Process Coordination (2) and Scheduling

Lecture 20

Today

Operating System support for Process Coordination

- Monitors
- When multiple thread/processes interact in a system, new species of bugs arise
- We must design the system to prevent or avoid them
- Bugs and solutions

Operating System task scheduling

- Traditional (non-real-time) scheduling
- Real-time scheduling

Monitors

Semaphores have a few limitations: unstructured, difficult to program correctly. Monitors eliminate these limitations and are as powerful as semaphores

A monitor consists of a software module with one or more procedures, an initialization sequence, and local data (can only be accessed by procedures)

Structure

- The critical section of each concurrent task is replaced by a call to the **monitor** operation
- An implicit semaphore is associated with each **monitor**, called the **monitor** lock

Rules

- User doesn't directly access monitor lock
- Only one task is active in the **monitor** at any one time
- A call to a **monitor** operation results in the calling task acquiring the associated semaphore
- If the lock is already taken, the calling task blocks until the lock is acquired
- An exit from the **monitor** operation releases the semaphore -- the **monitor** lock is released so it can be acquired by a different task

Monitors and Programming Languages

Where are they?

- Most programming languages do not specify concurrency and synchronization mechanisms, must be added
- Some do: Java, Concurrent Pascal, Modula 2, Modula 3

Details

- Identify method as a critical section using **synchronized** keyword
- The Java compiler inserts code to
  - Get lock immediately after entering increment()
  - Release lock immediately before returning from it

```
class Counter {
  long value=0;
  public synchronized void
      increment() {
         value++;
  }
}
```

Deadlock

A needs resources X and Y

B needs resources X and Y

Sequence leading to deadlock

- A requests and gets (locks) X
- context switch
- B locks Y
- B requests X, doesn't get it, leading to…
- context switch
- A can't get Y
- B can't get X

```
A() {
     lock(X);
     lock(Y);
     ....
     unlock(Y);
     unlock(X);
}

B() {
     lock(Y);
     lock(X);
     ....
     unlock(X);
     unlock(Y);
}
```

Context Switch

B never gets X

Deadlock (Cont'd)

Deadlock: A situation where two or more processes are unable to proceed because each is waiting for one of the others to do something.

Livelock: When two or more processes continuously change their state in response to changes in the other process(es) without doing any useful work. This is similar to deadlock in that no progress is made but differs in that neither process is blocked or waiting for anything.

Deadlock can occur whenever multiple parties are competing for exclusive access to multiple resources -- what can be done?

- Deadlock prevention
- Deadlock avoidance
- Deadlock detection and recovery

Deadlock Prevention

Deny one of the four necessary conditions

- Make resources sharable
  - *No mutual exclusion*
- Processes MUST request ALL resources at the same time.
  - Either all at start or release all before requesting more
  - “Hold and wait for” not allowed
  - *Poor resource utilization and possible starvation*
- If process requests a resource which is unavailable
  - It must release all resources it currently holds and try again later
  - Allow preemption
  - *Leads loss of work*
- Impose an ordering on resource types.
  - Process requests resources in a pre-defined order
  - No circular wait
  - *This can be too restrictive*

More Deadlock Strategies

Avoidance

- Allow necessary conditions to occur, but use algorithms to predict deadlock and refuse resource requests which could lead to deadlock – Called Banker's Algorithm
- *Running this algorithm on all resource requests eats up compute time*

