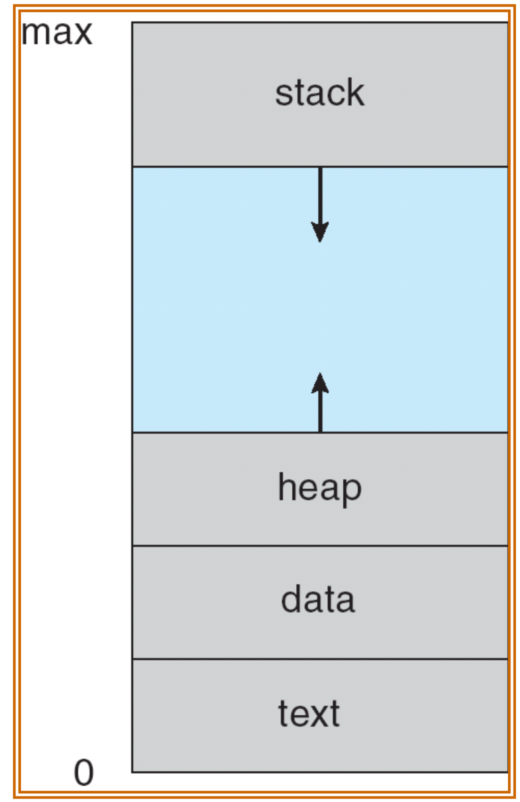
Address Space

- Address Space (AS): all memory a process can address
  - Really large memory to use
  - Linear array of bytes: [0, N), N roughly 2^32, 2^64
- Process ⇔ address space: 1 : 1 mapping
- Address space = protection domain
  - OS isolates address spaces
  - One process can't access another's address space
  - Same pointer address in different processes point to different memory

