Scheduling

What is Scheduling?
– On a multi-programmed system
  • We may have more than one Ready process
– On a batch system
  • We may have many jobs waiting to be run
– On a multi-user system
  • We may have many users concurrently using the system
  • The scheduler decides who to run next.
  – The process of choosing is called scheduling.

Is scheduling important?
• It is not in certain scenarios
  – If you have no choice
    • Early systems
      – Usually batching
      – Scheduling algorithm simple
        > Run next on tape or next on punch tape
    – Only one thing to run
      • Simple PCs
        – Only ran a word processor, etc....
      • Simple Embedded Systems
        – TV remote control, washing machine, etc....

Is scheduling important?
• It is in most realistic scenarios
  – Multitasking/Multi-user System
    • Example
      – Email daemon takes 2 seconds to process an email
      – User clicks button on application.
      • Scenario 1
        – Run daemon, then application
        > System appears really sluggish to the user
      • Scenario 2
        – Run application, then daemon
        > Application appears really responsive, small email delay is unnoticed
  • Scheduling decisions can have a dramatic effect on the perceived performance of the system
  – Can also affect correctness of a system with deadlines

Application Behaviour
• Bursts of CPU usage alternate with periods of I/O wait

Application Behaviour
a) CPU-Bound process
  • Spends most of its computing
  • Time to completion largely determined by received CPU time
Application Behaviour

b) I/O-Bound process
- Spend most of its time waiting for I/O to complete
- Small bursts of CPU to process I/O and request next I/O
- Time to completion largely determined by I/O request time

Observations

- Generally, technology is increasing CPU speed much faster than I/O speed
  ⇒ CPU bursts becoming shorter, I/O waiting is relatively constant
  ⇒ Processes are becoming more I/O bound

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Observations

- We need a mix of CPU-bound and I/O-bound processes to keep both CPU and I/O systems busy
- Process can go from CPU-to I/O-bound (or vice versa) in different phases of execution

When is scheduling performed?
- A new process
  - Run the parent or the child?
- A process exits
  - Who runs next?
  - A process waits for I/O
    - Who runs next?
  - A process blocks on a lock
    - Who runs next? The lock holder?
- An I/O interrupt occurs
  - Who do we resume, the interrupted process or the process that was waiting?
  - On a timer interrupt? (See next slide)
- Generally, a scheduling decision is required when a process (or thread) can no longer continue, or when an activity results in more than one ready process.

Preemptive versus Non-preemptive Scheduling

- Non-preemptive
  - Once a thread is in the running state, it continues until it completes, blocks on I/O, or voluntarily yields the CPU
  - A single process can monopolised the entire system
- Preemptive Scheduling
  - Current thread can be interrupted by OS and moved to ready state.
  - Usually after a timer interrupt and process has exceeded its maximum run time
  - Can also be as a result of higher priority process that has become ready (after I/O interrupt).
  - Ensures fairer service as single thread can’t monopolise the system
  - Requires a timer interrupt
Categories of Scheduling Algorithms
• The choice of scheduling algorithm depends on the goals of the application (or the operating system)
  – No one algorithm suits all environments
• We can roughly categorise scheduling algorithms as follows
  – Batch Systems
    • No users directly waiting, can optimise for overall machine performance
  – Interactive Systems
    • Users directly waiting for their results, can optimise for users perceived performance
  – Realtime Systems
    • Jobs have deadlines, must schedule such that all jobs (mostly) meet their deadlines.

