Scheduling I

Today

- Introduction to scheduling
- Classical algorithms

Next Time

- Advanced topics on scheduling

Scheduling out there

- You are the manager of a supermarket (ok, things don’t always turn out how we plan them!)

- It’s a busy time at 5-6PM and you have one register working; how do you optimize the queue to reduce waiting time?
  - You have a handful of customers waiting, each with about equally filled carts
  - A new guy, apparently planning to go on hiding, is now in front of the queue and a bunch of people with 2-3 items wait behind
  - An 8-month expectant mother has joined the back of the queue
  - …

Scheduling

- Problem
  - Several ready processes and much fewer CPUs
- A choice has to be made
  - By the *scheduler,* using a *scheduling algorithm*
- The decision, *scheduling*, is policy
- *Context switching* is a mechanism

Scheduling through time

- Early batch systems – Just run the next job in the tape
- Early timesharing systems – Scarce CPU time so scheduling is critical
- PCs – Commonly one active process so scheduling is easy; with fast & per-user CPU scheduling is not critical
- Networked workstations & servers – All back again, multiple ready processes & expensive CS, scheduling is critical

Environments and goals

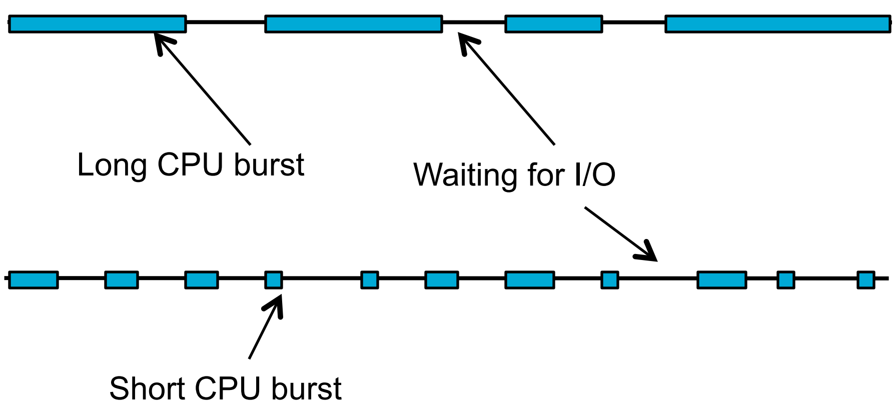
- Different scheduling algorithms, with different goals, for different application areas
  - Batch
  - Interactive
  - Real-time
- Goals for all/most systems
  - Fairness – comparable processes getting comparable service
  - Policy enforcement – seeing that stated policy is carried out
  - Balance – keeping all parts of the system busy (mix pool of processes)

Environments and goals

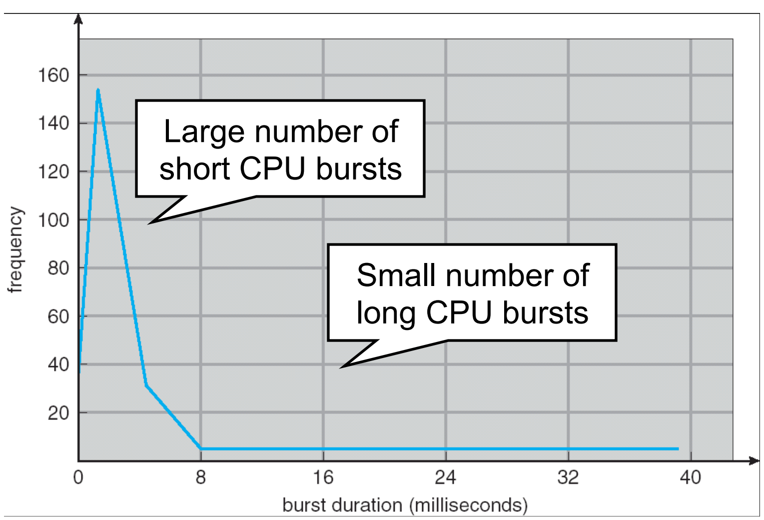
- Batch systems
  - CPU utilization – keep CPU busy all the time *(anything wrong?)*
  - Throughput – max. jobs per hour
  - Turnaround time – min. time bet/ submission & termination
- Interactive systems
  - Response time – respond to requests quickly (time to start responding)
  - Proportionality – meet users' expectations
- Real-time system
  - Meeting deadlines – avoid losing data
  - Predictability – avoid quality degradation in multimedia systems
- Average, maximum, minimum or *variance*?

