CS 423
Operating System Design: Concurrency (more Threads)

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Goals for Today

- Learning Objectives:
  - Dive yet further into concurrency and threading
- Announcements:
  - **MP1 out on Friday!**

Reminder: Please put away devices at the start of class

HW1 Wrap-Up

- Average Score: 88.8%…

- Three questions of medium difficulty (<80%):
  - “Hold-and-wait” situations?
  - which code snippets are wrong?
  - UNIX shell?

HW1 Wrap-Up

Which of the following systems may never exhibit a "hold-and-wait" situation? You may assume that the only blocking that occurs in these systems occurs on mutexes.

a. Systems that ensure that all resources needed for an application are locked in a single atomic operation that either succeeds and locks all requested resources or fails and locks none.
b. Systems with only one mutex.
c. Systems where all mutexes are numbered. A user cannot lock a mutex with a lower number, X, after they have locked a mutex with a larger number, Y > X.
d. Systems of type (a) and (b) only
e. Systems of type (a), (b), or (c)

HW1 Wrap-Up

Which of the following code snippets are wrong?

Case 1

```
int *p;
 *p=10;
```

Case 2

```
char a[2];
 strcpy (a, “Hi”);
```

Case 3

```
int b[10];
 *b=11;
```

HW1 Wrap-Up

Which of the following best describes a UNIX shell?

a. Part of the UNIX kernel that executes user commands

b. A process forked off at UNIX initialization to accept inputs from a user

c. A system call executed by the UNIX startup routine to accept commands from users

d. A library that implements various UNIX commands

e. The UNIX keyboard device driver that interprets keyboard input

Why Concurrency?

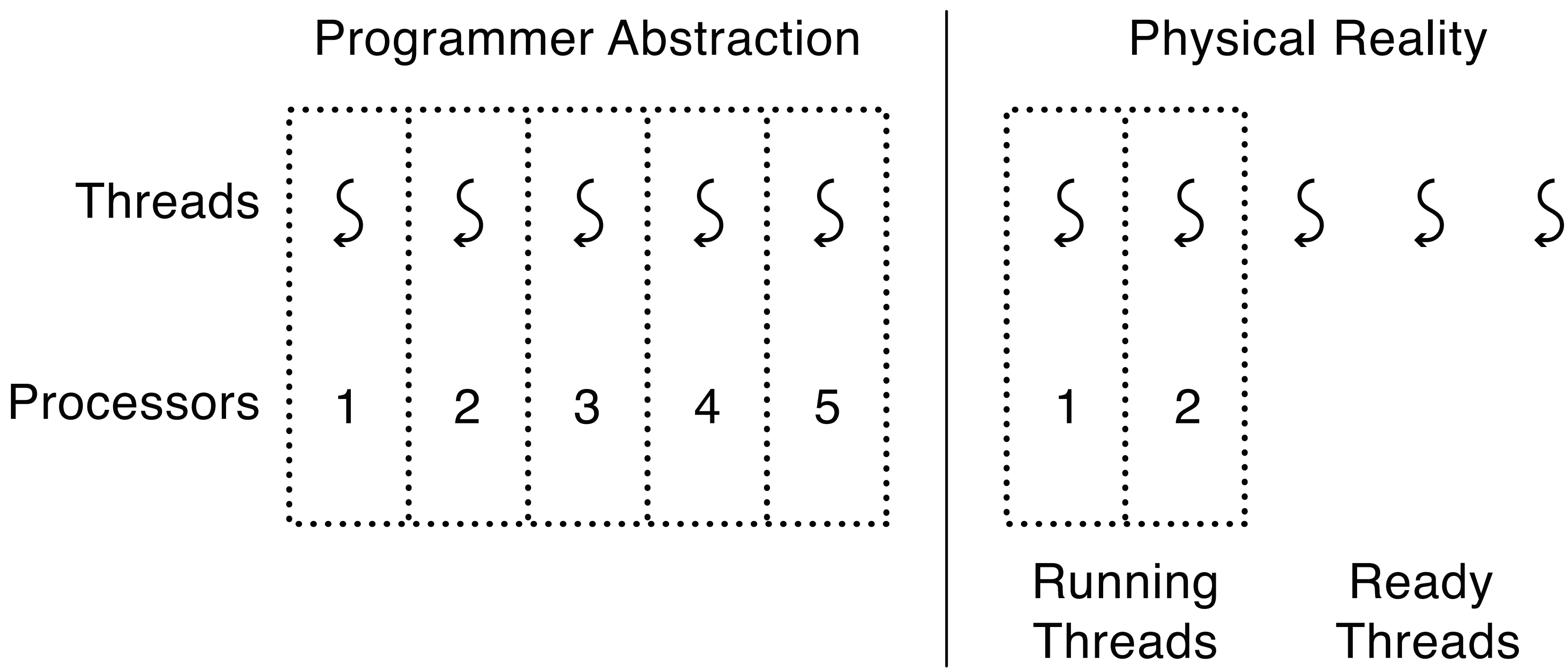
- Servers
  - Multiple connections handled simultaneously
- Parallel programs
  - To achieve better performance
- Programs with user interfaces
  - To achieve user responsiveness while doing computation
- Network and disk bound programs
  - To hide network/disk latency

