CS 423
Operating System Design:
Systems Programming Review

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* Thanks for Prof. Adam Bates for the slides.

MP-0 is out

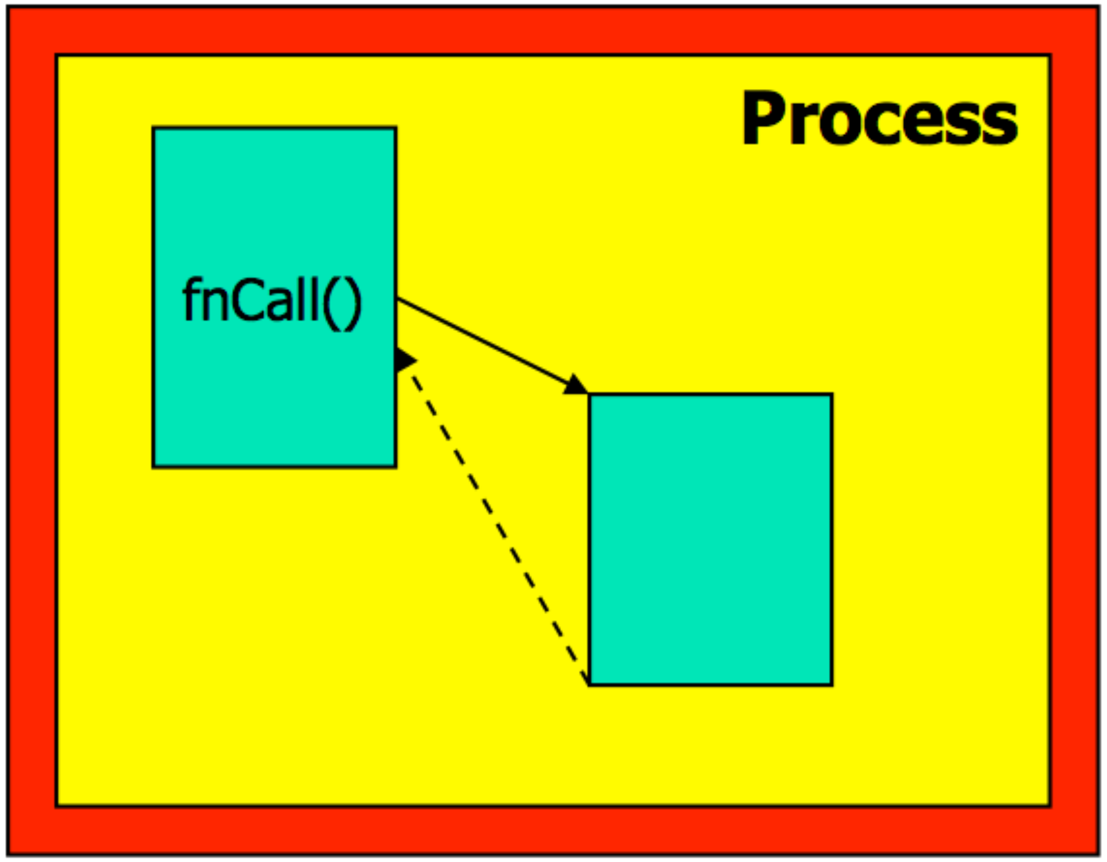
- MP-0 is out.
- C4 Readings are out.
- If you are enrolled, you should have a VM.
- If you haven't enrolled, you will have a VM after enrollment.
  - We will make sure you have enough time to finish MP-0 if you have a late VM.

Creating a Process - fork()

- What UNIX call creates a process?
- fork() duplicates a process so that instead of one process you get two.
  - The new process and the old process both continue in parallel from the statement that follows the fork()

System Calls

Function Calls



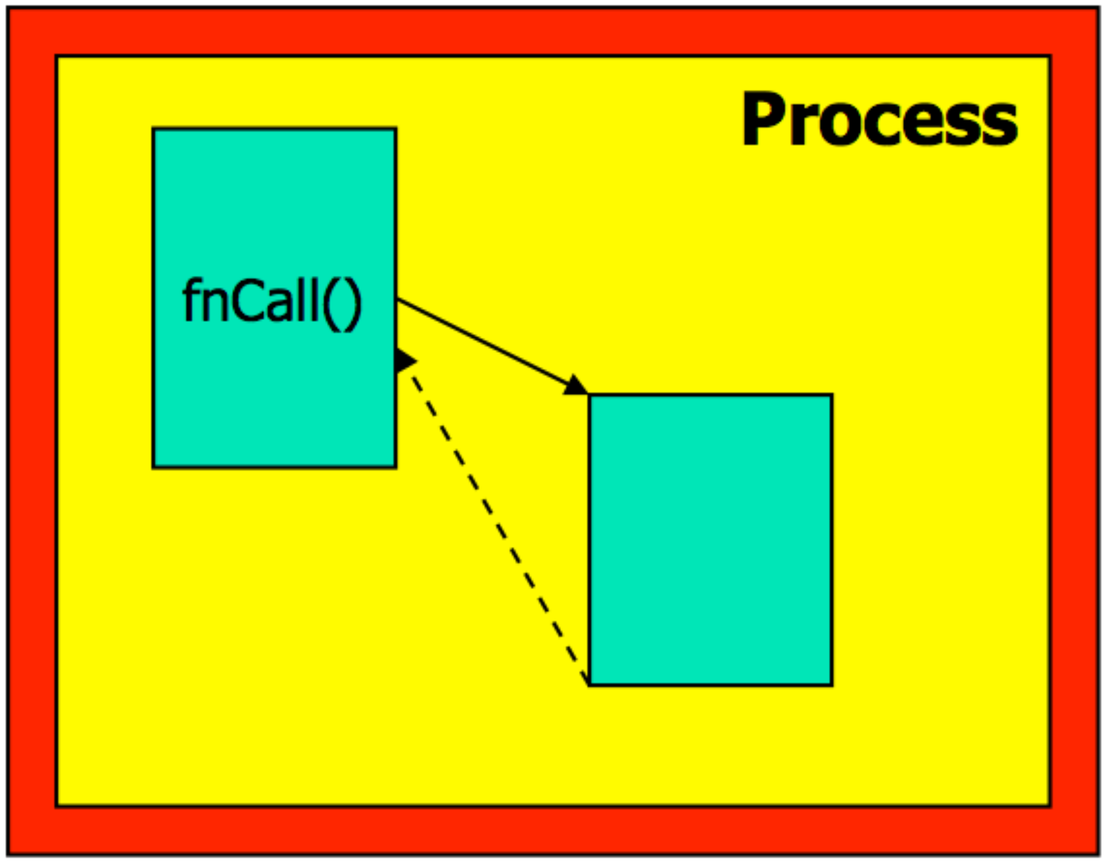
Caller and callee are in the same Process
- Same user
- Same "domain of trust"

