# COS 318: Operating Systems

# Non-Preemptive and Preemptive Threads

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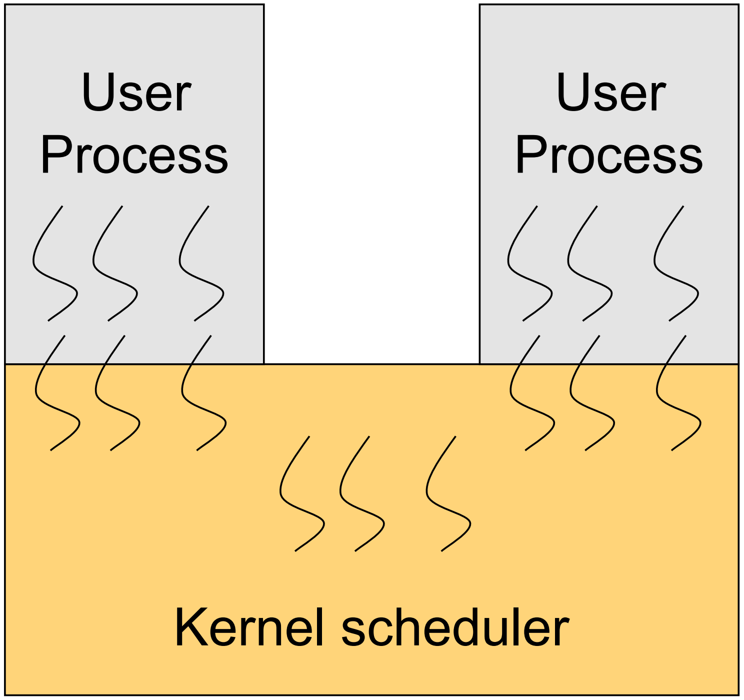
http://www.cs.princeton.edu/courses/archive/fall11/cos318

# Today’s Topics

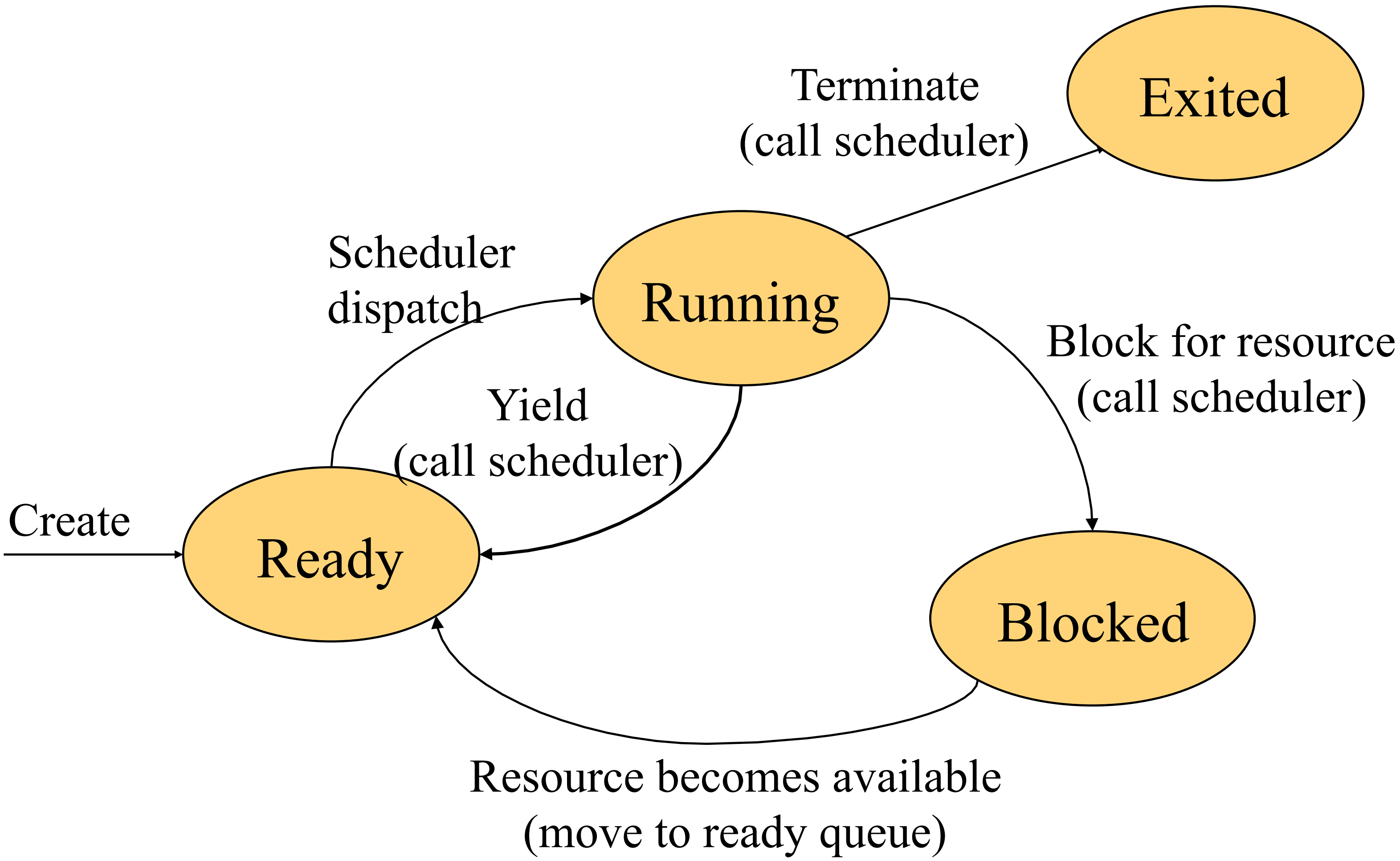
- Non-preemptive threads
- Preemptive threads
- Kernel vs. user threads
- Too much milk problem