Definitions

- Thread: A single execution sequence that represents a separately schedulable task.
  - *Single execution sequence*: intuitive and familiar programming model
  - *separately schedulable*: OS can run or suspend a thread at any time.
  - Schedulers operate over threads/tasks, both kernel and user threads.
- *Does the OS protect all threads from one another?*

The Thread Abstraction

- Infinite number of processors
- Threads execute with variable speed



Programmer vs. Processor View

Programmer View

Programmer's View

```
.
.
.
x = x + 1;
y = y + x;
z = x + 5y;
.
.
.
```

Possible Execution #1

```
.
.
.
x = x + 1;
y = y + x;
z = x + 5y;
.
.
.
```

Possible Execution #2

```
.
.
.
x = x + 1;
..............
```

Thread is suspended.
Other thread(s) run.
Thread is resumed.

```
...............
y = y + x;
z = x + 5y;
```

Possible Execution #3

```
.
.
.
x = x + 1;
y = y + x;
...............
```

Thread is suspended.
Other thread(s) run.
Thread is resumed.

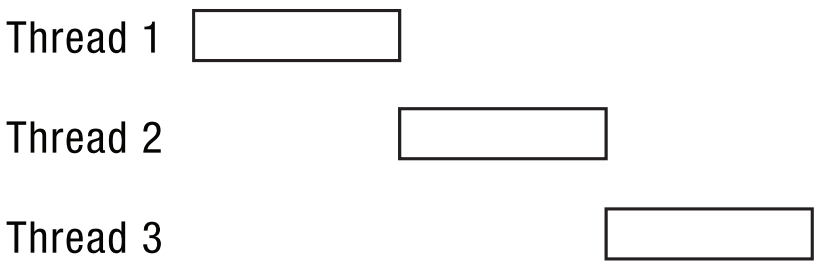
```
................
z = x + 5y;
```

Variable Speed: Program must anticipate all of these possible executions

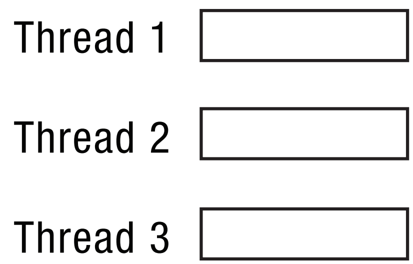
Possible Executions

Processor View

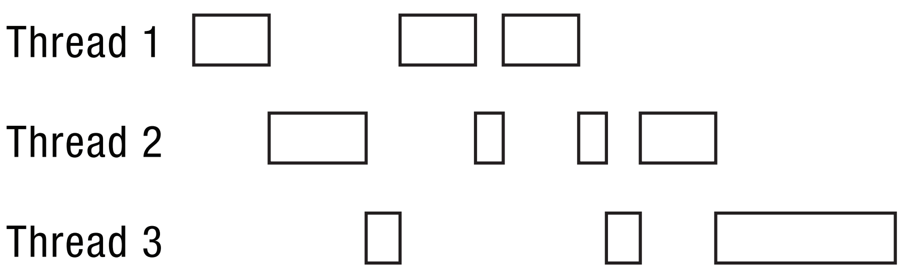
One Execution



Another Execution



Another Execution



Something to look forward to when we discuss scheduling!