System Calls

?

Review: System Calls

Function Calls



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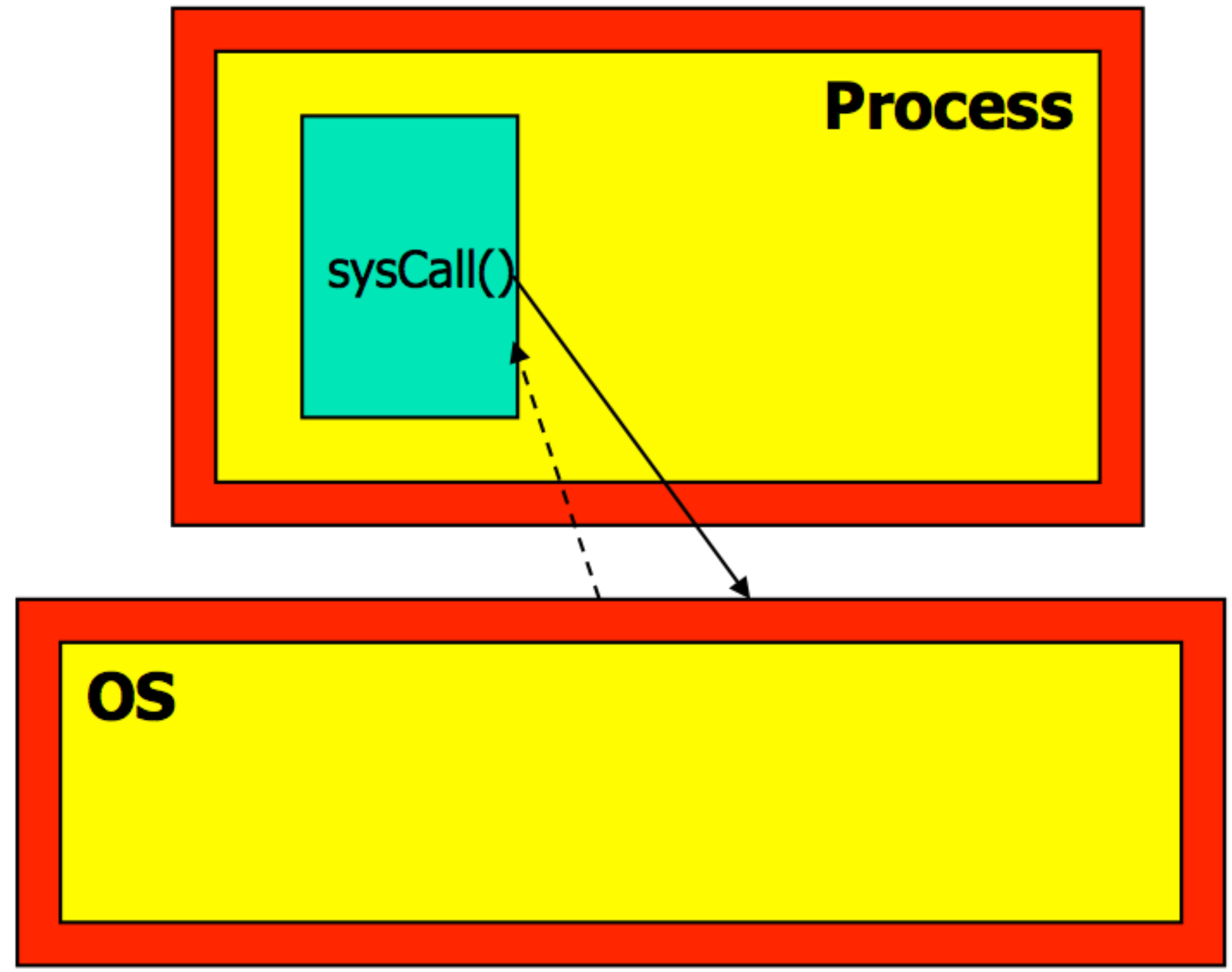
System Calls



- OS is trusted; user is not.
- OS has super-privileges; user does not
- Must take measures to prevent abuse

Example System Calls?

