Threads

CS449 Spring 2016

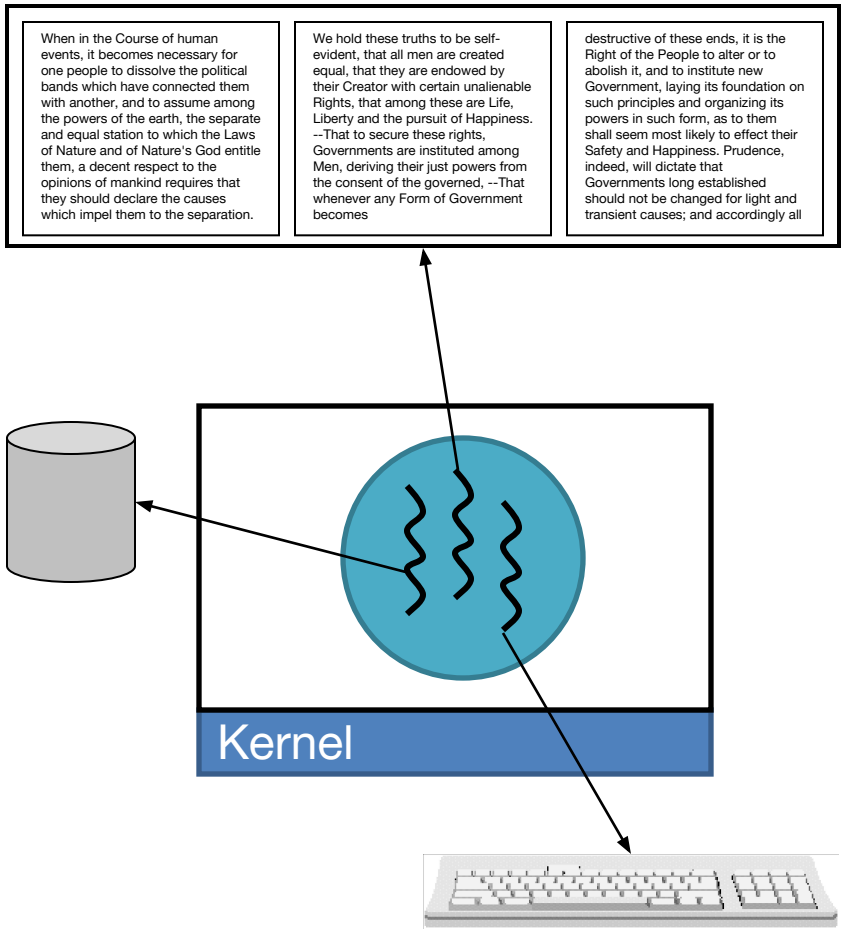
Midterm 2 Statistics

- Max: 86
- Min: 11
- Average: 55.4
- Median: 59

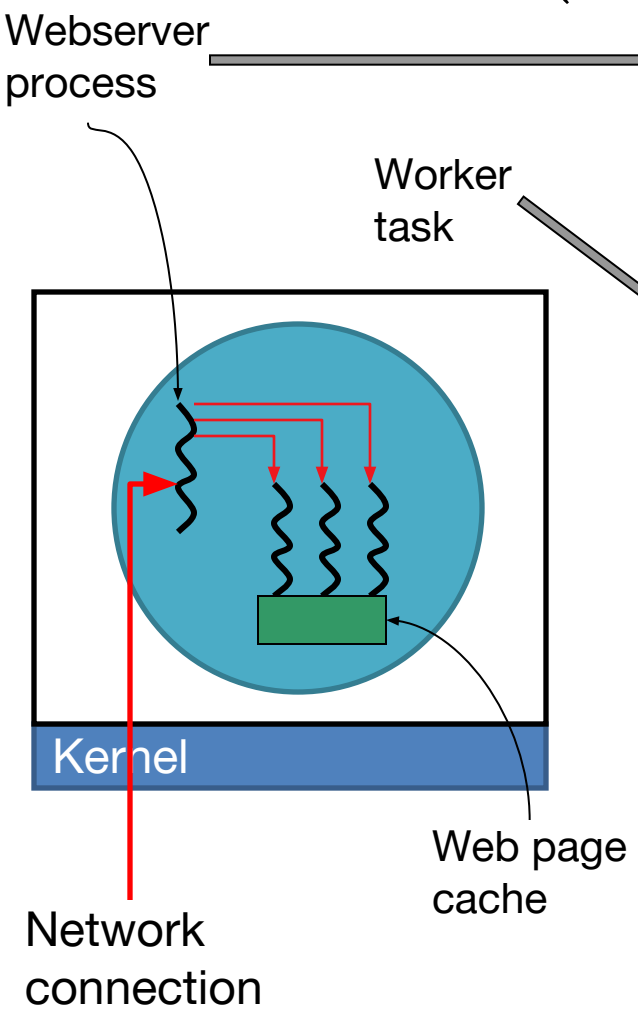
Concurrency and Parallelism

- Many programs need to perform mostly independent tasks that do not need to be serialized
  - Web server: page requests
  - Text editor: auto-save, spell checking, text entry
  - Web client: tabbed browsing
- Parallel Programming
  - Make multiple runtime copies of the same task
  - Underlying system runs each task on a separate CPU
  - For performance
  - Makes sense only on a multiprocessor machine
- Concurrent Programming
  - Divide program into multiple, generally different, tasks
  - Underlying system provides illusion of concurrent progress
  - For responsiveness (i.e. spell check does not delay text entry)
  - Can make sense even on a single processor machine
