CPU SCHEDULING

Shivaram Venkataraman
CS 537, Spring 2019
- Project 1a is due today! **Thursday at 11.59pm**
- No office hours from 5pm Tue to noon Thu
- Fill out office hours form? https://goo.gl/forms/5VxrwRawtEFkrjO23

- No more waitlist!
- Project 1b out tomorrow. Schedule updates
Scheduling

How does the OS decide what process to run?
What are some of the metrics to optimize for?

Policies

How to handle interactive and batch processes?
What to do when OS doesn’t have complete information?
RECAP
Process: Abstraction to virtualize CPU

Use time-sharing in OS to switch between processes
PROCESS STATE TRANSITIONS

- Running
- Ready
- Blocked

State Transitions:
- Running to Ready (Scheduled)
- Ready to Running (Descheduled)
- Blocked to I/O: initiate
- I/O: done to Blocked
RECAP: SCHEDULING MECHANISM

Limited Direct Execution

Use system calls to run access devices etc. from user mode

Context-switch using interrupts for multi-tasking
Handle the trap
Call switch() routine
  save kernel regs(A) to proc-struct(A)
  restore kernel regs(B) from proc-struct(B)
  switch to k-stack(B)
return-from-trap (into B)

Hardware

timer interrupt
save regs(A) to k-stack(A)
move to kernel mode
jump to trap handler

Process B
POLICY?
VOCABULARY

Workload: set of jobs (arrival time, run_time)

Job ~ Current execution of a process
    Alternates between CPU and I/O
    Moves between ready and blocked queues

Scheduler: Decides which ready job to run
Metric: measurement of scheduling quality
APPROACH

Assumptions ➔ Scheduling policy ➔ Metric
ASSUMPTIONS

1. Each job runs for the same amount of time
2. All jobs arrive at the same time
3. All jobs only use the CPU (no I/O)
4. Run-time of each job is known
**METRIC 1: TURNAROUND TIME**

Turnaround time = \( completion\_time - arrival\_time \)

**Example:**

- Process A arrives at time \( t = 10 \), finishes \( t = 30 \)
- Process B arrives at time \( t = 10 \), finishes \( t = 50 \)

Turnaround time

- \( A = 20 \), \( B = 40 \)
- Average = 30
FIFO / FCFS
**FIFO / FCFS**

FIFO: First In, First Out  
FCFS: First Come, First Served

<table>
<thead>
<tr>
<th>Job</th>
<th>Arrival(s)</th>
<th>run time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>~0</td>
<td>10</td>
</tr>
<tr>
<td>B</td>
<td>~0</td>
<td>10</td>
</tr>
<tr>
<td>C</td>
<td>~0</td>
<td>10</td>
</tr>
</tbody>
</table>
### FIFO / FCFS

<table>
<thead>
<tr>
<th>Job</th>
<th>Arrival(s)</th>
<th>run time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>~0</td>
<td>10</td>
</tr>
<tr>
<td>B</td>
<td>~0</td>
<td>10</td>
</tr>
<tr>
<td>C</td>
<td>~0</td>
<td>10</td>
</tr>
</tbody>
</table>

**Average Turnaround Time?**
ASSUMPTIONS

1. Each job runs for the same amount of time
2. All jobs arrive at the same time
3. All jobs only use the CPU (no I/O)
4. Run-time of each job is known
2-MINUTE QUIZ

How will FIFO perform without this assumption?

What scenarios can lead to bad performance?
### BIG FIRST JOB

<table>
<thead>
<tr>
<th>Job</th>
<th>Arrival(s)</th>
<th>run time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>~0</td>
<td>100</td>
</tr>
<tr>
<td>B</td>
<td>~0</td>
<td>10</td>
</tr>
<tr>
<td>C</td>
<td>~0</td>
<td>10</td>
</tr>
</tbody>
</table>

Average Turnaround Time:

\[
\frac{(100 + 110 + 120)}{3} = 110\text{s}
\]
Convoy Effect
CHALLENGE

Turnaround time suffers when short jobs must wait for long jobs

New scheduler:
  SJF (Shortest Job First)
  Choose job with smallest run_time!
SHORTEST JOB FIRST (SJF)

<table>
<thead>
<tr>
<th>Job</th>
<th>Arrival(s)</th>
<th>run time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>~0</td>
<td>100</td>
</tr>
<tr>
<td>B</td>
<td>~0</td>
<td>10</td>
</tr>
<tr>
<td>C</td>
<td>~0</td>
<td>10</td>
</tr>
</tbody>
</table>

Average Turnaround Time

\[
\frac{(10 + 20 + 120)}{3} = 50s!
\]