Detection and Recovery

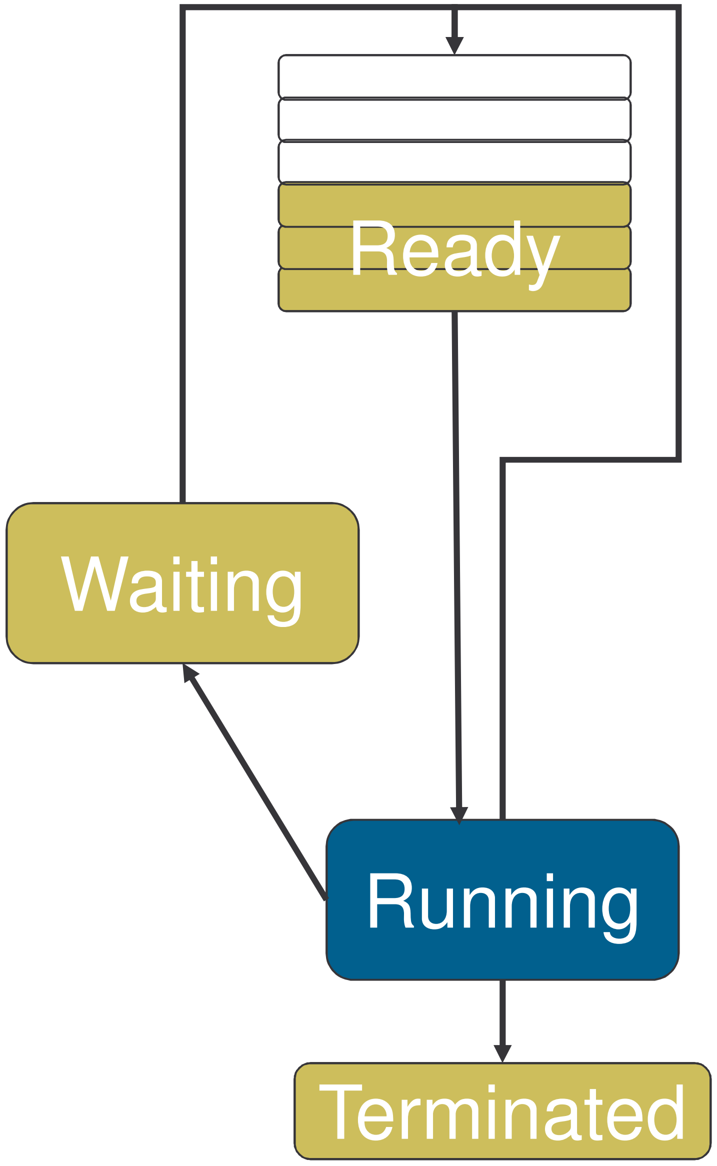
- Check for circular wait periodically. If detected, terminate all deadlocked processes (extreme solution but very common)
- *Checking for circular wait is expensive*
- *Terminating all deadlocked processes might not be appropriate*

Scheduling

Choosing which *ready* thread to run next

Common criteria

- CPU Utilization –fraction of time is the CPU busy
- Throughput – number of tasks are completed per unit time
- Turnaround time – time delay from task first being submitted to OS to finally completing
- Waiting time – amount of time a task spends in waiting queue
- Response time – time delay from request submission to first processing in response to that request



Common Scheduling Algorithms

First-Come, First Served (FCFS)

- All queues operate as strict FIFOs without priority
- Problems: large average delay, not preemptive

Round Robin: add time-sharing to FCFS

- At end of time tick, move currently running task to end of ready queue
- Problems: Still have a large average delay, choosing time-tick is trade-off of context-switching overhead vs. responsiveness

Shortest Job First (SJF)

- Job = process
- SJF is provably optimal in minimizing average waiting time
- Problem: How do we determine how long the next job will take?
  - Could predict it based on previous job?

Priority Scheduling

- Run the ready task with highest priority
- Define priority
  - Internal: Time limits, memory requirements
  - External: Importance to application, fees paid, department submitting task
- Problem: indefinite blocking (starvation)
  - Low level processes may never get to run in heavily loaded system
  - Two outcomes
    - Processes run during winter break
    - Processes disappear when computer eventually crashes

From OS to RTOS

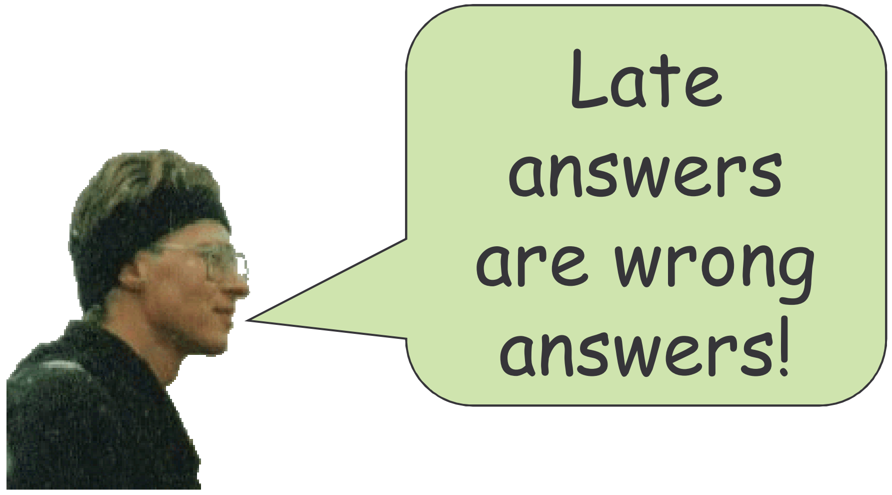
Traditional (non-real-time) Operating System