- The need for parallelism has become more acute with multicores

Concurrency Example (Word Processor)



Parallelism Example (Webserver)




```
while(TRUE) {
  getNextRequest(&buf);
  handoffWork(&buf);
}
```

```
while(TRUE) {
  waitForWork(&buf);
  lookForPageInCache(&buf,&page);
  if(pageNotInCache(&page)) {
    readPageFromDisk(&buf,&page);
  }
  returnPage(&page);
}
```

Programs and Processes

- Program: Executable binary (code and static data)
- Process: A program loaded into memory
  - Program (executable binary with data and text section)
  - Execution state (heap, stack, and processor registers)

Program

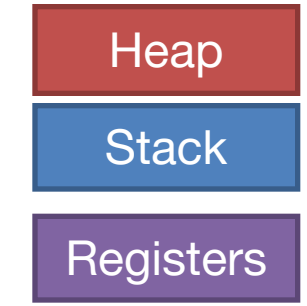
```
int foo() {
    return 0;
}

int main() {
    foo();
    return 0;
}
```

Process

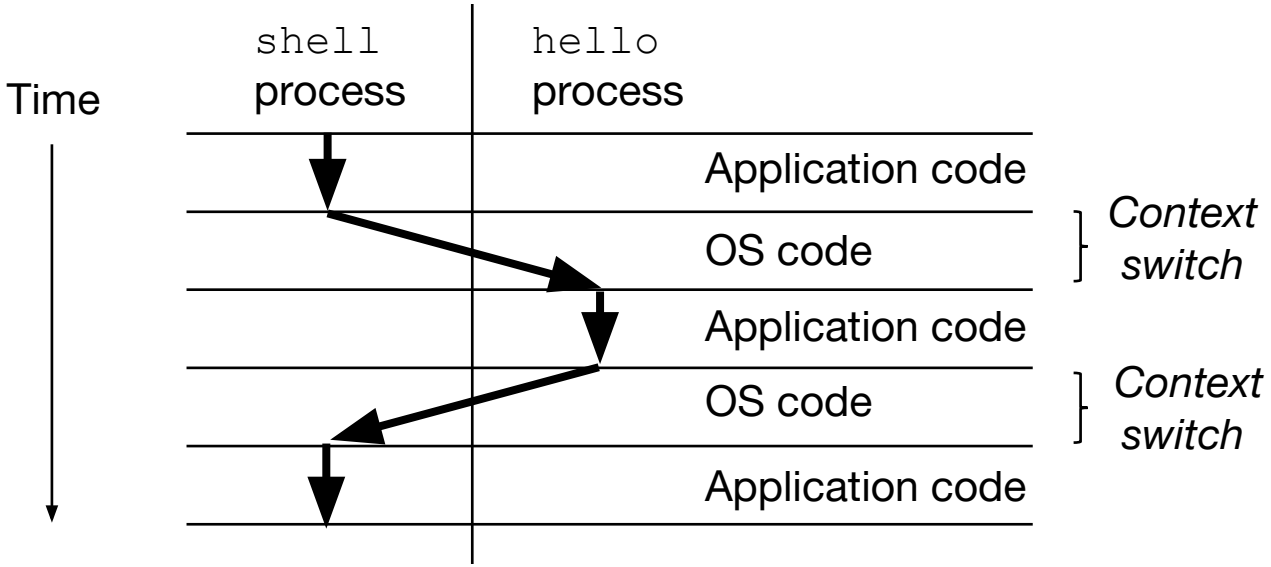
```
int foo() {
    return 0;
}

int main() {
    foo();
    return 0;
}
```