Address space illustration

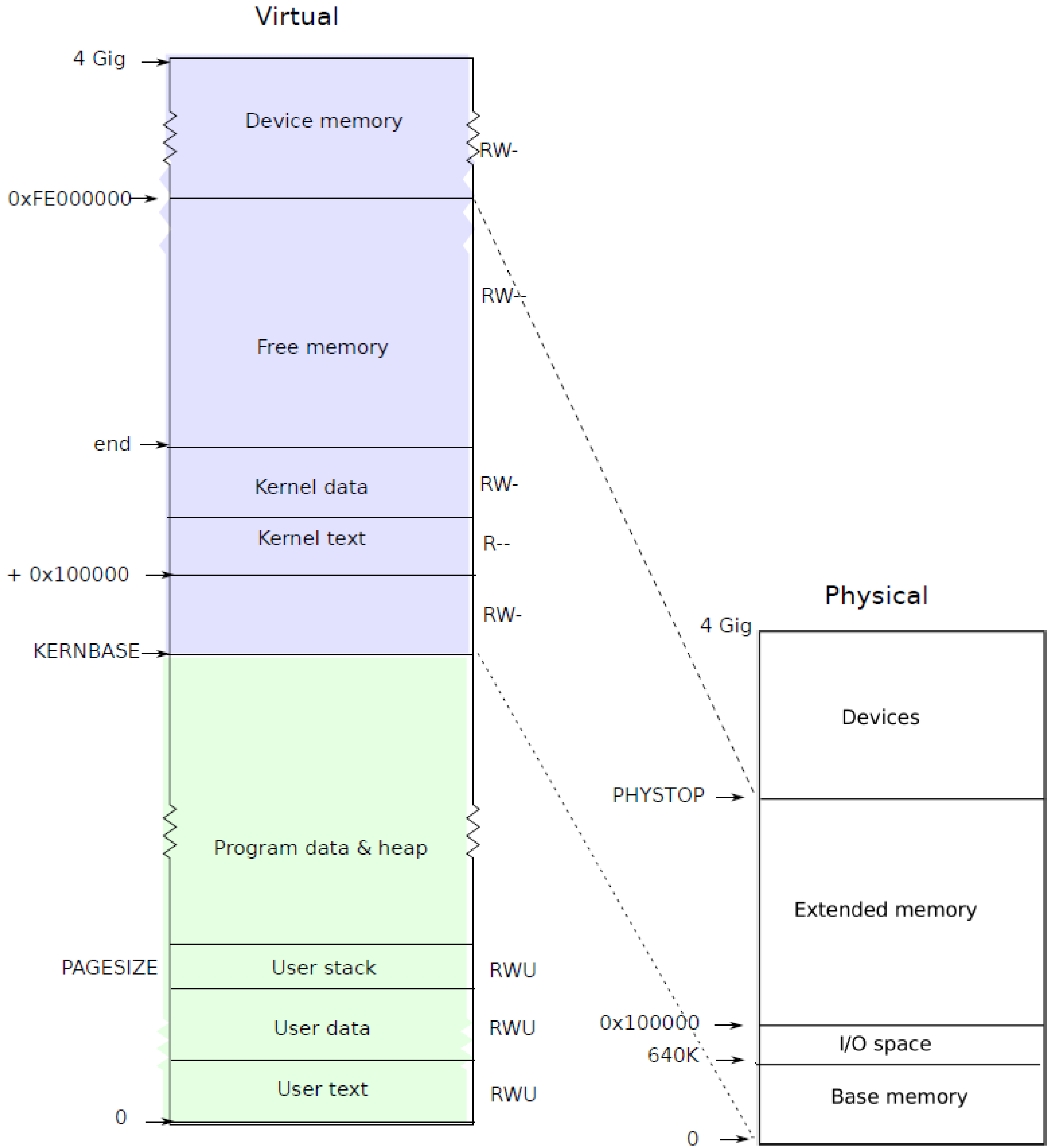


Process A



Process B

xv6 address space (memlayout.h)



Process dispatching mechanism

OS dispatching loop:

```
while(1) {
    run process for a while;
    save process state;
    next process = schedule (ready processes);
    load next process state;
}
```

Q1: how to gain control?

Q2: how to switch context?

Q1: How does Dispatcher gain control?

- Must switch from user mode to kernel mode
- Cooperative multitasking: processes voluntarily yield control back to OS
  - When: system calls that relinquish CPU
  - OS trusts user processes!
- True multitasking: OS preempts processes by periodic alarms
  - Processes are assigned time slices
  - Counts timer interrupts before context switch
  - OS trusts no one!

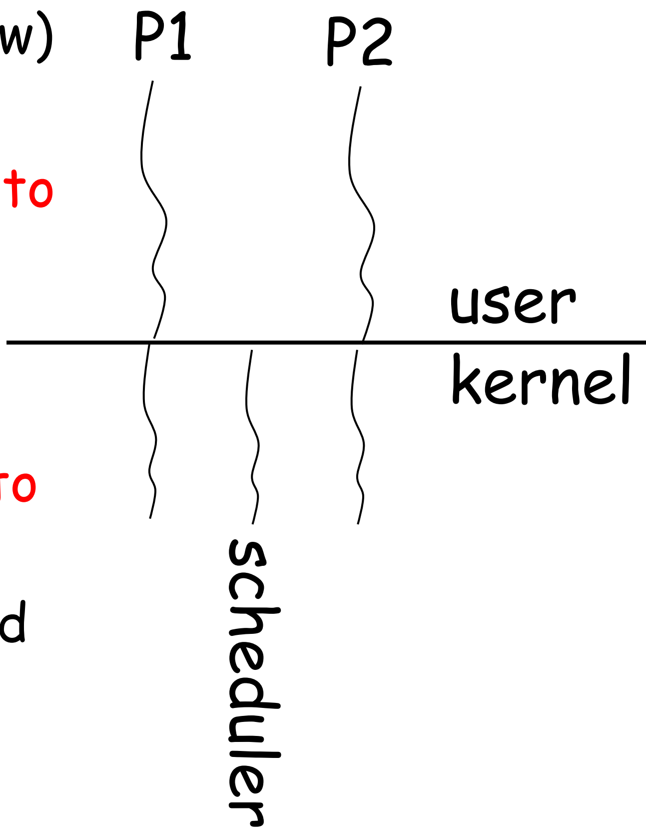
Q2: how to switch context?