# Revisit Monolithic OS Structure

- Kernel has its address space shared with all processes
- Kernel consists of
  - Boot loader
  - BIOS
  - Key drivers
  - Threads
  - Scheduler
- Scheduler
  - Use a ready queue to hold all ready threads
  - Schedule in the same address space (thread context switch)
  - Schedule in a new address space (process context switch)



# Non-Preemptive Scheduling



Terminate
(call scheduler)

Exited

Scheduler
dispatch

Running

Block for resource
(call scheduler)

Yield
(call scheduler)

Create

Ready

Blocked

Resource becomes available
(move to ready queue)

# Scheduler

- A non-preemptive scheduler invoked by calling
  - block()
  - yield()

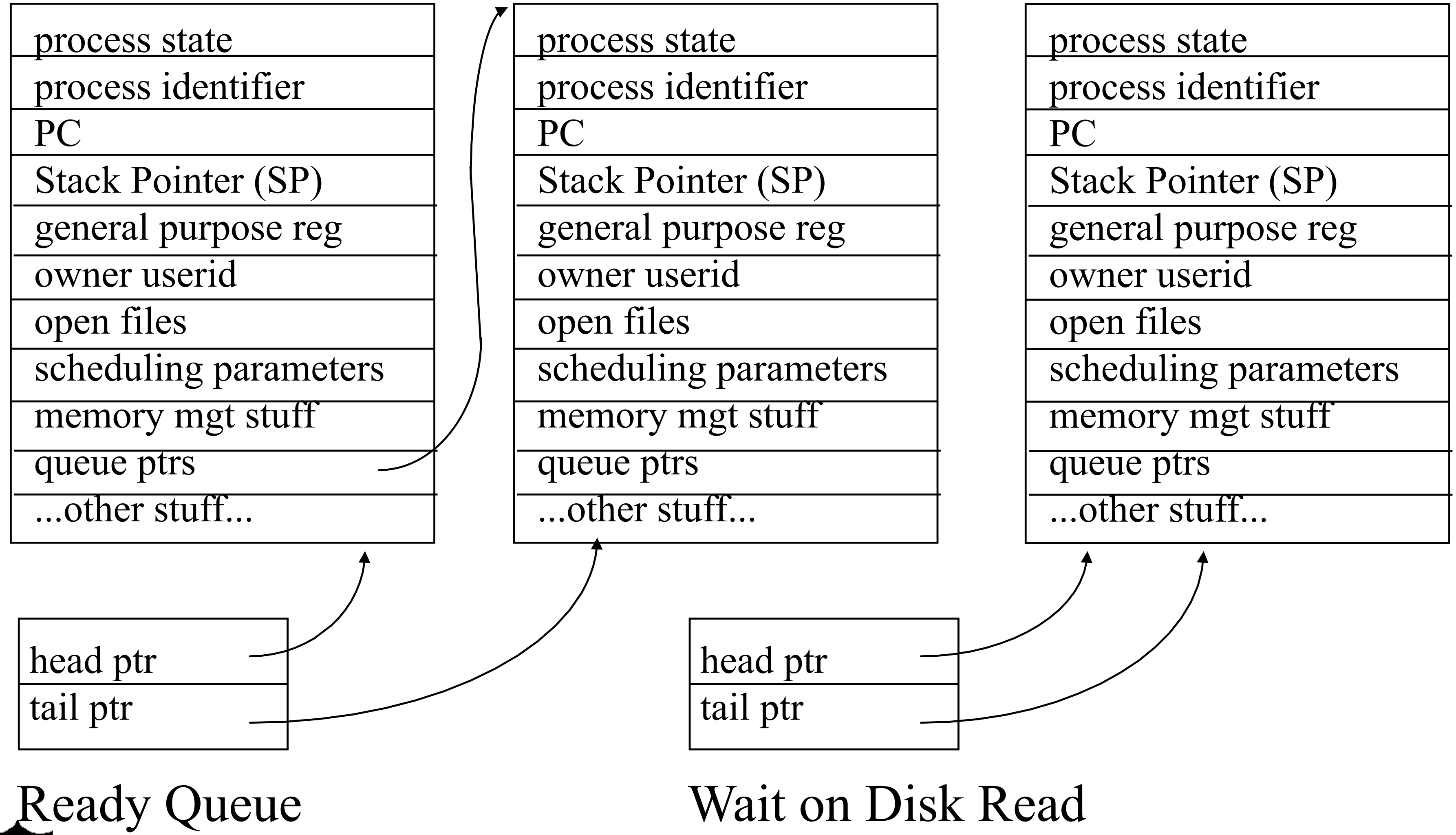
- The simplest form

  Scheduler:

  ```
      save current process/thread state
      choose next process/thread to run
      dispatch (load PCB/TCB and jump to it)
  ```

- Does this work?