Process behavior

- Task – a request to be scheduled (a process may be responsible for multiple tasks)
- Workload – a set of tasks for some systems to perform, the input to the scheduling algorithm
- Bursts of CPU usage alternate with periods of I/O wait
  - Key to scheduling – CPU-bound & I/O bound process
  - As CPU gets faster – more I/O bound processes

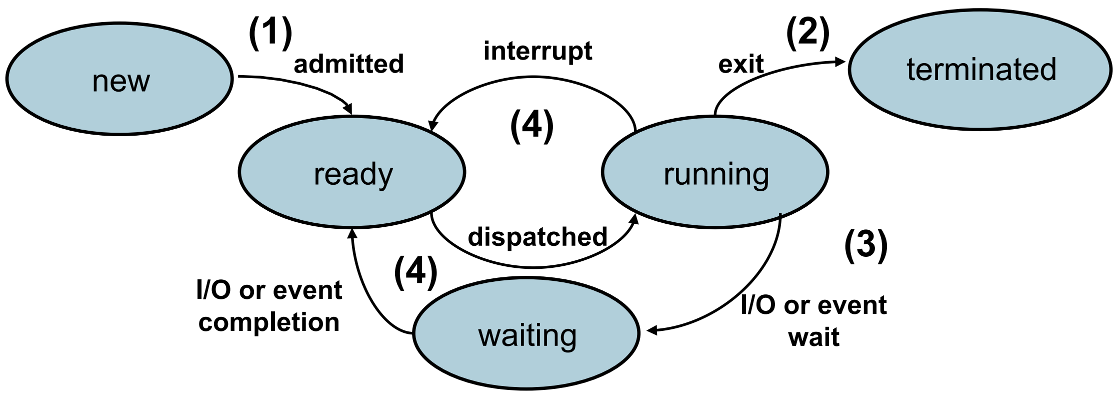


Histogram of CPU-burst times



When to schedule?

- When to make scheduling decisions?
  1. At process creation
  2. When a process exits
  3. When a process blocks on I/O, a semaphore, etc
  4. When an I/O interrupts occurs
  5. A fix periods of time – Need a HW clock interrupting



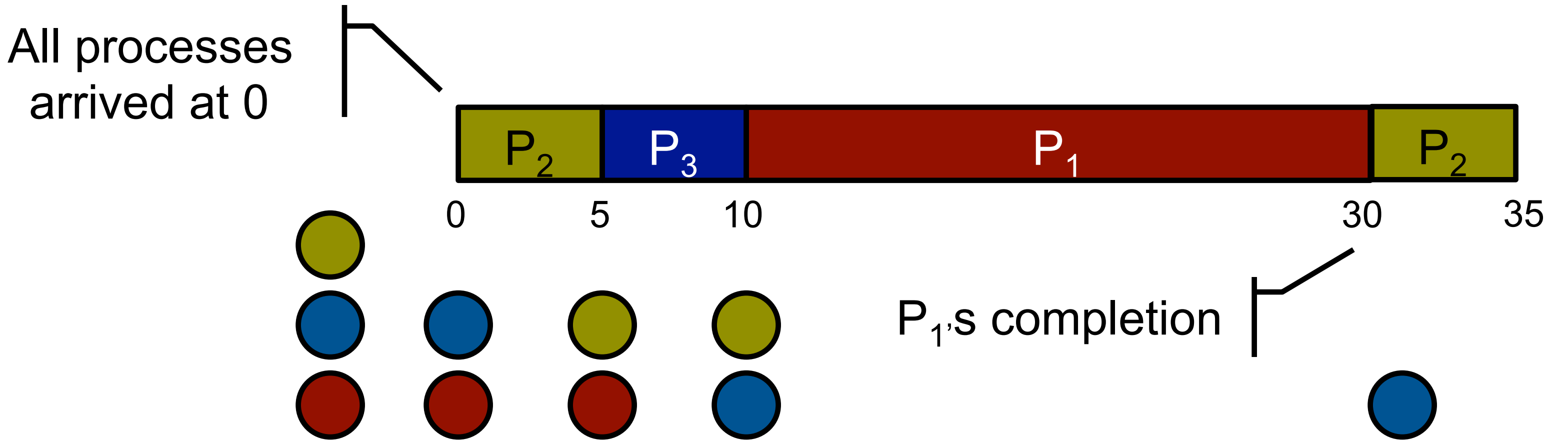
When to schedule?