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Example:

```
getuid()   //get the user ID
fork()     //create a child process
exec()     //executing a program
```

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Don't confuse system calls with stdlib calls

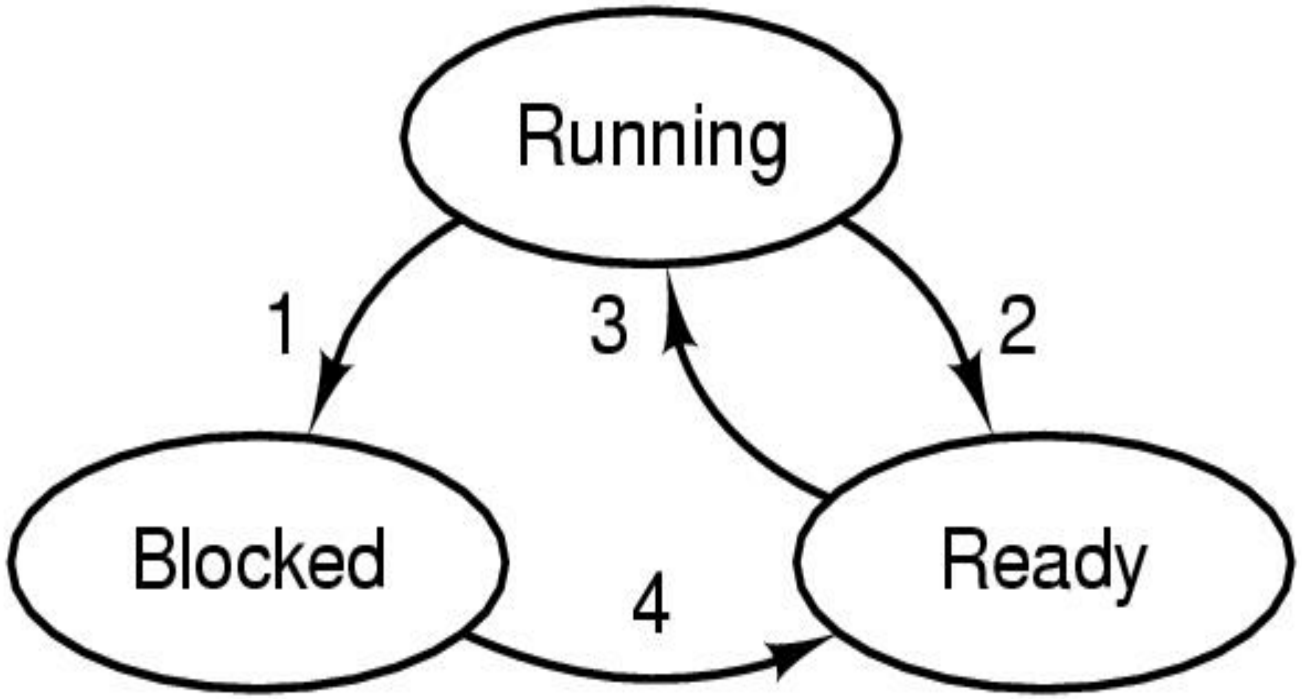
- Differences?
- Is printf() a system call?
- Is rand() a system call?

Syscalls vs. I/O Lib Calls

Each system call has analogous procedure calls from the standard I/O library:

System Call	Standard I/O call
open	fopen
close	fclose
read/write	getchar/putchar
	getc/putc
	fgetc/fputc
	fread/fwrite
	gets/puts
	fgets/fputs
	scanf/printf
	fscanf/fprintf
lseek	fseek