Goals of Scheduling Algorithms
• All Algorithms
  – Fairness
    • Give each process a fair share of the CPU
  – Policy Enforcement
    • What ever policy chosen, the scheduler should ensure it is carried out
  – Balance/Efficiency
    • Try to keep all parts of the system busy

Goals of Scheduling Algorithms
• Interactive Algorithms
  – Minimise response time
    • Response time is the time difference between issuing a command and getting the result
      – E.g selecting a menu, and getting the result of that selection
    • Response time is important to the user’s perception of the performance of the system.
  – Provide Proportionality
    • Proportionality is the user expectation that short jobs will have a short response time, and long jobs can have a long response time.
    • Generally, favour short jobs

Goals of Scheduling Algorithms
• Real-time Algorithms
  – Must meet deadlines
    • Each job/task has a deadline.
      • A missed deadline can result in data loss or catastrophic failure
        – Aircraft control system missed deadline to apply brakes
    – Provide Predictability
      • For some apps, an occasional missed deadline is okay
        – E.g. DVD decoder
      • Predictable behaviour allows smooth DVD decoding with only rare skips

Interactive Scheduling

Round Robin Scheduling
• Each process is given a timeslice to run in
  • When the timeslice expires, the next process preempts the current process, and runs for its timeslice, and so on
    – The preemption process is placed at the end of the queue
• Implemented with
  – A ready queue
  – A regular timer interrupt
5 Process
- Process 1 arrives slightly before process 2, etc...
- All are immediately runnable
- Execution times indicated by scale on x-axis

Round Robin Schedule

Round Robin
- Pros
  - Fair, easy to implement
- Cons
  - Assumes everybody is equal
- Issue: What should the timeslice be?
  - Too short
    - Waste a lot of time switching between processes
    - Example: timeslice of 4ms with 1ms context switch = 20% round robin overhead
  - Too long
    - System is not responsive
    - Example: timeslice of 100ms
      - If 10 people hit “enter” key simultaneously, the last guy to run will only see progress after 1 second.
    - Degenerates into FCFS if timeslice longer than burst length

Priorities
- Each Process (or thread) is associated with a priority
- Provides basic mechanism to influence a scheduler decision:
  - Scheduler will always choose a thread of higher priority over lower priority
- Priorities can be defined internally or externally
  - Internal: e.g. I/O bound or CPU bound
  - External: e.g. based on importance to the user

Example
- 5 Jobs
  - Job number equals priority
  - Priority 1 > priority 5
  - Release and execution times as shown
- Priority-driven preemptively scheduled
Priorities

- Usually implemented by multiple priority queues, with round robin on each queue
- Con
  - Low priorities can starve
  - Need to adapt priorities periodically
    - Based on ageing or execution history

Traditional UNIX Scheduler

- The highest priority (lower number) is scheduled
- Priorities are re-calculated once per second, and re-inserted in appropriate queue
  - Avoid starvation of low priority threads
  - Penalise CPU-bound threads

Example

Traditional UNIX Scheduler

- Two-level scheduler
  - High-level scheduler schedules processes between memory and disk
  - Low-level scheduler is CPU scheduler
    - Based on a multi-level queue structure with round robin at each level
Traditional UNIX Scheduler

- Priority = CPU_usage + Nice + base
- CPU_usage = number of clock ticks
- Nice is a value given to the process by a user to permanently boost or reduce its priority
- Base is a set of hardwired, negative values used to boost priority of I/O bound system activities
- Swap, disk I/O, Character I/O

Real-time Scheduling

- that guarantees all requested timely behaviour

- RTS accepts an activity that can be enforced by the RTS.

- CPU_usage = number of clock ticks

Real Time Scheduling

- Correctness of the system may depend not only on the logical result of the computation but also on the time when these results are produced.

- Tasks attempt to control events or to react to events that take place in the outside world
- These external events occur in real time and processing must be able to keep up
- Processing must happen in a timely fashion, neither too late, nor too early

Typical Real Time Systems

- Control of laboratory experiments
- Robotics
- (Air) Traffic control
- Controlling Cars / Trains / Planes
- Telecommunications
- Medical support (Remote Surgery, Emergency room)
- Multi-Media

- Remark: Some applications may have only soft-real time requirements, but some have really hard real-time requirements

Hard-Real Time Systems

- Requirements:
  - Must always meet all deadlines (time guarantees)
  - You have to guarantee that in any situation these applications are done in time, otherwise dangerous things may happen

Examples:
1. If the landing of a fly-by-wire jet cannot react to sudden side-winds within some milliseconds, an accident might occur.
2. An airbag system or the ABS has to react within milliseconds
Soft-Real Time Systems

Requirements:
Must mostly meet all deadlines, e.g. 99.9% of cases

Examples:
1. Multi-media: 100 frames per day might be dropped (late)
2. Car navigation: 5 late announcements per week are acceptable
3. Washing machine: washing 10 sec over time might occur once in 10 runs, 50 sec once in 100 runs.

