CS 162 Operating Systems and Systems Programming

Professor: Anthony D. Joseph

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Lecture 11: CPU Scheduling

11.0 Main Points

- Scheduling policy goals
- Policy options
- Implementation considerations

Earlier, said dispatcher can choose any thread on the ready list to run. But how is the OS to decide, when it has a choice?

11.1 Scheduling Policy Goals

1. **Minimize response time**: elapsed time to do an operation (or job)
   Response time is what the user sees: elapsed time to
   - echo a keystroke in editor
   - compile a program
   - run a large scientific problem
2. **Maximize throughput**: operations (or jobs) per second

   Two parts to maximizing throughput
   a. **Minimize overhead** (for example, context switching)
   b. **Efficient use of system resources** (not only CPU, but disk, memory, etc.)
3. **Fairness**: share CPU among users in some equitable way
   What does fairness mean?

   Minimize average response time? We will argue fairness is a tradeoff against average response time; can get better *average* response time by making system **less** fair.

11.2 Assumptions

Bunch of algorithms for CPU scheduling – big area of research in the early 70's.

These assume:

- one program per user
- one thread per program
- programs are independent

Clearly, these are unrealistic but they simplify the problem so it can be solved. Open issue is: what happens if you remove these constraints?
Also assume an execution model consisting of CPU/IO bursts. That is, a program typically uses the CPU for some period of time, then does I/O, then uses the CPU again. Thus, for each scheduling decision the question is which job to give the CPU to for use by its next CPU burst. Note that in a timeslicing system a job may be forced to give up the CPU before its current CPU burst is finished. Likewise, a job may give up the CPU before its timeslice is expired.

11.3 Scheduling policies:

11.3.1 FIFO

Different names for the same thing:

- FCFS – first come first serve
- FIFO – first in first out
- Run until done

In early systems, FIFO meant, one program kept CPU until it completely finished. With strict uniprogramming, if have to wait for I/O, keep processor.

Later, FIFO just means, keep CPU until thread blocks (this is what I'll assume).

FIFO Pros & Cons:

+ simple
– short jobs get stuck behind long jobs

11.3.2 Round Robin

Solution? Add timer, and preempt CPU from long-running jobs. Just about every real operating system does something of this flavor.

Round-robin: after time slice, move thread to back of the queue
In some sense, it's fair – each job gets equal shot at the CPU.

11.3.2.1 How do you choose time slice?

1) What if too big?
   Response time suffers

2) What if too small?
   Throughput suffers. Spend all your time context switching, none getting real work done.

In practice, need to balance these two. Typical time slice today is between 10—100 milliseconds; typical timeslice overhead is 0.1 – 1 millisecond, so roughly 1% overhead due to time-slicing.

11.3.2.2 Comparison between FIFO and Round Robin

Assuming zero-cost time slice, is RR always better than FIFO?
For example: 10 jobs, each take 100 seconds of CPU time. Round Robin time slice of 1 second. All start at the same time:

Job completion times

Job #	FIFO	Round Robin
1	100	991
2	200	992
...	...	...
9	900	999

10	1000	1000

Round robin runs one second from each job, before going back to the first. So each job accumulates 99 seconds of CPU time before any finish.

Both round robin and FIFO finish at the same time, but **average** response time is much worse under RR than under FIFO.

Thus, round robin Pros & Cons:

+ better for short jobs
– poor when jobs are same length

11.3.3 SJF/SRTF

SJF: *Shortest Job First (*sometimes called **STCF** - *Shortest Time to Completion Firs)t*. Run whatever job has the least amount of stuff to do.

SRTF: *Shortest Remaining Time First* (sometimes called **STRCF:** *Shortest Remaining Time to Completion First).* Preemptive version of SJF – if job arrives that has a shorter time to completion than the remaining time on the current job, immediately preempt CPU to give to new job.

These can be applied either to a whole program or to the current CPU burst of each program.

Idea is get short jobs out of the system. Big effect on short jobs, small effect on long jobs. Result is better **average** response time.

In fact, SJF/SRTF are the best you can possibly do, at minimizing average response time (SJF among non-preemptive policies, SRTF among preemptive policies). Can prove they're optimal. Since SRTF is always at least as good as SJF, focus on SRTF.

11.3.3.1 Comparison of SRTF with FIFO and Round Robin

What if all jobs are the same length? SRTF becomes the same as FIFO (in other words, FIFO is as good as you can do if all jobs are the same length).

What if jobs have varying length? SRTF (and round robin): short jobs don't get stuck behind long jobs.