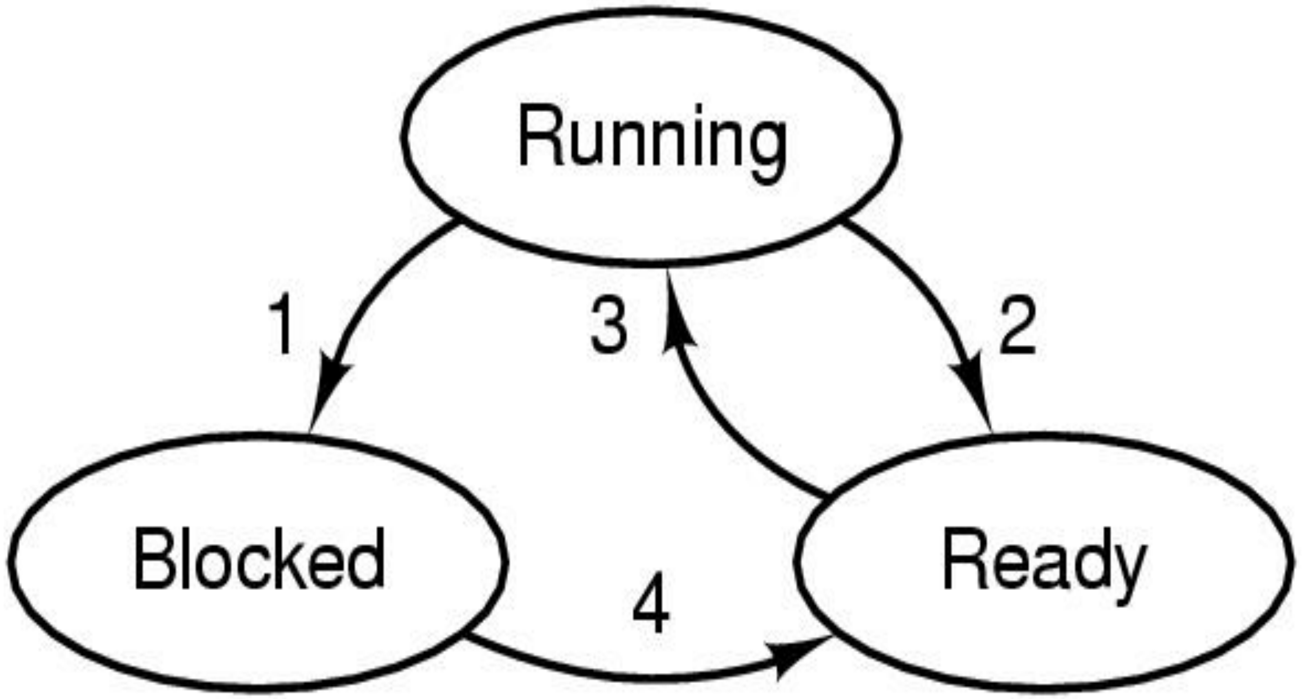
Processes



1. Process blocks for input
2. Scheduler picks another process
3. Scheduler picks this process
4. Input becomes available

- Possible process states
  - Running (occupy CPU)
  - Blocked
  - Ready (does not occupy CPU)
  - Other states: suspended, terminated

Processes



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Question: in a single processor machine, how many process can be in running state?

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    - Child's PID to parent process
- If the parent code changes a global variable, will the child see the change?
  - Nope! On fork, child gets new program counter, stack, file descriptors, heap, globals, pid!

Creating a Process

- What if we need the child process to execute different code than the parent process?

Creating a Process - exec()

- What if we need the child process to execute different code than the parent process?
  - Exec function allows child process to execute code that is different from that of parent
  - Exec family of functions provides a facility for overlaying the process image of the calling process with a new image.
  - Exec functions return -1 and sets errno if unsuccessful

Threads vs. Processes

- What is the difference between a thread and a process?

Threads vs. Processes

- What is the difference between a thread and a process?
  - Both provided independent execution sequences, but…
  - Each process has its own memory space
    - Remember how child processes can't see changes to parent's global variable??
  - Threads run in a shared memory space

Threads vs. Processes

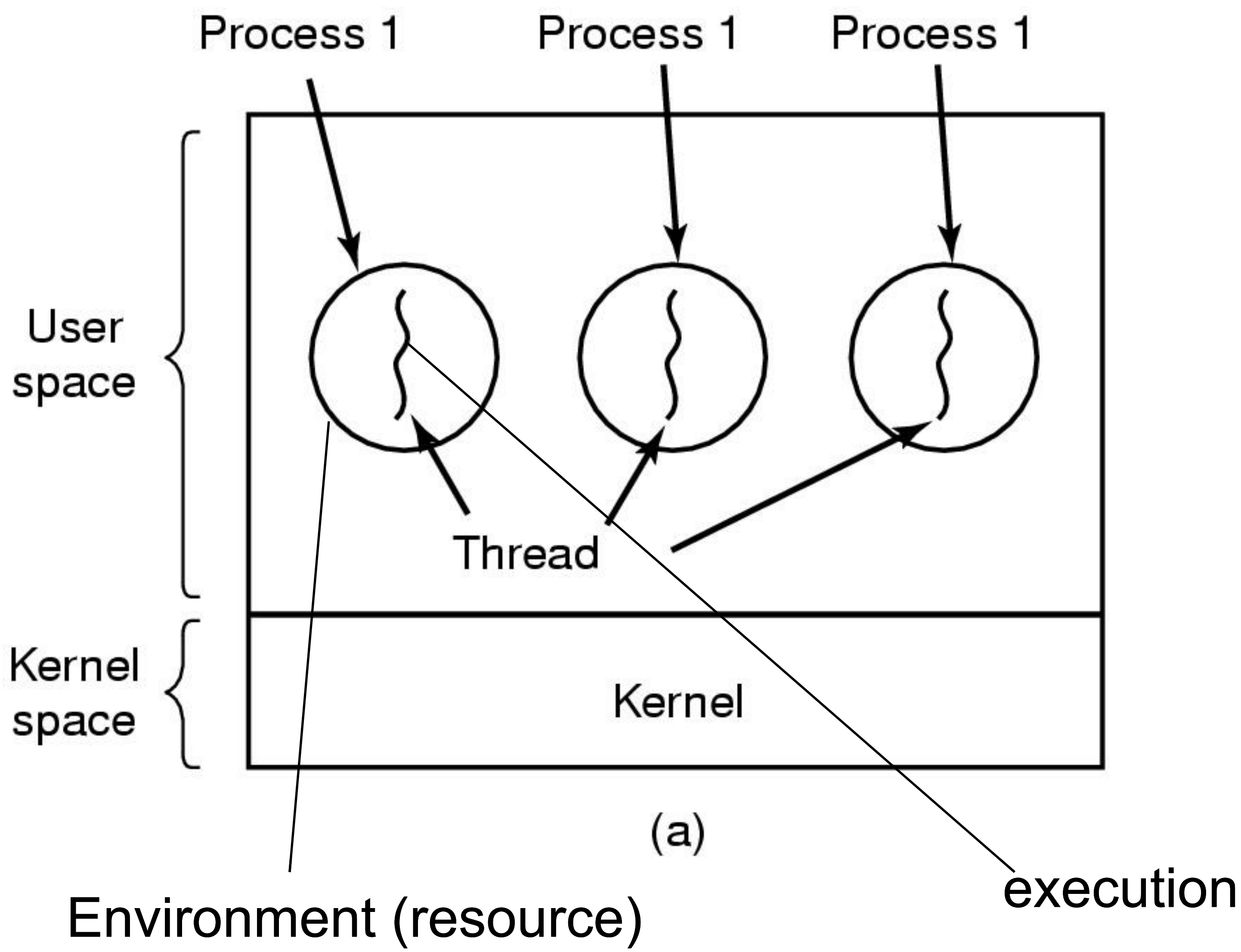
- What is POSIX?
- How do you create a POSIX thread?

