CS 343 - Operating Systems

Module-3B

Process Synchronization Techniques

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Session Outline

- Background
- The Critical-Section Problem
- Peterson′s Solution
- Semaphores
- Mutex Locks
- Monitors

Objectives of Process Synchronization

- To introduce the concept of process synchronization.
- To introduce the critical-section problem, whose solutions can be used to ensure the consistency of shared data
- To present both software and hardware solutions of the critical-section problem
- To examine several classical process-synchronization problems
- To explore several tools that are used to solve process synchronization problems

Background

- Processes can execute concurrently
  - May be interrupted at any time, partially completing execution
- Concurrent access to shared data may result in data inconsistency
- Maintaining data consistency requires mechanisms to ensure the orderly execution of cooperating processes
- Illustration of the problem:

  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 `counter` that keeps track of the number of full buffers. Initially, `counter` 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

```
item buffer[BUFFER_SIZE]; int in = 0; int out = 0;
```

Producer

```
while (true) {
    /* produce an item
    in next produced */

    while (counter == BUFFER_SIZE)
    ;         /* do nothing */

    buffer[in] = next_produced;

    in = (in + 1) % BUFFER_SIZE;

    counter++;

}
```

Consumer

```
while (true) {

    while (counter == 0)

        ; /* do nothing */

    next_consumed = buffer[out];

    out = (out + 1) % BUFFER_SIZE;

    counter--;

    /* consume the item in next
    consumed */

}
```

Race Condition

- **counter++** could be implemented as

  register1 = counter

  register1 = register1 + 1

  counter = register1

- **counter--** could be implemented as

  register2 = counter

  register2 = register2 - 1

  counter = register2

- Consider this execution interleaving with count = 5 initially:

  S0: producer execute **register1 = counter** {register1 = 5}
  S1: producer execute **register1 = register1 + 1** {register1 = 6}
  S2: consumer execute **register2 = counter** {register2 = 5}
  S3: consumer execute **register2 = register2 – 1** {register2 = 4}
  S4: producer execute **counter = register1** {counter = 6 }
  S5: consumer execute **counter = register2** {counter = 4}

Critical Section Problem

- Consider system of **n** processes $\{\mathbf{p_0}, \mathbf{p_1}, \ldots \mathbf{p_{n-1}}\}$
- Each process has **critical section** segment of code
  - Process may be changing common variables, updating table, writing file, etc
  - When one process in critical section, no other may be in the same critical section
- **Critical section problem** is to design protocol to solve this

Critical Section

- Each process must ask permission to enter critical section in **entry section**, may follow critical section with **exit section**, then **remainder section**

- General structure of process **P**

```
do {
    entry section
        critical section
    exit section
        remainder section
} while (true);
```

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

Peterson's Solution

- Applicable for two process solution
- Assume that the **load** and **store** machine-language 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 $\mathbf{P_i}$ is ready!

Peterson's Solution

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);
```

Algorithm for Process P_j

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

    critical section

    flag[j] = false;

    remainder section

  } while (true);
```

Peterson's Solution

- All three CS requirement are met:

1. Mutual exclusion is preserved

   P_i enters CS only if:

   either **flag[j] = false** or **turn = i**

2. Progress requirement is satisfied

3. Bounded-waiting requirement is met

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);
```

Semaphore

- Synchronization tool for processes to synchronize their activities.
- Semaphore **S** – integer variable
- Can only be accessed via two indivisible (atomic) operations

```
wait(S)
{   while (S <= 0)
      ; // busy wait
      S--;
}
```

```
signal(S)
{
      S++;
}
```

Semaphore Usage

- **Binary semaphore** – value can range only between 0 and 1
  - Represents single access to a resource
- **Counting semaphore** – integer value (unrestricted range)
  - Represents a resource with N concurrent access
- Consider P_1 and P_2 that require S_1 to happen before S_2
  - Create a semaphore "**synch**" initialized to 0

```
P1:
   S1;
   signal(synch);
```

```
P2:
      wait(synch);
      S2;
```

Semaphore Implementation

- With each semaphore there is an associated waiting queue
- 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

- Semaphore uses two atomic operations
- Each semaphore has a queue of waiting processes
- When wait() is called by a thread:
  - If semaphore is open, thread continues
  - If semaphore is closed, thread blocks on queue
- When signal() opens the semaphore:
  - If a thread is waiting on the queue, the thread is unblocked
  - If no threads are waiting on the queue, the signal is remembered for the next thread

```
wait(S)
{   while (S <= 0)
    ;// busy wait
    S--;
}
```

```
signal(S)
{
    S++;
}
```

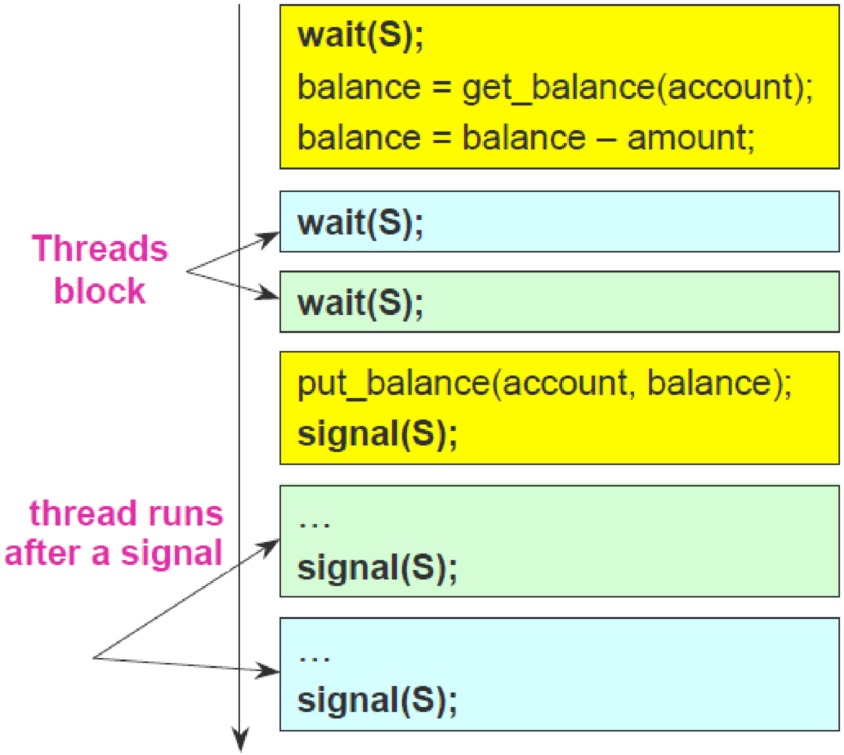
Semaphore Implementation

```
wait(semaphore *S)

{   S->value--;

    if (S->value < 0)

    {
        add this process to
        S->list;

        block();

    }

}
```

```
signal(semaphore *S)

{   S->value++;

    if (S->value <= 0)

    {
        remove a process P
        from S->list;

        wakeup(P);

    }

}
```

Semaphore Implementation

```
struct Semaphore {
    int value;
    Queue q;
} S;
withdraw (account, amount) {
    wait(S);
    balance = get_balance(account);
    balance = balance – amount;
    put_balance(account, balance);
    signal(S);
    return balance;
}
```



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