Context Switching

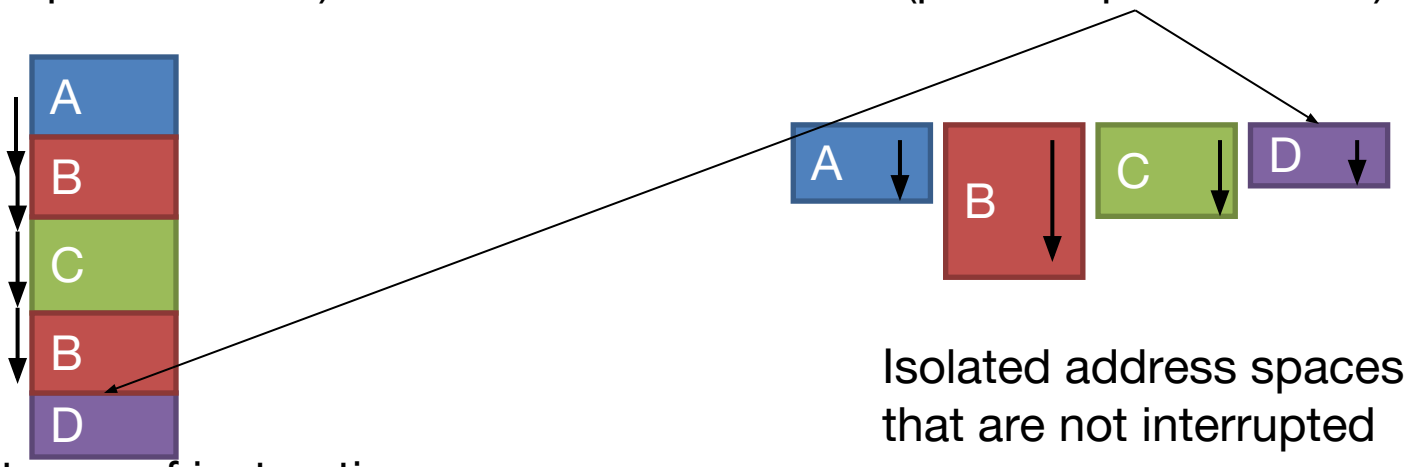
- OS provides the illusion of a dedicated machine per process
- Context switch
  - Saving context of one process, restoring that of another one
  - Processor alternates between executing different processes



Multiprogramming: Concurrently Running Programs

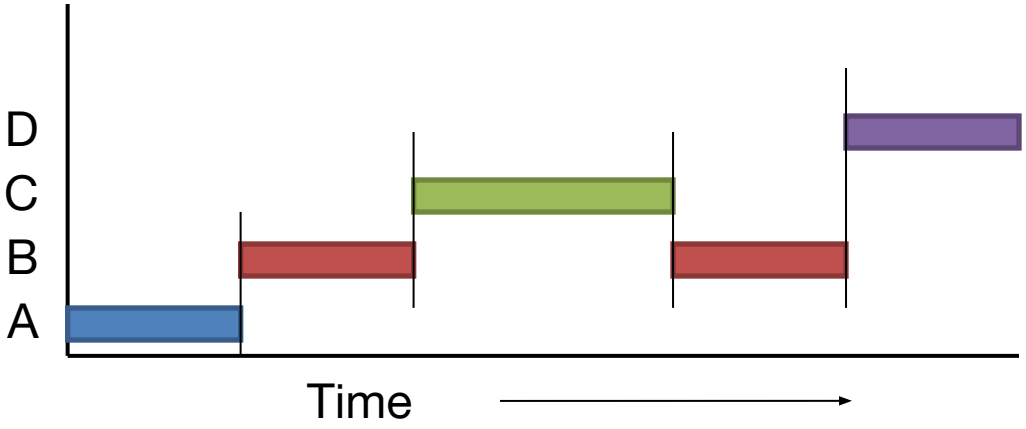
Single $PC
(CPU's point of view)

