CPU Scheduling

DM510 Operating Systems

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Windows macOS Android iOS

Disclaimer

These slides contain (modified) content and media from the official Operating System Concepts slides:
https://www.os-book.com/OS10/slide-dir/index.html

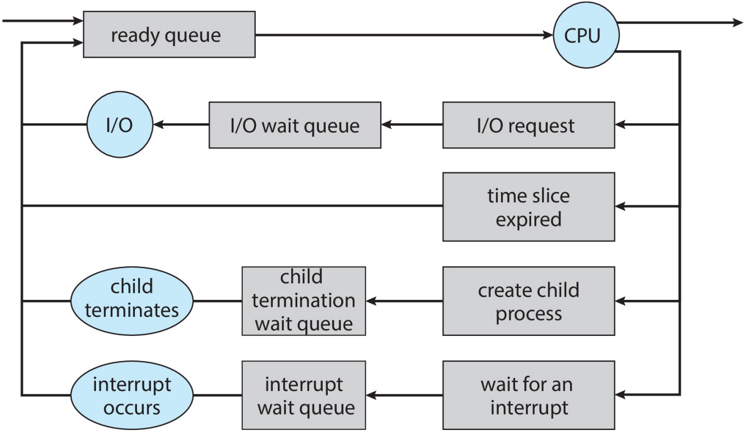
Today's lecture

- Chapter 5 of course book

Overview

Setting

- Typically many processes compete for computation time on CPU
- Processes ready to run wait in a queue
- **Key question:** How does the kernel decide which process to run?



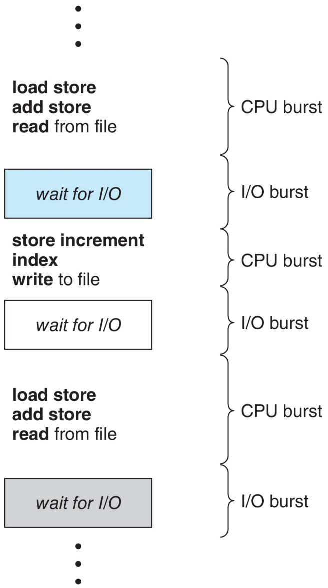
Scheduling criteria

When choosing a scheduling strategy, we can optimize several criteria that are sometimes conflicting (we might to decide what is more important)

- **CPU utilization:** Executing as many process instructions as possible
- **Throughput:** Complete as many processes/tasks per time unit as possible
- **Turnaround time:** Minimize time to complete a process
- **Waiting time:** Minimize time a process waits in ready queue
- **Response time:** Minimize time between incoming request and first response
- **Fairness:** Make sure that every process/task gets a fair share of CPU time and no task “starves” (never gets CPU time)
- **Efficiency of algorithm:** Scheduling algorithm itself should not create significant latency/overhead

CPU-I/O cycle

- Typically, processes do not need CPU all the time
- They have **CPU bursts**, in which they execute instructions on the CPU, then need to waits for I/O (**I/O burst**)



CPU-I/O cycle

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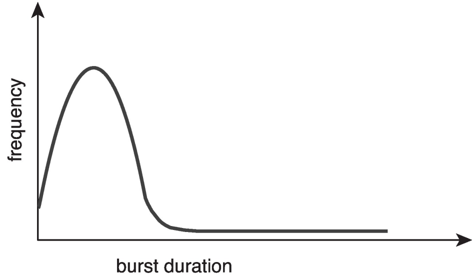
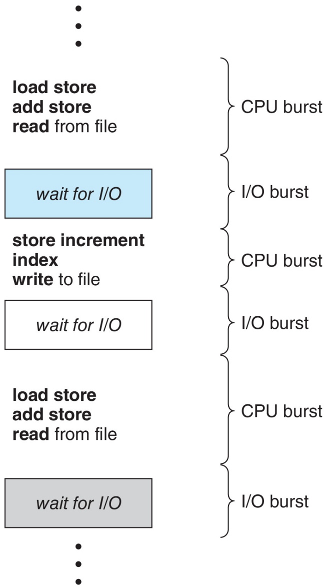
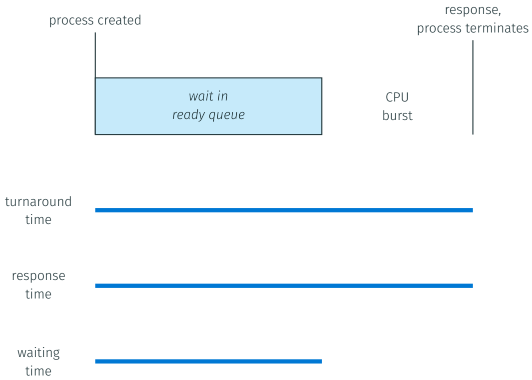
- They have **CPU bursts**, in which they execute instructions on the CPU, then need to waits for I/O (**I/O burst**)
- Typical distribution: many short CPU bursts, very few long ones