# PCBs & Queues



process state
process identifier
PC
Stack Pointer (SP)
general purpose reg
owner userid
open files
scheduling parameters
memory mgt stuff
queue ptrs
...other stuff...

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queue ptrs
...other stuff...

head ptr
tail ptr

Ready Queue

head ptr
tail ptr

Wait on Disk Read

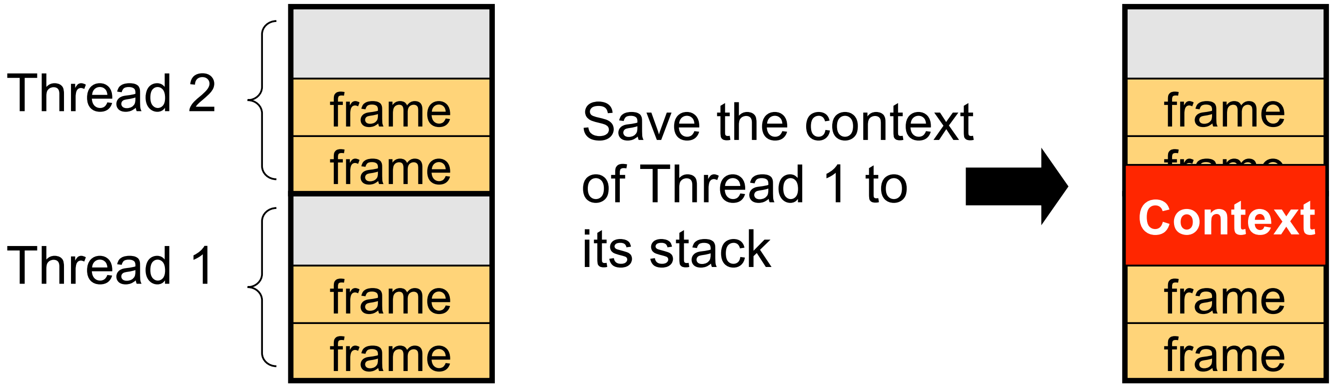
# More on Scheduler

- Should the scheduler use a special stack?

- Should the scheduler simply be a kernel thread?

# Where and How to Save Thread Context?

- Save the context on the thread’s stack
  - Need to deal with the overflow problem
- Check before saving
  - Make sure that the stack has no overflow problem
- Copy it to the TCB residing in the kernel heap
  - No overflow problems



