Synchronization Principles

CS 256/456

Dept. of Computer Science, University of Rochester

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, SJB, Priority
  - Round-Robin
  - Earliest Deadline First
- Multiple scheduling policies in system
- Linux 2.4 task scheduling

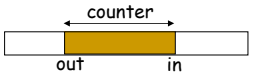
Synchronization Principles

- 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

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



- Producer process

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

- Consumer process

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

Bounded Buffer

- The following statements must be performed *atomically*.

```
counter++;
counter--;
```

- Atomic operation means an operation that completes in its entirety without interruption.
- The statement "**counter++**" may be compiled into the following instruction sequence:

```
register1 = counter;
register1 = register1 + 1;
counter   = register1;
```

- The statement "**counter--**" may be compiled into:

```
register2 = counter;
register2 = register2 - 1;
counter   = register2;
```


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:
  - *n* 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)

```
do {
    entry section
        critical section
    exit section
        remainder section
} 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` ⇒ P_i can enter its critical section
- Process P_i

```
do {
   while (turn != i) ;
      critical section
   turn = j;
      remainder section
} while (1);
```

- Satisfies mutual exclusion, but not progress

Algorithm 2

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

```
do {
   flag[i] = true;
   while (flag[j]) ;
      critical section
   flag[i] = false;
      remainder section
} 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
- What is the fundamental problem here?
- 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:

```
wait(S) or P(S):
   wait until S>0;
   S--;

signal(S) or V(S):
   S++;
```

- Solving the critical section problem:

Shared data:

```
semaphore mutex=1;
```

Process Pi:

```
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 Pi:

lock(mutex);
critical section
unlock(mutex);
remainder section

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