Recap of Last Class: CPU Scheduling

- CPU scheduling may take place at:
  - Hardware interrupt/software exception, system calls.
- Objectives:
  - Minimize completion time; maximize throughput
  - Minimize response time
  - Maintain fairness
- Policies:
  - FCFS, SJF, Priority
  - Round-Robin
  - Earliest Deadline First
- Multiple scheduling policies in system

Linux Task Scheduling

- Linux uses two task-scheduling classes:
  - A time-sharing class for fair preemptive scheduling between multiple tasks. This is the default
  - A real-time class that conforms to POSIX real-time standard (FIFO/RR). Use system call sched_setscheduler to specify.
- For time-sharing tasks, Linux uses a prioritized, credit based algorithm.
  - Scheduling is prioritized based on the initial credit
  - Credit of the running task decrements by one at every clock tick
  - Recrediting when no runnable tasks have any credit
  - credits = \( \frac{\text{credits}}{2} + \text{priority} \)
- This crediting system automatically prioritizes interactive or I/O-bound tasks.

Synchronization Principles

- Background
  - Concurrent access to shared data may result in data inconsistency.
  - Maintaining data consistency requires mechanisms to ensure the orderly execution of cooperating processes.
- The Critical-Section Problem
  - Pure software solution
  - With help from the hardware
- Synchronization without busy waiting (with the support of process/thread scheduler)
  - Semaphore
  - Mutex lock
  - Condition variables
Bounded Buffer

Shared data

```c
typedef struct { ... } item;
item buffer[BUFFER_SIZE];
int in = 0, out = 0;
int counter = 0;
```

Producer process

```c
item nextProduced;
while (1) {
    while (counter==BUFFER_SIZE)
        ; /* do nothing */
    buffer[in] = nextProduced;
in = (in+1) % BUFFER_SIZE;
counter++;
}
```

Consumer process

```c
item nextConsumed;
while (1) {
    while (counter==0)
        ; /* do nothing */
    nextConsumed = buffer[out];
    out = (out+1) % BUFFER_SIZE;
    counter--;
}
```

Race Condition

- **Race condition:**
  - The situation where several processes access and manipulate shared data concurrently.
  - The final value of the shared data and/or effects on the participating processes depends upon the order of process execution.

- To prevent race conditions, concurrent processes must be synchronized.

The Critical-Section Problem

- **Problem context:**
  - Multiple processes all competing to use some shared data
  - Each process has a code segment, called critical section, in which the shared data is accessed.

- **Find a solution that satisfies the following:**
  1. Mutual Exclusion. No two processes simultaneously in the critical section.
  2. Progress. No process running outside its critical section may block other processes.
  3. Bounded Waiting/Fairness. A bound must exist on the number of times that other processes are allowed to enter their critical sections after a process has made a request to enter its critical section and before that request is granted.
Eliminating Concurrency

- First idea: eliminating the chance of context switch when a process runs in the critical section.
  - software exceptions
  - hardware interrupts
  - system calls

- Disabling interrupts?
  - not feasible for user programs since they shouldn’t be able to disable interrupts
  - feasible for OS kernel programs
    - for short critical sections
    - on single-processor machines

Critical Section for Two Processes

- Only 2 processes, $P_0$ and $P_1$
- General structure of process $P_i$ (other process $P_j$)

\[
\text{do}\{ \\
\quad \text{entry section} \\
\quad \text{critical section} \\
\quad \text{exit section} \\
\quad \text{remainder section} \\
\} \text{ while (1);}
\]

- Processes may share some common variables to synchronize their actions.
- Assumption: instructions are atomic and no re-ordering of instructions.

Algorithm 1

- Shared variables:
  - int turn;
    - initially turn = 0;
  - turn==i $\Rightarrow P_i$ can enter its critical section

- Process $P_i$
  
  \[
  \text{do}\{ \\
  \quad \text{while (turn != i);} \\
  \quad \text{critical section} \\
  \quad \text{turn = j;} \\
  \quad \text{remainder section} \\
  \} \text{ while (1);} 
  \]

- Satisfies mutual exclusion, but not progress

Algorithm 2

- Shared variables:
  - boolean flag[2];
    - initially flag[0] = flag[1] = false;
  - flag[i]==true $\Rightarrow P_i$ ready to enter its critical section