- Implementation: machine dependent
  - Tricky: OS must save state w/o changing state!
    - Need to save all registers to PCB in memory
    - Run code to save registers? Code changes registers
  - Solution: software + hardware

- Performance?
  - Can take long. Save and restore many things. The time needed is hardware dependent
  - Context switch time is pure overhead: the system does no useful work while switching
  - Must balance context switch frequency with scheduling requirement

xv6 context switch

1. Save P1's user-mode CPU context and switch from user to kernel mode (need hw)
2. Handle system call or interrupt
3. Save P1's kernel CPU context and switch to scheduler CPU context (need hw)
4. Select another process P2
5. Switch to P2's address space (need hw)
6. Save scheduler CPU context and switch to P2's kernel CPU context (need hw)
7. Switch from kernel to user mode and load P2's user-mode CPU context (need hw)



- swtch.S

Outline

- What is a process?
- Address space
- Process dispatch
- Common process operations

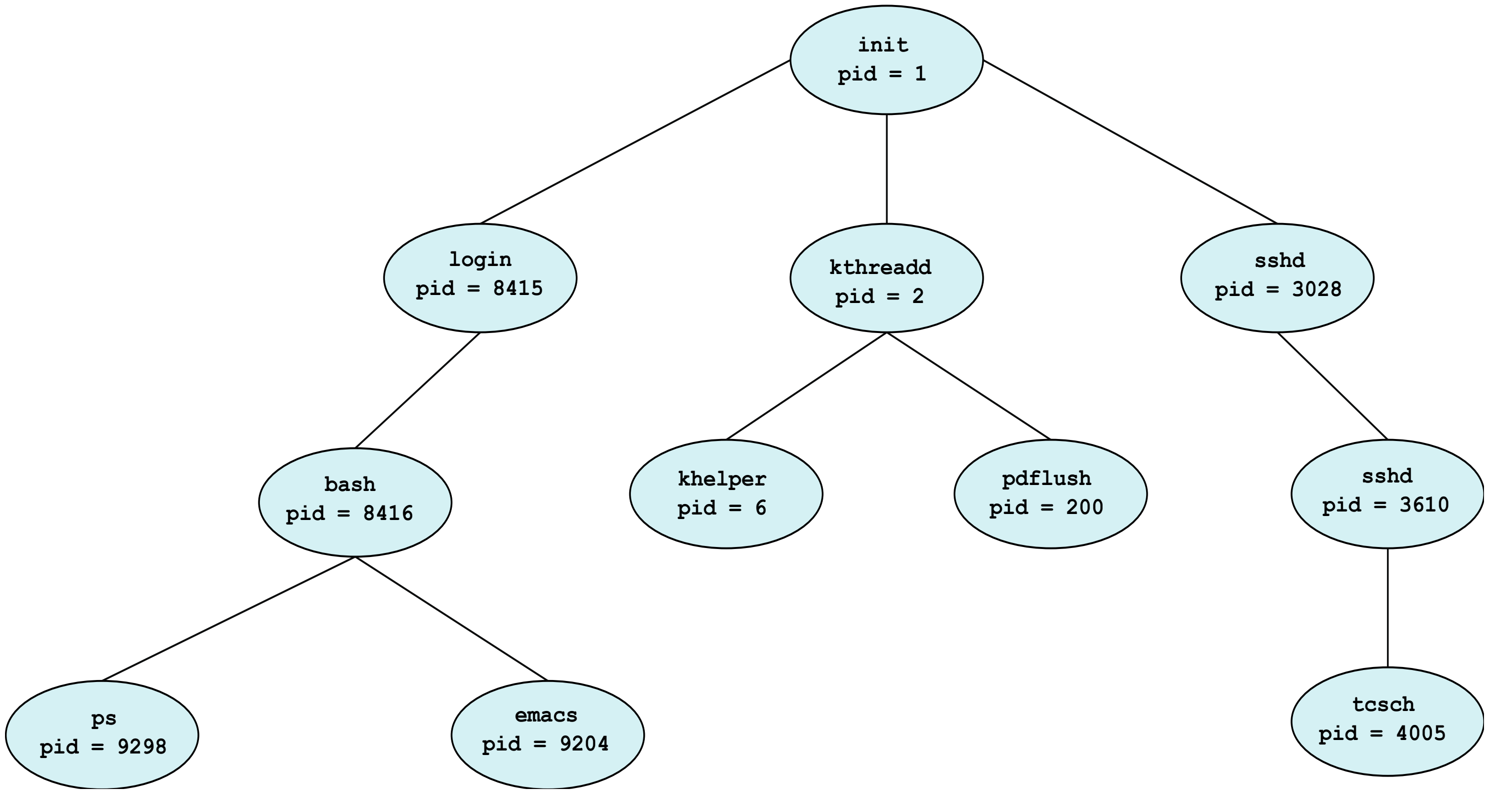
Process creation

- Option 1: cloning (e.g., Unix fork(), exec())
  - Pause current process and save its state
  - Copy its PCB (can select what to copy)
  - Add new PCB to ready queue
  - Must distinguish parent and child
- Option 2: from scratch (Win32 CreateProcess)
