04. Scheduling

9th ed: Ch. 6

10th ed: Ch. 5

Objectives

- To introduce CPU scheduling, the basis for multi-programmed operating systems, and the CPU I/O burst cycle
- To distinguish pre-emptive and non-preemptive scheduling
- To understand some different metrics used to make scheduling decisions
  - Utilisation, Throughput
  - Turnaround time, Waiting time, Response time

Outline

- Queues
- Scheduling
- Multiple processor scheduling

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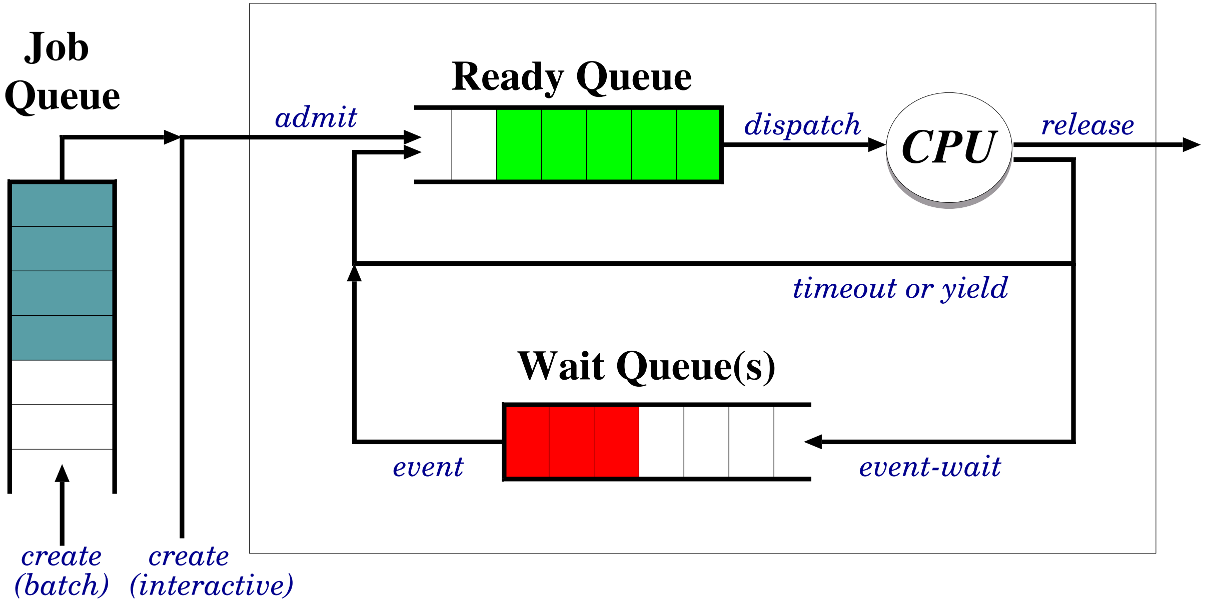
- Queues
  - CPU I/O burst cycle
  - CPU scheduler vs job scheduler
  - Idling
- Scheduling
- Multiple processor scheduling

