Process scheduling

- **Goal: High throughput**
  - Minimize context switches to avoid wasting CPU, TLB misses, cache misses, even page faults.
- **Goal: Low latency**
  - People typing at editors want fast response
  - Network services can be latency-bound, not CPU-bound
- **BSD time quantum:** $1/10$ **sec (since** $\sim$**1980)**
  - Empirically longest tolerable latency
  - Computers now faster, but job queues also shorter
- **Solaris SVR4:** $1/100$ **sec**

Scheduling algorithms

- **Round-robin**
- **Priority scheduling**
- **Shortest process next (if you can estimate it)**
- **Fair-Share Schedule (try to be fair at level of users, not processes)**
- **Fancy combinations of the above (e.g., SMART)**

Real-time scheduling

- **Two categories:**
  - *Soft real time*—miss deadline and CD will sound funny
  - *Hard real time*—miss deadline and plane will crash
- **System must handle periodic and aperiodic events**
  - E.g., procs A, B, C must be scheduled every 100, 200, 500 msec, require 50, 30, 100 msec respectively
  - *Schedulable* if $\sum \frac{CPU}{\text{period}} \leq 1$ (not counting switch time)
- **Variety of scheduling strategies**
  - E.g., first deadline first (works if schedulable)

Multiprocessor scheduling issues

- **For TLB and cache, care about which CPU**
  - *Affinity scheduling*—try to keep threads on same CPU
- **Want related processes scheduled together**
  - Good if threads access same resources (e.g., cached files)
  - Even more important if threads communicate often (otherwise would spend all their time waiting)
- ***Gang scheduling*—schedule all CPUs synchronously**
  - With synchronized quanta, easier to schedule related processes/threads together

Multilevel feeedback queues (BSD)

- **Every runnable proc. on one of 32 run queues**
  - Kernel runs proc. on highest-priority non-empty queue
  - Round-robins among processes on same queue
- **Process priorities dynamically computed**
  - Processes moved between queues to reflect priority changes
  - If a proc. gets higher priority than running proc., run it
- **Idea: Favor interactive jobs that use less CPU**

Process priority

- `p_nice` **– user-settable weighting factor**
- `p_estcpu` **– per-process estimated CPU usage**
  - Incremented whenever timer interrupt found proc. running
  - Decayed every second while process runnable

$$\texttt{p\_estcpu} \leftarrow \left(\frac{2 \cdot \text{load}}{2 \cdot \text{load} + 1}\right) \texttt{p\_estcpu} + \texttt{p\_nice}$$

- **Run queue determined by** $\texttt{p\_usrpri}/4$

$$\texttt{p\_usrpri} \leftarrow 50 + \left(\frac{\texttt{p\_estcpu}}{4}\right) + 2 \cdot \texttt{p\_nice}$$

(value clipped if over 127)

Sleeping process increases priority

- `p_estcpu` **not updated while asleep**
  - Instead `p_slptime` keeps count of sleep time
- **When process becomes runnable**

$$\texttt{p\_estcpu} \leftarrow \left(\frac{2 \cdot \text{load}}{2 \cdot \text{load} + 1}\right)^{\texttt{p\_slptime}} \times \texttt{p\_estcpu}$$

  - Approximates decay ignoring nice and past loads

Limitations of BSD scheduler

- **Hard to have isolation / prevent interference**
  - Priorities are absolute
- **Can’t transfer priority (e.g., to server on RPC)**
- **No flexible control**
  - E.g., In monte carlo simulations, error is 1/sqrt(N) after N trials
  - Want to get quick estimate from new computation
  - Leave a bunch running for a while to get more accurate results
- **Multimedia applications**
  - Often fall back to degraded quality levels depending on resources
  - Want to control quality of different streams

Lottery scheduling [Waldspurger]

- **Issue lottery tickets to processes**
  - Let p_i have t_i tickets, let $T = \sum_i t_i$
  - Chance of winning next quantum is t_i/T.
- **Control avg. proportion CPU for each process**
  - Can also group processes hierarchically for control
  - Subdivide lottery tickets allocated to a particular process
  - Modeled as currencies, funded through other currencies
- **Can transfer tickets to other processes**
  - Perfect for IPC
  - Avoids priority inversion with mutexes

Compensation tickets

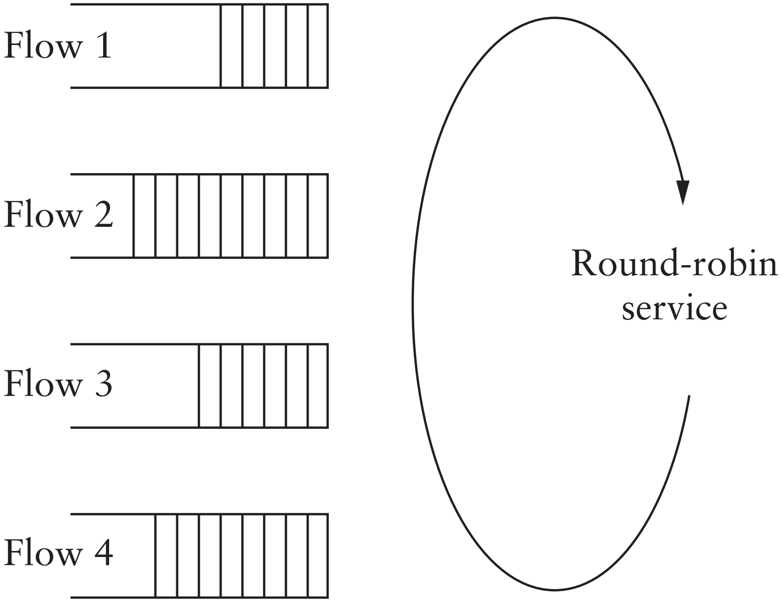
- **What if proc. only uses fraction f of quantum**
  - Say A and B have same number of lottery tickets
  - Proc. A uses full quantum, proc. B uses f fraction
  - Each wins the lottery as often
  - B gets fraction f of B's CPU time. No fair!
- **Solution: Compensation tickets**
  - If B uses f of quantum, inflate B's tickets by $1/f$ until it next wins CPU
  - E.g., process that uses half of quantum gets schecules twice as often