Threads vs. Processes

- What is POSIX?
- How do you create a POSIX thread?

POSIX function	description
pthread_create	create a thread
pthread_detach	set thread to release resources
pthread_equal	test two thread IDs for equality
pthread_exit	exit a thread without exiting process
pthread_kill	send a signal to a thread
pthread_join	wait for a thread
pthread_self	find out own thread ID

Threads: Lightweight Proc's



- (a) Three processes each with one thread
- (b) One process with three threads

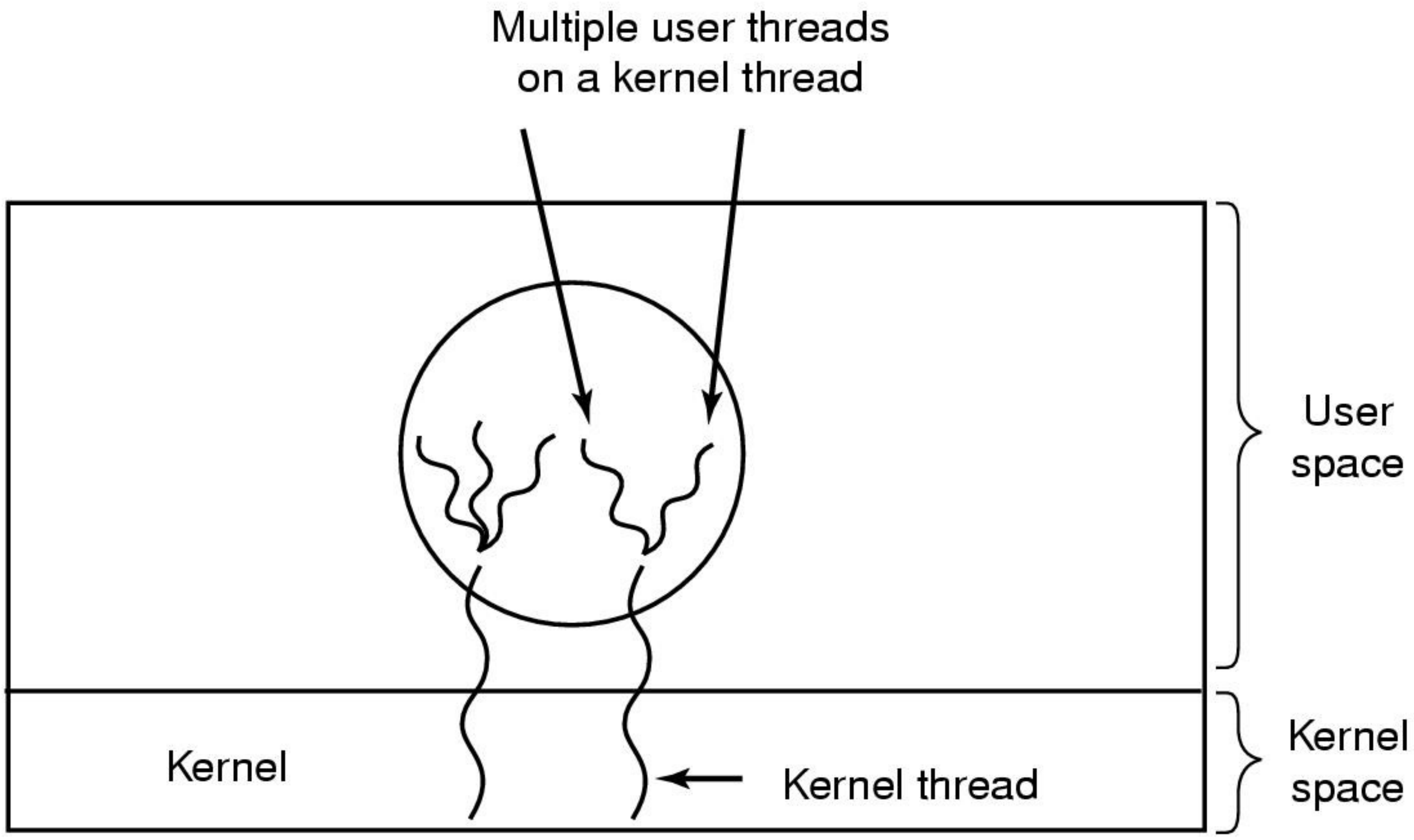
Threads: Kernel v. User

- What is the difference between kernel and user threads? Pros and Cons?