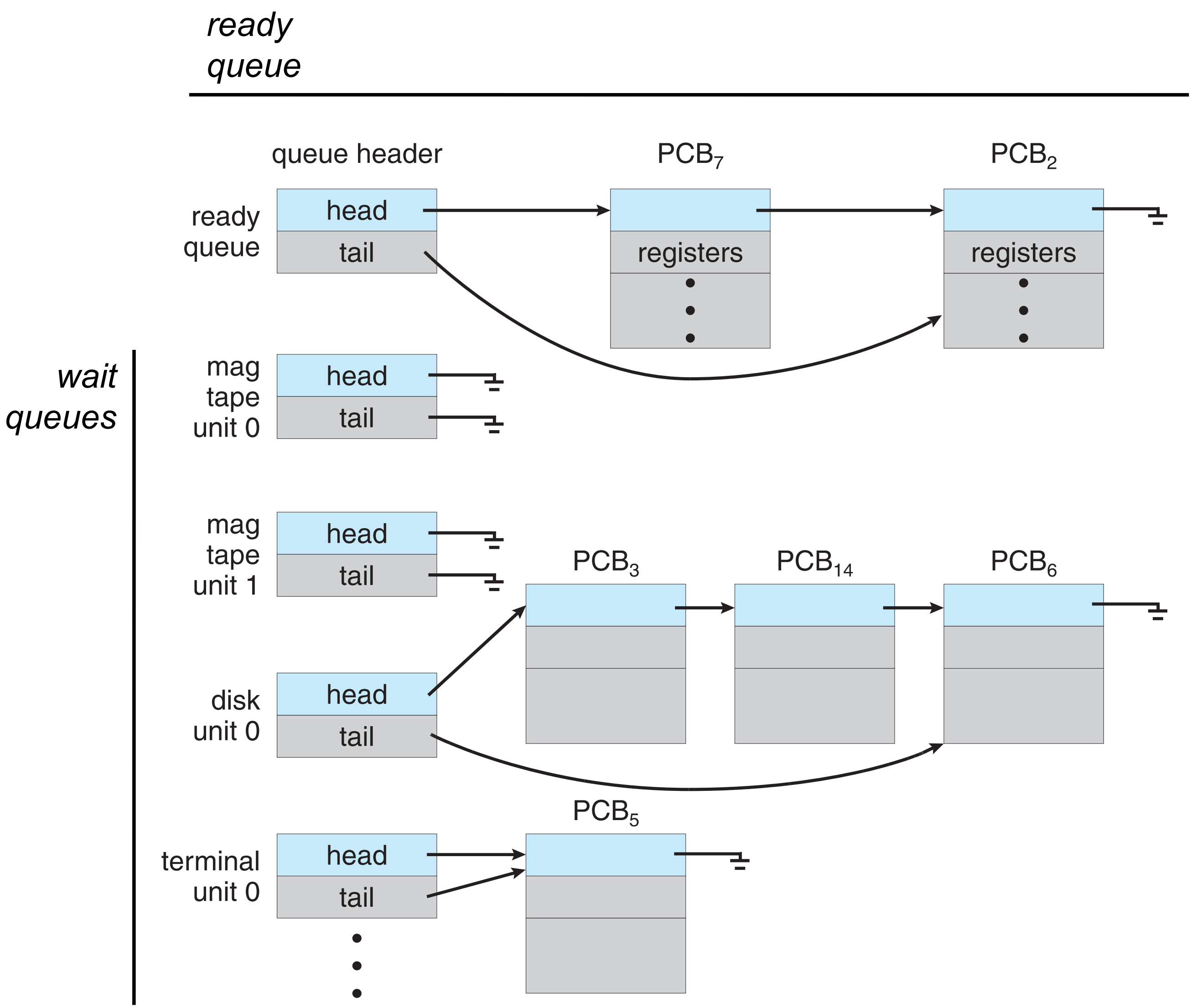
Queues

- **Job Queue**: batch processes awaiting admission
- **Ready Queue**: processes in main memory, ready and waiting to execute
- **Wait Queue(s)**: set of processes waiting for e.g., I/O devices or other processes