Save the context of Thread 1 to its stack

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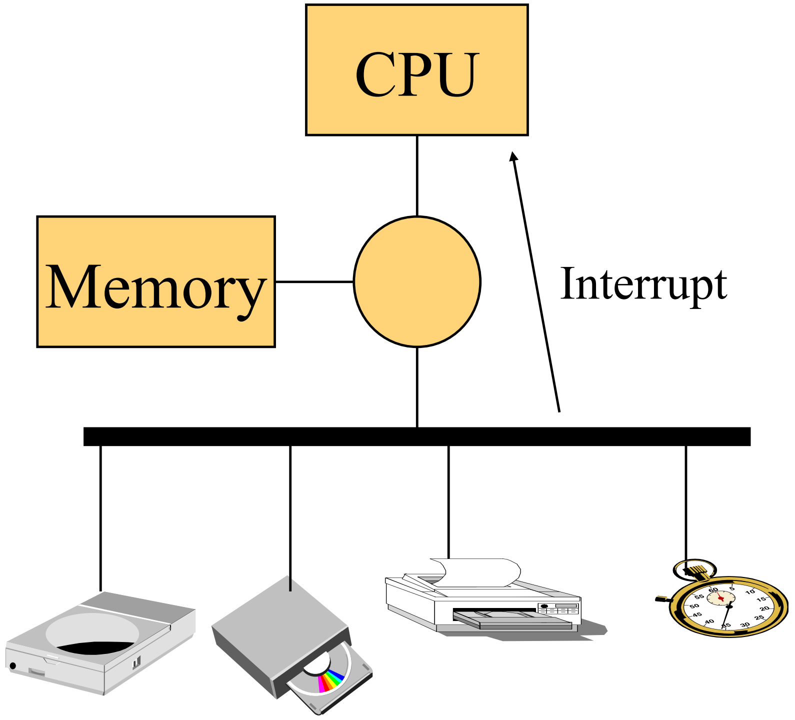
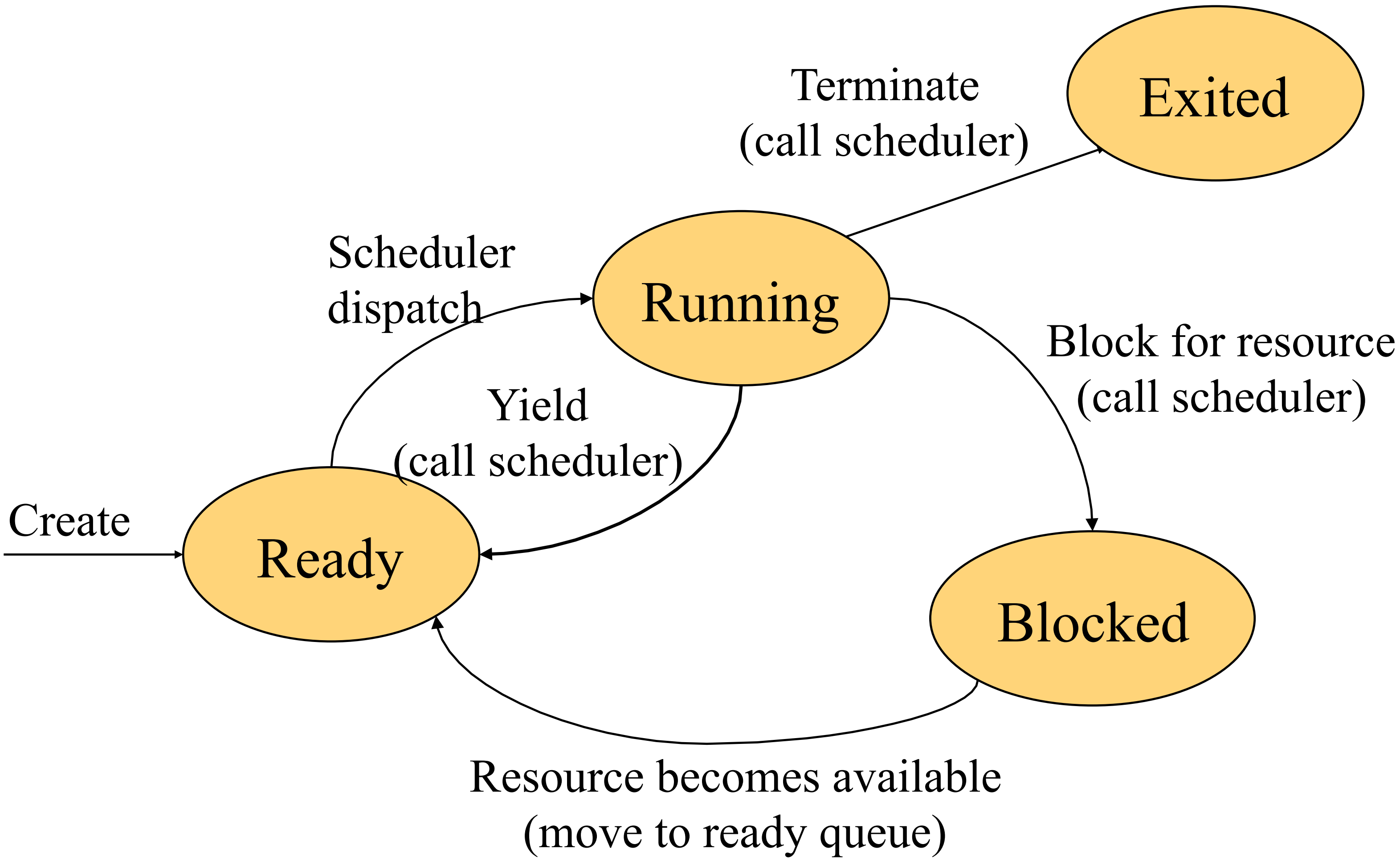
# Preemption by I/O and Timer Interrupts

- Why
  - Timer interrupt to help CPU management
  - Asynchronous I/O to overlap with computation
- Interrupts
  - Between instructions
  - Within an instruction except atomic ones
- Manipulate interrupts
  - Disable (mask) interrupts
  - Enable interrupts
  - Non-Masking Interrupts



# State Transition for Non-Preemptive Scheduling



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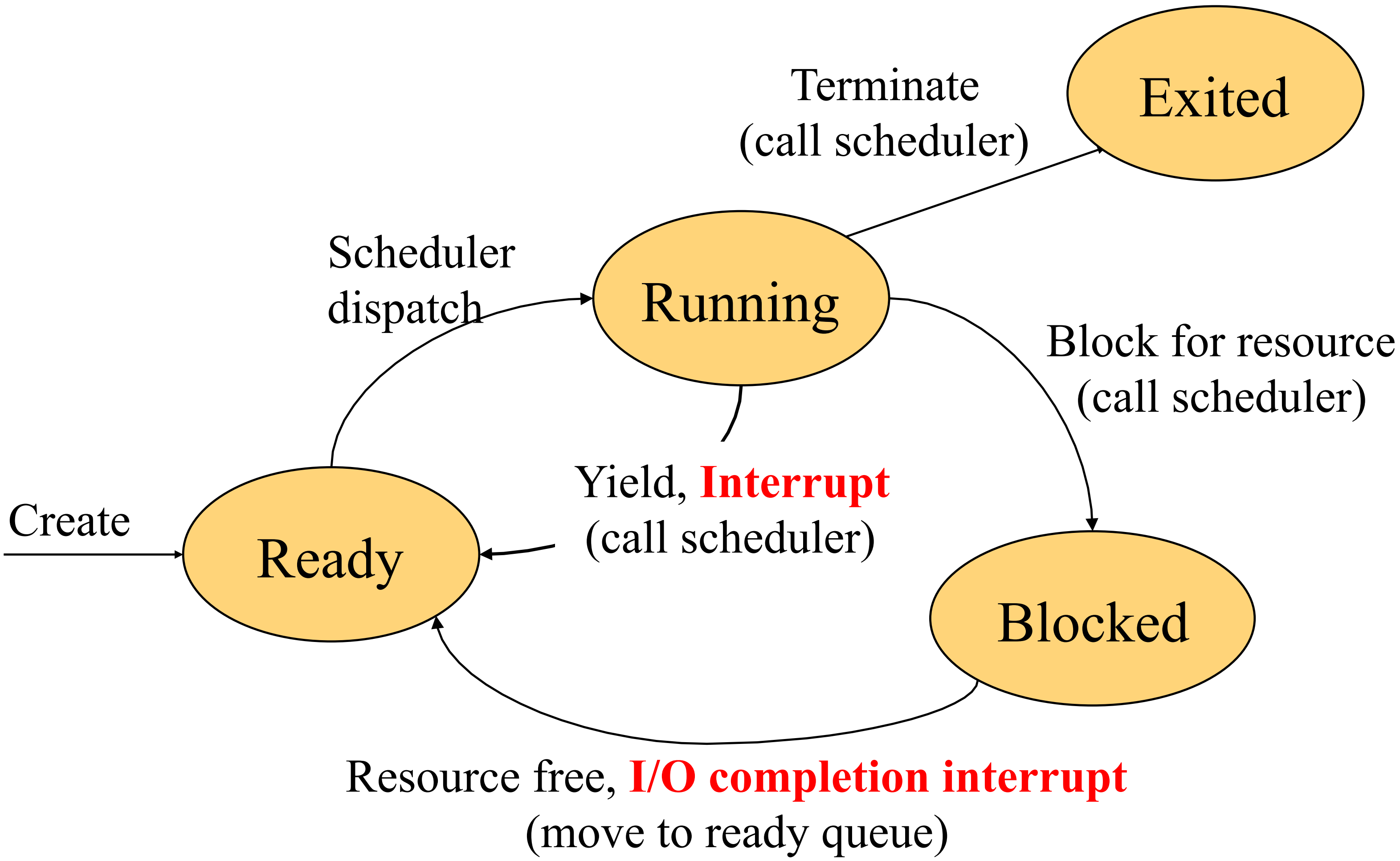
# State Transition for Preemptive Scheduling