  - Load code and data into memory
  - Create and initialize PCB (make it like saved from context switch)
  - Add new PCB to ready queue

Distinguished Processes

- The UNIX init process: /sbin/init
  - First and only user process instantiated by the kernel
  - Kernel forks init and goes idle
  - Responsible for forking all other processes
    - login screen, window manager
  - Can be configured to start different things
    - Read scripts in /etc/init.d on Linux
- The Android zygote process
  - Parent of all managed (Java) applications
  - Preloaded version of Dalvik runtime, libraries
  - fork() makes new application loading very efficient
  - Less memory, faster app start

A Process Tree



- On Linux: ps axjf to see process tree

Process termination

- Normal: exit(int status)
  - OS passes exit status to parent via wait(int *status)
  - OS frees process resources

- Abnormal: kill(pid_t pid, int sig)
  - OS can kill process
  - Process can kill process

Zombie and orphan

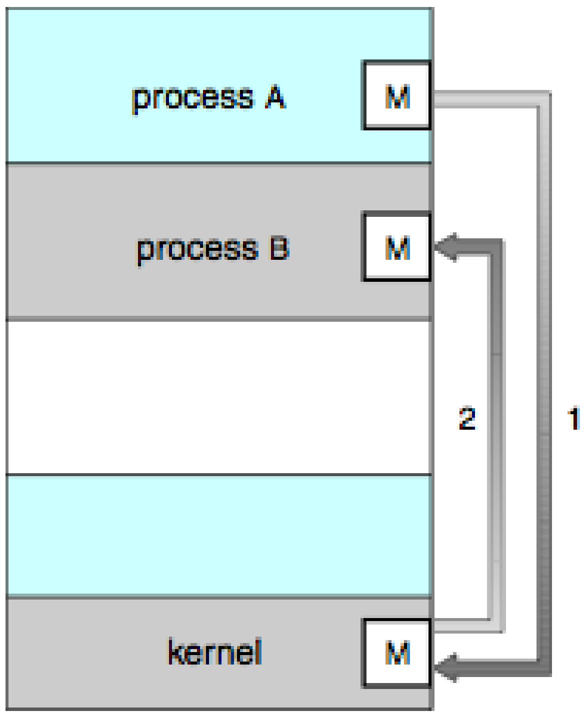
- What if child exits before parent?
  - Child becomes zombie
    - Need to store exit status
    - OS can't fully free
  - Parent must call wait() to reap child
- What if parent exits before child?
  - Child becomes orphan
    - Need some process to query exit status and maintain process tree
  - Re-parent to the first process, the init process

