Scheduling I

- Introduction to scheduling
- Scheduling algorithms
Role of Dispatcher vs. Scheduler

- **Dispatcher**
  - Low-level mechanism
  - Responsibility: context switch

- **Scheduler**
  - High-level policy
  - Responsibility: deciding which process to run

- *Could have an allocator for CPU as well*
  - Parallel and distributed systems
When to schedule?

- When does scheduler make decisions?
  - When a process
    1. switches from running to waiting state
    2. switches from running to ready state
    3. switches from waiting to ready
    4. terminates

- Minimal: nonpreemptive
  - ?

- Additional circumstances: preemptive
  - ?
Overview of scheduling algorithms

- **Criteria:** workload and environment

- **Workload**
  - Process behavior: alternating sequence of CPU and I/O bursts
  - CPU bound v.s. I/O bound

- **Environment**
  - Batch v.s. interactive?
  - Specialized v.s. general?
Scheduling performance metrics

- **Min waiting time**: don’t have process wait long in ready queue
- **Max CPU utilization**: keep CPU busy
- **Max throughput**: complete as many processes as possible per unit time
- **Min response time**: respond immediately
- **Fairness**: give each process (or user) same percentage of CPU
First-Come, First-Served (FCFS)

- Simplest CPU scheduling algorithm
  - First job that requests the CPU gets the CPU
  - Nonpreemptive

- Implementation: FIFO queue
Example of FCFS

<table>
<thead>
<tr>
<th>Process</th>
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<tbody>
<tr>
<td>P₁</td>
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</tr>
<tr>
<td>P₂</td>
<td>0</td>
<td>4</td>
</tr>
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<td>0</td>
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- **Gantt chart**

Schedule: $P₁ \quad P₂ \quad P₃ \quad P₄$

- **Average waiting time:** $(0 + 7 + 11 + 12)/4 = 7.5$
Example of FCFS: different arrival order

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Arrival order: P₃ P₂ P₄ P₁

Average waiting time: (9 + 1 + 0 + 5)/4 = 3.75
FCFS advantages and disadvantages

- **Advantages**
  - Simple
  - Fair

- **Disadvantages**
  - Waiting time depends on arrival order
  - *Convoy effect*: short process stuck waiting for long process
  - Also called *head of the line blocking*
Shortest Job First (SJF)

- Schedule the process with the shortest time
- FCFS if same time
Example of SJF (w/o preemption)

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Gantt chart

Schedule: P₁ P₃ P₂ P₄

Arrival: P₁ P₂ P₃ P₄

Average waiting time: \( \frac{0 + 6 + 3 + 7}{4} = 4 \)
SJF Advantages and Disadvantages

- **Advantages**
  - Minimizes average wait time. Provably optimal if no preemption allowed

- **Disadvantages**
  - Not practical: difficult to predict burst time
    - Possible: past predicts future
  - May starve long jobs
Shortest Remaining Time First (SRTF)

- If new process arrives w/ shorter CPU burst than the remaining for current process, schedule new process.

- Also known as:
  - SJF with preemption
  - Shortest Time-to-Completion First (STCF)

- Advantage: reduces average waiting time
  - Provably optimal
Example of SRTF

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- **Gantt chart**

Schedule: P₁ P₂ P₃ P₂ P₄ P₁

Arrival: P₁ P₂ P₃ P₄

- **Average waiting time:** \((9 + 1 + 0 + 2)/4 = 3\)
Round-Robin (RR)

- Process runs for a predetermined time slice, and then moves to back of queue
- Process gets preempted at the end of time slice
- How long should the time slice be?
Example of RR:
time slice = 3

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- **Average waiting time:** \((8 + 8 + 5 + 7)/4 = 7\)
- **Average response time:** \((0 + 1 + 5 + 5)/4 = 2.75\)
- **# of context switches:** 7
Smaller time slice = 1

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- Average waiting time: \((8 + 6 + 1 + 7)/4 = 5.5\)
- Average response time: \((0 + 0 + 1 + 2)/4 = 0.75\)
- # of context switches: 14
Larger time slice = 10

Average waiting time: \((0 + 5 + 7 + 7)/4 = 4.75\)

Average response time: same

# of context switches: 3 (minimum)
RR advantages and disadvantages

- **Advantages**
  - Low response time, good interactivity
  - Fair allocation of CPU across processes
  - Low average waiting time when job lengths vary widely

- **Disadvantages**
  - Poor average waiting time when jobs have similar lengths
    - Average waiting time is even worse than FCFS!
  - Performance depends on length of time slice
    - Too high ➔ degenerate to FCFS
    - Too low ➔ too many context switches, costly
Priorities

- Priority is associated with each process
  - Run highest priority process that is ready
  - Round-robin among processes of equal priority

- Priority can be statically assigned
  - Some always have higher priority than others

- Priority can be dynamically changed by OS
  - Aging: increase the priority of processes that wait in the ready queue for a long time

```c
for (pp = proc; pp < proc+NPROC; pp++) {
    if (pp->prio != MAX)
        pp->prio++;    
    if (pp->prio > curproc->prio)
        reschedule();
}
```

Priority inversion

- High priority process depends on low priority process (e.g. to release a lock)
  - Another process with in-between priority arrives?

| P1 (low): lock(my_lock) (gets my_lock) |
| P2(high): lock(my_lock) |
| P3(medium): while (...) {} |
| P2 waits, P3 runs, P1 waits |
| P2's effective priority less than P3! |

- Solution: priority inheritance
  - Inherit highest priority of waiting process
  - Must be able to chain multiple inheritances
  - Must ensure that priority reverts to original value

- Google for “mars pathfinder priority inversion”
Multi-Level Feedback Queue (MLFQ)

- Processes move between queues
  - Queues have different priority levels
  - Priority of process changes based on observed behavior

- **MLFQ scheduler parameters:**
  - number of queues
  - scheduling algorithms for each queue
  - when to upgrade a process
  - when to demote a process
  - which queue a process will start in
MLFQ example from OSTEP book

- **Rule 1:** If Priority(A) > Priority(B), A runs (B doesn’t)
- **Rule 2:** If Priority(A) = Priority(B), A & B run in RR using the time slice of the queue
- **Rule 3:** When a job enters the system, it starts in the topmost queue (of the highest priority)
- **Rule 4:** Once a job uses up its time allotment at a given level (regardless of how many times it has given up the CPU), its priority is reduced (i.e., it moves down one queue)
- **Rule 5:** After some time period S, move all the jobs in the system to the topmost queue