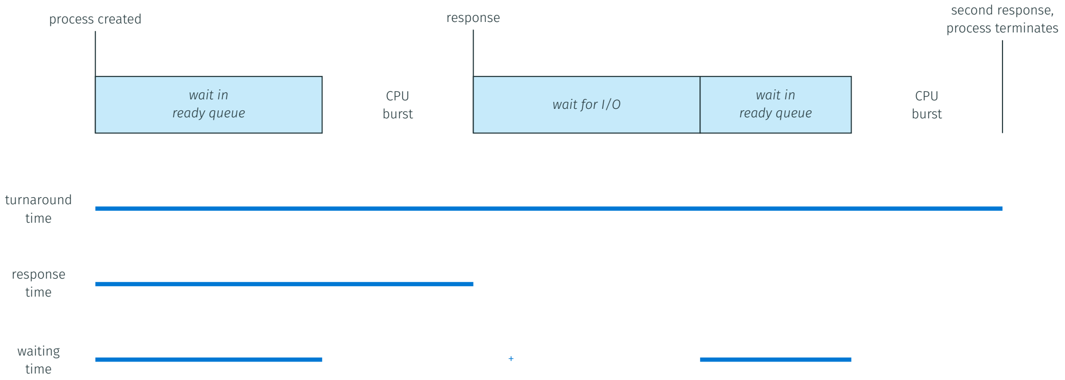




Example of CPU-I/O and different measures



Longer example of CPU-I/O and different measures



Preemption

- A scheduler is **non-preemptive** if it allows processes to continue running until they voluntarily suspend (for example because of an I/O burst)
- A scheduler that may preempt (involuntarily suspend) a process currently running on CPU is called **preemptive**
- Preemption is used in all major operating systems, but requires careful programming practices to avoid race conditions

Algorithms

First-come-first-serve (FCFS)

- Schedule processes in the order they arrive

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> Schedule processes in the order they arrive

Example

process	burst time	waiting time
P2	3	0
P3	3	3
P1	24	6
average		3

First-come-first-serve (FCFS)

- Schedule processes in the order they arrive
- Suffers from **convoy effect**: long process delays many small processes

Example

Example 2

process	burst time	waiting time
P1	24	0
P2	3	24
P3	3	27
average		17

Shortest-job-first (SJF)

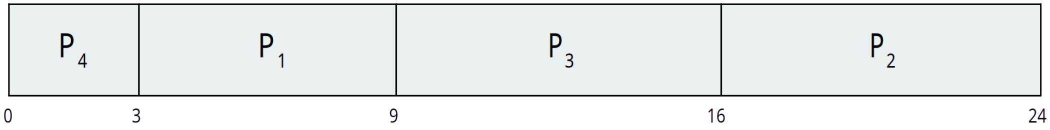
- Schedule processes increasingly by burst time

Shortest-job-first (SJF)

> Schedule processes increasingly by burst time
> Minimizes average waiting time

Example

process	burst time	waiting time
P1	6	3
P2	8	16
P3	7	9
P4	3	0
average		7

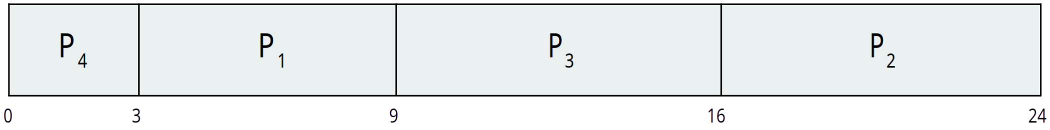


Shortest-job-first (SJF)

- Schedule processes increasingly by burst time
- Minimizes average waiting time
- How can we know the burst time in advance?
  Either provided by process or via estimate

Example

process	burst time	waiting time
P1	6	3
P2	8	16
P3	7	9
P4	3	0
average		7



Estimation of burst time

- Guess next burst time based on previous ones from same process
- Several ways to make prediction

