Operating Systems

04. Processes

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Key concepts from last week

Boot Loader

- Multi-stage boot loader
- Old Intel PC architecture (*still used!*)
  - BIOS
  - Master Boot Record – located at block 0
  - Volume Boot Record
  - OS Loader
- Current PC architecture (2005+)
  - UEFI – knows how to read one or more file systems
  - Loads OS loader from a boot partition
- Embedded systems (e.g., ARM-based devices)
  - Custom boot firmware on the processor chip

Operating System vs. Kernel

- Kernel
  - "nucleus" of the OS; main component
  - Provides abstraction layer to underlying hardware
  - Manages system resources (CPU, file systems, memory, network)
  - 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

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

Context Switch

- Mode switch + change executing process

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

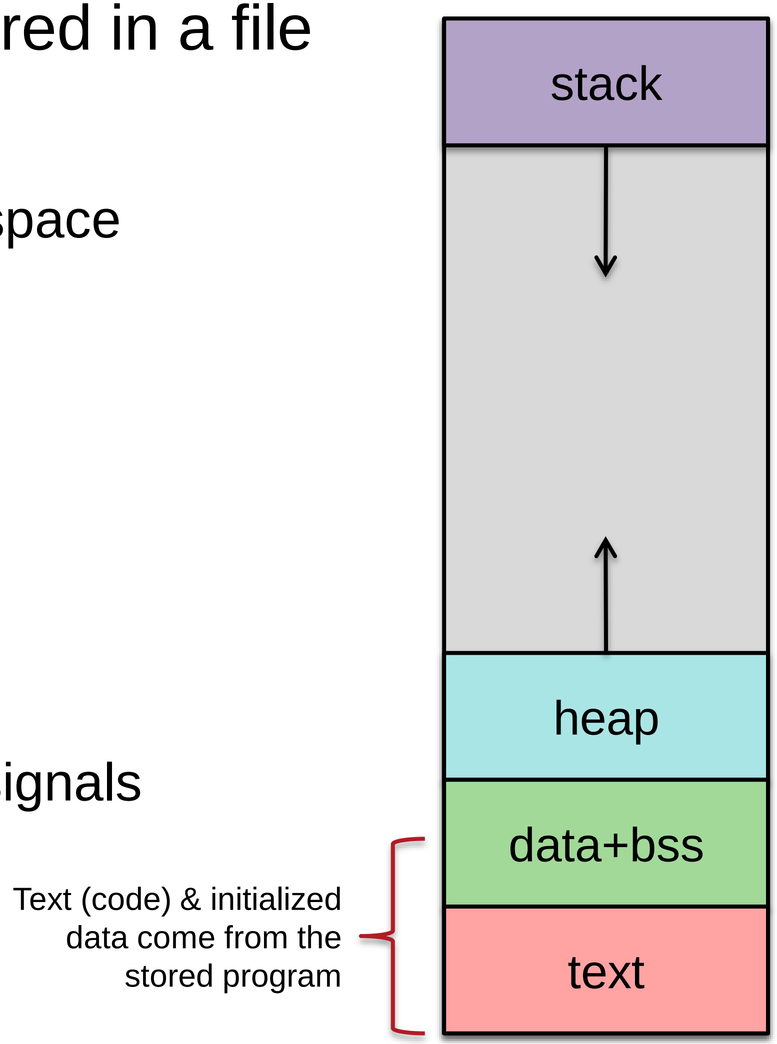
Timer interrupts

- 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 (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 and beyond: aperiodic – tickless kernel
      - PIT not used for periodic interrupts; just APIC timer interrupts
      - Kernel determines when the next interrupt should take place

