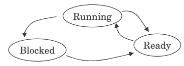
# Scheduling



## Issue

- When a computer is multiprogrammed it frequently has multiple processes competing for the CPU at the same time




- A choice has to be made which process to run next



- the part of the operating system that makes this decision is called the **scheduler**
- the algorithm it uses is called the **scheduling algorithm**
- scheduling may involve both processes and threads

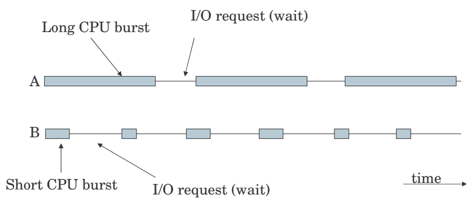


## Other issues

- depending on the application different scheduling strategies can make a difference
  example:
  simple PC
  networked server
- process switching is expensive
  user mode → kernel mode
  save the state of current process
  run the scheduler
  load MMU
  run new program
  → the cache is now spoiled



## Process behavior




**A** spends most of his time computing, it is called **compute-bound**
**B** spends most of his time waiting for I/O, it is called **I/O-bound**



## When to schedule

- a new process is created
  - select the new one or keep the current one running
- a process terminates
  - select and run another process, if any
- a process blocks (semaphore, I/O)
  - dependencies btw processes may improve scheduling
- I/O interrupt
  - run a waiting process
- hardware clock
  - run the scheduler each clock interrupt or every k-th clock interrupt

## Scheduling can be divided:

- **non preemptive**
  - picks a process to run
  - lets it run until it blocks, terminates or voluntary releases the CPU
  - after clock interrupt, resume the process that was running before
- **preemptive**
  - picks a process to run
  - after a maximum amount of some fixed time suspends it (if still running)
  - picks another process to run (if any available)
  - requires clock



## Scheduling: common goals

- fairness
  - comparable processes should get comparable service (CPU time)
- policy enforcement
  - different categories of processes may be treated differently
- balance
  - try to keep all the part of the system busy when possible



## Scheduling: specific goals

- batch systems
  - throughput: # of processes completed per unit of time (hour)
  - turnaround time: average time to completion
  - CPU utilization
- interactive systems
  - response time (clear)
  - proportionality (with the difficulty of the task)
- real-time systems
  - meeting deadlines
  - predictability



## Scheduling in Batch Systems (1)

- First-Come First-Served

  nonpreemptive
  the CPU is assigned in the order processes require it
  when the running process blocks the following one in the queue is selected
  when a blocked process becomes ready it is put on the end of the queue
  simple (a single queue), fair
  not optimal
- Shortest Job First

  nonpreemptive
  suppose we know the run-time in advance
  the CPU is assigned to the shortest job in the queue
  optimal if all the jobs are available at the same time



## Example (1)

| 8 | 4 | 4 | 4 |
|---|---|---|---|
| A | B | C | D |

turnaround:
A = 8
B = 12
C = 16
D = 20
average= 16

| 4 | 4 | 4 | 8 |
|---|---|---|---|
| B | C | D | A |

turnaround:
B = 4
C = 8
D = 12
A = 20
average= 11

suppose a,b,c,d
ta = a
tb = a+b
tc = a+b+c
td = a+b+c+d

average = ¼(4a+3b+2c+d) → shortest time first is optimal



## Scheduling in Batch Systems (2)

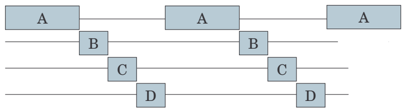
- Shortest Remaining Time Next

  <u>preemptive</u> (it is a preemptive version of the SJF)
  the scheduler here chooses the process whose remaining run-time is the shortest
  the time has to be known in advance
  new short jobs get good service

# Example (2)
compare with a preemptive algorithm

A, runs for 1s and blocks for I/O

B, C, D blocks after short time, they need to perform 1000 disk reads

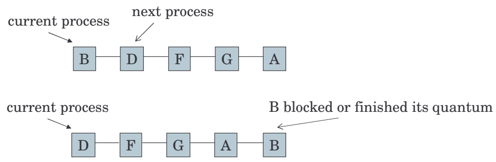



B, C, D, take at least 1000s to complete



# Scheduling in Interactive Systems (1)

- Round Robin
  each process is assigned a time interval, called **quantum**
  if the process is still running at the end of its quantum, the CPU is **preempted** and given to another process