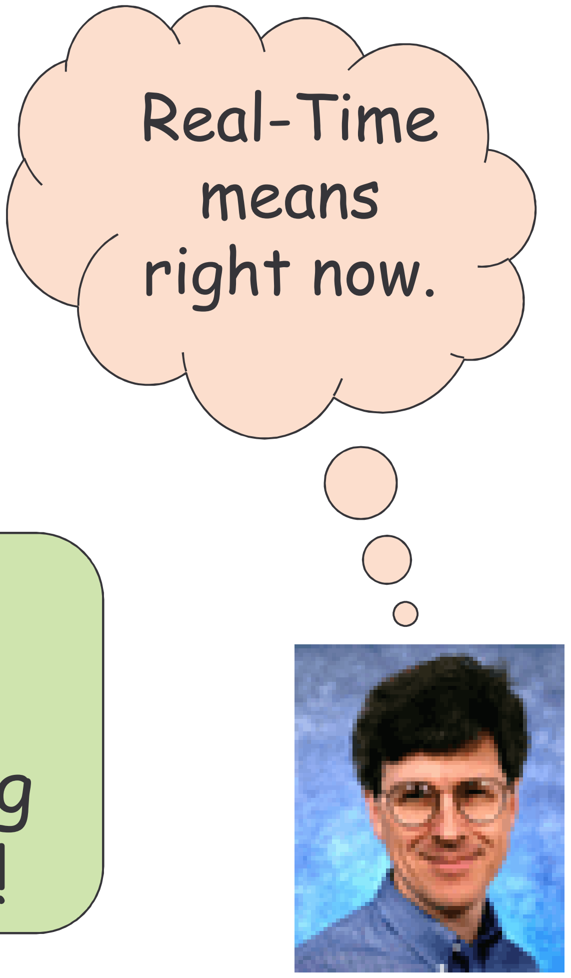
- Hard to predict response time…
- Hard to guarantee that a task will always run before its deadline

Real-Time Operating System

- Easy to determine that a task will always run before its ***deadline***
- Designed for ***periodic*** tasks

What does Real-Time mean?





Scheduling – Selecting a *Ready* task to run

Goals

- Meet all task deadlines
- Maximize processor *utilization* (U)
  - U = Fraction of time CPU performs useful work
  - Limit scheduling overhead (choosing what to run next)
  - Limit context switching overhead

Assigning priority based *only* on importance doesn't work – why not?

How do we assign priorities to task?

- Statically – priority based on period (doesn't change)
- Dynamically – priority based on time left (changes)

Definitions for Task i

- Task execution time = T_i
- Task execution period = τ_i: time between arrivals
- Utilization = fraction of time which CPU is used
  - For a task i

$$U_i = \frac{T_i}{\tau_i}$$

  - Overall, for all n tasks in the system

$$U = \sum_{i=1}^{n} \frac{T_i}{\tau_i}$$

- Completion Time = time at which task finishes
- Critical Instant = time at which task’s completion time is maximized. All tasks arrive simultaneously.
- Schedulable = a schedule exists which allows all tasks to meet their deadlines, even for the critical instant