Threads: Kernel v. User

- What is the difference between kernel and user threads? Pros and Cons?
- Kernel thread packages
  - Each thread can make blocking I/O calls
  - Can run concurrently on multiple processors
- Threads in User-level
  - Fast context switch
  - Customized scheduling

Hybrid Threads (Solaris)



M:N model multiplexes N user-level threads onto M kernel-level threads

Good idea? Bad Idea?

Synchronization

- Processes and threads can be preempted at arbitrary times, which may generate problems.
- Example: What is the execution outcome of the following two threads (initially x=0)?

Thread 1:	**Thread 2:**
Read X	**Read X**
Add 1	**Add 1**
Write X	**Write X**

How do we account for this?

Critical Regions/Sections

```
Process {
    while (true) {
        ENTER CRITICAL SECTION
        Access shared variables;
        LEAVE CRITICAL SECTION
        Do other work
    }
}
```

Mutex

- Simplest and most efficient thread synchronization mechanism
- A special variable that can be either in
  - locked state: a distinguished thread that holds or owns the mutex; or
  - unlocked state: no thread holds the mutex
- When several threads compete for a mutex, the losers block at that call
  - The mutex also has a queue of threads that are waiting to hold the mutex.
- POSIX does not require that this queue be accessed FIFO.
- Helpful note — Mutex is short for “Mutual Exclusion”

POSIX Mutex Functions

- int **pthread_mutex_init**(pthread_mutex_t *restrict mutex, const pthread_mutexattr_t *restrict attr);
  - Also see PTHREAD_MUTEX_INITIALIZER
- int **pthread_mutex_destroy**(pthread_mutex_t *mutex);
- int **pthread_mutex_lock**(pthread_mutex_t *mutex);
- int **pthread_mutex_trylock**(pthread_mutex_t *mutex);
- int **pthread_mutex_unlock**(pthread_mutex_t *mutex);

Semaphores

Pseudocode for a blocking implementation of semaphores:

```
void wait (semaphore_t *sp)
  if (sp->value >0) sp->value--;
  else {
    <Add this process to sp->list>
    <block>
  }

void signal (semaphore_t *sp)
  if (sp->list != NULL)
        <remove a process from sp->list,
         put it in ready state>
  else sp->value++;
```

Scheduling

- Basic scheduling algorithms
  - FIFO (FCFS)
  - Shortest job first
  - Round Robin
  - Priority Scheduling

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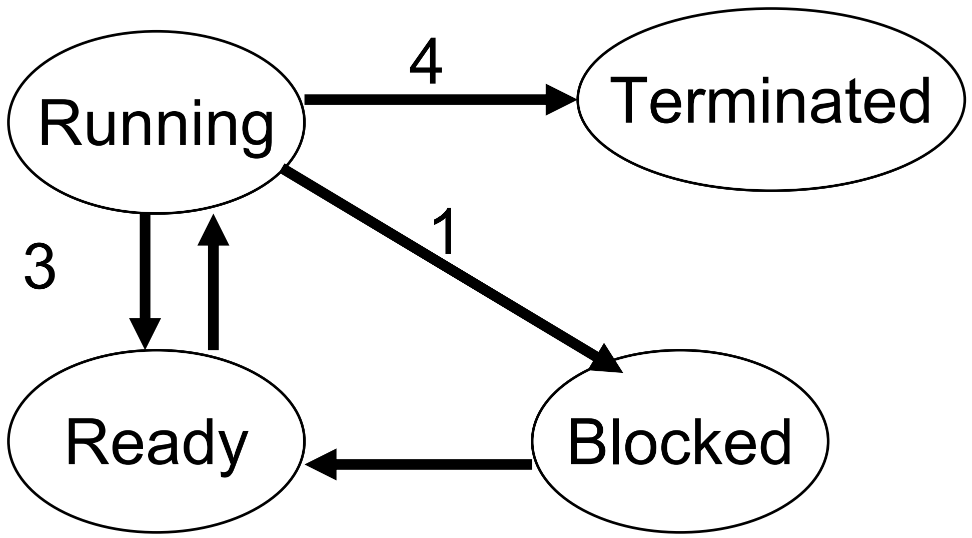
- What is an optimal algorithm in the sense of maximizing the number of jobs finished?

Scheduling

- Basic scheduling algorithms
  - FIFO (FCFS)
  - Shortest job first
  - Round Robin
  - Priority Scheduling
- What is an optimal algorithm in the sense of meeting the most deadlines (of real time tasks)?

Scheduling

- **Non-preemptive scheduling:**
  - The running process keeps the CPU until it voluntarily gives up the CPU
    - process exits
    - switches to blocked state
    - 1 and 4 only (no 3)



- **Preemptive scheduling**:
  - The running process can be interrupted and must release the CPU (can be forced to give up CPU)

Signals

- What is a signal in UNIX/Linux?