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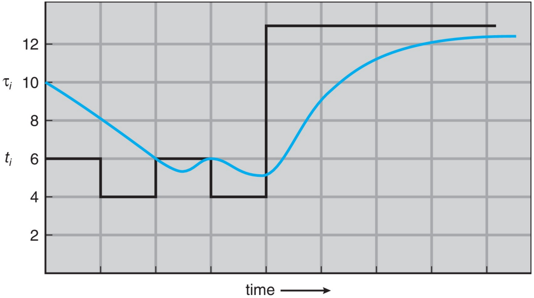
Example: exponential smoothing

Choose appropriate value $\alpha \in [0, 1]$ and define guess

$$\tau_{n+1} = \alpha t_n + (1 - \alpha)\tau_n$$

For typical choice of $\alpha = 1/2$ this simplifies to

$$\tau_{n+1} = \frac{1}{2} t_n + \frac{1}{4} t_{n-1} + \frac{1}{8} t_{n-2} + \cdots$$



CPU burst (t_i)		6	4	6	4	13	13	13	...
"guess" (τ_i)	10	8	6	6	5	9	11	12	...

Shortest-remaining-time (SRT)

SJF still suffers from convoy effect if large job arrives first and shorter jobs only arrive later

Solution: a preemptive version known as shortest-remaining-time (SRT)

- Schedule the process with shortest (remaining) burst time, preempting current process if shorter one arrives

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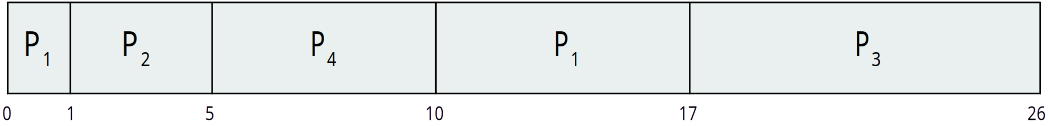
Solution: a preemptive version known as shortest-remaining-time (SRT)

- Schedule the process with shortest (remaining) burst time, preempting current process if shorter one arrives

Example

process	arrival time	burst time	waiting time
P1	0	8	9
P2	1	4	0
P3	2	9	15
P4	3	5	2
average			6.5



Round-robin (RR)

- Choose time quantum q (typically 10-100ms)
- Preempt a process if it has run for duration q. Afterwards, put process at end of queue
- Low values of q would lead to high overhead due to context-switches

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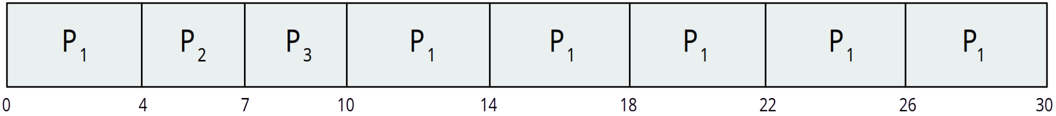
Example

$q = 4$

process	burst time
P1	24
P2	3
P3	3



Priority scheduling

- Each process has priority (integer number)
- Kernel schedules process with highest priority (smallest number), either preemptively or non-preemptively
- To avoid starvation, **aging** can be used where priority increases over time

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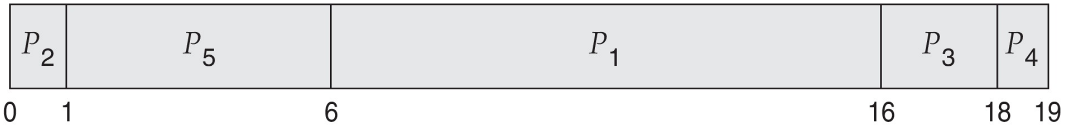
Example

process	burst time	priority
P1	24	3
P2	1	1
P3	2	4
P4	1	5
P5	5	2



Priority scheduling with round-robin

- Run process with highest priority
- If multiple processes have highest priority, perform round robin on them

Priority scheduling with round-robin

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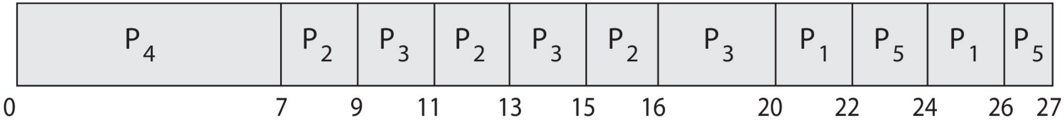
Example