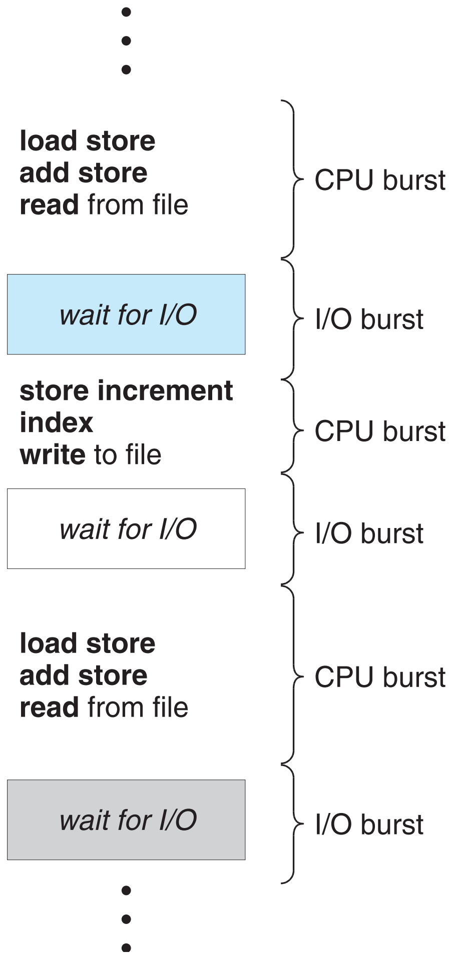


Queues

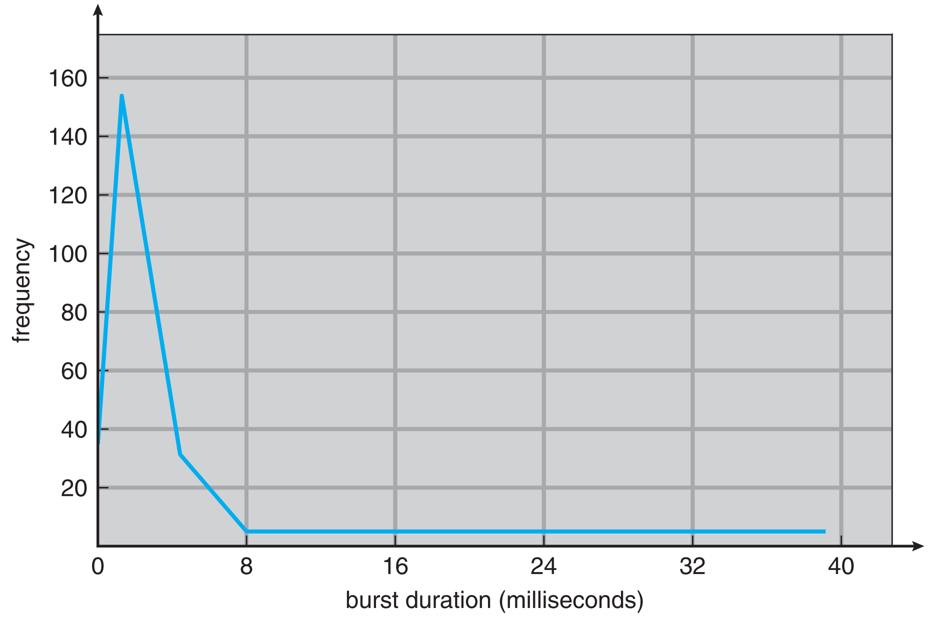
- For example,
    - Two processes (7, 2) in the Ready queue
    - No processes waiting for either magnetic tape unit
    - Three processes (3, 14, 6) waiting for the disk
    - One process (5) waiting for the terminal
- …etc



CPU I/O Burst Cycle



- Process execution interleaves CPU execution with waiting for I/O
- Maximising CPU utilization means **multiprogramming**
  - Need something to do while waiting for I/O
- CPU burst distribution helps parameterise scheduling
  - Often (*hyper-*)*exponential*
- **I/O-bound**
  - Many short CPU bursts
- **CPU-bound**
  - Fewer longer CPU bursts



Schedulers

- Short-term or **CPU scheduler**
  - Selects which process should be executed next and allocates it to the CPU
  - Sometimes the only scheduler in a system
  - Invoked frequently (milliseconds) so must be fast
- Long-term or **Job scheduler**
  - Controls the degree of multiprogramming
  - Selects which processes should be brought into the ready queue
  - Invoked infrequently (seconds, minutes) so may be slow
  - Strives for good process mix between CPU- and I/O-bound processes

Idling

- Will assume there's always something to do – but what if there isn't?
  - An important question on a modern (interactive) machine
- Three options:
  1. Busy wait in the scheduler: short-response times but ugly, inefficient
  2. Halt CPU until interrupted: saves energy but increases latency
  3. Invent an **idle process**:
     - nice uniform structure and could do some housekeeping
     - …but consumes resources and might slow interrupt response