Thread Ops

- thread_create(thread, func, args)
  Create a new thread to run func(args)
- thread_yield()
  Relinquish processor voluntarily
- thread_join(thread)
  In parent, wait for forked thread to exit, then return
- thread_exit
  Quit thread and clean up, wake up joiner if any

Ex: threadHello

```
#define NTHREADS 10
thread_t threads[NTHREADS];
main() {
    for (i = 0; i < NTHREADS; i++)  thread_create(&threads[i], &go, i);
    for (i = 0; i < NTHREADS; i++) {
        exitValue = thread_join(threads[i]);
        printf("Thread %d returned with %ld\n", i, exitValue);
    }
    printf("Main thread done.\n");
}
void go (int n) {
    printf("Hello from thread %d\n", n);
    thread_exit(100 + n);
    // REACHED?
}
```

Ex: threadHello output

```
bash-3.2$ ./threadHello
Hello from thread 0
Hello from thread 1
Thread 0 returned 100
Hello from thread 3
Hello from thread 4
Thread 1 returned 101
Hello from thread 5
Hello from thread 2
Hello from thread 6
Hello from thread 8
Hello from thread 7
Hello from thread 9
Thread 2 returned 102
Thread 3 returned 103
Thread 4 returned 104
Thread 5 returned 105
Thread 6 returned 106
Thread 7 returned 107
Thread 8 returned 108
Thread 9 returned 109
Main thread done.
```

- Must "thread returned" print in order?
- What is maximum # of threads running when thread 5 prints hello?
- Minimum?

Fork/Join Concurrency

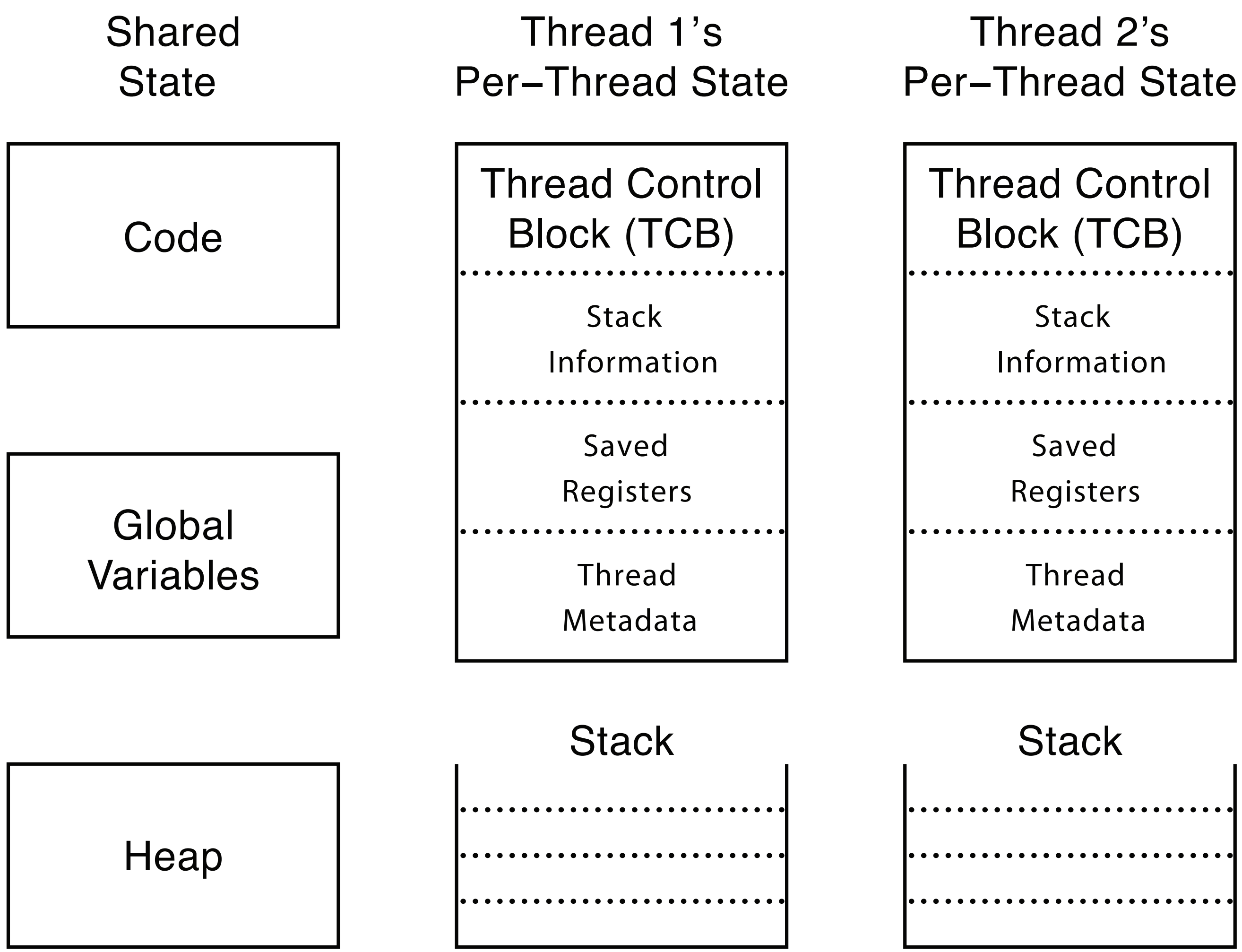
- Threads can create children, and wait for their completion
- Data only shared before fork/after join
- Examples:
  - Web server: fork a new thread for every new connection
    - As long as the threads are completely independent
  - Merge sort
  - Parallel memory copy