Processes

Process

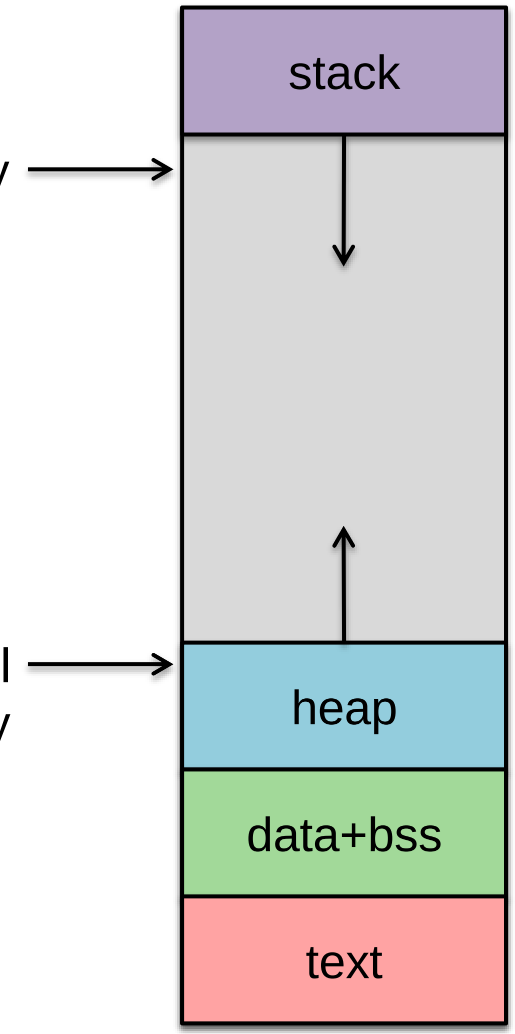
- Program: code & static data stored in a file
- Process: a running program
  - Each process has its own address space (we'll look at this later)
  - **Memory map**
    - Text: compiled program
    - Data: initialized static data
    - BSS: uninitialized static data
    - Heap: dynamically allocated memory
    - Stack: call stack
  - **System state**: open files, pending signals
  - **Processor statte**:
    - Program counter
    - CPU registers



Growing memory

Stack expanded automatically

Data area (heap) can grow via a system call that requests more memory