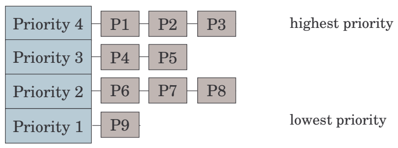

# Scheduling in Interactive Systems (2)

- Issues with Round Robin
  length of the quantum
  too short → context switch overhead
  too long → poor response to short interactive requests
  usually a reasonable value is 20-50 ms
- Priority Scheduling
  each process is assigned a priority
  priorities can be assigned:
  - statically
  - dynamically: e.g. assign more CPU to I/O bound processes

  divide processes in classes depending on priority
  use priority scheduling within classes
  round robin within classes



# Example, 4 priority classes






# Example: dynamic priority

assign priority depending on the fraction of quantum each process has used

$$P = \frac{1}{f}$$

example: time slice 50ms

process A uses 1ms, f=1/50, priority = 50

process B uses 50 ms, f=50/50, priority = 1



# Scheduling in Interactive Systems (3)

- Shortest Process Next
  shortest job produces the minimum average response time for batch systems
  the problem here is figuring which of the runnable processes is the shortest one
  solution: use estimates based on past behavior

  $T_i$ measured run-time at time i

  $\hat{T}_i$ estimate run-time at time i

  $\hat{T}_n = a\hat{T}_{n-1} + (1-a)T_n$

  Example: $a = 0.5$

  $T_0, \frac{T_0}{2}+\frac{T_1}{2}, \frac{T_0}{4}+\frac{T_1}{4}+\frac{T_2}{2}, \frac{T_0}{8}+\frac{T_1}{8}+\frac{T_2}{4}+\frac{T_3}{2}$

# Scheduling in Interactive Systems (4)

- Guaranteed Scheduling
  make promises about performance to the users/processes
  compute the real amount of CPU a user/process has consumed
  increase priority accordingly
  difficult to implement
- Lottery Scheduling
  basic idea: give processes lottery tickets for various system resources (CPU time)
  whenever a scheduling decision is required a lottery ticket is randomly chosen
  similar to priority scheduling, but:
  - the rule is clearer
  - interesting properties: tickets can be exchanged (a process/user can own/trade tickets)



# Scheduling in Interactive Systems (4)

- Fair-Share Scheduling

Example:
User A has 9 processes, User B has 1 process
A and B have same priority, Round Robin:
B1, A1, A2, A3, A4, … A9, B1, A1, A2, …, A9
A gets 90% if the CPU, B gets 10%

Possible solution: take into account who owns a process before scheduling it:
B1, A1, B1, A2, B1, A3, B1, A4…, B1, A9



# Policy versus Mechanism

- Often a process has many children running under its control performing different tasks. In this case only the process itself knows which one is the most important or time critical
- For this reason it is important to separate **scheduling mechanism** from the **scheduling policy**
- The scheduling mechanism (algorithm) defines the parameters used by the scheduler
- The user process is responsible for filling in those parameters for its children (policy)



# Scheduling in Real Time Systems

In **real time** systems time plays a crucial role. Usually the system is connected to one or more external devices which generate stimuli and the OS has to react appropriately to them within a fixed amount of time.

Examples: aircraft control, over-temperature monitor in nuclear power station, ABS, biomedical systems, robotics

- **hard-real time**, missing a deadline has catastrophic effects
- **soft-real time**, missing a deadline is undesirable but tolerable

Stimuli (events) may be:

- **periodic** (occurring at regular intervals)
- **aperiodic** (unpredictable)



# Schedulability

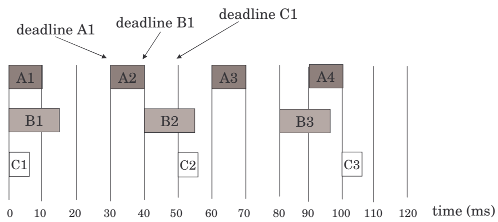
- Depending on the situation, it may happen that not all the events can be handled
- Consider *m* periodic events
  event *i* occurs with period *Pi* and requires *Ci* second of CPU time
  the system is **schedulable** if:

$$\sum_{i=1}^{m} \frac{C_i}{P_i} \leq 1$$



# Let's consider the following situation:

Multimedia system: three processes A, B, C
A is periodic, T = 30ms, and uses 10 ms of CPU time
B is periodic, f = 25 Hz (T=40ms) and uses 15 ms of CPU time
C is periodic, f = 20 Hz, (T=50ms) and uses 5 ms of CPU time
Schedulability ? 10/30 + 15/40 + 5/50 = 0.808 < 1