Limitations of lottery scheduling

- **Expected error** $O(sqrt(n_a))$ **for** n_a **allocations**
  - E.g., process A should have had 1/3 of CPU yet after 1 minute has had only 19 seconds
- **Unpredictable latencies**
- **Idea: Apply ideas from weighted fair queuing**
  - Used for scheduling network routing
  - Can achieve similar goals to lottery scheduling
  - But done deterministically
  - Stride scheduling [Waldspurger] was follow-on to lottery scheduling work

Fair Queuing (FQ)

- **Which network packet to send next over a link?**
- **Ideally, would send one bit from each flow**
  - In weighted fair queuing (WFQ), more bits from some flows



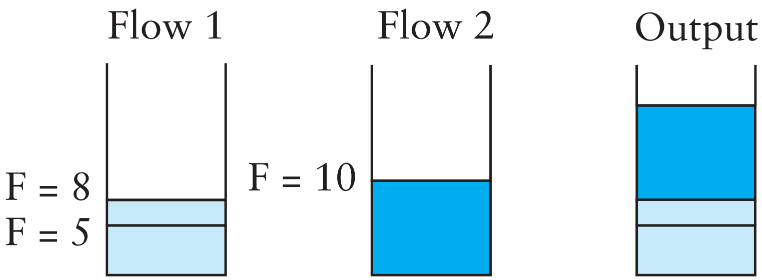
- **Complication: must send whole packets**

FQ Algorithm

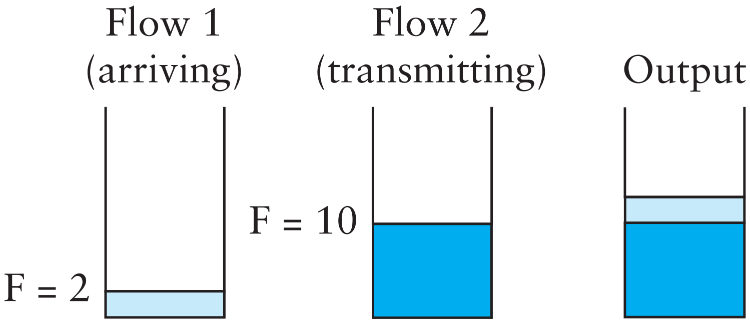
- **Suppose clock ticks each time a bit is transmitted**
- **Let** P_i **denote the length of packet** i
- **Let** S_i **denote the time when start to transmit packet** i
- **Let** F_i **denote the time when finish transmitting packet** i
- $F_i = S_i + P_i$
- **When does router start transmitting packet** i**?**
  - If arrived before router finished packet $i - 1$ from this flow, then immediately after last bit of $i - 1$ (F_{i-1})
  - If no current packets for this flow, then start transmitting when arrives (call this A_i)
- **Thus:** $F_i = \max(F_{i-1}, A_i) + P_i$

FQ Algorithm (cont)

- **For multiple flows**
  - Calculate F_i for each packet that arrives on each flow
  - Treat all F_is as timestamps
  - Next packet to transmit is one with lowest timestamp
- **Not perfect: can't preempt current packet**
- **Example:**



(a)



(b)

OS support for periodic tasks

```
struct timeval {
  long tv_sec;                          /* seconds */
  long tv_usec;                         /* microseconds */
};
struct itimerval {
  struct timeval it_interval;    /* timer interval */
  struct timeval it_value;       /* current value */
};

#define ITIMER_REAL      0
#define ITIMER_VIRTUAL   1
#define ITIMER_PROF      2
int setitimer(int which, const struct itimerval *value,
              struct itimerval *ovalue);
```

- **Delivers SIGALRM, SIGVTALRM, or SIGPROF periodically**
  - E.g., use ITIMER_REAL to display frames in mpeg player

SMART

- **Goal: Support multimedia + real-time applications**
- **RT interface: Specify *time constraints* & *notifications***
  - constraint = deadline + amount of CPU needed before then
  - notification = time + handler (like sig handler)
- **Track "virtual finishing time" of scheduling a process**
  - Like WFQ packet scheduling algorithm
  - But can temporarily "bias" value to capture urgency
- **Assign processes priority to capture importance**
- **Basic algorithm:**
  - Sort processes by <priority, VFT>
  - If first process conventional, just run it
  - Else, consider all schedulable RT processes more important than first conventional one, run most urgent of them