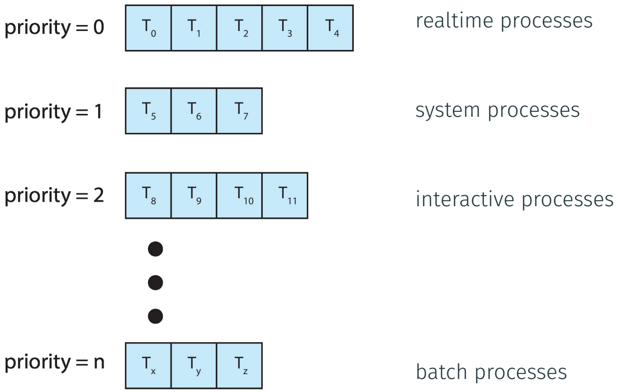
$q = 2$

process	burst time	priority
P1	4	3
P2	5	2
P3	8	2
P4	7	1
P4	3	3



Implementation of priority scheduling via multi-level queue

- To implement priority scheduling, use separate queue for each priority level
- Scheduler runs next task from first non-empty queue
- Scheduler can decide different algorithm (for example round-robin) for each queue



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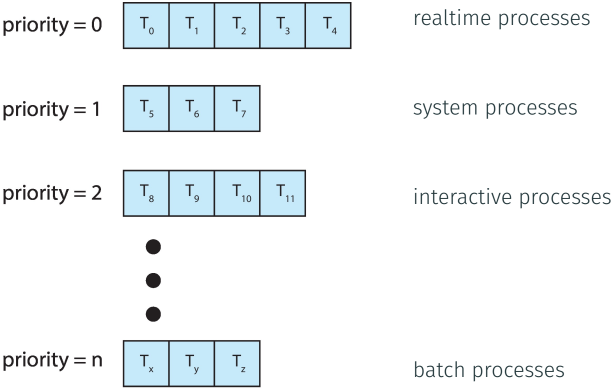


Multilevel feedback queue

- Extension where process can be moved between queues (**upgraded** or **demoted**)
- Can be used for example to implement aging

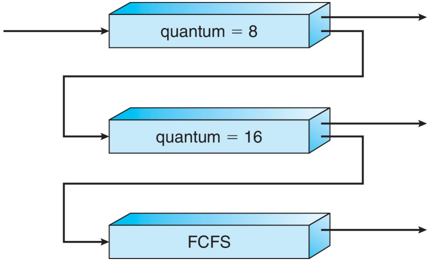
Example of multilevel feedback queue

Queues:

- Q_0: RR with $q = 8ms$
- Q_1: RR with $q = 16ms$
- Q_2: FCFS

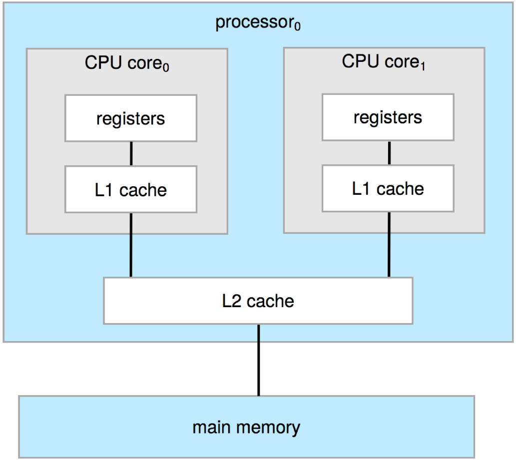
Scheduling:

- New processes go to Q_0
- If process running in Q_0 needs to be preempted (does not finish CPU burst in $8ms$), move process to Q_1
- If process running in Q_1 needs to be preempted (does not finish CPU burst in $16ms$), move process to Q_2



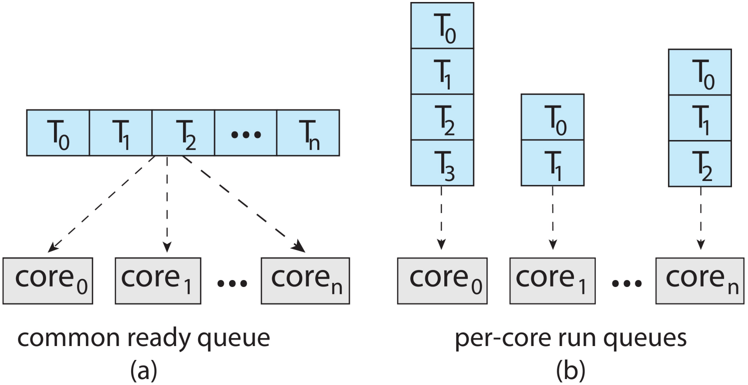
Multi-Core Scheduling

Setting


processor$_0$
CPU core$_0$
registers
L1 cache
CPU core$_1$
registers
L1 cache
L2 cache
main memory