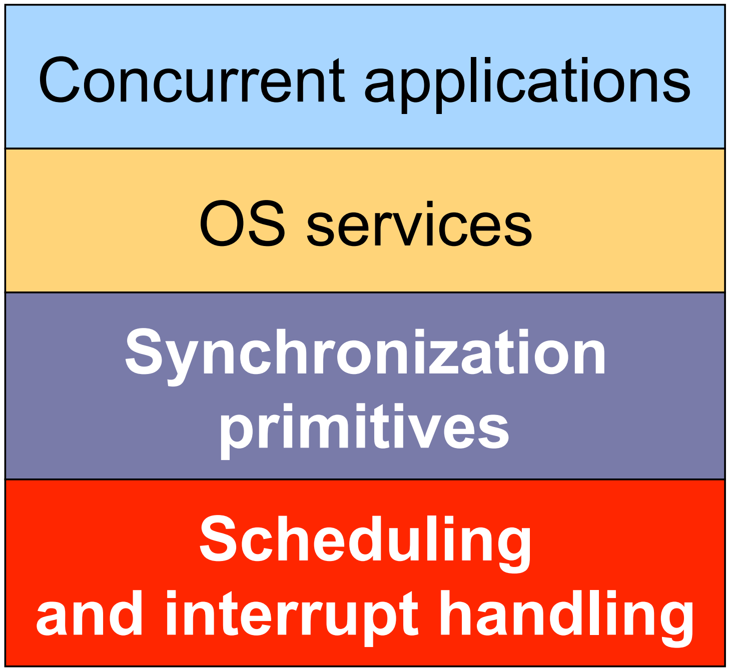
# Interrupt Handling for Preemptive Scheduling

- Timer interrupt handler:
  - Save the current process / thread to its PCB / TCB
  - … (What to do here?)
  - Call scheduler
- Other interrupt handler:
  - Save the current process / thread to its PCB / TCB
  - Do the I/O job
  - Call scheduler

- When to disable/enable interrupts?

# Dealing with Preemptive Scheduling

- Problem
  - Interrupts can happen anywhere
- An obvious approach
  - Worry about interrupts and preemptions all the time
- What we want
  - Worry less all the time
  - Low-level behavior encapsulated in “primitives”
  - Synchronization primitives worry about preemption
  - OS and applications use synchronization primitives


Concurrent applications

OS services

**Synchronization primitives**

**Scheduling and interrupt handling**

# Preemption

- Scheduling policies may be *preemptive* or *non-preemptive*.
    - *Preemptive*: scheduler may unilaterally force a task to relinquish the processor before the task blocks, yields, or completes.
- *timeslicing* prevents jobs from monopolizing the CPU
    - Scheduler chooses a job and runs it for a *quantum* of CPU time.
    - A job executing longer than its quantum is forced to yield by scheduler code running from the clock interrupt handler.
- use preemption to honor priorities
    - Preempt a job if a higher priority job enters the *ready* state.

# Priority

- Some goals can be met by incorporating a notion of *priority* into a “base” scheduling discipline.
    - Each job in the ready pool has an associated priority value; the scheduler favors jobs with higher priority values.
- *External priority* values:
    - imposed on the system from outside
    - reflect external preferences for particular users or tasks
        - “All jobs are equal, but some jobs are more equal than others.”
    - *Example*: Unix **nice** system call to lower priority of a task.
    - *Example*: Urgent tasks in a real-time process control system.
- *Internal priorities*
    - scheduler dynamically calculates and uses for queuing discipline. System adjusts priority values internally as as an *implementation technique* within the scheduler.