- Process $P_i$
  
  \[
  \text{do}\{ \\
  \quad \text{flag[i] = true;} \\
  \quad \text{while (flag[j]) ;} \\
  \quad \text{critical section} \\
  \quad \text{flag[i] = false;} \\
  \quad \text{remainder section} \\
  \} \text{ while (1);} 
  \]

- Satisfies mutual exclusion, but not progress requirement.
Algorithm 3

- Combined shared variables of algorithms 1 and 2.
- Process \( P_i \)
  
  ```
  do {
    flag[i] = true;
    turn = j;
    while (flag[j] && turn==j) {
      critical section
      flag[i] = false;
      remainder section
    }
  } while (1);
  ```

- Meets all three requirements; solves the critical-section problem for two processes. ⇒ called Peterson's algorithm.

Synchronization Using Special Instruction:
TSL (test-and-set)

````
entry_section:
TSL R1, LOCK | copy lock to R1 and set lock to 1
CMP R1, #0 | was lock zero?
JNE entry_section | if it wasn’t zero, lock was set, so loop
RET | return; critical section entered

exit_section:
MOV LOCK, #0 | store 0 into lock
RET | return; out of critical section
```

- Does it solve the synchronization problem?
- Does it work for multiple (>2) processes?
- What if you have special instruction SWP (swap the value of a register and a memory word)?

Solving Critical Section Problem with Busy Waiting

- In all our solutions, a process enters a loop until the entry is granted ⇒ busy waiting.
- Problems with busy waiting:
  - waste of CPU time
  - priority inversion
- Develop solutions that do not busy wait. Need cooperation from the thread/process scheduler.

Semaphore

- Synchronization tool that does not require busy waiting.
- Semaphore \( S \) - integer variable which can only be accessed via two atomic operations
- Semantics (roughly) of the two operations:
  - \( \text{wait}(S) \) or \( \text{P}(S) \): wait until \( S > 0 \);
  - \( S -- \);
  - \( \text{signal}(S) \) or \( \text{V}(S) \): \( S ++ \);

- Solving the critical section problem:
  - Shared data:
  ```
  semaphore mutex=1;
  ```
  - Process \( P_i \):
    ```
    wait(mutex);
    critical section
    signal(mutex);
    remainder section
    ```
Semaphore Implementation

- Define a semaphore as a record

  ```
  typedef struct { 
      int value; 
      proc_list *L;  
  } semaphore; 
  ```

- Assume two simple operations:
  - block suspends the process that invokes it.
  - wakeup(P) resumes the execution of a blocked process P.

- Semaphore operations now defined as (both are atomic):
  - `wait(S);`
    - `S.value--;`
    - if (S.value < 0) {
        - add this process to S.L;
        - block;
    }
  - `signal(S);`
    - `S.value++;
    - if (S.value <= 0) {
        - remove a process P from S.L;
        - wakeup(P);
    }

 Does this completely solve the critical section problem?
 How to make sure wait(S) and signal(S) are atomic?
 So have we truly removed busy waiting?

Mutex Lock

- Mutex lock - a semaphore with only two state: locked/unlocked

  - Semantics of the two (atomic) operations:
    - `lock(mutex);`
      - wait until mutex==unlocked; mutex=locked;
    - `unlock(mutex);`
      - mutex=unlocked;

  - Solving the critical section problem:
    - Shared data:
      - mutex=unlocked;
    - Process P:
      - lock(mutex);
      - critical section
      - unlock(mutex);
      - remainder section

Assignment #2

- Repeat your measurement many times and take the average; the goal is to have stable results.
- Use a high-resolution timer.

  - Q: measure the cost of process context switching
    - force process context switch to happen a precise number of times
    - use a pipe or a semaphore

  - Q: measure the cost of thread context switching
    - force thread switch to happen a precise number of times
    - use locks/condition variables

Synchronization Primitives in Pthreads

- Mutex lock
  - `pthread_mutex_init`
  - `pthread_mutex_destroy`
  - `pthread_mutex_lock`
  - `pthread_mutex_unlock`

- Condition variable (used in conjunction with a mutex lock)
  - `pthread_cond_init`
  - `pthread_cond_destroy`
  - `pthread_cond_wait`
  - `pthread_cond_signal`
  - `pthread_cond_broadcast`
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