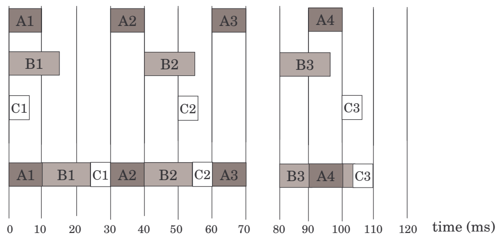


## Rate Monotonic Scheduling (RMS)

- Assumptions:
  - each periodic process must complete within its period
  - no process is dependent on any other process
  - each process needs the same amount of CPU time on each burst
  - any non periodic processes have no deadlines
  - preemption has no overhead
- Assign each process a fixed (static) priority equal to the frequency of occurrence of its triggering event
(priorities are linear with the rate)



## Example: Rate Monotonic



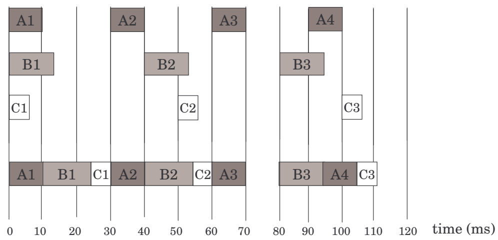



## Earliest Deadline First Scheduling (EDF)

- Assumptions:
  - the same as rate monotonic but
  - it doesn't require processes to be periodic
  - processes can use different amounts of CPU for different bursts
- runnable processes are kept in a list with their deadline
- the scheduler runs the process with the closest deadline
- preempts the current process if another one with a closer deadline is ready



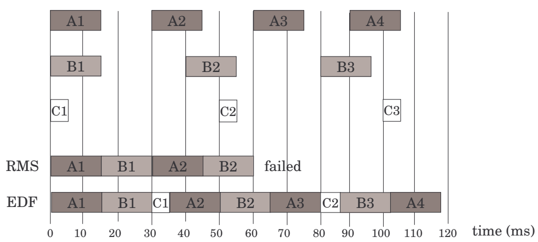
## Example: Earliest Deadline First






## RMS versus EDF

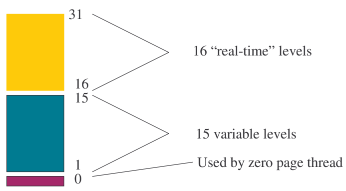
RMS uses static priorities and fails if CPU utilization is too high.
EDF always works if CPU utilization is < 100%
now A takes 15 ms of CPU time to complete
Schedulability ? 15/30 + 15/40 + 5/50 = 0.975 < 1






## Case study: scheduling in win32

- Only threads are scheduled, not processes
- Time-sliced, round robin with priorities
- Threads have priorities 0 through 31



## How are priorities assigned ?

**Win32 Process Classes**

**Win32 Thread Priorities**

| | Real Time | High | Above Normal | Normal | Below Normal | Idle |
|---|---|---|---|---|---|---|
| Time-critical | 31 | 15 | 15 | 15 | 15 | 15 |
| Highest | 26 | 15 | 12 | 10 | 8 | 6 |
| Above-normal | 25 | 14 | 11 | 9 | 7 | 5 |
| Normal | 24 | 13 | 10 | 8 | 6 | 4 |
| Below-Normal | 23 | 12 | 9 | 7 | 5 | 3 |
| Lowest | 22 | 11 | 8 | 6 | 4 | 2 |
| Idle | 16 | 1 | 1 | 1 | 1 | 1 |



## Priority Boost

- dynamic boost (< 15)
  - foreground threads get doubled time slice
  - if resumed by keyboard/mouse + 6
  - if resumed on wait +1
- decay: after boost priority is reduced of one level until it reaches base priority (the priority before boost)



## CPU Starvation

- Balance Set Manager (priority 16, every second)
  - looks for “starved thread” that have been ready for more than 4 seconds
- Special boost:
  - set priority to 15
  - doubled quantum
- Apply only to non real-time threads