Multiple $PCs
(process point of view)



One stream of instructions

Isolated address spaces
that are not interrupted

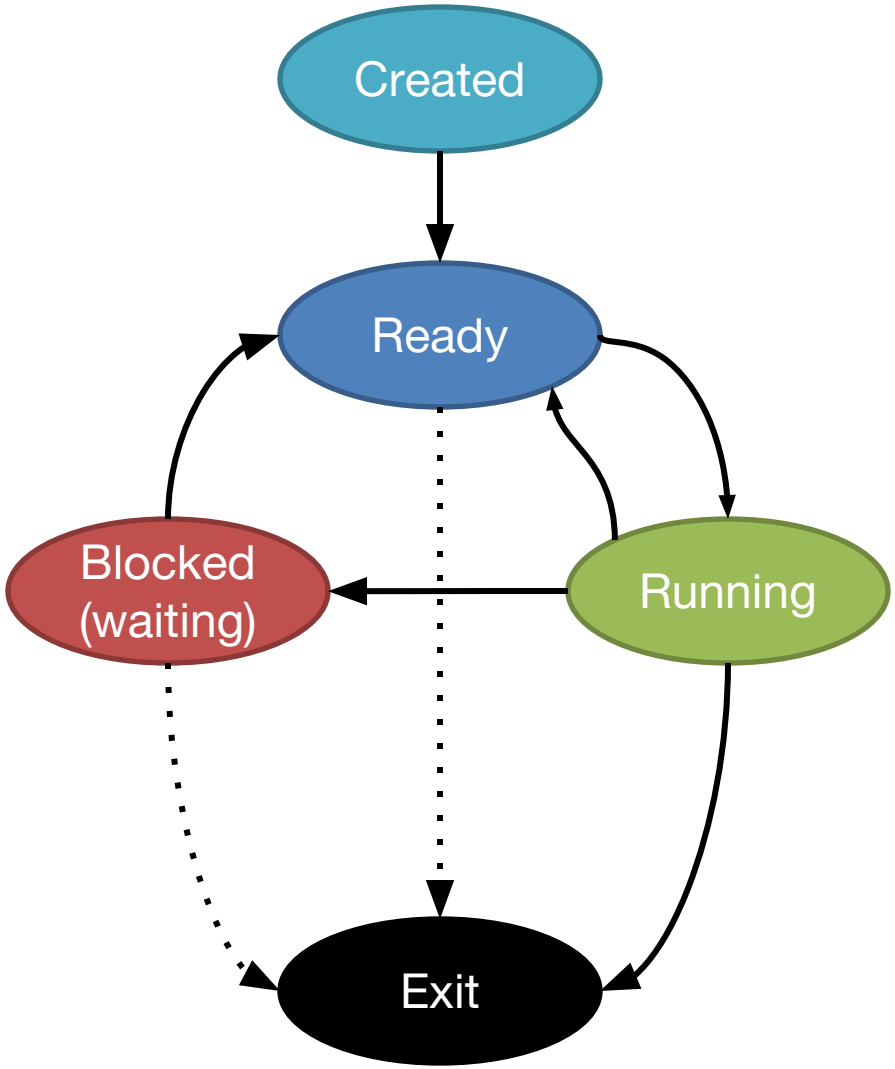


Dispatch Mechanism

- OS maintains list of all processes (PCBs)
- Each process has a mode
  - Running: Executing on the CPU
  - Ready: Waiting to execute on CPU
  - Blocked: Waiting for I/O or synchronization with another thread
- Dispatch Loop

```
while (1) {
    run process for a while;
    stop process and save its state;
    load state of another process;
}
```

