Operating Systems Design
4. Processes

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Key concepts from last week

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Boot Loader

- Multi-stage boot loader
- Traditional Intel PC architecture
  - BIOS
  - Master Boot Record
  - Volume Boot Record
  - OS Loader
- Newer PC architecture (2005+)
  - UEFI – knows how to read one or more file systems
  - Loads OS loader from a boot partition
- Embedded systems
  - Boot firmware on chip

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Operating System vs. Kernel

- Kernel
  - "nucleus" of the OS; main component
  - Provides abstraction layer to underlying hardware
  - Enforces policies
- Rest of the OS
  - Utility software, windowing system, print spoolers, etc.
- Kernel mode vs. user mode execution
  - Flag in the CPU
  - Kernel mode = can execute privileged instructions

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Mode switch

- Transition from user to kernel mode (and back)
- Includes a change in flow
  - Cannot just execute user's instructions in kernel mode!
  - Well-defined addresses set up at initialization
- Change mode via:
  - Hardware interrupt
  - Software trap (or syscall)
  - Violations (exceptions): illegal instruction or memory reference

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Context Switch

- Mode switch + change executing process

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Timer interrupts

- Crucial for:
  - Preempting a running process to give someone else a chance (force a context switch)
    - Including ability to kill the process
  - Giving the OS a chance to poll hardware
  - OS bookkeeping

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Timer interrupts

- Windows
  - Typically 64 or 100 interrupts per second
  - Apps can raise this to 1024 interrupts per second
- Linux
  - Interrupts from Programmable Interval Timer (PIT) or HPET (High Precision Event Timer) and from a local APIC timer (Advanced Programmable Interrupt Controller; one per CPU) – all at the same rate
  - Interrupt frequency varies per kernel and configuration
    - Linux 2.4: 100 Hz
    - Linux 2.6.0 – 2.6.13: 1000 Hz
    - Linux 2.6.14+ : 250 Hz
    - Linux 2.6.18: aperiodic – tickless kernel
      - PIT not used for periodic interrupts; just APIC timer interrupts

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Processes

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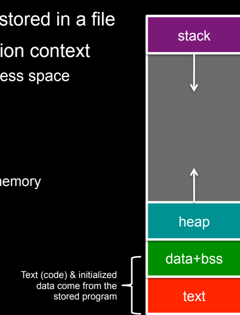
Process

- Program: code & static data stored in a file
- Process: a program's execution context
  - Each process has its own address space
  - Memory map
    - Text: compiled program
    - Data: initialized static data
    - BSS: uninitialized static data
    - Heap: dynamically allocated memory
    - Stack: call stack
  - Process context:
    - Program counter
    - CPU registers



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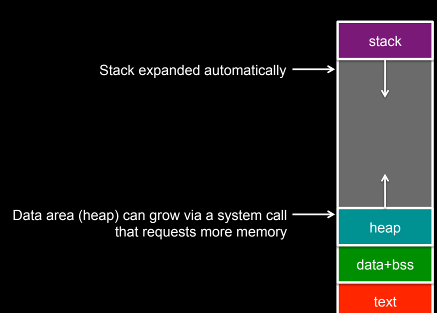
Growing memory



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Contexts

- Entering the kernel
  - Hardware interrupts
    - Asynchronous events (I/O, clock, etc.)
    - Do not relate to the context of the current process
      - Because they are asynchronous, *any* process might be running when they occur
  - Software traps
    - Are related to the context of the current process [process context]
    - Examples: illegal memory access, divide by zero, illegal instruction
  - Software initiated traps
    - System call from the current process [process context]
  - *The current executing process' address space is active on a trap*
- Saving state
  - Kernel stack switched in upon entering kernel mode
  - Kernel must save machine state before servicing event
    - Registers, flags (program status word), program counter, …

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System calls

- Entry: Trap to system call handler
  - Save state
  - Verify parameters are in a valid address
  - Copy them to kernel address space
  - Call the function that implements the system call
    - If the function has to (cannot be satisfied immediately) then
      - Context switch to let another ready process run
      - Put our process on a blocked list
- Return from system call or interrupt
  - Check for signals to the process
    - Call the appropriate handler if signal is not ignored
  - Check if another process should run
    - Context switch to let the other process run
    - Put our process on a *ready* list
  - Calculate time spent in the call for profiling/accounting
  - Restore user process state
  - Return from interrupt

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Processes in a Multitasking Environment

- Multiple concurrent processes
  - Each has a unique identifier: Process ID (PID)
- Asynchronous events (interrupts) may occur
- Processes may request operations that take a long time
- Goal: have some process running at all times
- Context saving/switching
  - Processes may be suspended and resumed
  - Need to save all state about a process so we can restore it

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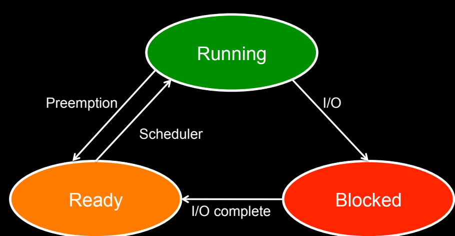
Process states



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Keeping track of processes

- Process list stores a Process Control Block (PCB) per process
- A Process Control Block contains:
  - Process ID
  - Machine state (registers, program counter, stack pointer)
  - Parent & list of children
  - Process state (ready, running, blocked)
  - Memory map
  - Open file descriptors
  - Owner (user ID) – determine access & signaling privileges
  - Event descriptor if the process is blocked
  - Signals that have not yet been handled
  - Policy items: Scheduling parameters, memory limits
  - Timers for accounting (time & resource utilization)
  - (Process group)

