Operating Systems: Synchronization Tools and examples

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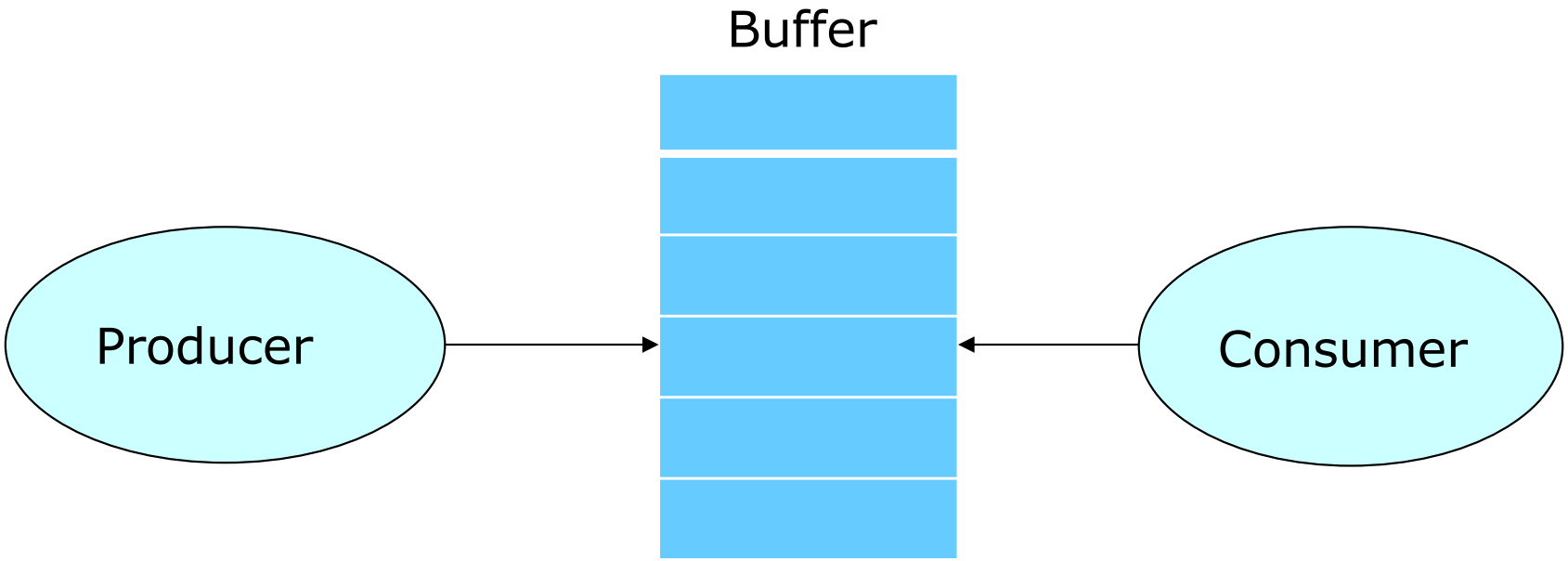
Acknowledgements: Material based on the textbook Operating Systems Concepts (Chapters 6 & 7)

Background

- Processes (and threads) can execute concurrently
- Concurrent access to shared data may result in data inconsistency
- Maintaining data consistency requires mechanisms to ensure the orderly execution of cooperating processes

Producer Consumer Problem

- A producer produces information and places in the buffer (bounded buffer).
- Consumer consumes information from the buffer.
- The producer and consumer must be synchronized, so that the consumer does not try to consume an item that has not yet been produced, and the producer must wait if the buffer is full.



Producer Consumer Problem contd..

- A solution to the consumer-producer problem can maintain an integer **`counter`** that keeps track of the number of full buffers.
- Initially, **`counter`** is set to 0.
- `counter` is incremented (`counter++`) by the producer after it produces a new buffer item and is decremented (`counter--`) by the consumer after it consumes a buffer.