Contexts

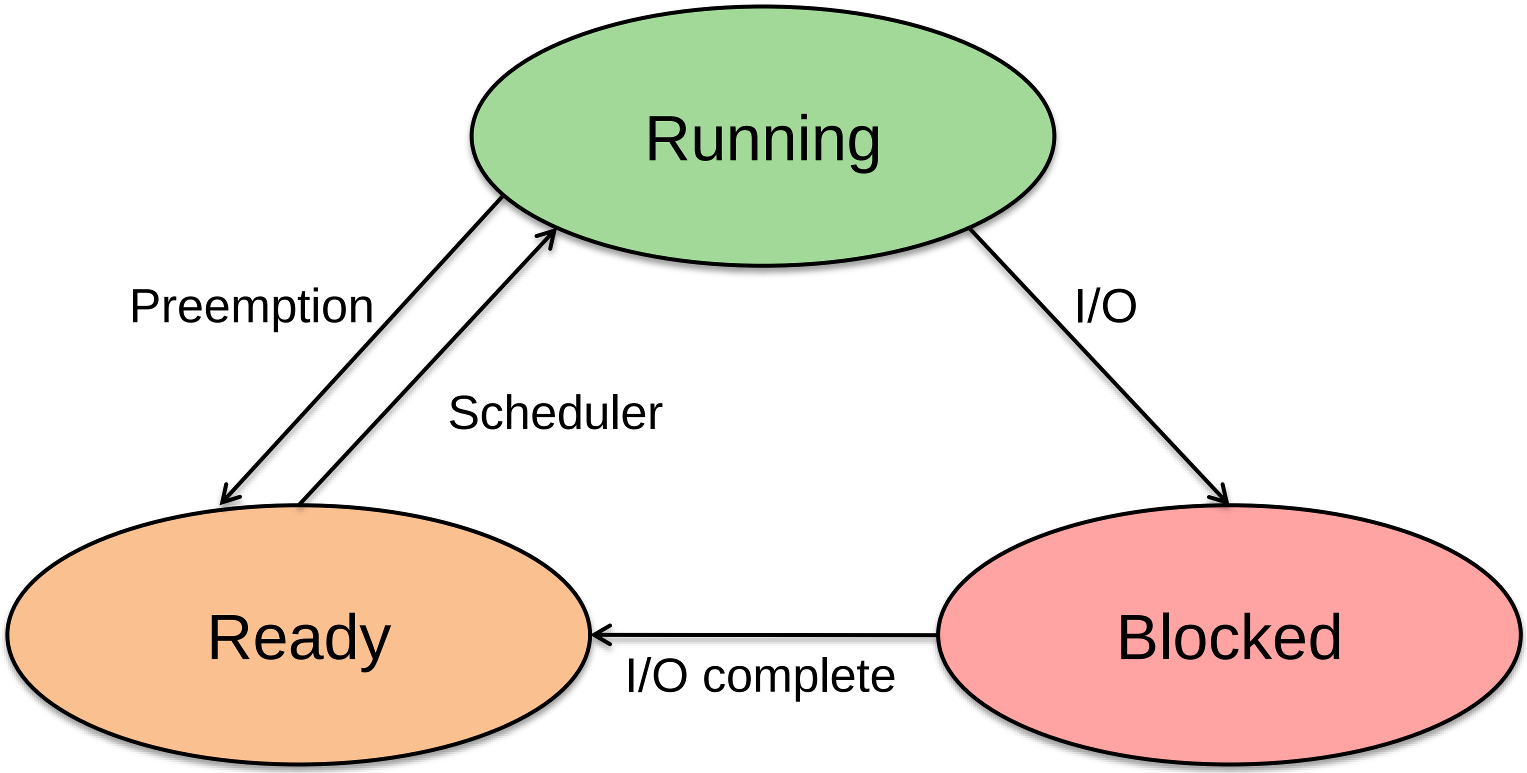
- Entering the kernel
  - Hardware interrupts
    - Asynchronous events (I/O, clock, etc.)
    - *Do not* relate to the context of the current process [**kernel context**]
  - Violations
    - Are related to the context of the current process [**process context**]
    - Examples: illegal memory access, divide by zero, illegal instruction
  - Software initiated traps (software interrupts)
    - System call from the current process [**process context**]
- *The view of memory does not change on a trap*
  - *The currently 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, …