Cooperating Processes

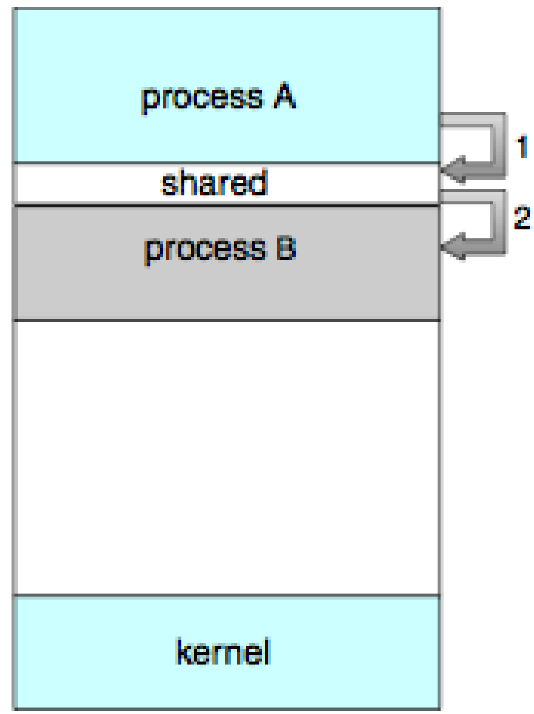
- Independent process cannot affect or be affected by the execution of another process.
- Cooperating process can affect or be affected by the execution of another process
- Advantages of process cooperation
  - Information sharing
  - Computation speed-up
  - Modularity/Convenience

Interprocess Communication Models

Message Passing



Shared Memory



Message Passing v.s. Shared Memory

- Message passing
  - Why good? All sharing is explicit ➔ less chance for error
  - Why bad? Overhead. Data copying, cross protection domains
- Shared Memory
  - Why good? Performance. Set up shared memory once, then access w/o crossing protection domains
  - Why bad? Things change behind your back ➔ error prone

IPC Example: Unix signals

- Signals
  - A very short message: just a small integer
  - A fixed set of available signals. Examples:
    - 9: kill
    - 11: segmentation fault
- Installing a handler for a signal
  - sighandler_t signal(int signum, sighandler_t handler);
- Send a signal to a process
  - kill(pid_t pid, int sig)

IPC Example: Unix pipe

- int pipe(int fds[2])
  - Creates a one way communication channel
  - fds[2] holds the returned two file descriptors
  - Bytes written to fds[1] will be read from fds[0]

```
int pipefd[2];
pipe(pipefd);
      switch(pid=fork()) {
      case -1: perror("fork"); exit(1);
      case 0:  close(pipefd[0]);
               // write to fd 1
               break;
      default:  close(pipefd[1]);
               // read from fd 0
         break;
}
```

IPC Example: Unix Shared Memory

- int shmget(key_t key, size_t size, int shmflg);
  - Create a shared memory segment; returns ID of segment
  - key: unique key of a shared memory segment, or IPC_PRIVATE
- int shmat(int shmid, const void *addr, int flg)
  - Attach shared memory segment to address space of the calling process
  - shmid: id returned by shmget()
- int shmdt(const void *shmaddr);
  - Detach from shared memory
- Problem: synchronization! (later)

Next lecture

- Memory management

Process v.s. Thread

- Thread: separate streams of execution that share the same address space
- Process != Thread
  - One process can have multiple threads
  - Threads communicate more efficiently
- More on thread later