FIFO: 110s ?!
ASSUMPTIONS

1. Each job runs for the same amount of time
2. All jobs arrive at the same time
3. All jobs only use the CPU (no I/O)
4. Run-time of each job is known
<table>
<thead>
<tr>
<th>Job</th>
<th>Arrival(s)</th>
<th>run time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>~0</td>
<td>100</td>
</tr>
<tr>
<td>B</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>C</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

**Average Turnaround Time with SJF?**
### Job Arrivals and Run Times

<table>
<thead>
<tr>
<th>Job</th>
<th>Arrival(s)</th>
<th>Run time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>~0</td>
<td>100</td>
</tr>
<tr>
<td>B</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>C</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

Average Turnaround Time?

\[
\frac{100 + 110 + 120}{3} = 110\text{s}
\]
PREEMPTIVE SCHEDULING

Prev schedulers:

FIFO and SJF are non-preemptive
Only schedule new job when previous job voluntarily relinquishes CPU

New scheduler:

Preemptive: Schedule different job by taking CPU away from running job
STCF (Shortest Time-to-Completion First)
Always run job that will complete the quickest
## PREMPTIVE SCTF

<table>
<thead>
<tr>
<th>Job</th>
<th>Arrival(s)</th>
<th>run time (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>~0</td>
<td>100</td>
</tr>
<tr>
<td>B</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>C</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

**Average Turnaround Time**

\[
\frac{(10 + 20 + 120)}{3} = 50s
\]
**METRIC 2: RESPONSE TIME**

Response time = \textit{first\_run\_time} - \textit{arrival\_time}

B’s turnaround: 20s

B’s response: 10s
ROUND ROBIN SCHEDULER

Average Response Time

\[(0 + 5 + 10)/3 = 5s\]  \[(0 + 1 + 2)/3 = 1s\]
2-MINUTE QUIZ

What is the turnaround time for two cases?
Is round robin better or worse?
TRADE-OFFS

Round robin increases turnaround time decreases response time

Tuning challenges:
  What is a good time slice for round robin?
  What is the overhead of context switching?
ASSUMPTIONS

1. Each job runs for the same amount of time
2. All jobs arrive at the same time
3. All jobs only use the CPU (no I/O)
4. Run-time of each job is known
Job holds on to CPU while blocked on disk!
Treat Job A as 3 separate CPU bursts.
When Job A completes I/O, another Job A is ready.
I/O AWARE SCHEDULING

Treat Job A as 3 separate CPU bursts.
When Job A completes I/O, another Job A is ready.

Each CPU burst is shorter than Job B.
With SCTF, Job A preempts Job B.
ASSUMPTIONS

1. Each job runs for the same amount of time
2. All jobs arrive at the same time
3. All jobs only use the CPU (no I/O)
4. Run-time of each job is known
MULTI-LEVEL FEEDBACK QUEUE
MLFQ: GENERAL PURPOSE SCHEDULER

Must support two job types with distinct goals
- “interactive” programs care about response time
- “batch” programs care about turnaround time

Approach:
Multiple levels of round-robin
Each level has higher priority than lower level
Can preempt them
MLFQ EXAMPLE

“Multi-level” – Each level is a queue!

Rules for MLFQ

Rule 1: If priority(A) > Priority(B)
    A runs

Rule 2: If priority(A) == Priority(B),
    A & B run in RR
CHALLENGES

How to set priority?
What do we do when a new process arrives?
Does a process stay in one queue or move between queues?

Approach: Use past behavior of process to predict future!
Guess how CPU burst (job) will behave based on past CPU bursts
MORE MLFQ RULES

Rule 1: If priority(A) > Priority(B), A runs
Rule 2: If priority(A) == Priority(B), A & B run in RR

Rule 3: Processes start at top priority
Rule 4: If job uses whole slice, demote process
(longer time slices at lower priorities)
INTERACTIVE PROCESS JOINS

Q0

Q1

Q2
What is the problem with this schedule?
AVOIDING STARVATION

Problem: Low priority job may never get scheduled

Periodically **boost** priority of all jobs (or all jobs that haven’t been scheduled)
GAMING THE SCHEDULER?

Job could trick scheduler by doing I/O just before time-slice end

Account for total run time at priority
Downgrade when exceed threshold
SUMMARY

Scheduling Policies
- Understand **workload characteristics** like arrival, CPU, I/O
- Scope out goals, **metrics** (turnaround time, response time)

Approach
- Trade-offs based on goals, metrics (RR vs. SCTF)
- Past behavior is good predictor of future behavior?
NEXT STEPS

Project 1a: Due Jan 31 (Thursday) at 11.59pm
Project 1b: Out on Jan 30th

Thursday class, discussion
- More advanced scheduling policies
- Summary / review of process, CPU scheduling
- xv6 introduction, walk through
- Go through xv6 context switch / syscall?