Ex: bzero

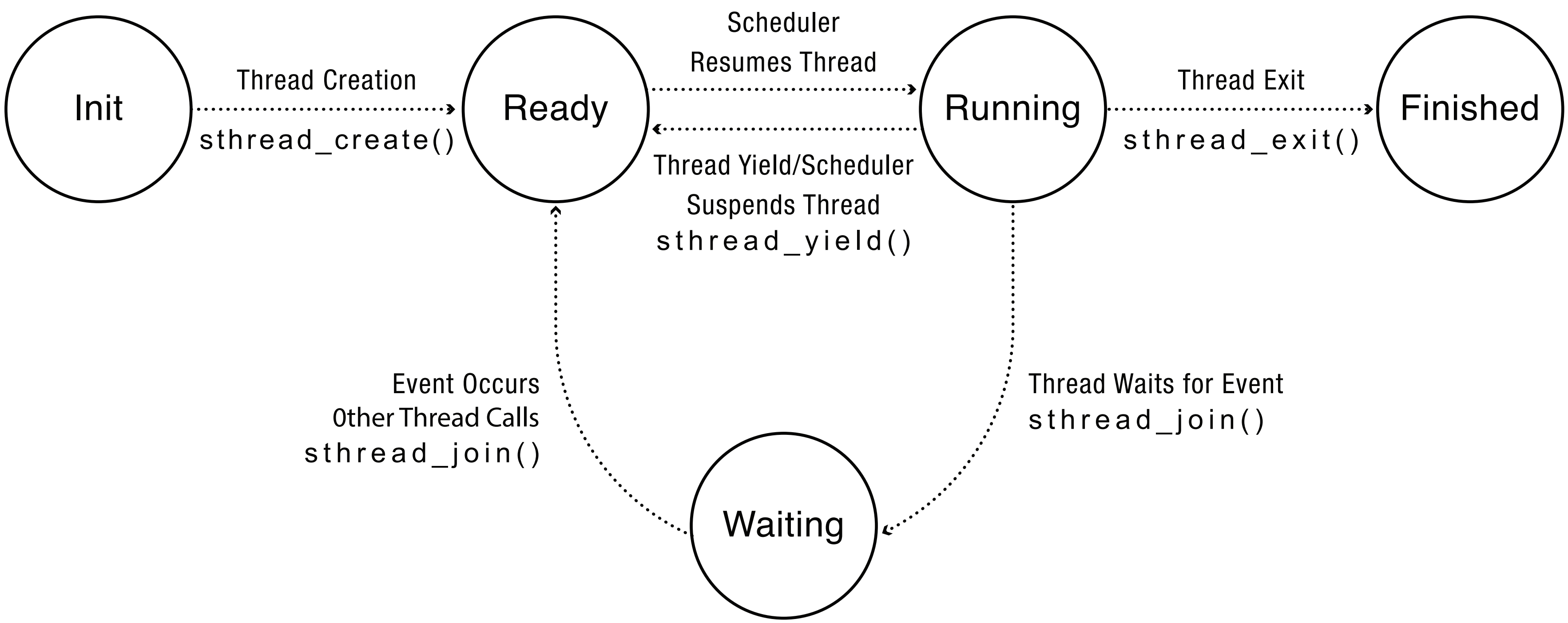
```
void blockzero (unsigned char *p, int length) {
    int i, j;
    thread_t threads[NTHREADS];
    struct bzeroparams params[NTHREADS];

// For simplicity, assumes length is divisible by NTHREADS.
for (i = 0, j = 0; i < NTHREADS; i++, j += length/NTHREADS) {
        params[i].buffer = p + i * length/NTHREADS;
        params[i].length = length/NTHREADS;
        thread_create_p(&(threads[i]), &go, &params[i]);
    }
    for (i = 0; i < NTHREADS; i++) {
        thread_join(threads[i]);
    }
}
```