Rate Monotonic Scheduling

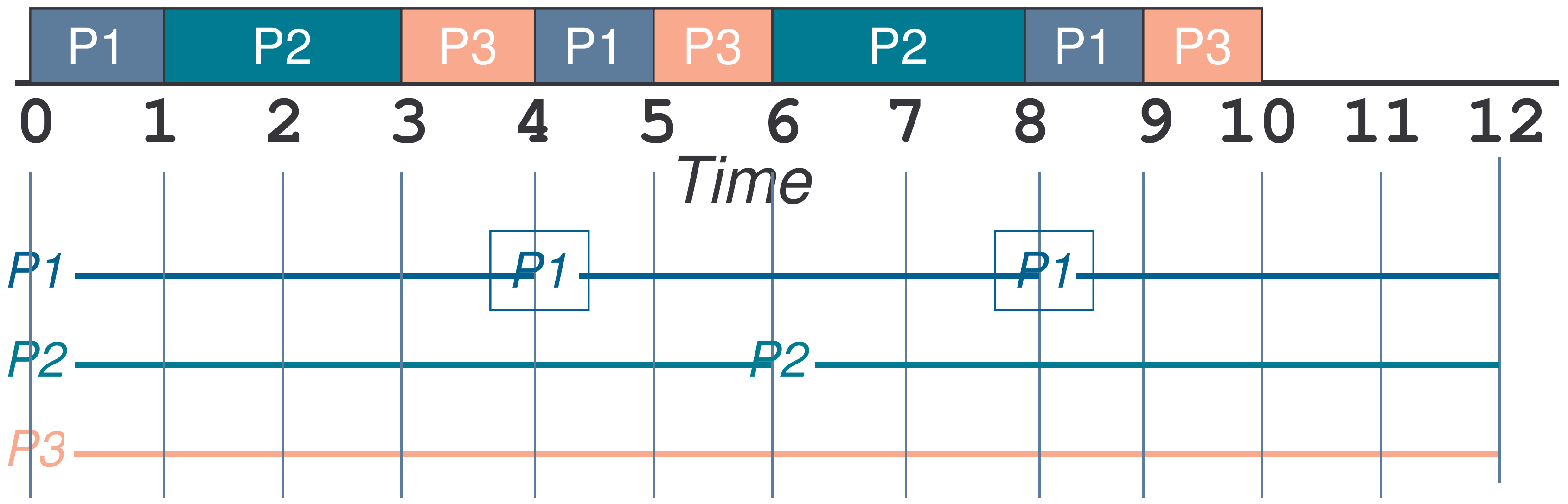
Assumptions

- Tasks are periodic with period τ_i
- Single CPU
- $T_{ContextSwitch} = T_{scheduler} = 0$
- No data dependencies between tasks
- Constant process execution time T_i
- Deadline = end of period = τ_i

Assign priority based on period (rate)

- Shorter period means higher priority

Processor Behavior – Graphical Analysis



Task	Exec. Time T	Period t	Priority
P1	1	4	High
P2	2	6	Medium
P3	3	12	Low

Exact Schedulability Test for Task *i*

Account for all processing at critical instant

Consider possible additional task arrivals

a_n = *n*th estimate of time when task *i* completes

Loop

- Estimate higher priority job arrivals, compute completion time
- Recompute based on any new arrivals

$$a_0 = \sum_{j=0}^{i} T_j$$

Iterate until

- $a_n > \tau_i$: not schedulable
- $a_n = a_{n-1} <= \tau_i$: schedulable

$$a_{n+1} = T_i + \sum_{j=0}^{i-1} \left\lceil \frac{a_n}{\tau_j} \right\rceil T_j$$

Exact Schedulability Test for Example

$$a_0 = \sum_{j=0}^{i} T_j = 1 + 2 + 3 = 6$$

$$a_1 = 3 + \sum_{j=0}^{i-1} \left\lceil \frac{6}{\tau_j} \right\rceil T_j = 3 + \left\lceil \frac{6}{4} \right\rceil * 1 + \left\lceil \frac{6}{6} \right\rceil * 2 = 3 + 2 + 2 = 7$$

$$a_2 = 3 + \sum_{j=0}^{i-1} \left\lceil \frac{7}{\tau_j} \right\rceil T_j = 3 + \left\lceil \frac{7}{4} \right\rceil * 1 + \left\lceil \frac{7}{6} \right\rceil * 2 = 3 + 2 + 4 = 9$$

$$a_3 = 3 + \sum_{j=0}^{i-1} \left\lceil \frac{9}{\tau_j} \right\rceil T_j = 3 + \left\lceil \frac{9}{4} \right\rceil * 1 + \left\lceil \frac{9}{6} \right\rceil * 2 = 3 + 3 + 4 = 10$$

$$a_4 = 3 + \sum_{j=0}^{i-1} \left\lceil \frac{10}{\tau_j} \right\rceil T_j = 3 + \left\lceil \frac{10}{4} \right\rceil * 1 + \left\lceil \frac{10}{6} \right\rceil * 2 = 3 + 3 + 4 = 10$$