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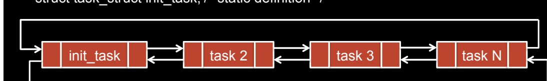
Processes in Linux

- The OS creates one task on startup:
  init: the parent of all tasks
  launchd: replacement for *init* on Mac OS X and FreeBSD
- Process state stored in `struct task_struct`
  - Defined in `linux/sched.h`
- Stored as a circular, doubly linked list
  - `struct list_head` in `linux/list.h`

struct task_struct init_task; /* static definition */



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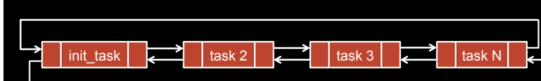
Processes in Linux

- Iterating through processes

```
for (p = &init_task; ((p = next_task(p)) != &init_task; ) {
    /* whatever */
}
```

- The current process on the current CPU is obtained from the macro `current`

```
current->state = TASK_STOPPED;
```



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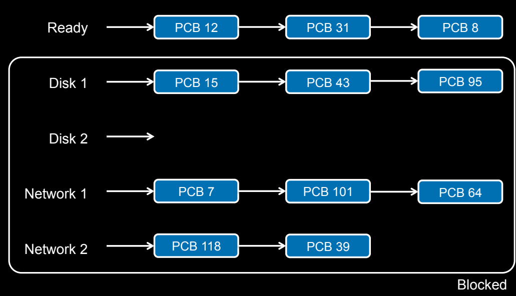
Processes on Ready & Blocked Queues



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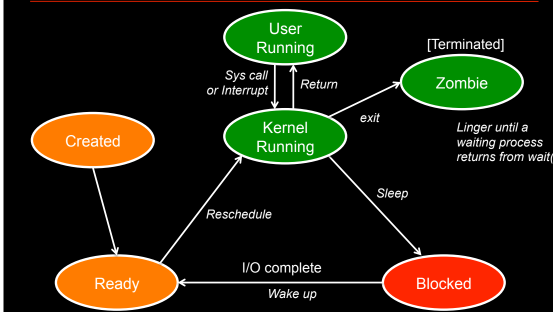
Process States: a bit more detail



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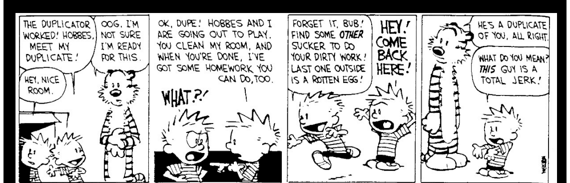
Creating a process under POSIX

fork system call

- Clones a process into two processes
  - New context is created: duplicate of parent process
- *fork* returns 0 to the child and the process ID to the parent



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What happens?

- Check for available resources
- Allocate a new PCB
- Assign a unique PID
- Check process limits for user
- Set child state to "created"
- Copy data from parent PCB slot to child
- Increment counts on current directory & open files
- Copy parent context in memory (or set *copy on write*)
- Set child state to "ready to run"
- Wait for the scheduler to run the process

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Fork Example

```
#include <stdio.h>

main(int argc, char **argv) {
    int pid;

    switch (pid=fork()) {
    case 0:   printf("I'm the child\n");
        break;
    default:
        printf("I'm the parent of %d\n", pid);
        break;
    case -1:
        perror("fork");
    }
}
```

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Running other programs

execve: replace the current process image with a new one
- *See also execl, execle, execlp, execvp, execvP*

- New program inherits:
  - Processes group ID
  - Open files
  - Access groups
  - Working directory
  - Root directory
  - Resource usages & limits
  - Timers
  - File mode mask
  - Signal mask

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Exec Example

```
#include <unistd.h>

main(int argc, char **argv) {
        char *av[] = { "ls", "-al", "/", 0 };

        execvp("ls", av);
}
```

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Fork & exec combined

- UNIX creates processes via *fork* followed by *exec*
- Windows approach
  - *CreateProcess* system call to create a new child process
  - Specify the executable file and parameters
  - Identify startup properties (windows size, input/output handles)
  - Specify directory, environment, and whether open files are inherited

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Exiting a process

exit system call

```
#include <stdlib.h>

main(int argc, char **argv) {
    exit(0);
}
```

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exit: what happens?

- Ignore all signals
- If the process is associated with a controlling terminal
  - Send a hang-up signal to all members of the process group
  - reset process group for all members to 0
- close all open files
- release current directory
- release current changed root, if any
- free memory associated with the process
- write an accounting record (if accounting)
- make the process state zombie
- assign the parent process ID of any children to be 1 (init)
- send a "death of child" signal to parent process (SIGCHLD)
- context switch (we have to!)

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Wait for a child process to die

wait system call

- Suspend execution until a child process exits
- *wait* returns the exit status of that child.

```
int pid, my_pid, status;

switch (my_pid=fork()) {
case 0:      /* do child stuff */ break;
case -1:     /* do error stuff */ break;

default:     /* wait for child to exit */
    while (pid=wait(&status))
        if (pid==my_pid)
            printf("got exit of %d\n", WEXITSTATUS(status));
            break;
}
```

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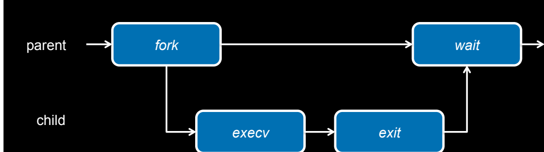
Parent & child processes



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Signals

- Inform processes of asynchronous events
  - Processes may specify signal handlers
- Processes can poke each other (if they are owned by the same user)
- Sending a signal:
  - *kill (int pid, int signal_number)*
- Detecting a signal:
  - *signal (signal_number, function)*

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The End

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