Thread Data Structures



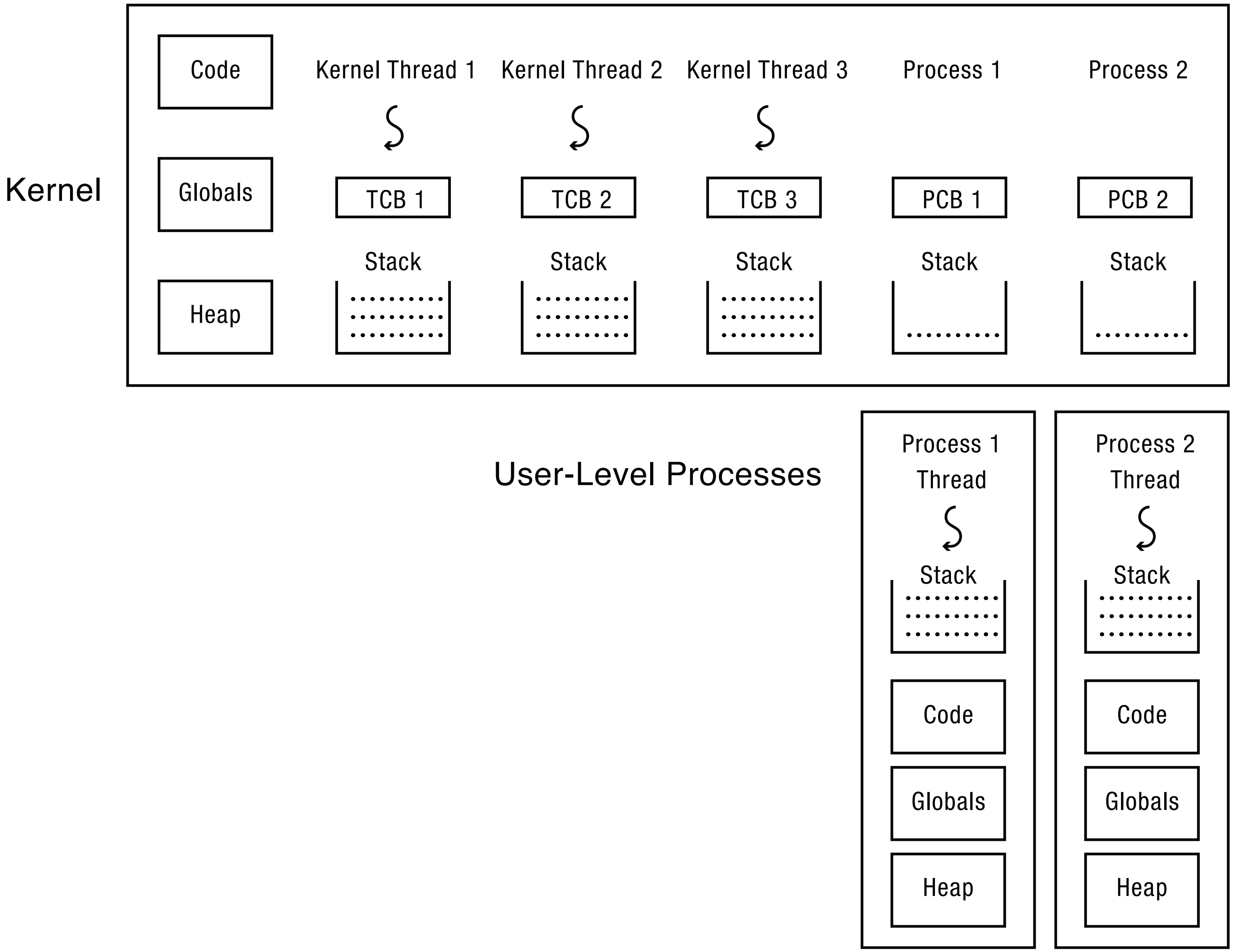
Thread Lifecycle



Thread Implementations

- Kernel threads
  - Thread abstraction only available to kernel
  - To the kernel, a kernel thread and a single threaded user process look quite similar
- Multithreaded processes using kernel threads
  - Kernel thread operations available via syscall
- User-level threads
  - Thread operations without system calls

Multithreaded OS Kernel



Implementing Threads

- Thread_fork(func, args)
  - Allocate thread control block
  - Allocate stack
  - Build stack frame for base of stack (stub)
  - Put func, args on stack
  - Put thread on ready list
  - Will run sometime later (maybe right away!)

- stub(func, args):
  - Call (*func)(args)
  - If return, call thread_exit()

Implementing Threads

- Thread_Exit
  - Remove thread from the ready list so that it will never run again
  - Free the per-thread state allocated for the thread

switchframe

How do we switch out thread state? (i.e., ctx switch)

```
# Save caller's register state
#  NOTE: %eax, etc. are ephemeral
pushl %ebx
pushl %ebp
pushl %esi
pushl %edi

# Get offsetof (struct thread, stack)
mov thread_stack_ofs, %edx
# Save current stack pointer to old thread's stack, if any.
movl SWITCH_CUR(%esp), %eax
movl %esp, (%eax,%edx,1)

# Change stack pointer to new thread's stack
# this also changes currentThread
movl SWITCH_NEXT(%esp), %ecx