Scheduling on multi-core systems

- Cores can share queues or have separate ones



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- If core has its own cache, we want to keep threads on same core. **Hard affinity**: Thread is guaranteed to run only on specific core. **Soft affinity**: Preference, but no guarantee

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- May need to balance loads. **Push migration**: core gives work to other cores if overloaded, **pull migration**: core takes work from other cores if underloaded

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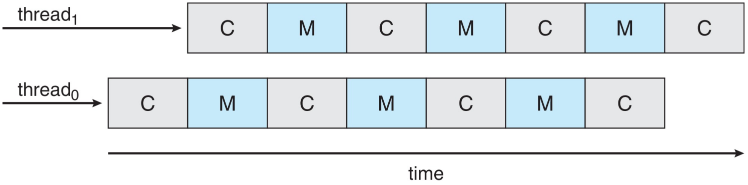
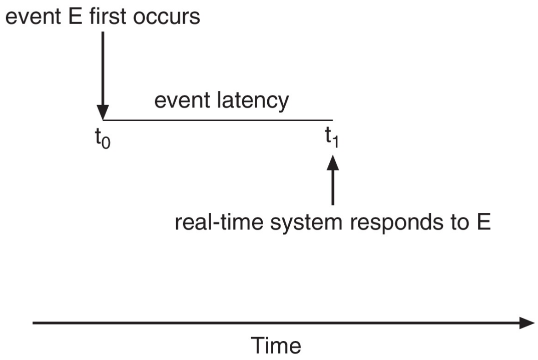
- May need to balance loads. **Push migration**: core gives work to other cores if overloaded, **pull migration**: core takes work from other cores if underloaded
- **Multi-threading/hyper-threading:** Some processors can run several threads (with their own register set, etc.) interleaved on one core, executes one thread while other is in **memory stall** (waiting for RAM access). To software, this looks like several cores



Real-time Scheduling

Setting

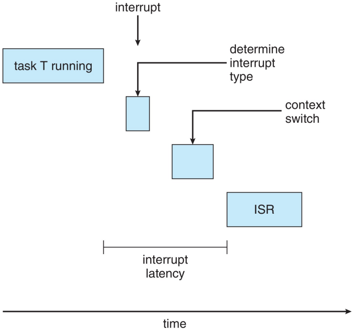
- **Soft real-time system:** missing deadlines is tolerated in extreme cases
- **Hard real-time system:** tasks guaranteed to meet their deadline (fixed bound on event latency)



Latency

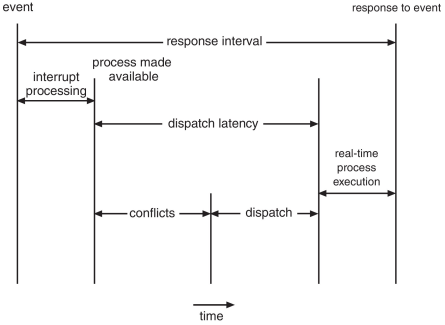
Interrupt latency

Time between interrupt appearing and interrupt handler (ISR) running



Dispatch latency

- Preempt ongoing task and schedule high priority process
- Release resources used by other processes if necessary

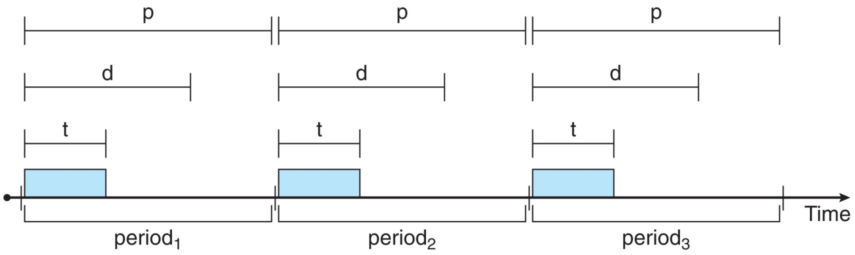


High priority for real-time task will only lead to low, predictable latency (**soft real-time**)

Periodic tasks

To design hard real-time systems, software must follow strict specification on their CPU usage: a process emits tasks **periodically**.

- period p: at which rate does the process emit tasks
- deadline d: how long after each task is emitted does it need to be completed
- processing time t: how long does each task need on CPU
- hard real-time guarantees can be proven, assuming low enough system load and all components follow specification



Evaluating Schedulers

Evaluation

- Can be via mathematical models (e.g. queueing theory), but often unrealistic
- More practical: **simulations** on data from traces of live system