- A fixed periods of times … preemptive and non-preemptive
  - No-preemptive
    - Once a process gets the CPU, it doesn’t release it until the process terminates or switches to waiting
  - Preemptive
    - Using a timer, the OS can preempt the CPU even it the thread doesn’t relinquish it voluntarily
    - Of course, re-assignment involves overhead

And now some example policies

- Remember these are *example policies* – in practice, any real system uses some hybrid approach
- We will start comparing them based on turnaround time

$$T_{turnaround} = T_{completion} - T_{arrival}$$



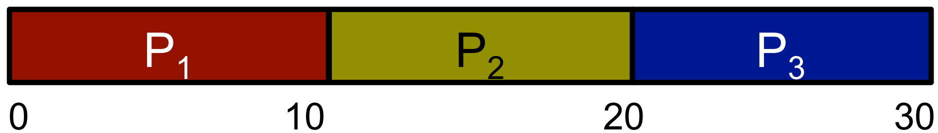
$P_{1\ turnaround} = 30 - 0 = 30u$

And now some example policies

- Other possible metrics (sometimes in conflict)
  - Maximize *CPU utilization*
  - Maximize *throughput* (requests completed / sec)
  - Minimize *average response time* (avg. time from submission of request to first response)
  - Minimize *energy* (joules per instruction) subject to some constraint (e.g., frames/sec)

First-Come First-Served scheduling

- First-Come First-Served (FCFS)
  - Simplest, easy to implement, non-preemptive



Turnaround time:
(10 + 20 + 30)/3 = 20

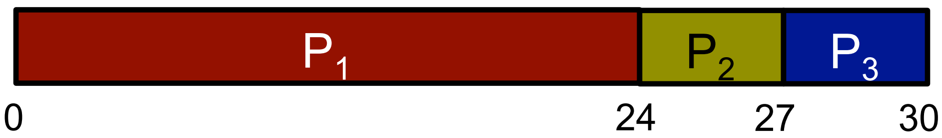
Different burst times

Process	Burst Time
P1	24
P2	3
P3	3

Turnaround time:
(30 + 3 + 6)/3 =13

FCFS Issues

Process	Burst Time
P1	24
P2	3
P3	3



Turnaround time:
(24 + 27 + 30)/3 =27

- The convoy effect
  - 1 CPU-bound process (burst of 1 sec.)
  - Many I/O-bound ones (needing to read 1000 records)
  - Each I/O-bound process reads one block per sec!
- Potentially bad average response time
- May lead to poor utilization of resources
  - Poor overlap of CPU and I/O