movl (%ecx,%edx,1), %esp

# Restore caller's register state.
popl %edi
popl %esi
popl %ebp
popl %ebx
ret
```

A subtlety

- Thread_create puts new thread on ready list
- When it first runs, some thread calls switchframe
  - Saves old thread state to stack
  - Restores new thread state from stack
- Set up new thread's stack as if it had saved its state in switchframe
  - "returns" to stub at base of stack to run func

Ex: Two Threads call Yield

Thread 1's instructions	Thread 2's instructions	Processor's instructions
"return" from thread_switch into stub		"return" from thread_switch into stub
call go		call go
call thread_yield		call thread_yield
choose another thread		choose another thread
call thread_switch		call thread_switch
save thread 1 state to TCB		save thread 1 state to TCB
load thread 2 state		load thread 2 state
	"return" from thread_switch into stub	"return" from thread_switch into stub
	call go	call go
	call thread_yield	call thread_yield
	choose another thread	choose another thread
	call thread_switch	call thread_switch
	save thread 2 state to TCB	save thread 2 state to TCB
	load thread 1 state	load thread 1 state
return from thread_switch		return from thread_switch
return from thread_yield		return from thread_yield
call thread_yield		call thread_yield
choose another thread		choose another thread
call thread_switch		call thread_switch