Life Cycle of a Process



Processes Sometimes Infeasible

- Expensive in terms of memory
  - Must maintain PCB for each process in OS
  - In particular page tables
- Expensive in terms of performance
  - Forking: must duplicate PCB (including page tables)
  - Context Switching: involves system call into OS and flushing cached page table entries in MMU
  - Inter-process Communication: involves system call to invoke OS to move data
- When memory needs to be *shared* instead of *duplicated*:
  - When there is a shared modified data structure

Thread

A stream of instructions and their associated state

Threads and Processes

- Process: Execution stream + Program State
- Thread: Execution stream + Thread State (in same process address space)
  - "Lightweight process"

Process

```
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    return 0;
}

int main() {
    foo();
    return 0;
}
```

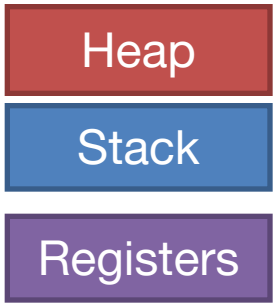

Threads

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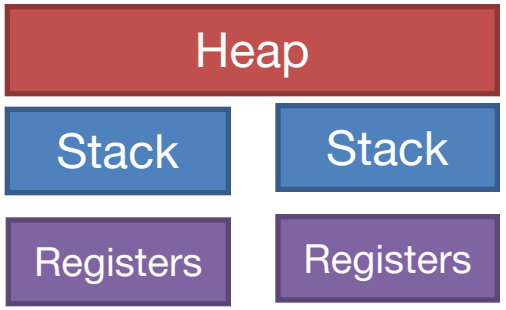
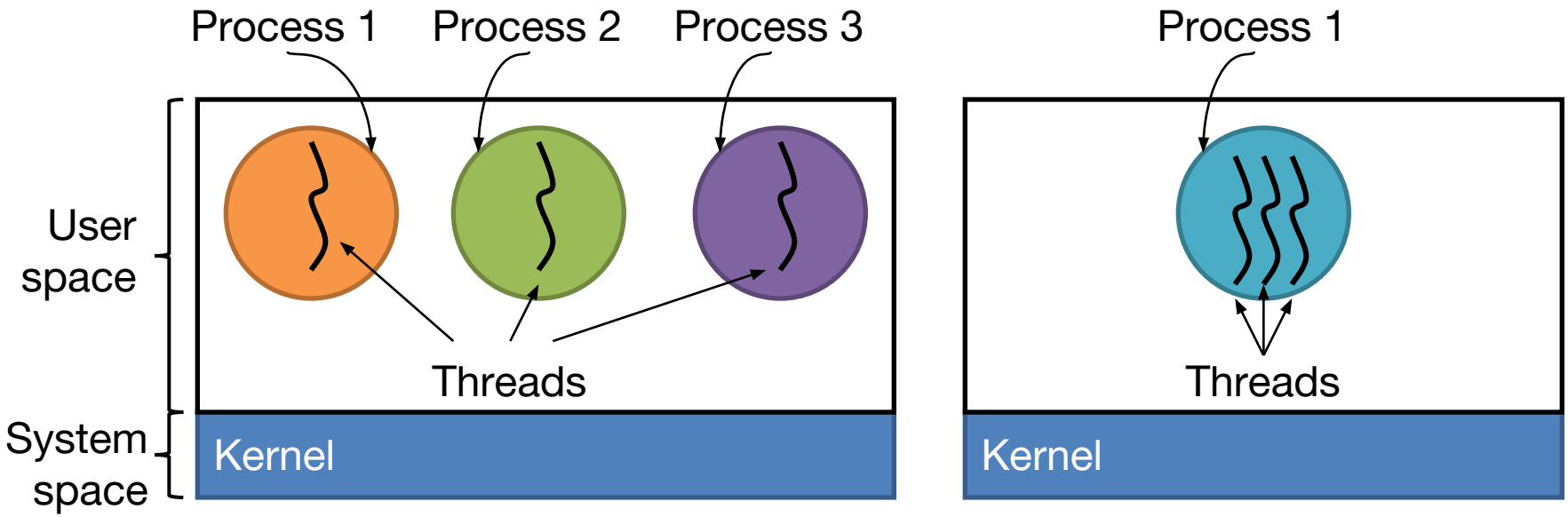