Example to illustrate the benefits of SRTF:

Three jobs:

A, B: both CPU bound, run for week

C: I/O bound, loop

1 ms of CPU

10 ms of disk I/O

By itself, C uses 90% of the disk; by itself, A or B could use 100% of the CPU. What happens if we try to share system between A, B, and C?

With FIFO:

Once A or B get in, keep CPU for two weeks

With Round Robin (100 ms time slice):

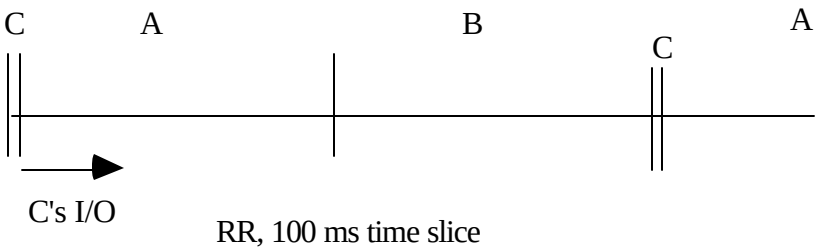
Only get 5% disk utilization

With Round Robin (1 ms time slice):

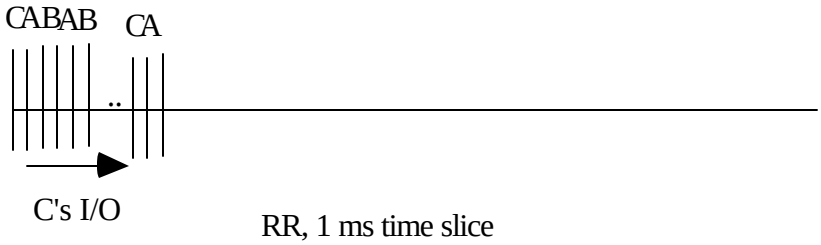
Get nearly 90% disk utilization – almost as good as C alone.

But we haven't slowed A or B by all that much: they still get 90% of the CPU. (Lots of wakeups, however!)

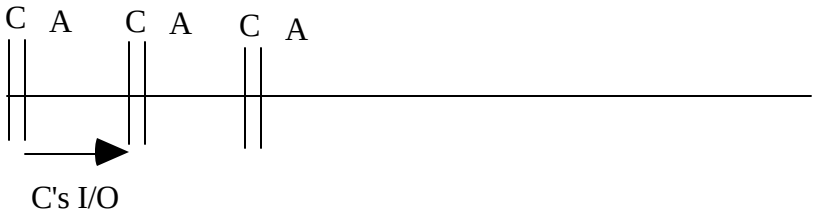
With SRTF: no needless preemptions (run C as soon as possible, run either A or B to completion)



RR, 100 ms time slice



RR, 1 ms time slice



SRCTF

Effect of RR time quanta and SRTF on I/O bound jobs

A downside to SRTF is that it can lead to starvation. Lots of short jobs can keep long jobs from making any progress.

SRTF Pros& Cons:

+ optimal (average response time)
– hard to predict the future
– unfair

11.3.3.2 Knowledge of future

Problem: SJF/SRTF require knowledge of the future.

How do you know how long program will run for, or how long its next CPU burst will be?

Some systems ask the user: when you submit a job like a compile, have to say how long it will take.

To stop cheating, if your job takes more than what you said, system kills your job. Start all over. Like with the Banker's algorithm – hard to predict resource usage in advance.

Instead, can't really know how long things will take, but can use SRTF as a yardstick, for measuring other policies. Optimal, so can't do any better than that!

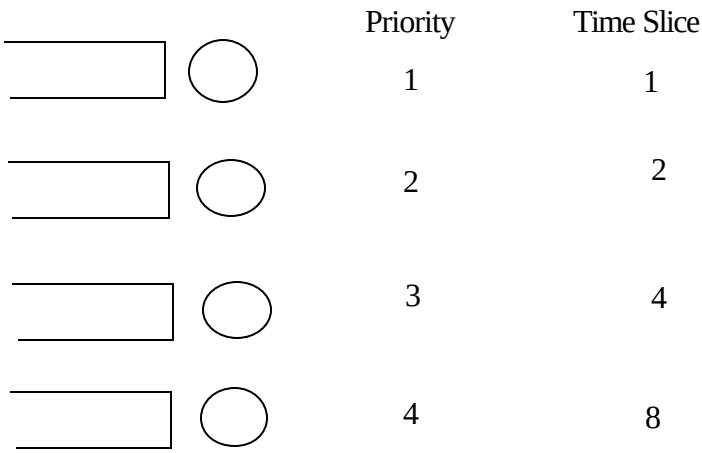
11.3.4 Multilevel feedback

Central idea in computer science (occurs in lots of places): **use past to predict future**.
If program was I/O bound in past, likely to be in future.
If computer behavior was random, induction wouldn't help. Or if past behavior was opposite of current behavior.