Iterate until $a_{n-1} = a_n$

$a_3 = a_4 < 12$, so system is schedulable

Utilization Bound for RMS

Utilization *U* for *n* tasks

- Fraction of time spent on tasks

$$U = \sum_{i=1}^{n} \frac{T_i}{\tau_i}$$

Maximum utilization U_{Max} for *m* tasks

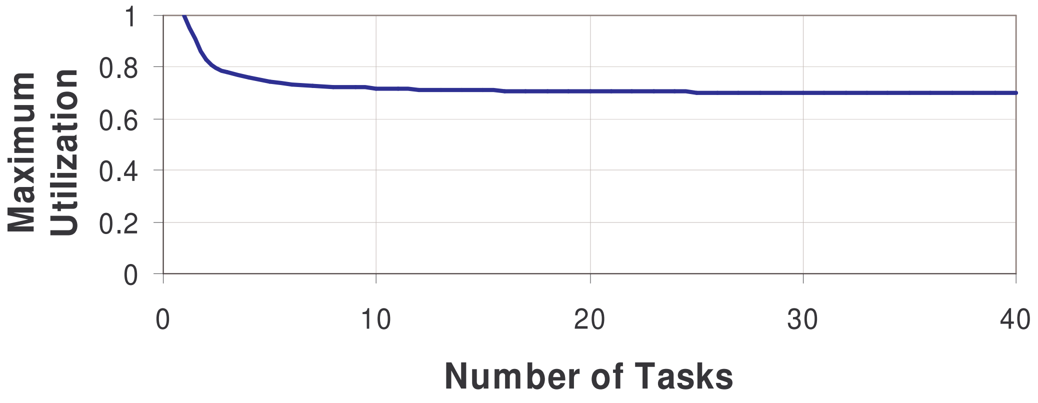
- Max. value of *U* for which we can guarantee RMS works

$$U_{Max} = m\left(2^{1/m} - 1\right)$$

Utilization bound test

- $U < U_{Max}$: always schedulable with RMS
- $U_{Max} < U < 1.0$: inconclusive
- $U > 1.0$: Not schedulable

Why is U_{Max} so small? (approaches ln(2)) *Conservative*



Example of Scheduling with RMS and UB

Task	Exec. Time T	Period τ	Priority
P1	1	4	High
P2	2	6	Medium
P3	3	12	Low

$$U = \frac{T_1}{\tau_1} + \frac{T_2}{\tau_2} + \frac{T_3}{\tau_3} = \frac{1}{4} + \frac{2}{6} + \frac{3}{12} = 0.833$$

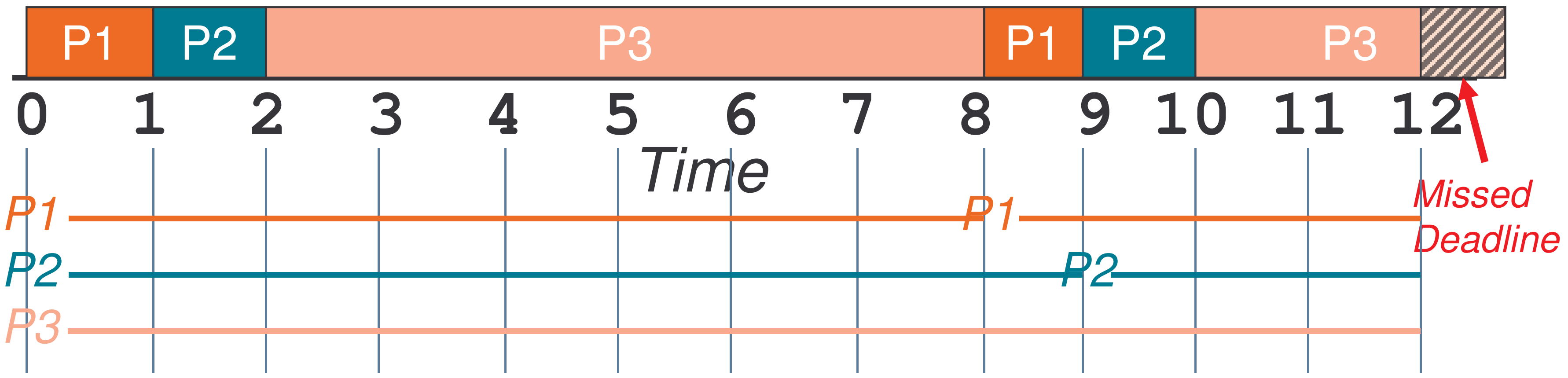
$$U_{Max} = m(2^{1/m} - 1) = 3(2^{1/3} - 1) = 0.780$$