Race Condition

Race condition results when several threads try to access and modify the same data concurrently – This creates data inconsistencies.

- `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 "counter = 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* parallel** processes {p_0, p_1, … p_{n-1}}
- Each process has **critical section** segment of code
  - Process may be changing common variables, updating table, writing file, etc
- **Goal:** When one process is in its critical section, no other process may be in its critical section and each process gets a turn (in bounded time) to execute its critical section
- ***Critical section problem*** is to design protocol to achieve this goal.
- To achieve the goal state above, each process must ask permission to enter critical section in **entry section**, may follow critical section with **exit section**, then **remainder section**
- **We will use Critical Section and CS interchangeably**

Critical Section

- General structure of process P_i

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

Solution requirement to CS Problem

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

Progress - If no process is executing in its critical section and some processes wish to enter their critical sections, then

1. Only those processes not executing in their remainder section can participate in deciding which will enter its CS next
2. This selection cannot be postponed indefinitely

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

Assumptions:

Assume that each process executes at a nonzero speed

No assumption concerning **relative speed** of the ***n*** processes

Critical-Section Handling in OS

- **Preemption**: The operating system removes the process running on the CPU after it has executed for the specified period of time, and brings another program in to run on the CPU. This act is called *preemption*.
- Two approaches taken by the kernel to handle CS:
  - **Preemptive** – allows preemption of process when running in kernel mode
  - **Non-preemptive** – runs until exits kernel mode, blocks, or voluntarily yields CPU
    - Essentially free of race conditions in kernel mode

- **Why would you prefer a Preemptive kernel?**
  - As it is more responsive,
  - Less risk for a kernel-mode process to use the processor for arbitrarily long period before relinquishing the processor to other waiting processes.

Peterson's Solution

- Good algorithmic description of solving the problem
- Two concurrent process solution (P_0 and P_1)
- Unfortunately, this solution not guaranteed to work on modern hardware, due to vagaries of load and store operations.
- The two processes share two variables:
  - **`int turn;`**
  - **`Boolean flag[2]`**
- The variable **`turn`** indicates whose turn it is to enter the CS
- 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!
  - Values of **`flag`** initialized to **`False`**.

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);
```

Entry Section

Exit Section

- Processes can execute this code arbitrarily many times.
- If `i=0` then `j=1` and visa versa.
- While loop in the entry section functions like a filter/trap.

Correctness of Peterson's Solution

- All three CS requirements are met.
- **Mutual exclusion** is preserved
  - If both P_0 and P_1 want to enter their CS this will result in both

    `flag[0] = T` and `flag[1] = T`
  - But `turn = 0` or `turn = 1`.
  - Since turn can be either 0 or 1 at any given time only one process can enter and thus execute in its CS.

Correctness of Peterson's Solution

- **Progress** is satisfied:
  - At any given time if both $\mathbf{P_0}$ and $\mathbf{P_1}$ want to enter the CS the decision which process enters its CS happens in finite time.
    - If both $\mathbf{P_0}$ and $\mathbf{P_1}$ want to enter this will result in both

      `flag[0] = T` and `flag[1] = T`
    - But `turn = 0` or `turn = 1.` The value of turn depends on the order of execution of the statement `turn = j;` in both processes $\mathbf{P_0}$ and $\mathbf{P_1}$
    - The value of **`turn`** will determine which process gets to enter its CS first.
    - This decision is made in finite time.
  - Additionally if process $\mathbf{P_0}$ (or $\mathbf{P_1}$) is executing in its remainder CS, it does not affect the other process from entering its CS.
  - Therefore progress is satisfied.

Correctness of Peterson's Solution

- **Bounded waiting** is satisfied
- Consider, $\mathbf{P_0}$ and $\mathbf{P_1}$ both want to enter their CS.
  - From Progress we know that one will enter its CS (lets say $\mathbf{P_0}$ gets its turn)
  - When $\mathbf{P_0}$ is in CS then `flag[0]=T` and `flag[1] = T` and `turn = 0`
  - When $\mathbf{P_0}$ exits its CS then `flag[0]=F`, `flag[1] = T` and `turn = 0`
  - Thus, $\mathbf{P_1}$ is the process that gets to enter its CS next.
  - Therefore, bounded waiting is satisfied, and a process will enter its critical section after at most one entry by *the other process* (bounded waiting).

Some pointers to check correctness of CS solution

- The trickiest requirement to prove is progress
  - If it is possible for ALL processes to be stuck at the while loop statement (remember processes can be preempted any time and any no. of times).
    - Progress requirement (condition 2) is violated.
  - Check if a process can enter its CS arbitrarily many times if the other processes do not wish to enter their CS. If this is not possible, then
    - Progress requirement (condition 1) is violated.
  - If strict order exists in which processes access their CS, then again
    - Progress requirement (condition 1) is violated.
- If it is possible for a process to enter its CS infinitely many times without giving other processes that wish to enter their CS a turn then
  - bounded waiting cannot be achieved.

Other Synchronization solutions

- Peterson's Algorithm drawbacks:
  - works for only two processes and
  - is not guaranteed to work on modern hardware.
- Systems with single processors – could **disable interrupts**
  - Currently running code would execute without preemption
  - Generally too inefficient on a multiprocessor systems
    - Disabling interrupts on a multiprocessor can be time consuming and system efficiency is decreased.
- All solutions hereafter based on idea of **locking**
  - Protecting critical regions via locks

Solution to Critical-section Problem - For Multiple Processes: Using Locks