# Internal Priority

- Drop priority of tasks consuming more than their share
- Boost tasks that already hold resources that are in demand
- Boost tasks that have starved in the recent past
- Adaptive to observed behavior: typically a continuous, dynamic, readjustment in response to observed conditions and events
  - May be visible and controllable to other parts of the system
  - Priority reassigned if I/O bound (large unused portion of quantum) or if CPU bound (nothing left)

# Keeping Your Priorities Straight

◆ Priorities must be handled carefully when there are dependencies among tasks with different priorities.

- A task with priority ***P*** should never impede the progress of a task with priority ***Q*** > ***P***.
  - This is called *priority inversion*, and it is to be avoided.
- The basic solution is some form of *priority inheritance*.
  - When a task with priority ***Q*** waits on some resource, the holder (with priority ***P)*** temporarily inherits priority ***Q*** if ***Q*** > ***P***.
  - Inheritance may also be needed when tasks coordinate with IPC.
- Inheritance is useful to meet deadlines and preserve low-jitter execution, as well as to honor priorities.

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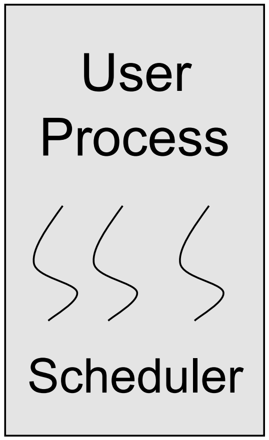
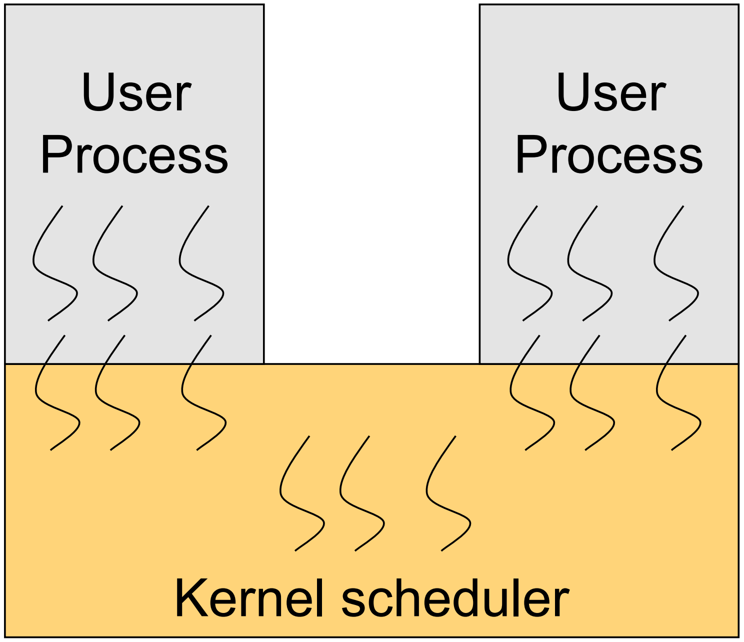
# User Threads vs. Kernel Threads





- Context switch at user-level without a system call (Java threads)
- Is it possible to do preemptive scheduling?
- What about I/O events?

- A user thread
  - Makes a system call (e.g. I/O)
  - Gets interrupted
- Context switch in the kernel

# Summary of User vs. Kernel Threads

- User-level threads
  - User-level thread package implements thread context switches
  - Timer interrupt (signal facility) can introduce preemption
  - When a user-level thread is blocked on an I/O event, the whole process is blocked
- Kernel-threads
  - Kernel-level threads are scheduled by a kernel scheduler
  - A context switch of kernel-threads is more expensive than user threads due to crossing protection boundaries
- Hybrid
  - It is possible to have a hybrid scheduler, but it is complex

# Interactions between User and Kernel Threads

- Two approaches
  - Each user thread has its own kernel stack
  - All threads of a process share the same kernel stack

| | Private kernel stack | Shared kernel stack |
|---|---|---|
| Memory usage | More | Less |
| System services | Concurrent access | Serial access |
| Multiprocessor | Yes | Not within a process |
| Complexity | More | Less |

# Today’s Topics

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# “Too Much Milk” Problem

- Do not want to buy too much milk
- Any person can be distracted at any point

| | Student A | Student B |
|---|---|---|
| 15:00 | Look at fridge: out of milk | |
| 15:05 | Leave for Wawa | |
| 15:10 | Arrive at Wawa | Look at fridge: out of milk |
| 15:15 | Buy milk | Leave for Wawa |
| 15:20 | Arrive home; put milk away | Arrive at Wawa |
| 15:25 | | Buy milk |
| | | Arrive home; put milk away<br>Oh No! |

# “Too Much Milk” : A different interleaving

| | Student A | Student B |
|---|---|---|
| 15:00 | Look at fridge: out of milk | |
| 15:05 | Leave for Wawa | |
| 15:10 | Arrive at Wawa | |
| 15:15 | Buy milk | |
| 15:20 | Arrive home; put milk away | |
| 15:25 | | Look at fridge: plenty of milk |
| | | Yay! |