Processes in a Multitasking Environment

- Multiple concurrent processes
  - Each process has a unique identifier: Process ID (PID)

- Asynchronous events (interrupts) may occur
  - The OS will have to take care of them
- Processes may request operations that take a long time
  - They have nothing to do now but wait
- Goal: always have *some* process running
  - Context saving/switching
    - Processes may be suspended and resumed
    - Need to save all state about a process so we can restore it

Process states



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)

System calls

Entry
Trap to system call handler

- Save CPU 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 cannot be satisfied immediately then
    - Put process on a ***blocked*** list
    - ***Context switch*** to let another *ready* process run

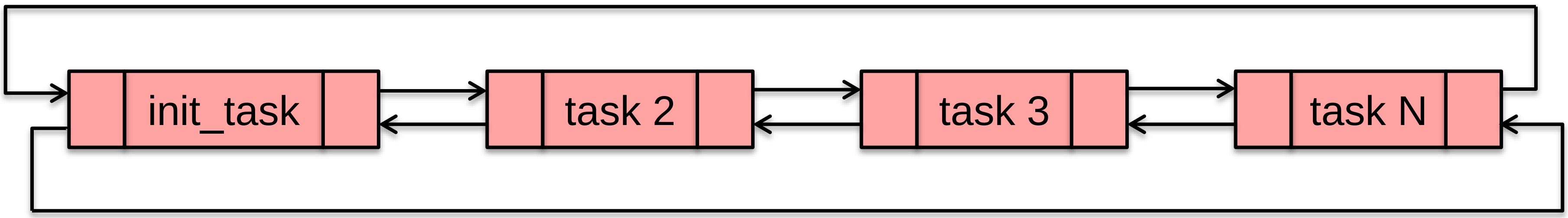
Return from system call or interrupt

- 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

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 task_struct init_task;     /* static definition of the first task*/
```



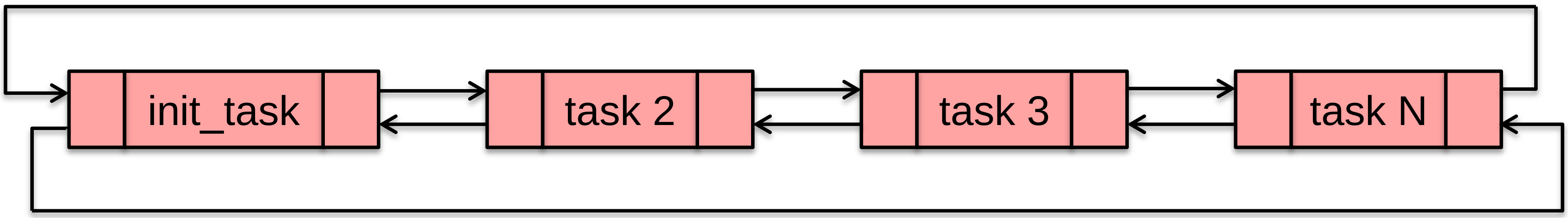
Processes in Linux

Iterating through processes

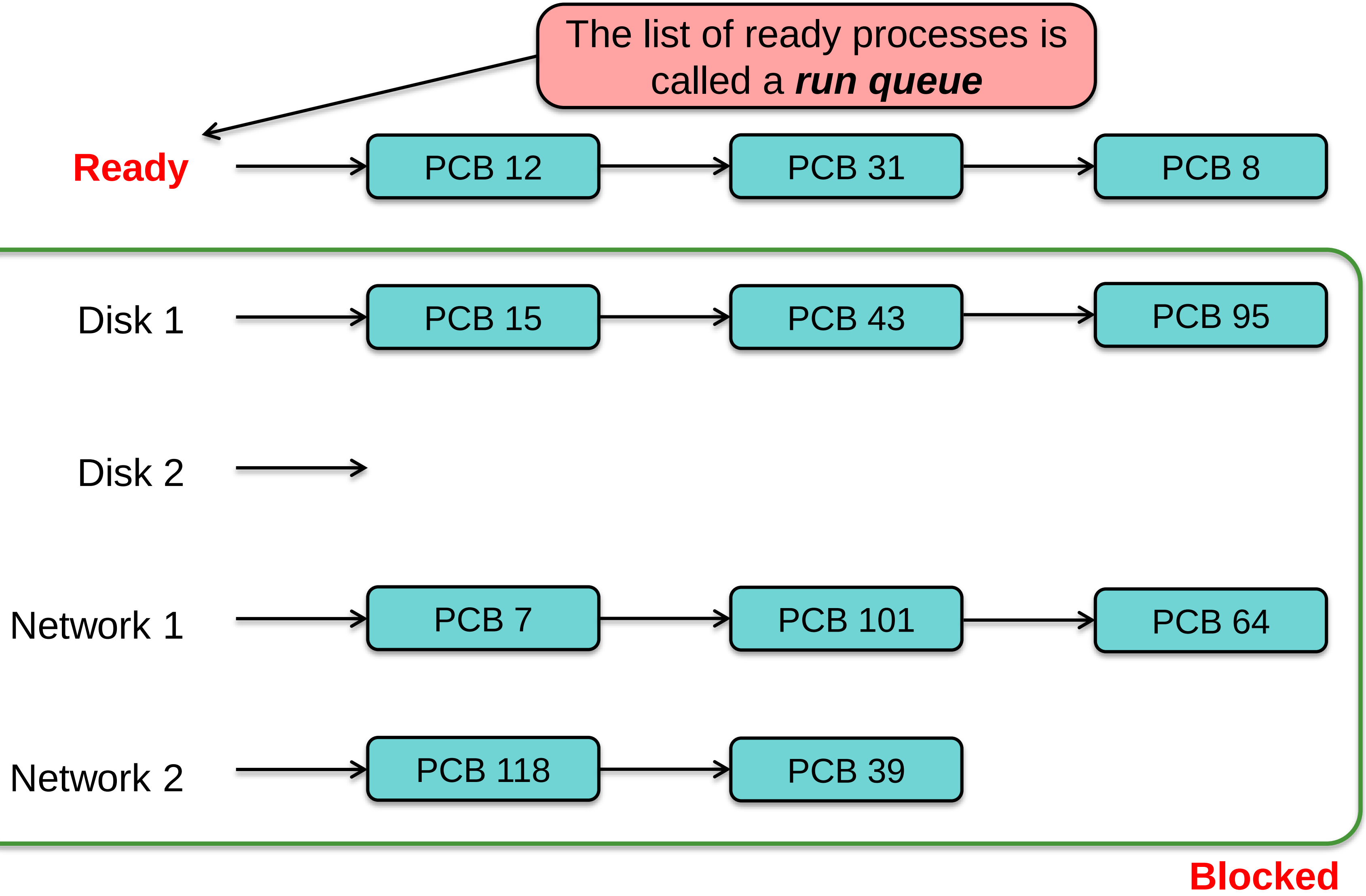
```
    for (p = &init_task; ((p = next_task(p)) != &init_task; )