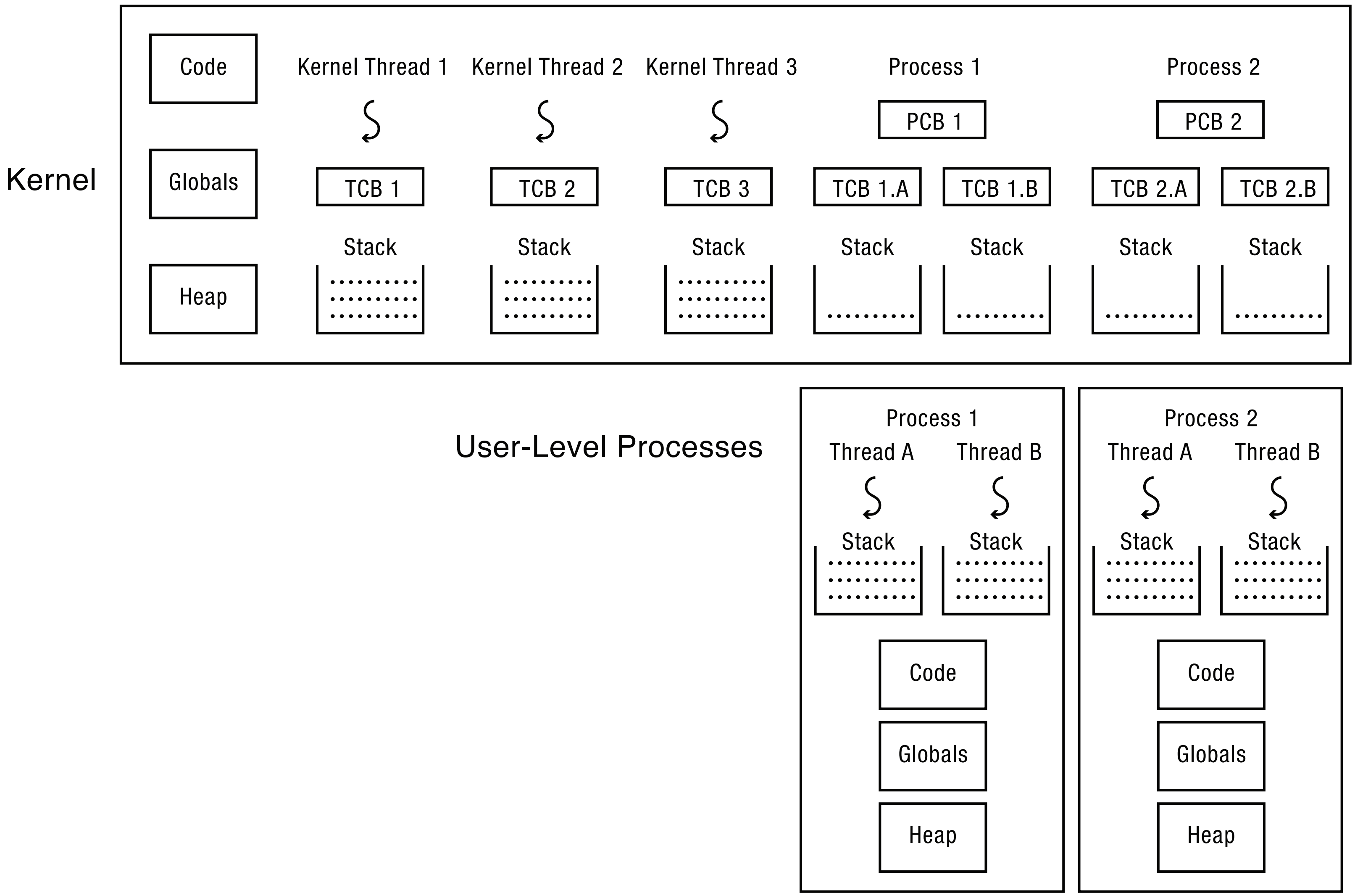
Multi-threaded User Processes

<u>Take 1</u>:

- User thread = kernel thread (Linux, MacOS)
  - System calls for thread fork, join, exit (and lock, unlock,…)
  - Kernel does context switch
  - Simple, but a lot of transitions between user and kernel mode

Multi-threaded User Processes

<u>Take 1</u>:



Multi-threaded User Processes

Take 2:

- Green threads (early Java)
  - User-level library, within a single-threaded process
  - Library does thread context switch
  - Preemption via upcall/UNIX signal on timer interrupt
  - Use multiple processes for parallelism
  - Shared memory region mapped into each process