Shortest Job First

- Taken from Operation Research

Process	Burst Time
P1	24
P2	3
P3	3

Turnaround time:
(30 + 3 +6)/3 =13

- Provably optimal wrt average response time

First job finishes at time a; second job at time a + b; …

Mean turnaround time
(4a + 3 b + 2c + d)/4

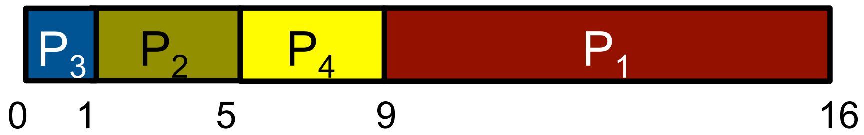
Biggest contributor

Job #	Finish time
1	a
2	b
3	c
4	d

And now a short break …

Shortest Job First

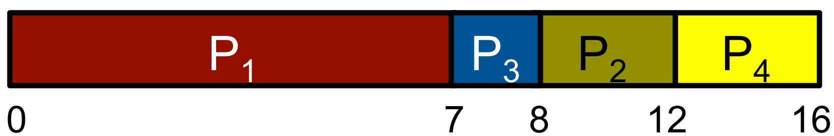
- Another example



Turnaround time: (16 + 5 + 1+ 9)/4 =7.75

Process	Burst Time
P1	7
P2	4
P3	1
P4	4

- *What if they don't all arrive at the same time?*



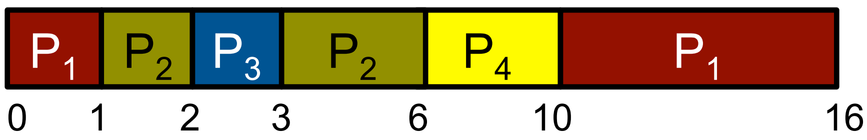
Process	Arrival	Burst Time
P1	0.0	7
P2	1.0	4
P3	2.0	1
P4	3.0	4

Turnaround time: (7 + 11 + 6 + 13)/4 = 9.25

**Note P2 run at 12 but arrived at 1, so it only waited 11; similar with P3 and P4.*

Shortest Remaining Time First

- A preemptive variation



Turnaround time: (16 + 5 + 1 + 7)/4 = 7.25

Process	Arrival	Burst Time
P1	0.0	7
P2	1.0	4
P3	2.0	1
P4	3.0	4

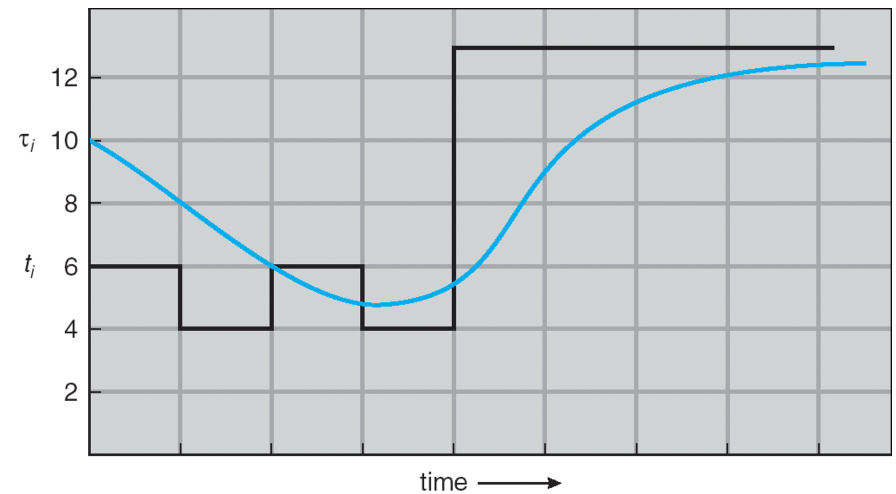
- *Great, but how do you know the burst time?*

Determining length of next CPU burst

- Can only *estimate* length
- Typically done using length of previous CPU bursts and exponential averaging