# “Too Much Milk”: A Third Interleaving

- Do not want to buy too much milk
- Any person can be distracted at any point

| | Student A | Student B |
|---|---|---|
| 15:00 | | Look at fridge: out of milk |
| 15:05 | | Leave for Wawa |
| 15:10 | Look at fridge: out of milk | Arrive at Wawa |
| 15:15 | Leave for Wawa | Buy milk |
| 15:20 | Arrive at Wawa | Arrive home; put milk away |
| 15:25 | Buy milk | |
| | Arrive home; put milk away<br>Oh No! | |

# Using A Note?

**Thread A**

```
if ( noMilk ) {
   if (noNote) {
      leave note;
      buy milk;
      remove note;
   }
}
```

**Thread B**

```
if ( noMilk ) {
   if (noNote) {
      leave note;
      buy milk;
      remove note;
   }
}
```

- Any issue with this approach?

# Another Possible Solution?

**Thread A**

```
leave noteA
if (noNoteB) {
   if (noMilk) {
      buy milk
   }
}
remove noteA
```

Didn't buy milk

**Thread B**

```
leave noteB
if (noNoteA)
   if (noMilk)
      buy milk
   }
}
remove noteB
```

Didn't buy milk

- Does this method work?

# Yet Another Possible Solution?

**Thread A**

```
leave noteA
while (noteB)
  do nothing;
if (noMilk)
  buy milk;
remove noteA
```

**Thread B**

```
leave noteB
if (noNoteA) {
  if (noMilk) {
    buy milk
  }
}
remove noteB
```

- Would this fix the problem?

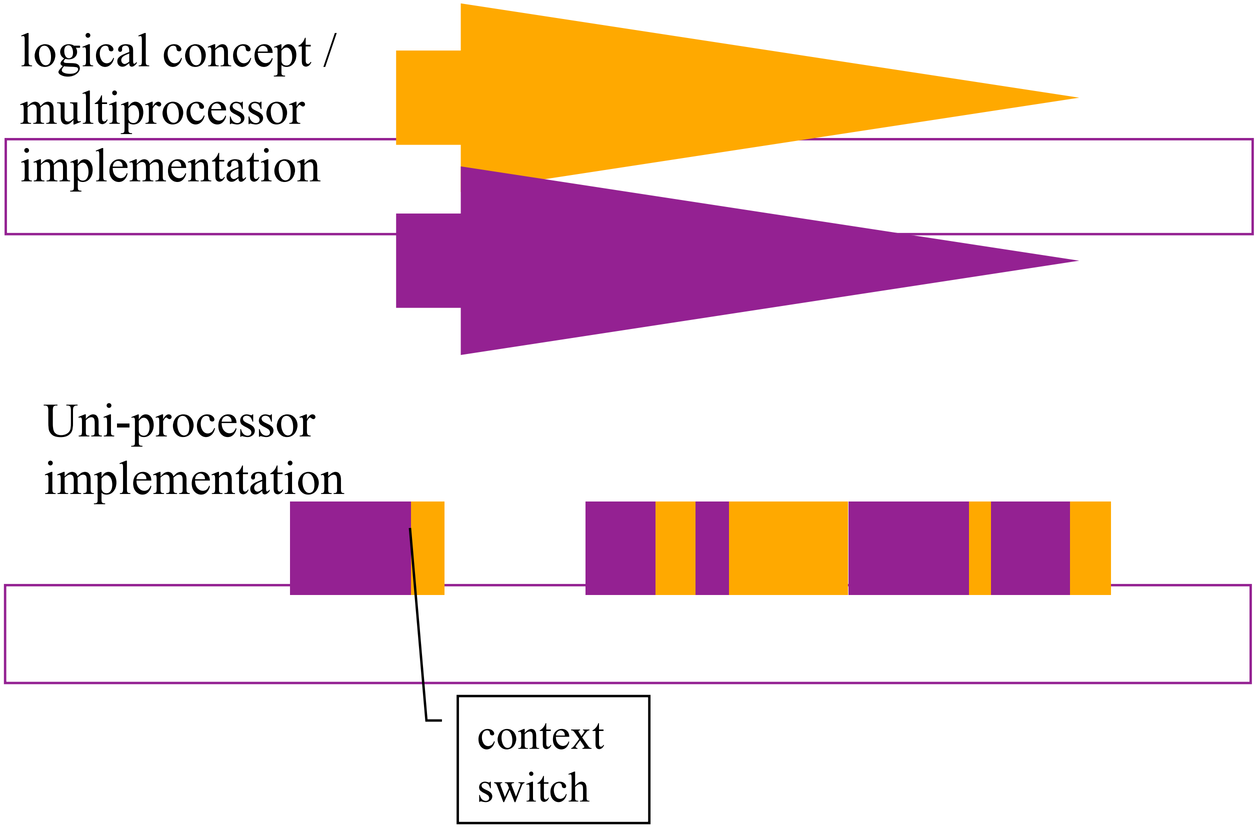
# Remarks

- The last solution works, but
  - Life is too complicated
  - A’s code is different from B’s
  - Busy waiting is a waste
- Peterson’s solution is also complex
- What makes these scenarios hard to reason about is arbitrary interleaving.
- What we want is:

```
Acquire(lock);
if (noMilk)
  buy milk;
Release(lock);
```