- Can have multiple threads within a process

Processes and Threads



Thread State

Per process items
Address space
Page table
Open files
Child processes
Signals & handlers
Heap space
Global variables

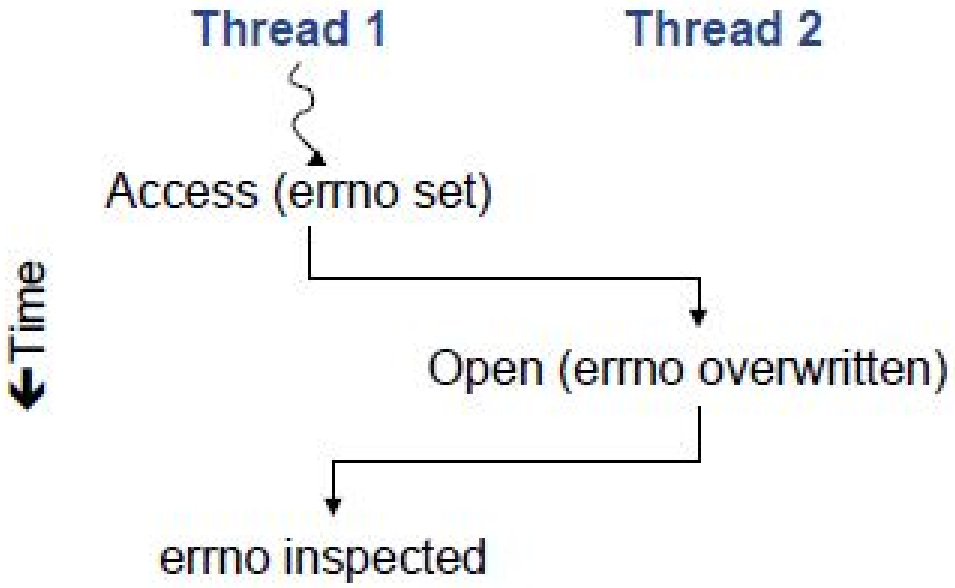
Per thread items	**Per thread items**	**Per thread items**
Program counter	Program counter	Program counter
Registers	Registers	Registers
Stack & stack pointer	Stack & stack pointer	Stack & stack pointer
State	State	State

Thread Pros/ Cons

- Pros
  - Less memory to maintain Thread State (mostly extra stack space)
  - Less performance overhead
  - Automatic data sharing (same address space)
- Cons
  - Shared memory can be source of data races
  - Less robust compared to processes:
    - Memory corruption on one thread corrupts entire program
    - A crash in one thread crashes the entire program

Data Races in Multithreading

- Global variables and heap locations are problems
  - Not just your global variables, also library variables
- File operations modify **errno** to indicate errors
  - What if two threads both operate on separate files?



Re-entrant Code

- *Re-entrant:* ability to handle multiple calls to the same function at the same time
- Many libraries are not re-entrant
- Example a library that formats and prints messages to a log file:

```
int print_log(char * msg) {
    fprintf(logfile, "%s", get_timestamp());
    fprintf(logfile, msg);
    fprintf(logfile, "\n");
}
```