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  - A signal can be “caught”, “ignored”, or “blocked”

Signals

- What is a signal in UNIX/Linux?
  - A way for one process to send a notification to another
  - A signal can be “caught”, “ignored”, or “blocked”
- Signal is generated when the event that causes it occurs.
- Signal is delivered when a process receives it.
- The lifetime of a signal is the interval between its generation and delivery.
- Signal that is generated but not delivered is pending.
- Process catches signal if it executes a signal handler when the signal is delivered.
- Alternatively, a process can ignore a signal when it is delivered, that is to take no action.
- Process can temporarily prevent signal from being delivered by blocking it.
- Signal Mask contains the set of signals currently blocked.

POSIX-required Signals*

Signal	Description	default action
SIGABRT	process abort	implementation dependent
SIGALRM	**alarm clock**	**abnormal termination**
SIGBUS	access undefined part of memory object	implementation dependent
SIGCHLD	child terminated, stopped or continued	ignore
SIGILL	invalid hardware instruction	implementation dependent
SIGINT	**interactive attention signal (usually ctrl-C)**	**abnormal termination**
SIGKILL	**terminated (cannot be caught or ignored)**	**abnormal termination**

** Not an exhaustive list*

POSIX-required Signals*

Signal	Description	default action
SIGSEGV	**Invalid memory reference**	**implementation dependent**
SIGSTOP	Execution stopped	stop
SIGTERM	**termination**	**Abnormal termination**
SIGTSTP	Terminal stop	stop
SIGTTIN	Background process attempting read	stop
SIGTTOU	Background process attempting write	stop
SIGURG	**High bandwidth data available on socket**	**ignore**
SIGUSR1	**User-defined signal 1**	**abnormal termination**

** Not an exhaustive list*

User- generated Signals

- How can you send a signal to a process from the command line?

User- generated Signals

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- **`kill`** 😰

User- generated Signals

- How can you send a signal to a process from the command line?
- **`kill`** 😰
- `kill -l` will list the signals the system understands
- `kill [-signal] pid` will send a signal to a process.
  - The optional argument may be a name or a number (default is SIGTERM).
- To unconditionally kill a process, use:
  - `kill -9 pid` which is
    kill -SIGKILL pid.

Signal Masks

- A process can temporarily prevent a signal from being delivered by blocking it.
- Signal Mask contains a set of signals currently blocked.
- **Important!** Blocking a signal is different from ignoring signal. Why?

Signal Masks

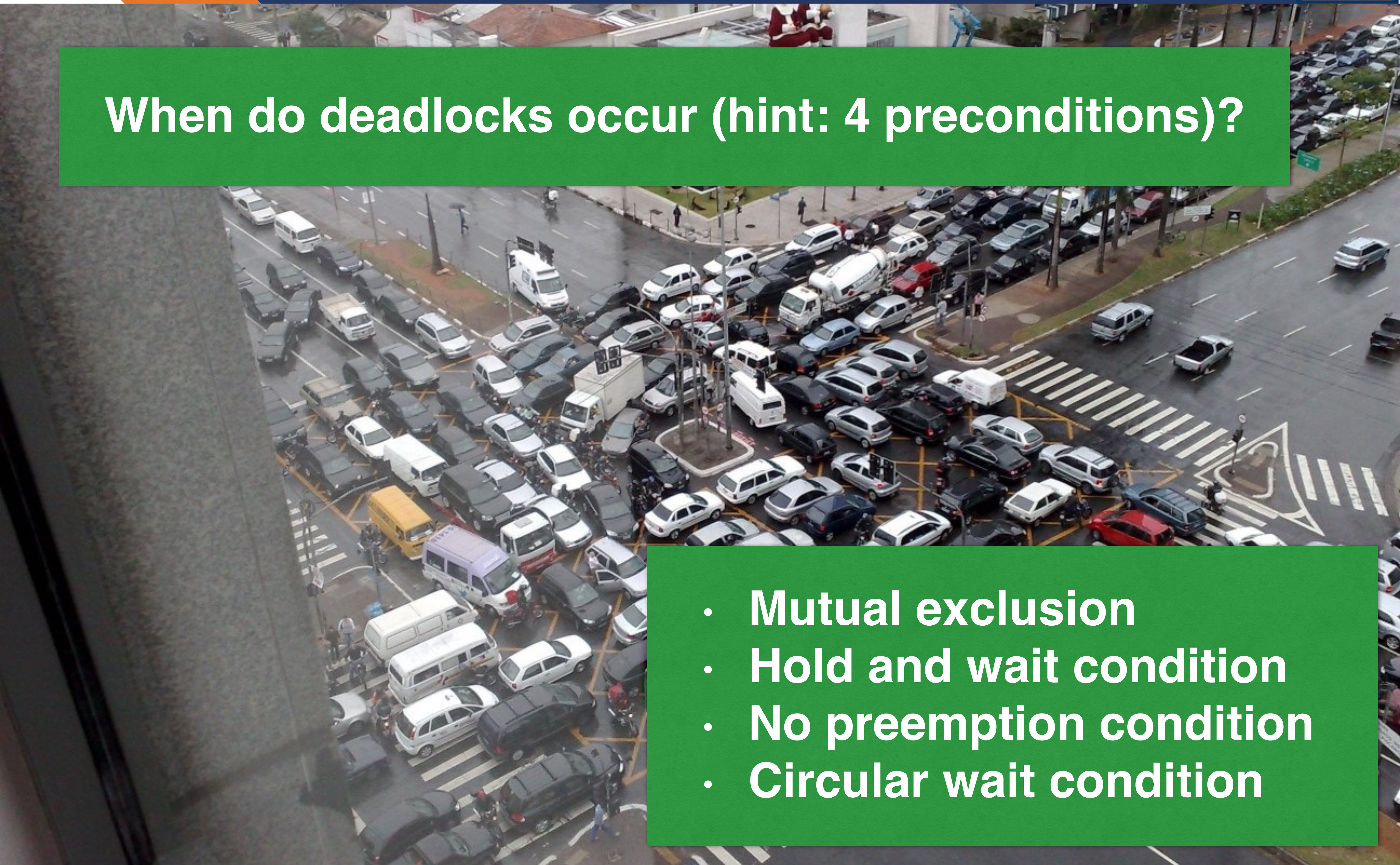
- A process can temporarily prevent a signal from being delivered by blocking it.
- Signal Mask contains a set of signals currently blocked.
- **Important!** Blocking a signal is different from ignoring signal. Why?
- When a process blocks a signal, the OS does not deliver signal until the process unblocks the signal
  - A blocked signal is not delivered to a process until it is unblocked.
- When a process ignores signal, signal is delivered and the process handles it by throwing it away.