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  - Dispatcher
  - Pre-emptive vs non-preemptive
  - Criteria
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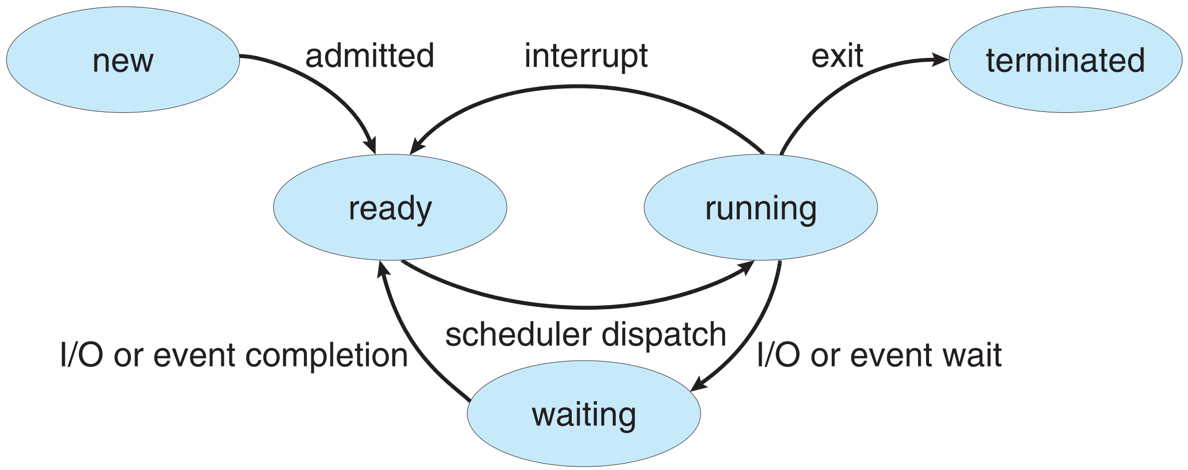
Dispatcher

- After scheduler, the **Dispatcher** gives control of the CPU to the selected process by
  - Switching context,
  - Switching to user mode,
  - Executing the user process from the selected location
- **Dispatch latency** is the time it takes to complete this stop/start procedure
- Two important questions:
  1. When to make a scheduling decision to select the next process?
  2. How to order the queue – which process to select next?

When to enter the scheduler?

- When can the scheduling decision be made? When
  1. ...a running process blocks (*running* → *waiting*)
  2. ...a running process terminates (*running* → *terminated*)
  3. ...a timer expires (*running* → *ready*)
  4. ...a waiting process unblocks (*waiting* → *ready*)

- If the scheduler is only invoked under 1 and 2, it is **non-preemptive**
  - Running process decides if/when to enter scheduler
- Otherwise, it is **pre-emptive**
  - OS can force scheduler entry



Pre-emptive vs Non-preemptive

- **Pre-emptive** scheduling
  - Hardware support for regular timer interrupts required to ensure scheduler entered
  - Precludes denial-of-service: the OS simply pre-empts a long-running process
  - More complex to implement: timer management, concurrency issues
- **Non-preemptive** scheduling
  - Typically uses an explicit *yield* system call or similar so running process can enter the scheduler, alongside implicit yields when, e.g., performing I/O
  - Simple to implement: no timers required, process holds CPU as long as desired
  - Open to denial-of-service: malicious or buggy process can refuse to yield
- Almost all modern schedulers are **pre-emptive**

Scheduling Criteria

- Typically there will be more than one process *runnable* – how to decide which one to pick?
- Many different metrics may be used, with different trade-offs and leading to different operating regimes
- Data structures introduce time and space overheads
  - …of measurement and computation for the metric
  - …of selecting the “best” next process

Scheduling Criteria

- **Turnaround time**, minimising the time for any process to complete
  - Aims to minimise total time from process submission to completion across all states
- **Waiting time**, minimising the time a process sits in the Ready queue
  - Scheduler only controls time in the Ready queue – rest is up to the process
  - But may penalise I/O heavy processes that spend a long time in the wait queue
- **Response time**, minimising the time to *start* responding
  - In interactive/time-sharing systems, users may prefer to total efficiency
  - But may penalise longer running sessions under heavy load

Scheduling Criteria

- **CPU utilisation**, maximising the time the CPU is actively in use
  - Aims to keep the (expensive) CPU as busy as possible
  - But may penalise I/O heavy processes as they appear to leave the CPU idle
- **Throughput**, maximising the rate at which processes complete execution
  - Aims to get useful work done at the highest possible rate
  - But may penalise long-running processes as short-run processes will be preferred
- Typically want to maximise utilisation and throughput, and minimise turnaround, waiting and response times
  - …but what exactly – optimise the average? Minimise the maximum?
  - What about the distribution, e.g., variance, confidence intervals?