{
        /* whatever */
    }
```

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

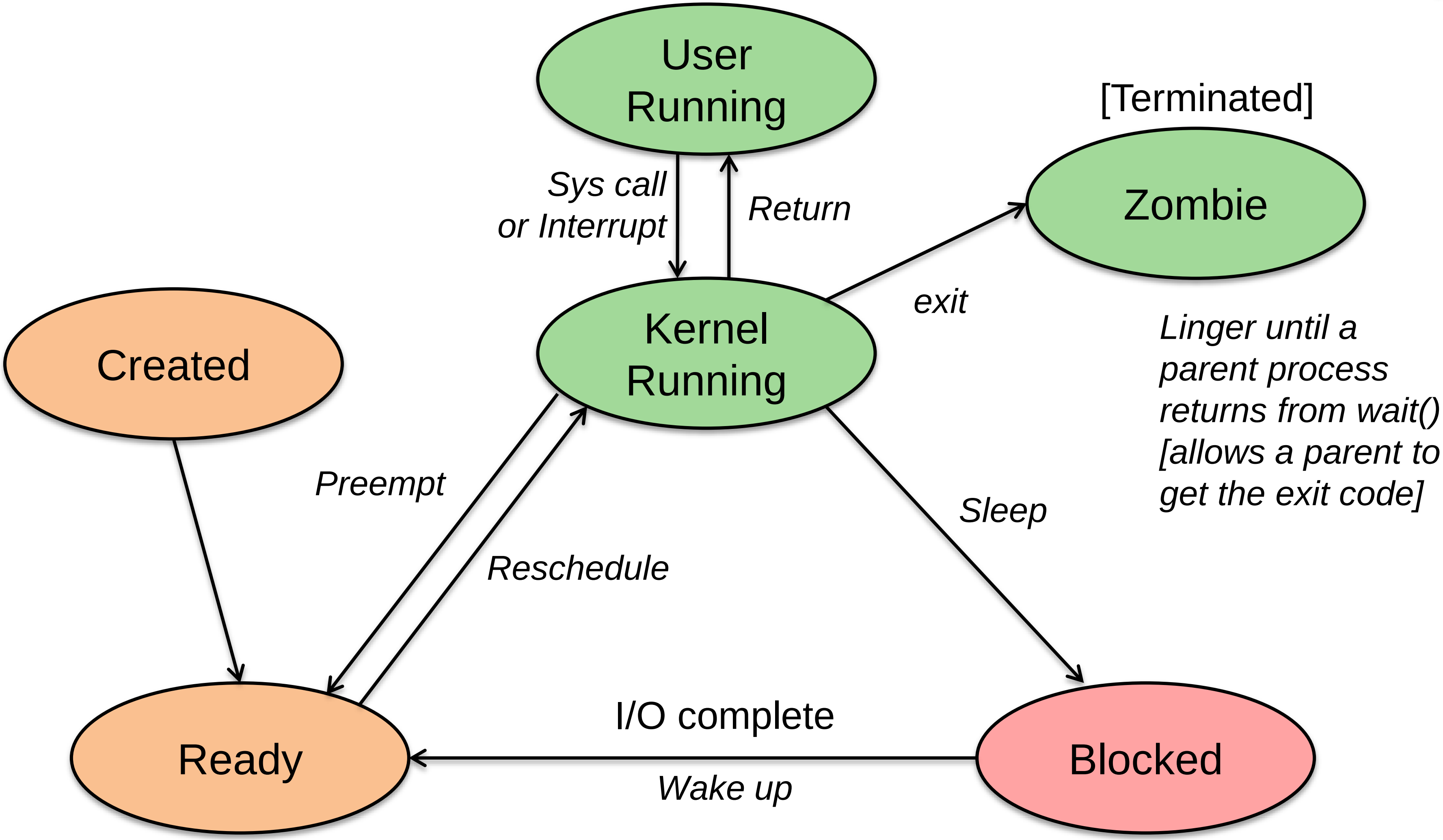
```
    current->state = TASK_STOPPED;
```



Processes on Ready & Blocked Queues



Process States: a bit more detail

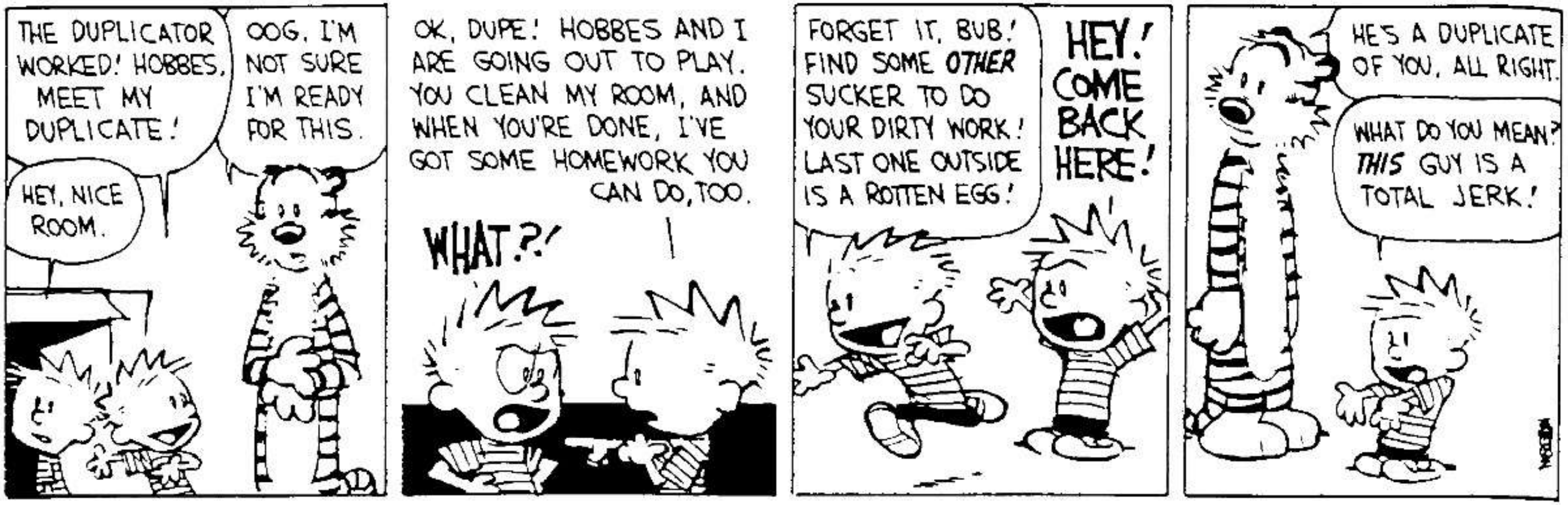


interrupt context: not part of any process state

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
  - Both processes execute at the point of the return from the *fork*



What happens in *fork*?

- 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

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");
    }
}
```