Predictability, not Speed
• Real time systems are NOT necessarily fast
• Real time systems can be slow, as long as they are predictably so.
  – It does not matter how fast they are, as long as they meet their deadlines.

Properties of Real-Time Tasks
• To schedule a real time task, its properties must be known \textit{a priori}
• The most relevant properties are
  – Arrival time (or release time) $a_i$
  – Maximum execution time (service time)
  – Deadline $d_i$

Categories of Real time tasks
• Periodic
  – Each task is repeated at a regular interval
  – Max execution time is the same each period
  – Arrival time is usually the start of the period
  – Deadline is usually the end
• Aperiodic (and sporadic)
  – Each task can arrive at any time

Real-time scheduling approaches
• Static table-driven scheduling
  – Given a set of tasks and their properties, a schedule (table) is precomputed offline.
    • Used for periodic task set
    • Requires entire schedule to be recomputed if we need to change the task set
• Static priority-driven scheduling
  – Given a set of tasks and their properties, each task is assigned a fixed priority
  – A preemptive priority-driven scheduler used in conjunction with the assigned priorities
    • Used for periodic task sets

Real-time scheduling approaches
• Dynamic scheduling
  – Task arrives prior to execution
  – The scheduler determines whether the new task can be \textit{admitted}
    • Can all other admitted tasks and the new task meet their deadlines?
      – If no, reject the new task
    • Can handle both \textit{periodic} and \textit{aperiodic} tasks
**Scheduling in Real-Time Systems**

- We will only consider periodic systems

Schedulable real-time system

- Given
  - \( m \) periodic events
  - Event \( i \) occurs within period \( P_i \) and requires \( C_i \) seconds
  - Then the load can only be handled if
    \[ \sum_{i=1}^{m} \frac{C_i}{P_i} \leq 1 \]

**Two Typical Real-time Scheduling Algorithms**

- Rate Monotonic Scheduling
  - Static Priority priority-driven scheduling
  - Priorities are assigned based on the period of each task
    - The shorter the period, the higher the priority

- Earliest Deadline First Scheduling
  - The task with the earliest deadline is chosen next

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**A Scheduling Example**

- Three periodic Tasks

<table>
<thead>
<tr>
<th>Task</th>
<th>Start</th>
<th>End</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0</td>
<td>10</td>
</tr>
<tr>
<td>B</td>
<td>10</td>
<td>30</td>
</tr>
<tr>
<td>C</td>
<td>30</td>
<td>50</td>
</tr>
</tbody>
</table>

**Is the Example Schedulable**

\[ \sum_{i=1}^{3} \frac{C_i}{P_i} \leq 1 \]

\[ \frac{10}{30} + \frac{15}{40} + \frac{5}{50} = 0.808 \]

- YES

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**Two Schedules: RMS and EDF**

**Let’s Modify the Example Slightly**

- Increase A’s CPU requirement to 15 msec
- The system is still schedulable

\[ \frac{15}{30} + \frac{15}{40} + \frac{5}{50} = 0.975 \]
RMS and EDF

RMS failed, why?

- It has been proven that RMS is only guaranteed to work if the CPU utilisation is not too high
  - For three tasks, CPU utilisation must be less than 0.780
    - We were lucky with our original example
      \[ \sum_{i=1}^{m} \frac{C_i}{P_i} \leq m(2^{\frac{1}{m}} - 1) \]

EDF

- EDF always works for any schedulable set of tasks, i.e. up to 100% CPU utilisation

Summary
  - If CPU utilisation is low (usual case, due to safety factor in estimating execution times)
    - Can use RMS which is simple and easy to implement
  - If CPU utilisation is high
    - Must use EDF