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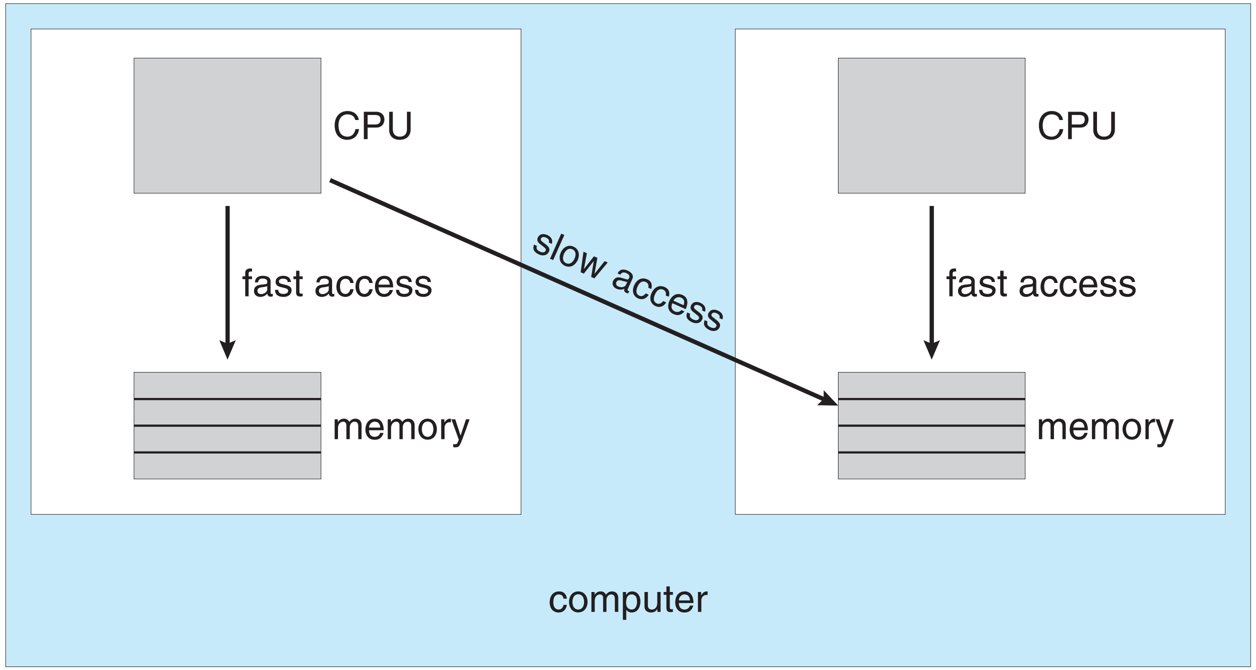
  - NUMA
  - Load balancing, multicore, virtualisation

Multiple processor scheduling

- Everything becomes more complex when multiple CPUs are available
  - Assume homogeneous processors within a multiprocessor
- Asymmetric multiprocessing
  - Only one processor accesses the system data structures
  - Alleviates the need for data sharing
- Symmetric multiprocessing (SMP) – currently the most common
  - Each processor is self-scheduling
  - All processes can be in a single ready queue, or each processor has its own private ready queue
- Processor affinity when a process has affinity for which processor it runs
  - Soft affinity indicates preference
  - Hard affinity indicates constraint
  - Variations including processor sets

Non-Uniform Memory Access (NUMA)

- Affects CPU scheduling as it means different CPUs have faster or slower access to parts of memory
  - E.g., because have combined CPU and memory boards
- Memory placement then affects affinity
- Costs of switching to a different CPU could be very much higher than without NUMA



Load balancing, multicore, virtualisation

- SMP means OS needs to keep all CPUs loaded for efficiency
- **Load balancing** attempts to keep workload evenly distributed
  - **Push migration** has a periodic task check load on each CPU and push tasks off overloaded CPUs onto other CPUs
  - **Pull migration** has idle CPUs pull waiting tasks off busy CPUs
- Recent trends include
  - **Multicore**, placing multiple CPU cores on same physical chip, increasing speed and efficiency
  - **Hyperthreading**, increasing the number of threads per core so that one thread can make progress while another is stalled on memory read
  - **Virtualisation** challenges OS scheduler as hypervisor and guests are all scheduling against each other

Summary

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  - CPU scheduler vs job scheduler
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  - Dispatcher
  - Pre-emptive vs non-preemptive
  - Criteria
- Multiple processor scheduling
  - NUMA
  - Load balancing, multicore, virtualisation