Running other programs

execve: replace the current process image with a new one

- *See also execl, execle, execlp, execvp, execvP*
  (these are just variation wrappers that take different parameters)

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

Exec Example

Execute the command: `ls -al /`

```
#include <unistd.h>

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

    execvp("ls", av);
    perror("ls failed to run!");
    exit(1);
}
```

The *perror* and *exit* functions run ONLY if *execvp* failed – otherwise the new program overlays the current process

Fork & exec combined

- UNIX runs new programs via *fork* followed by *exec*
  - Step 1. Clone
  - Step 2. Replace

- 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

Fork & exec combined

- UNIX creates processes via *fork* followed by *exec*
  - Step 1. Clone
  - Step 2. Replace
- Windo
  - *Create*
  - Specif
  - Identif   dles)
  - Specif   e inherited

```
BOOL WINAPI CreateProcess (
  _In_opt_       LPCTSTR lpApplicationName,
  _Inout_opt_  LPTSTR lpCommandLine,
  _In_opt_       LPSECURITY_ATTRIBUTES lpProcessAttributes,
  _In_opt_       LPSECURITY_ATTRIBUTES lpThreadAttributes,
  _In_              BOOL bInheritHandles,
  _In_              DWORD dwCreationFlags,
  _In_opt_       LPVOID lpEnvironment,
  _In_opt_       LPCTSTR lpCurrentDirectory,
  _In_              LPSTARTUPINFO lpStartupInfo,
  _Out_            LPPROCESS_INFORMATION lpProcessInformation
);
```

Exiting a process

exit system call

```
#include <stdlib.h>

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

Exit status that can be returned to the parent

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!)

Wait for a child process to die

wait system call

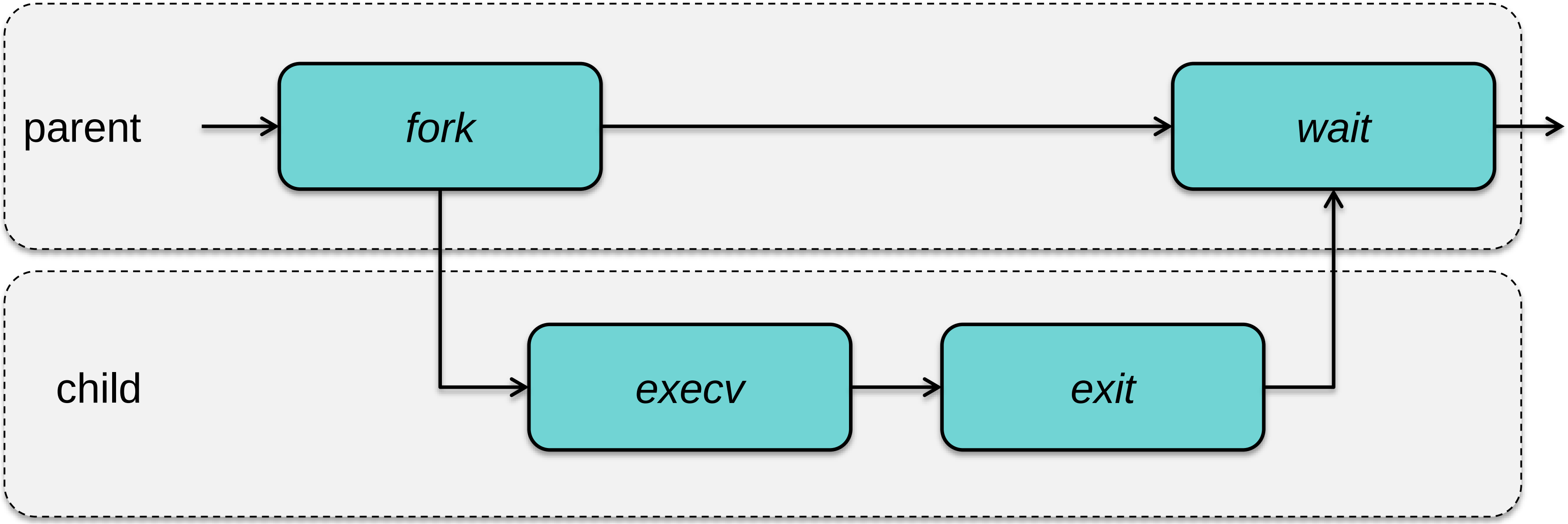
- Suspend execution until a child process exits
- *wait* returns the exit status of that child.

```
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 */
    pid=wait(&status);
    if (pid != -1)
            printf("got exit of %d\n", WEXITSTATUS(status));
            break;
}
```

Parent & child processes



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)*

The End