Utilization Bound test is inconclusive

RMS Sometimes Fails Under 100% Utilization

For some workloads with utilization below 100%, RMS priority allocation can fail
Tasks P1, P2 have later deadlines than P3 yet preempt it due to their shorter periods

Thread	Exec. Time T	Period τ	Priority
P1	1	8	High
P2	1	9	Medium
P3	9	12	Low



Counter-example provided by C. Palenchar

Earliest Deadline First

Can guarantee schedulability at up to 100% utilization

Can't use Exact Schedulability Test for EDF

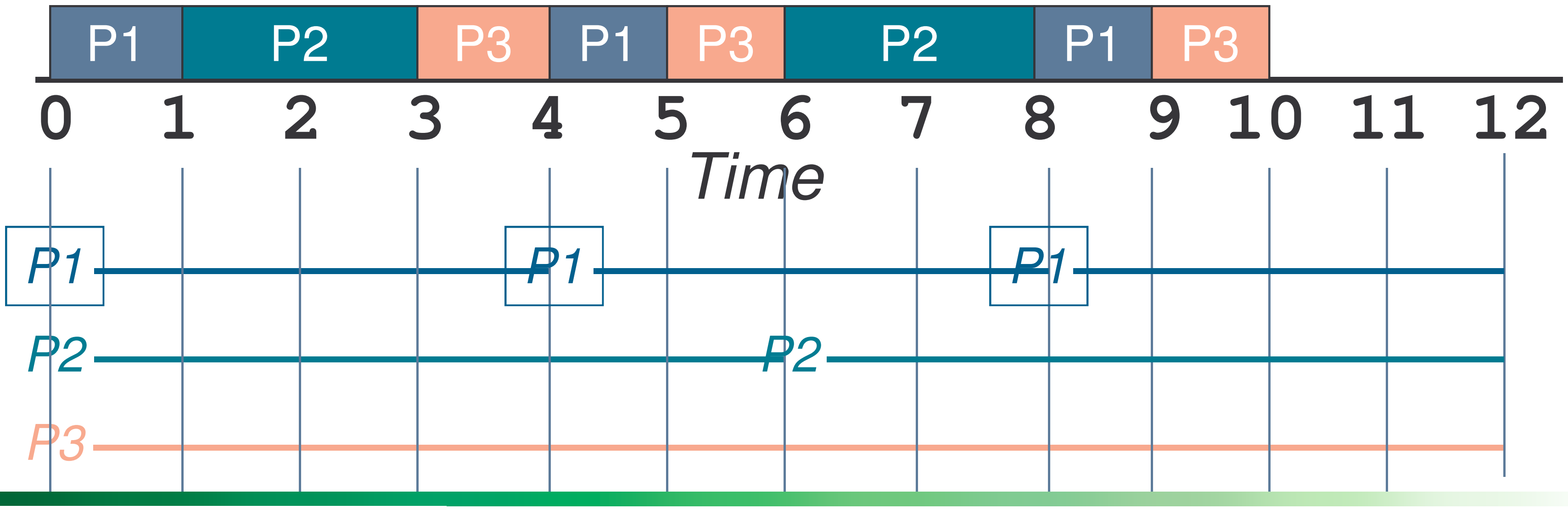
- Sum up all possible higher priority tasks, but priority depends on how close deadlines are!
- Can we modify the test to deal with this?

How does the kernel keep track of upcoming deadlines?

- Can determine priority when inserting task into ready queue
  - Need to search through queue to find correct location (based on deadline)
- Can determine which task to select from ready queue
  - Need to search through queue to find earliest deadline
- Both are up to O(n) search time
  - Can also do binary search tree

Earliest Deadline First Example

Thread	Execution Time T	Period τ
P1	1	4
P2	2	6
P3	3	12



System Performance During Transient Overload

RMS – Each task has fixed priority. *So?*

- This priority determines that tasks will be scheduled consistently
  - Task A will always preempt task B if needed
  - Task B will be forced to miss its deadline to help task A meet its deadline

EDF – Each task has varying priority. *So?*

- This priority depends upon when the task's deadline is, and hence when the task becomes ready to run (*arrival time*)
  - Task B may have higher priority than A depending on arrival times
  - To determine whether task A or B will miss its deadline we need to know their arrival times