- t_n = actual lenght of n^{th} CPU burst
- τ_{n+1} = predicted value for the next CPU burst
- $\alpha, 0 \le \alpha \le 1$
- Define:

$$\tau_{n=1} = \underbrace{\alpha\, t_n}_{\text{Most recent information}} + \overbrace{(1-\alpha)}^{\text{Weight of history}} \underbrace{\tau_n}_{\text{Past history}}.$$

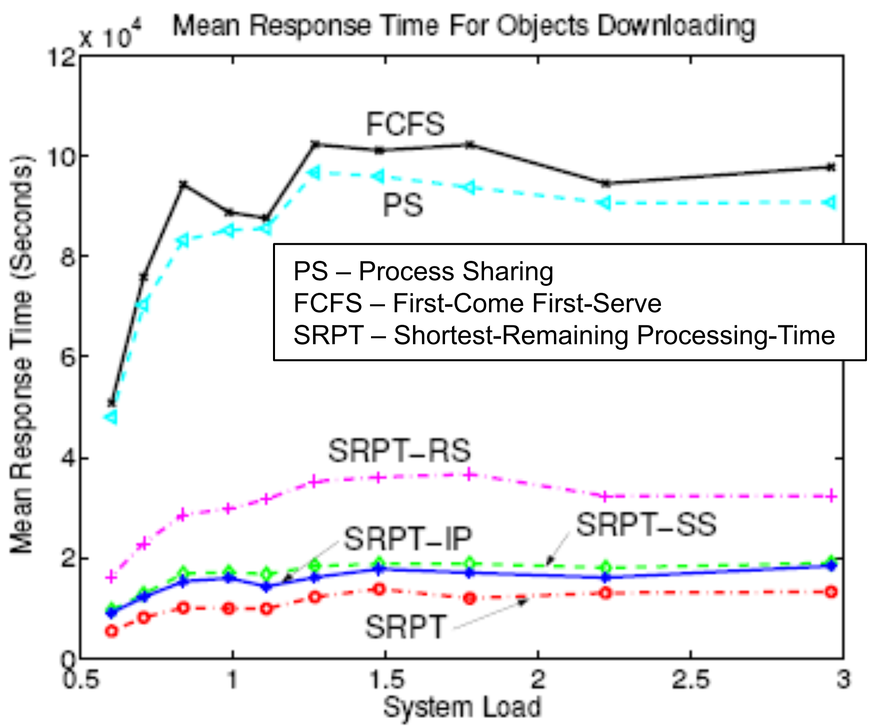


CPU burst (t_i)	6	4	6	4	13	13	13	…
"guess" (τ_i)	10	8	6	6	5	9	11	12 …

$$\tau_1 = 0.5\ t_0 + (1-0.5)\tau_0 = 8$$

Scheduling the server-side of P2P systems

- P2P users' response is dominated by download
  - >80% download requests in Kazaa are rejected due to capacity saturation at server peers
  - >50% of all requests for large objects (>100MB) take more than one day & ~20% take over one week to complete
- Most implementations use FCFS or PS
- *Apply SRPT!* Work from Northwestern



Mean response time of object download as a function of system load.

Priority scheduling

- SJF is a special case of priority-based scheduling
  - Priority = reverse of predicted next CPU burst
- Pick process with highest priority (lowest number)

Process	Burst time	Priority
P1	10	3
P2	1	1
P3	2	4
P4	1	5
P5	5	2

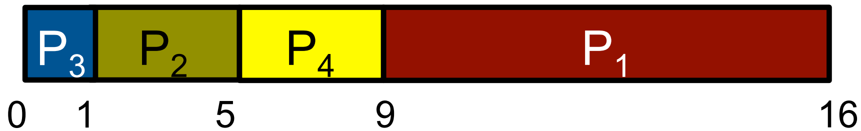
Turnaround time = (16 + 1 + 18 + 19 + 6)/5 = 12

Priority scheduling issues

- How do you assign priorities?
- Starvation
  – With an endless supply of high priority jobs, low priority processes may never execute
  – *What other recently discussed algorithm has the same problem?*
- Solution
  – Increases priority with age, i.e. accumulated waiting
  – Decrease priority as a function of accumulated processing time
  – Assigned maximum quantum