But program behavior is regular, most of the time. How do we exploit this? If past behavior predicts future behavior, then favor jobs that have been at CPU least amount of time, to approximate SRTF!

Adaptive policies: change policy based on past behavior. Used in CPU scheduling, in virtual memory, in file systems, etc.

Multi-level feedback queues (first used in CTSS, example of an adaptive policy for CPU scheduling): multiple queues, each with different priority. OS does round robin at each priority level – run highest priority jobs first; once those finish, run next highest priority, etc. Round robin time slice increases exponentially at lower priorities.



Multilevel feedback queues

Adjust each job's priority as follows (details vary):

1. Job starts in highest priority queue.
2. If timeout expires, drop one level
3. If timeout doesn't expire, push up one level (or back to top)

Result approximates SRTF: CPU bound jobs drop like a rock, while short-running I/O bound jobs stay near top.

Multilevel feedback queues (like SRTF) are still unfair: long running jobs may never get the CPU.

Countermeasure: user action that can foil intent of the OS designer. For multilevel feedback, countermeasure would be to put in meaningless I/O to keep job's priority high. Of course, if everyone did this, wouldn't work!

11.3.5 Fairness

What should we do about fairness? Since SRTF is optimal and unfair, any increase in fairness (for instance by giving long jobs a fraction of the CPU, even when there are shorter jobs to run) will have to hurt average response time.

How do we implement fairness?

Could give each queue a fraction of the CPU.

> But this isn't always fair. What if there's one long-running job, and 100 short-running ones?

Could adjust priorities: increase priority of jobs, as they **don't** get service. This is what's done in UNIX.

> Problem is that this is ad hoc – what rate should you increase priorities? And, as system gets overloaded, no job gets CPU time, so everyone increases in priority. The result is that interactive jobs suffer – both short **and** long jobs have high priority!

Instead, use **lottery scheduling:** give every job some number of lottery tickets, and on each time slice, randomly pick a winning ticket. On average, CPU time is proportional to # of tickets given to each job.

How do you assign tickets? To approximate SRTF, short running jobs get more, long running jobs get fewer. To avoid starvation, every job gets at least one ticket (so everyone makes progress).

Advantage over strict priority scheduling: behaves gracefully as load changes. Adding or deleting a job affects all jobs proportionately, independent of how many tickets each job has. For example, if short jobs get 10 tickets, and long jobs get 1 each, then:

# short jobs / # long jobs	% of CPU each short job gets	% of CPU each long job gets
1/1	91%	9%
0/2	NA	50%
2/0	50%	NA
10/1	10%	1%
1/10	50%	5%

11.4A Different Point-of-View

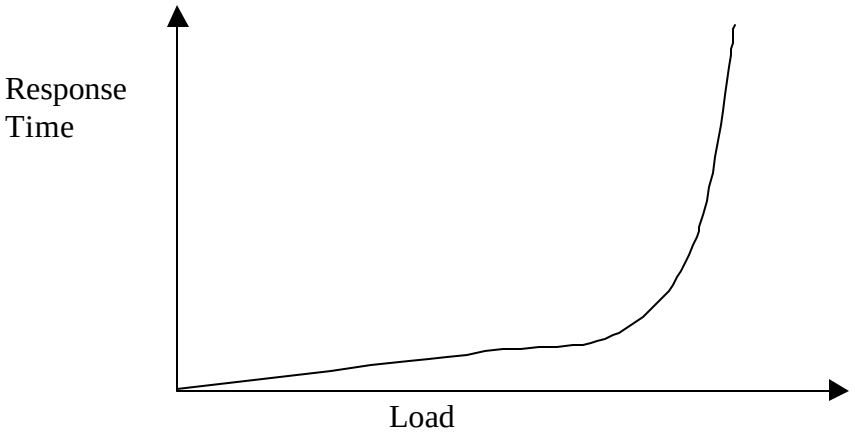
When do the details of scheduling policy and fairness really matter?

> When there aren't enough resources to go around.

Question: When should you simply buy a faster computer?
One approach: Buy when it will pay for itself in improved response time (assuming you're paying for worse response time in reduced productivity, customer angst, ...)

Might think that you should buy a faster X when X is utilized 100% of the time. But for most systems, response time goes to infinity, as utilization goes to 100%.

How does response time vary with load?



An interesting implication of this curve:

> Most scheduling algorithms will work just fine as long as you stay in the "linear" portion of the load curve, whereas life gets miserable no matter what you try to do when you're in the "steep" part of the load curve.

Argues for buying a faster X when you reach the "knee" of the load curve.