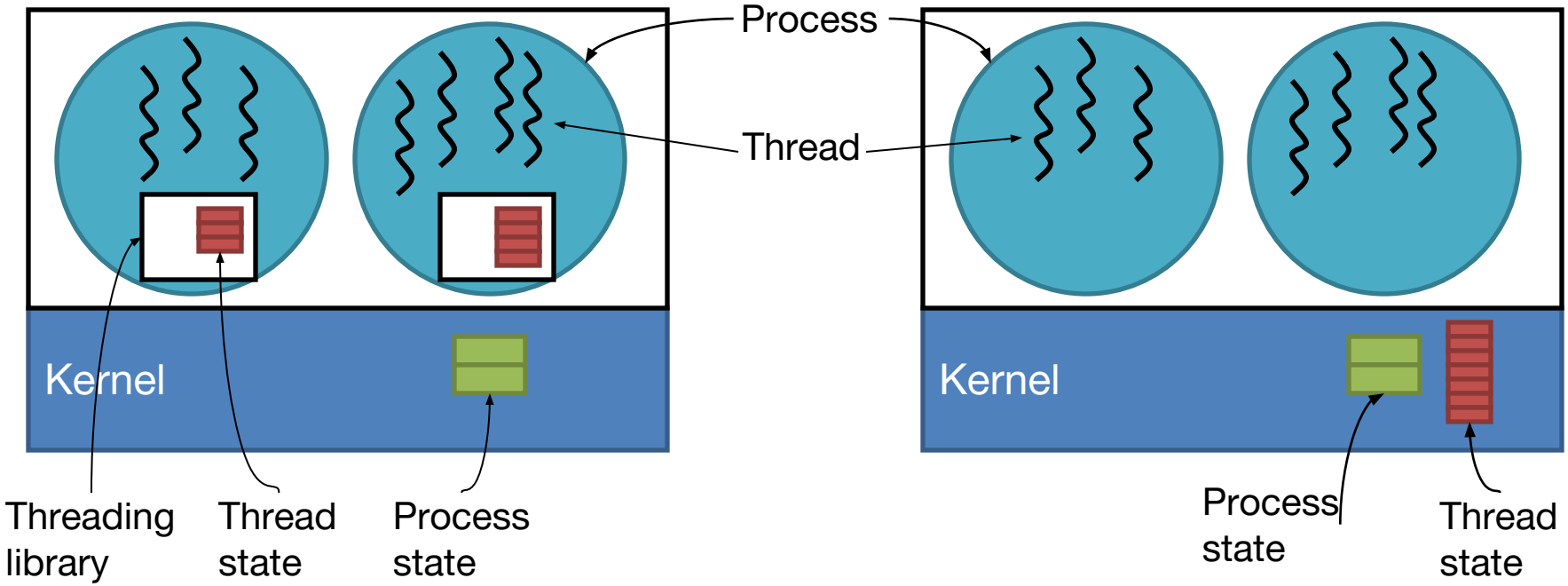
Thread Implementation

User-Level Threading vs.
Kernel-Level Threading

Who does thread management?

- User-level threading
  - User-level threading library
  - On thread create
    - Reserve new stack space using mmap()
  - On context-switch
    - Save / restore processor registers
    - Change stack pointer registers to stack of new thread
- Kernel-level threading
  - Kernel maintains thread state internally
  - Use system calls for thread creation / management

User Threads vs. Kernel Threads



User-level vs. Kernel-level

- User-level threading can be faster:
  - Do not need system calls for thread management
  - Context switching happens in user land
  - Can make application specific scheduling decisions for a tighter schedule
- However some issues with user-level:
  - Cannot run on multiple processors
    - To the kernel, it is still just one process
  - One thread can hog CPU with no OS intervention
  - If a thread performs I/O and blocks, all threads stop
    - The entire process transitions into a blocked state

CPU Hogging Solution

- Thread library provides an *yield()* function that allows thread to voluntarily give up CPU
  - Also called *cooperative threading*
  - Since within same process, no worry about malicious hogging by a third party
  - Voluntary yielding often results in a better schedule than blind OS scheduling
- To pre-empt thread, register a timer signal to fire after time slot
  - Perform context switch in signal handler

Blocking I/O Solution

- Avoid performing blocking I/O in threads
- Threading library provides own version of non-blocking I/O calls
  - Poll() and select() system calls inform whether an I/O on a file descriptor would block or not
  - Always check with poll() or select() before performing actual I/O
  - If I/O will block, sleep thread and schedule another thread

Multiple Processors Solution?

- None: Can't allocate CPU with no OS involvement
- Prevents user threading from being employed in an environment where parallelism is important (e. g. Servers)
- For small uniprocessor systems, it's perfectly fine (e.g. Embedded Systems)
  - Memory efficiency of user threading a plus
  - Fast context switches and cooperative scheduling help meet real-time constraints
  - Works even on simple kernels with no threading support

OS Threading Requirements

- User-level threading:
  - Support for non-blocking I/O in OS
- Kernel-level threading:
  - Thread management implementation in OS
- Most general purpose kernels support kernel threading
  - Linux Native POSIX Thread Library
  - Windows Threading API
- How about Java? Usually the Java Virtual Machine...
  - Maps threads to kernel-threads if it's supported
  - If no support for kernel-threads, uses user-level threading