Round-robin scheduling

- SJF is not bad if you know burst times or can estimate it fairly well – the case in many early batch systems
  - At least when measuring turnaround time!
- Time-sharing machines changed it all
  - Users want interactivity
  - Turnaround time is not a good metric for this
  - *Response time?* Time to first run minus time of arrival



Turnaround time: (16 + 5 + 1+ 9)/4 =7.75

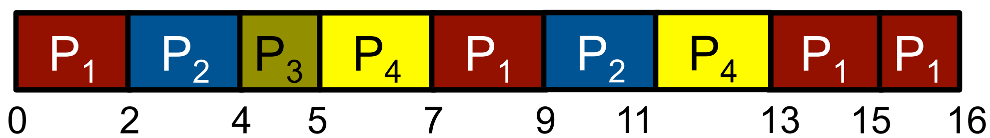
Response time: (9 + 1 + 0 + 5)/4 = 3.75

Process	Burst Time
P1	7
P2	4
P3	1
P4	4

Round-robin scheduling

- Simple, fair, easy to implement, & widely-used
- Each process gets a fix *quantum* or *time slice*
- When quantum expires, if running preempt CPU
- With n processes & quantum q, each one gets $1/n$ of the CPU time, no-one waits more than $(n-1)\,q$ to run first (i.e., response time)

$q = 2$



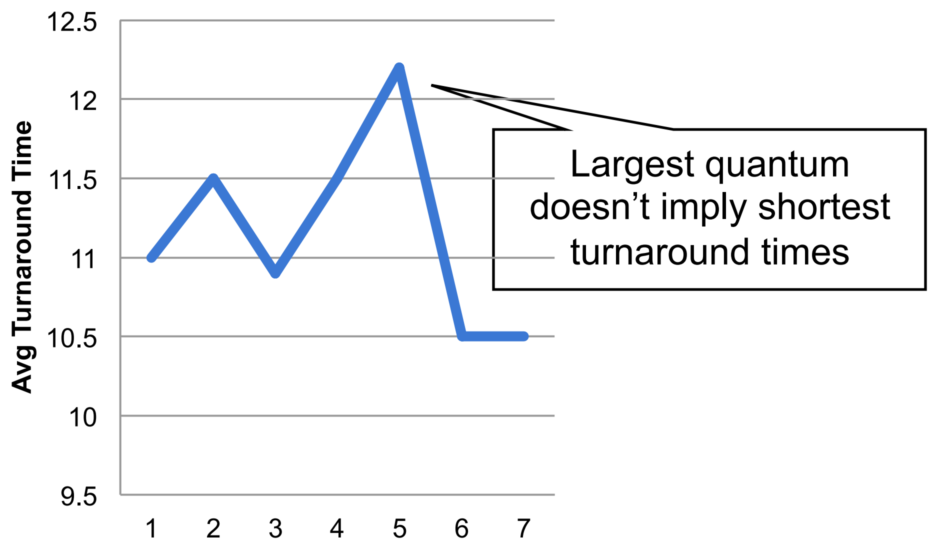
Process	Burst Time
P1	7
P2	4
P3	1
P4	4

Response time: (0 + 2 + 4 + 5)/4 = 2.75

Turnaround time: (16 + 11 + 5 + 13)/4 = 11.25

Quantum & Turnaround time

- Length of quantum
  - Too short – low CPU efficiency (*why?)*
  - Too long – low response time
    (*really long, what do you get?)*
  - Commonly ~ 50-100 msec.



Process	Time
P_1	6
P_2	3
P_3	1
P_4	7

Next time

- How do you support responsive, flexible scheduling? Priority? How are priorities set?
- How do you optimize turnaround time while minimizing response time?
  - Shortest Job First reduces turnaround time but hurts response time
  - Round Robin reduces response time but hurts average waiting time
  - *…?*