```
do {
    acquire lock
        critical section
    release lock
        remainder section
} while (TRUE);
```

Mutex Locks

- OS designers build software tools to solve critical section problem
  - The simplest of tools is **mutex lock**
- Protect a critical section by first acquiring the lock using the **acquire()** operation, and releasing the lock using the **release()** operation.
  - Boolean variable indicating if lock is available or not
- Calls to **acquire()** and **release()** must be atomic
  - Usually implemented via hardware atomic instructions

acquire() and release()

- **Shared** Boolean `available`.
- `available = True` -> lock is available
- `available = False` -> lock is unavailable.

- **Acquire Operation:**

```
acquire() {
    while (!available)
        ; /* busy wait */
    available = false;
}
```

- **Release Operation:**

```
release() {
    available = true;
}
```

Solution using Mutex lock

```
do {
        acquire(); /*acquire lock*/
                critical section
        release(); /*release lock*/
                remainder section
 } while (true);
```

Issues with Hardware Instructions and Mutex Locks

- The issue with mutex locks is ***busy waiting***
  - Busy waiting consumes CPU cycles without doing any useful work.
  - This type of lock is known as a ***spinlock***, because the lock just sits there and spins while it waits.
  - Although busy waiting wastes CPU cycles, it saves time by not invoking context switches
  - Therefore, useful in multi-processing systems when the wait time is expected to be short - One thread spins on one processor while another completes their critical section on another processor.

Pthreads Synchronization

- Pthreads API is available for programmers at the user level and is not part of any particular kernel.
  - Provides mutex locks, condition variables, and read–write locks for thread synchronization.

`pthread_mutex_t` data type for mutex locks.

- mutex initialized with `pthread_mutex_init()` function.

```
pthread_mutex_lock();
pthread_mutex_unlock();
pthread_mutex_destroy();
```

Pthread Mutex Example

```
/*Declaring mutex*/

pthread_mutex_t mutex;

/*Initialize mutex, it returns 0

if mutex initialized with no errors.*/

if (pthread_mutex_init(&mutex, NULL) !=0){

        printf("Error in initializing mutex \n");

}


/*Acquire mutex lock*/

pthread_mutex_lock(&mutex);

/*Critical Section*/

/*Release mutex locks*/

pthread_mutex_unlock(&mutex);
```

Null indicates default mutex attributes passed.