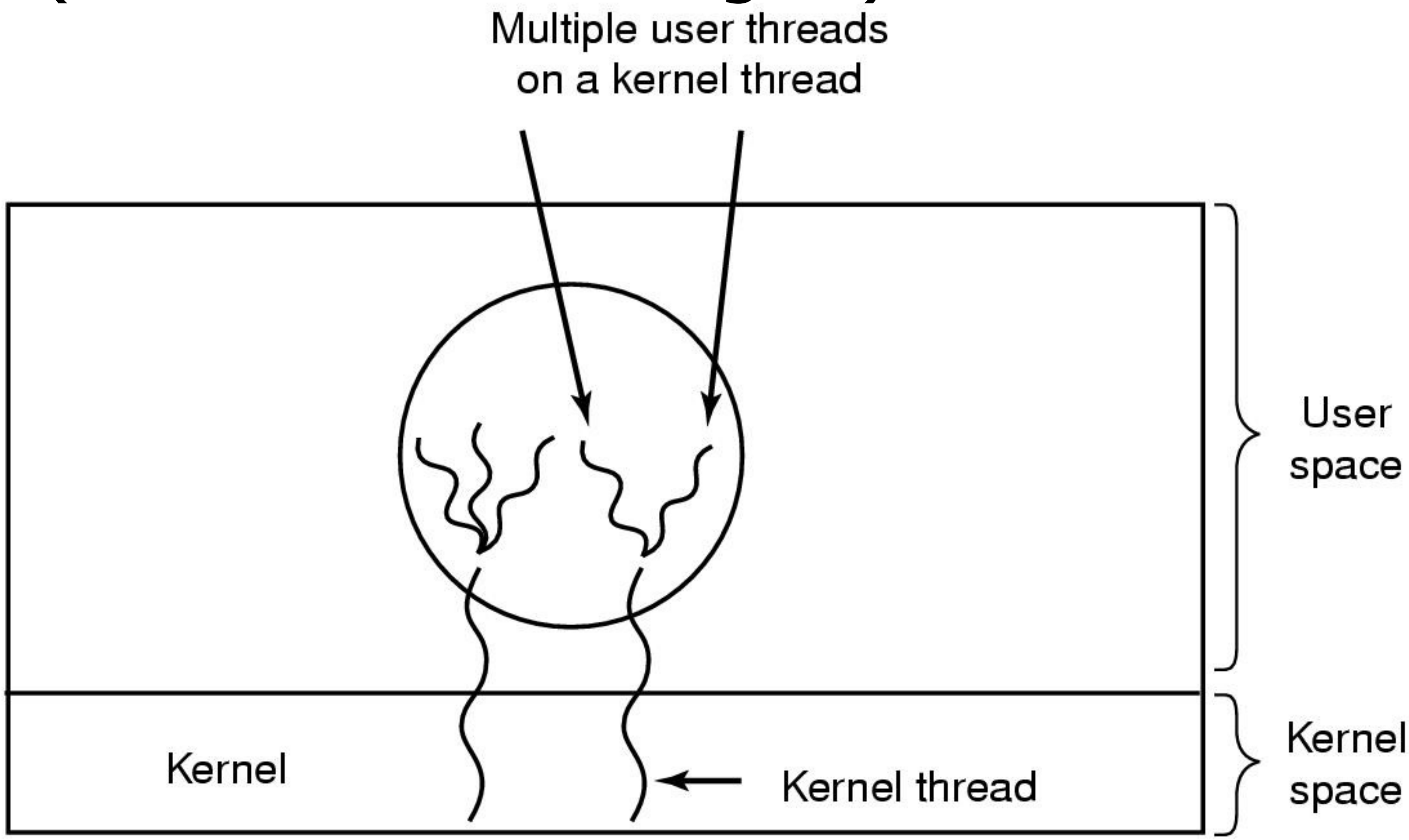
Multi-threaded User Processes

<u>Take 3</u>:

- Scheduler activations (Windows 8):
  - Kernel allocates processors to user-level library
  - Thread library implements context switch
  - Thread library decides what thread to run next
- Upcall whenever kernel needs a user-level scheduling decision:
  - Process assigned a new processor
  - Processor removed from process
  - System call blocks in kernel

Multi-threaded User Processes

Take 3: (What's old is new again)



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

Good idea? Bad Idea?

Question

Compare event-driven programming with multithreaded concurrency. Which is better in which circumstances, and why?