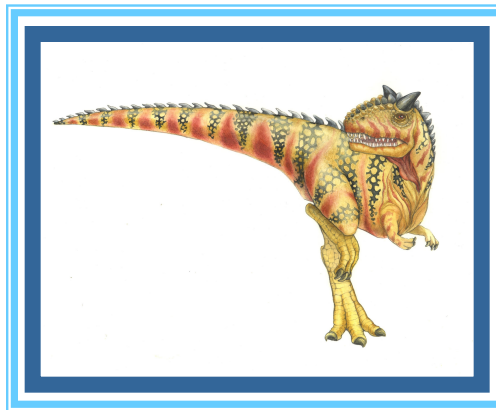


Process Synchronization





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	<code>register1 = counter</code>	{register1 = 5}
S1: producer execute	<code>register1 = register1 + 1</code>	{register1 = 6}
S2: consumer execute	<code>register2 = counter</code>	{register2 = 5}
S3: consumer execute	<code>register2 = register2 - 1</code>	{register2 = 4}
S4: producer execute	<code>counter = register1</code>	{counter = 6}
S5: consumer execute	<code>counter = register2</code>	{counter = 4}





Critical Section Problem

- Consider system of n processes $\{p_0, p_1, \dots, p_{n-1}\}$
- 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 its critical section
- **Critical section problem** is to design protocol to solve this
- Each process must ask permission to enter critical section in **entry section**, may follow critical section with **exit section**, then **remainder section**

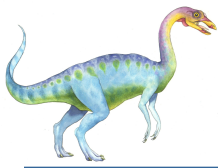




Solution to Critical-Section Problem

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





Mutex Locks

- OS designers build software tools to solve critical section problem
- Simplest is mutex lock
- Protect a critical section by first **acquire()** a lock then **release()** the lock
 - Boolean variable indicating if lock is available or not
- Calls to **acquire()** and **release()** must be atomic
 - Usually implemented via hardware atomic instructions
- But this solution requires **busy waiting**
 - This lock therefore called a **spinlock**





acquire() and release()

```
■ acquire() {  
    while (!available)  
        ; /* busy wait */  
    available = false;;  
}  
  
■ release() {  
    available = true;  
}  
  
■ do {  
    acquire lock  
    critical section  
    release lock  
    remainder section  
} while (true);
```





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

```
wait(S) ;  
wait(Q) ;  
...  
signal(S) ;  
signal(Q) ;
```

P_1

```
wait(Q) ;  
wait(S) ;  
...  
signal(Q) ;  
signal(S) ;
```

- **Starvation** – **indefinite blocking**
 - A process may never be removed from the semaphore queue in which it is suspended
- **Priority Inversion** – Scheduling problem when lower-priority process holds a lock needed by higher-priority process
 - Solved via **priority-inheritance protocol**





Condition Variables

- **condition x , y ;**
- Two operations are allowed on a condition variable:
 - **$x.\text{wait}()$** – a process that invokes the operation is suspended until **$x.\text{signal}()$**
 - **$x.\text{signal}()$** – resumes one of processes (if any) that invoked **$x.\text{wait}()$**
 - ▶ If no **$x.\text{wait}()$** on the variable, then it has no effect on the variable





Condition Variables Choices

- If process P invokes **`x.signal()`** , and process Q is suspended in **`x.wait()`** , what should happen next?
 - Both Q and P cannot execute in parallel. If Q is resumed, then P must wait
- Options include
 - **Signal and wait** – P waits until Q either leaves the monitor or it waits for another condition
 - **Signal and continue** – Q waits until P either leaves the monitor or it waits for another condition
 - Both have pros and cons – language implementer can decide
 - Monitors implemented in Concurrent Pascal compromise
 - ▶ P executing signal immediately leaves the monitor, Q is resumed
 - Implemented in other languages including Mesa, C#, Java





Pthreads Synchronization

- Pthreads API is OS-independent
- It provides:
 - mutex locks
 - condition variable
- Non-portable extensions include:
 - read-write locks
 - spinlocks





OpenMP

- OpenMP is a set of compiler directives and API that support parallel programming.

```
void update(int value)
{
    #pragma omp critical
    {
        count += value
    }
}
```

The code contained within the `#pragma omp critical` directive is treated as a critical section and performed atomically.