Deadlocks

Deadlocks

When do deadlocks occur (hint: 4 preconditions)?

Deadlocks

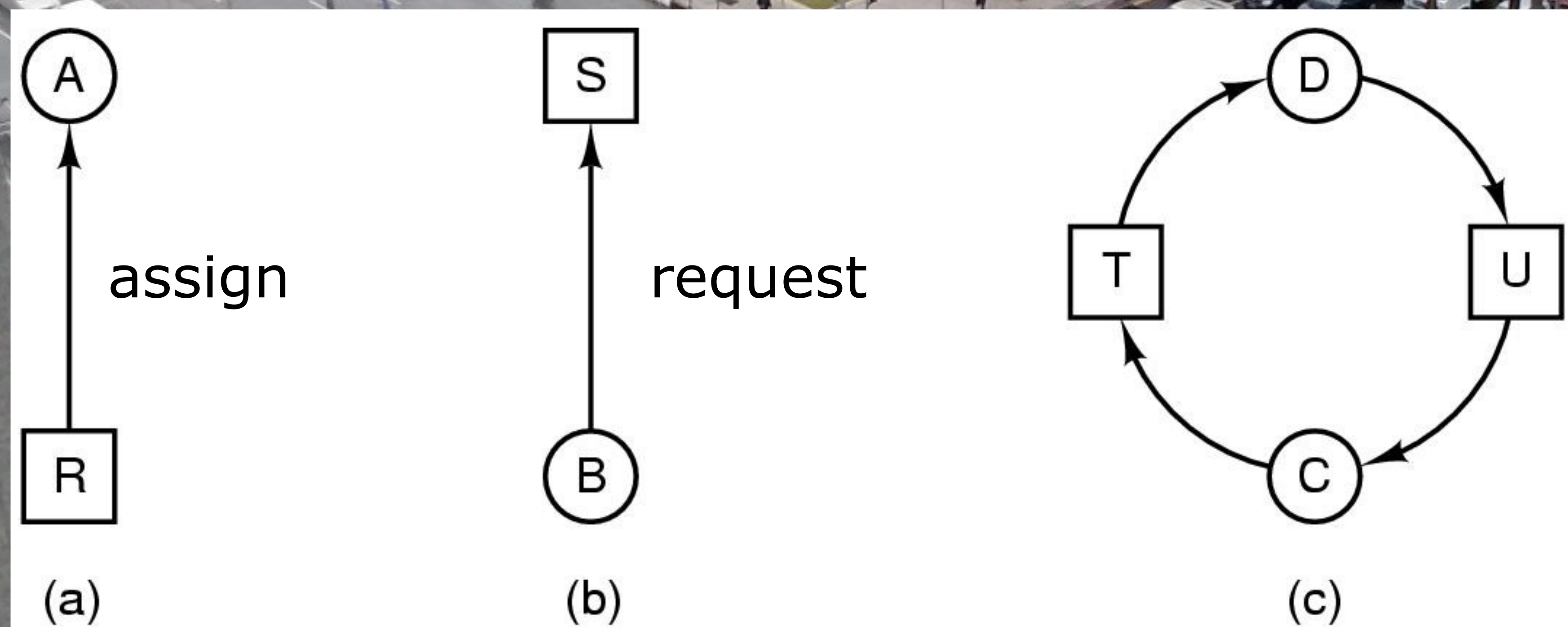


When do deadlocks occur (hint: 4 preconditions)?

- Mutual exclusion
- Hold and wait condition
- No preemption condition
- Circular wait condition

Deadlocks

Resource Allocation Graphs



- resource R assigned to process A
- process B is requesting/waiting for resource S
- process C and D are in deadlock over resources T and U

Deadlocks

Strategies for Dealing with Deadlocks

- ~~shouting~~
- detection and recovery
- dynamic avoidance (at run-time)
- prevention (by offline design)
  - by negating one of the four necessary conditions