Chapter 6: Process/thread Synchronization
Module 6: Process Synchronization

- Background
- The Critical-Section Problem
- Peterson’s Solution
- Synchronization Hardware
- Semaphores
- Classic Problems of Synchronization
- Monitors
- Synchronization Examples
- Atomic Transactions
Background

- Concurrent access to shared data may result in data inconsistency
- Maintaining data consistency requires mechanisms to ensure the orderly execution of cooperating processes
- Suppose that we wanted to provide a solution to the consumer-producer problem that fills all the buffers. We can do so by having an integer count that keeps track of the number of full buffers. Initially, count is set to 0. It is incremented by the producer after it produces a new buffer and is decremented by the consumer after it consumes a buffer.
Bounded-Buffer – Producer & Consumer Processes

Producer

item nextProduced;

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

Consumer

item nextConsumed;

while (1) {
    while (in == out)
        ; /* do nothing */
    nextConsumed = buffer[out];
    out = (out + 1) % BUFFER_SIZE;
}
while (true)

    /* produce an item and put in nextProduced */
    while (count == BUFFER_SIZE)
        ; // do nothing
    buffer [in] = nextProduced;
    in = (in + 1) % BUFFER_SIZE;
    count++;
Consumer

while (1)
{
    while (count == 0)
    {
        ; // do nothing
    }
    nextConsumed = buffer[out];
    out = (out + 1) % BUFFER_SIZE;
    count--; /* consume the item in nextConsumed */
}

Race Condition

- `count++` could be implemented as
  
  \[
  \begin{align*}
  \text{register1} &= \text{count} \\
  \text{register1} &= \text{register1} + 1 \\
  \text{count} &= \text{register1}
  \end{align*}
  \]

- `count--` could be implemented as
  
  \[
  \begin{align*}
  \text{register2} &= \text{count} \\
  \text{register2} &= \text{register2} - 1 \\
  \text{count} &= \text{register2}
  \end{align*}
  \]

- Consider this execution interleaving with “`count = 5`” initially:
  
  - S0: producer execute `register1 = count` \{`register1 = 5`\}
  - S1: producer execute `register1 = register1 + 1` \{`register1 = 6`\}
  - S2: consumer execute `register2 = count` \{`register2 = 5`\}
  - S3: consumer execute `register2 = register2 - 1` \{`register2 = 4`\}
  - S4: producer execute `count = register1` \{`count = 6`\}
  - S5: consumer execute `count = register2` \{`count = 4`\}
Solution to Critical-Section Problem

1. Mutual Exclusion - If process $P_i$ is executing in its critical section, then no other processes can be executing in their critical sections.

2. Progress - If no process is executing in its critical section and there exist some processes that wish to enter their critical section, then the selection of the processes that will enter the critical section next cannot be postponed indefinitely.

3. Bounded Waiting - 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.
   - Assume that each process executes at a nonzero speed
   - No assumption concerning relative speed of the $N$ processes

---

Operating System Concepts
Peterson’s Solution

- Two process solution
- Assume that the LOAD and STORE instructions are atomic; that is, cannot be interrupted.
- The two processes share two variables:
  - int turn;
  - Boolean flag[2]
- The variable turn indicates whose turn it is to enter the critical section.
- The flag array is used to indicate if a process is ready to enter the critical section. flag[i] = true implies that process P_i is ready!
Algorithm for Process $P_i$

do {
    flag[i] = TRUE;
    turn = j;
    while ( flag[j] && turn == j);

    CRITICAL SECTION
    flag[i] = FALSE;

    REMAINDER SECTION

} while (TRUE);
Many systems provide hardware support for critical section code

Uniprocessors – could disable interrupts
- Currently running code would execute without preemption
- Generally too inefficient on multiprocessor systems
  - Operating systems using this not broadly scalable

Modern machines provide special atomic hardware instructions
- Atomic = non-interruptable
  - Either test memory word and set value
  - Or swap contents of two memory words
TestAndndSet Instruction

Definition:

```c
boolean TestAndSet (boolean *target)
{
    boolean rv = *target;
    *target = TRUE;
    return rv;
}
```
Solution using TestAndSet

- Shared boolean variable lock, initialized to false.
- Solution:
  
  ```c
  do {
    while ( TestAndSet (&lock ))
      ; /* do nothing

    // critical section

    lock = FALSE;

    // remainder section
  } while ( TRUE);
  ```
Semaphore

- Synchronization tool that does not require busy waiting
- Semaphore $S$ – integer variable
- Two standard operations modify $S$: wait() and signal()
  - Originally called $P()$ and $V()$
- Less complicated
- Can only be accessed via two indivisible (atomic) operations
  - `wait (S) {
      while S <= 0
        ; // no-op
      S--;
    }
  - `signal (S) {
      S++;
    }`
Semaphore as General Synchronization Tool