**Critical section**

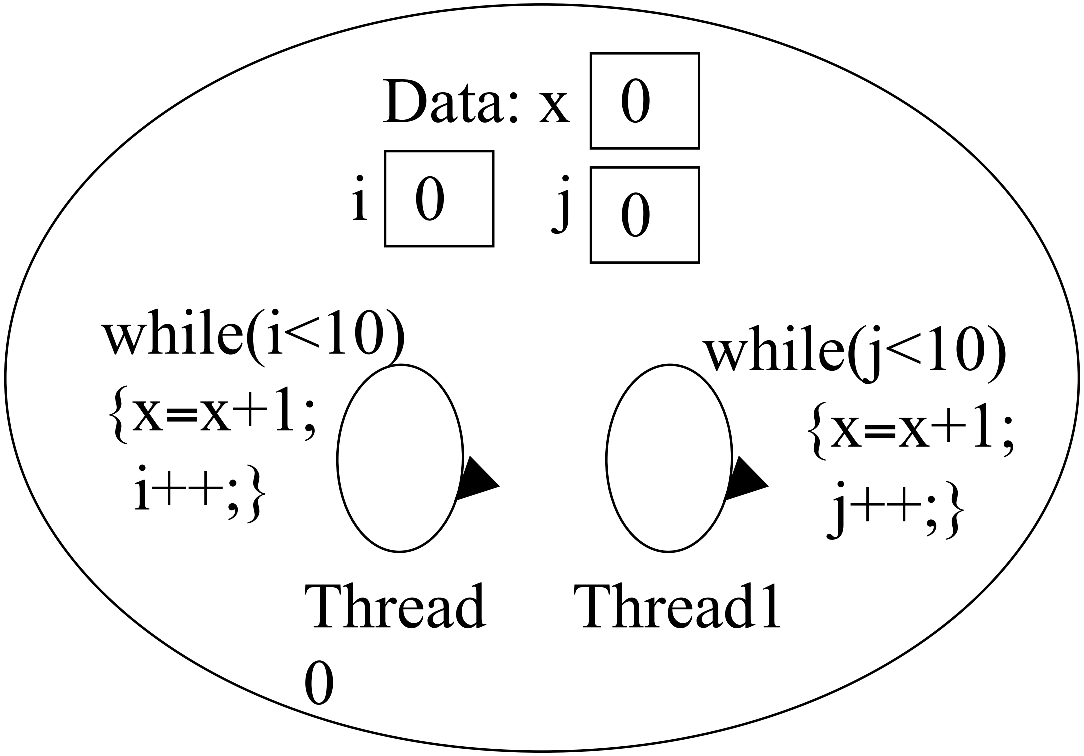
# Interleaved Schedules


logical concept / multiprocessor implementation

Uni-processor implementation

context switch

# The Trouble with Concurrency in Threads...



What is the value of x when both threads leave this while loop?

# Range of Answers

| Process 0 | Process1 |
|---|---|
| LD x // x currently 0 | |
| | LD x // x currently 0 |
| | Add 1 |
| | ST x // x now 1 |
| | Do 8 more full loops // x = 9 |
| Add 1 | |
| ST x // x now 1, stored over 9 | |
| | LD x // x now 1 |
| Do 9 more full loops // leaving x at 10 | |
| | Add 1 |
| | ST x // x = 2 stored over 10 |

# Nondeterminism

- What unit of work can be performed without interruption? ***Indivisible*** or ***atomic*** operations.
- ***Interleavings*** - possible execution sequences of operations drawn from all threads.
- ***Race condition*** - final results depend on ordering and may not be “correct”.

while (i<10) {x=x+1; i++;}

load value of x into reg

yield( )

add 1 to reg

yield ( )

store reg value at x

yield ( )

# Reasoning about Interleavings

- On a uniprocessor, the possible execution sequences depend on when context switches can occur
  - Voluntary context switch - the process or thread explicitly yields the CPU (blocking on a system call it makes, invoking a Yield operation).
  - Interrupts or exceptions occurring - an asynchronous handler activated that disrupts the execution flow.
  - Preemptive scheduling - a timer interrupt may cause an involuntary context switch at any point in the code.
- On multiprocessors, the ordering of operations on shared memory locations is the important factor.

# What Is A Good Solution

- Only one process/thread inside a critical section
- No assumption about CPU speeds
- A process/thread inside a critical section should not be blocked by any process outside the critical section
- No one waits forever

- Works for multiprocessors
- Same code for all processes/threads

# Summary

- Non-preemptive threads issues
  - Scheduler
  - Where to save contexts
- Preemptive threads
  - Interrupts can happen any where!
- Kernel vs. user threads
  - Main difference is which scheduler to use
- Too much milk problem
  - What we want is mutual exclusion

# Pitfalls:
# Mars Pathfinder Example

- In July 1997, Pathfinder's computer reset itself several times during data collection and transmission from Mars.
  - One of its processes failed to complete by a deadline, triggering the reset.
- Priority Inversion Problem.
  - Low priority process was inside a critical section to write a shared data structure, but was preempted to let higher priority processes run.
  - The higher priority process was blocked waiting, and failed to complete in time.
  - Meanwhile a bunch of medium priority processes ran, until finally the deadline ran out. They kept low priority process inside critical section from running again to release.
  - Priority inheritance had not been enabled on critical sections.
    - Low-pri "becomes" if holding an important resource!