Synchronization Principles

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

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

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

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

Consumer process
```c
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 – nondeterminism.
- 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. Given the set of concurrent processes, 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.
  - effective as a complete solution only on a single-processor machine
  - only for short critical sections
- How to eliminate context switch?
  - 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
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;
  ```

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

- Satisfies mutual exclusion, but not progress requirement.

Algorithm 2

- Shared variables:
  ```
  boolean flag[2];
  initially flag[0] = flag[1] = false;
  ```

- 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

- Combine 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. \( \Rightarrow \) called Peterson's algorithm.
Synchronization Using Special Instruction: TSL (test-and-set)

entry_section:
- TSL R1, LOCK
- CMP R1, #0
- JNE entry_section
- RET

exit_section:
- MOV LOCK, #0
- RET

- 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
  - If a process is switched out of CPU during critical section
    - other processes may have to waste a whole CPU quantum
    - may even deadlock with strictly prioritized scheduling

- Solution
  - Avoid busy wait as much as possible (yield the processor instead)
  - If you can’t avoid busy wait, you must prevent context switch during critical section (disable interrupts while in the kernel)

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