- **Counting** semaphore – integer value can range over an unrestricted domain

- **Binary** semaphore – integer value can range only between 0 and 1; can be simpler to implement
  - Also known as **mutex locks**

- Can implement a counting semaphore $S$ as a binary semaphore

- Provides mutual exclusion
  - Semaphore $S$; // initialized to 1
  - wait ($S$);
  - Critical Section
  - signal ($S$);
Semaphore Implementation

- Must guarantee that no two processes can execute `wait()` and `signal()` on the same semaphore at the same time.
- Thus, implementation becomes the critical section problem where the wait and signal code are placed in the critical section.
  - Could now have busy waiting in critical section implementation
    - But implementation code is short
    - Little busy waiting if critical section rarely occupied
  - Note that applications may spend lots of time in critical sections and therefore this is not a good solution.
Semaphore Implementation with no Busy waiting

- With each semaphore there is an associated waiting queue. Each entry in a waiting queue has two data items:
  - value (of type integer)
  - pointer to next record in the list

- Two operations:
  - block – place the process invoking the operation on the appropriate waiting queue.
  - wakeup – remove one of processes in the waiting queue and place it in the ready queue.
Semaphore Implementation with no Busy waiting (Cont.)

- Implementation of wait:

```c
wait (S){
    value--;  
    if (value <= 0) {
        add this process to waiting queue
        block();  }
}
```

- Implementation of signal:

```c
Signal (S){
    value++;  
    if (value > 0) {
        remove a process P from the waiting queue
        wakeup(P);  }
}
```
Deadlock and Starvation

- **Deadlock** – two or more processes are waiting indefinitely for an event that can be caused by only one of the waiting processes.
- Let $S$ and $Q$ be two semaphores initialized to 1
  
  \[
  P_0 \\
  \text{wait (S);} \\
  \text{wait (Q);} \\
  \text{..} \\
  \text{..} \\
  \text{..} \\
  \text{signal (S);} \\
  \text{signal (Q);} \\
  
  P_1 \\
  \text{wait (Q);} \\
  \text{wait (S);} \\
  \text{..} \\
  \text{..} \\
  \text{..} \\
  \text{signal (Q);} \\
  \text{signal (S);}
  \]

- **Starvation** – indefinite blocking. A process may never be removed from the semaphore queue in which it is suspended.
Classical Problems of Synchronization

- Bounded-Buffer Problem
- Dining-Philosophers Problem
Bounded-Buffer Problem

- $N$ buffers, each can hold one item
- Semaphore `mutex` initialized to the value 1
- Semaphore `full` initialized to the value 0
- Semaphore `empty` initialized to the value $N$. 
Bounded Buffer Problem (Cont.)

- The structure of the producer process

```c
do {
    // produce an item
    wait (empty);
    wait (mutex);

    // add the item to the buffer
    signal (mutex);
    signal (full);
} while (true);
```
Bounded Buffer Problem (Cont.)

- The structure of the consumer process

```c
do {
    wait (full);
    wait (mutex);

    // remove an item from buffer
    signal (mutex);
    signal (empty);

    // consume the removed item
} while (true);
```
Dining-Philosophers Problem

- Shared data
  - Bowl of rice (data set)
  - Semaphore `chopstick [5]` initialized to 1
The structure of Philosopher $i$:

```c
Do {
    wait (chopstick[i]);
    wait (chopStick[(i + 1) % 5]);

    // eat

    signal (chopstick[i]);
    signal (chopstick[(i + 1) % 5]);

    // think

} while (true);
```
## Problems with Semaphores

- Correct use of semaphore operations:
  - signal (mutex) .... wait (mutex)
  - What happens?

<table>
<thead>
<tr>
<th></th>
<th>P0</th>
<th>P1</th>
</tr>
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<tbody>
<tr>
<td>wait(S);</td>
<td>wait(Q);</td>
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<td>wait(Q);</td>
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<td></td>
</tr>
</tbody>
</table>
Synchronization Examples

- Windows XP
- Linux
- Pthreads
Windows XP Synchronization

- Uses interrupt masks to protect access to global resources on uniprocessor systems
- Uses spinlocks on multiprocessor systems
- Also provides dispatcher objects which may act as either mutexes and semaphores
- Dispatcher objects may also provide events
  - An event acts much like a condition variable
Linux Synchronization

- Linux:
  - disables interrupts to implement short critical sections

- Linux provides:
  - semaphores
  - spin locks
Pthreads Synchronization

- Pthreads API is OS-independent
- It provides:
  - mutex locks
  - condition variables
- Non-portable extensions include:
  - read-write locks
  - spin locks
End of Chapter 6