

Interprocess Communication (IPC)

Computer Operating Systems
BLG 312E

2016-2017 Spring

Types of Interaction

- three types of interaction between concurrent processes
 - resource sharing
 - communication
 - synchronization

Levels of Interaction

- interaction between processes can be on three levels
 - processes are not aware of each other (competing): using system resources (moderated by operating system)
 - processes are indirectly aware of each other (sharing): resource sharing through mutual exclusion and synchronization
 - processes are directly aware of each other (communicating)

Resource Sharing

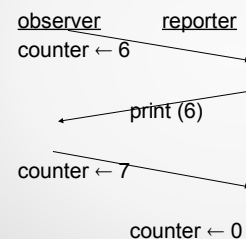
- mutual exclusion
 - two types of resources
 - 1) can be used by more than one process at a time (e.g. reading from a file)
 - 2) can be used by only one process at a time
 - due to physical constraints (e.g. some I/O units)
 - if the actions of one process interferes with those of another (e.g. writing to a shared memory location)
- synchronization
 - a process should proceed after another process completes some actions

Example

2 processes: Observer and Reporter
counter shared variable

```
observer:                reporter:
while TRUE {             while TRUE {
  observe;                print_counter;
  counter ++;             counter=0;
}
```

Example – Possible Errors



Example – Possible Errors

```
counter++  LOAD ACC, COUNTER
           INC  ACC
           SAVE COUNTER, ACC
```

Race:

- when processes access a shared variable
- when outcome depends on order and running speed of processes
- outcome may be different for different runs

Example – Possible Errors

P1: `k=0 (initial value)`
`while TRUE`
`k=k+1;`
what about the values of k depending on the order of P1 and P2 executions?

P2:
`while TRUE`
`k=k+1;`
SOLUTION: mutual exclusion

Sharing

- two types of sharing:
 - READ (no need for mutual exclusion)
 - WRITE (mutual exclusion needed)
- for consistency
 - mutual exclusion
 - synchronization

Synchronization

- outcome of programs should not be dependent on running order of processes
- programs working together may need to be synchronized at some points
 - e.g. a program uses output calculated by another program

Mutual Exclusion

critical section (CS): Part of code in a process in which operations on shared resources are performed.

mutual exclusion ensures that only one process executes a CS for a resource at a time

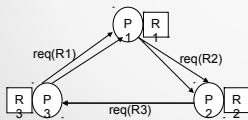
Example

P1:	P2:
<code>while TRUE {</code>	<code>while TRUE {</code>
<code><non-CS></code>	<code><non-CS></code>
<code>mx_begin</code>	<code>mx_begin</code>
<code><CS ops></code>	<code><CS ops></code>
<code>mx_end</code>	<code>mx_end</code>
<code><non-CS></code>	<code><non-CS></code>
<code>}</code>	<code>}</code>

Mutual Exclusion – Possible Problems

- deadlock
 - more than one process requires the same resources
 - each process does not release the resource required by the other

Example: 3 processes and 3 resources



P1() P2() P3()
 req(R1); req(R2); req(R3);
 req(R2); req(R3); req(R1);

Mutual Exclusion

- `mx_begin`
 - is there a process in its CS which has not yet executed `mx_end`?
 - if NOT
 - allow process to proceed into CS
 - leave mark for other processes
- `mx_end`
 - allow any process waiting to go into its CS to proceed
 - if there aren't any, then leave mark (empty)

Criteria for Mutual Exclusion Implementation

- only one process may be in its CS
- if a process wants to enter its CS and if there are no others executing their CS, it shouldn't wait
- any process not executing its CS should not prevent another process from entering its own CS
- no assumptions should be made about the order and speed of execution of processes
- no process should stay in its CS indefinitely
- no process should wait to enter its own CS indefinitely

Mutual Exclusion Solutions

- software based solutions
- hardware based solutions
- software and hardware based solutions

A Software Based Solution

- use a shared flag that shows whether a process is in its CS or not: `busy`
 - `busy ← TRUE` : process in CS
 - `busy ← FALSE` : no process in CS
- `mx_begin`: `while (busy);`
 - `busy = TRUE;`
 - wait until process in CS is finished
 - enter CS
- `mx_end`: `busy = FALSE;`

A Software Based Solution

- a possible error
 - `busy` is also a shared variable!
 - Example:
 - P1 checks and finds `busy=FALSE`
 - P1 interrupted
 - P2 checks and finds `busy=FALSE`
 - both P1 and P2 enter CS

Solutions Requiring *Busy Waiting*

```

shared variable turn = 1;
Process 1:      Process 2:
local variables  local variables
my_turn=1;        my_turn=2;
others_turn=2;    others_turn=1;

mx_begin: while (turn != my_turn);
mx_end  : turn = others_turn;
    
```

Solutions Requiring *Busy Waiting*

- uses up CPU time
- works properly but has limitations:
 - processes enter their CS in turn
 - depends on speed of process execution
 - depends on number of processes

Solutions Requiring *Busy Waiting*

- first correct solution: Dekker algorithm
- Peterson algorithm (1981)
 - similar approach to Dekker's algorithm
 - but is simpler

Peterson Algorithm

- shared variables:
 - req_1, req_2: bool and initialized to FALSE
 - turn: integer and initialized to "P1" or "P2"

```

P1:      P2:
mx_begin:  mx_begin:
req_1 = TRUE;  req_2 = TRUE;
turn = P2;    turn = P1;
while (req_2 && turn==P2);  while (req_1 && turn==P1);
< CS >      < CS >
mx_end: req_1 = FALSE;  mx_end: req_2 = FALSE;
    
```

Peterson Algorithm

- different scenarios:
 - P1 is active, P2 is passive
req_1=TRUE and turn=P2
req_2=FALSE so P1 proceeds after while loop
 - P1 in CS, P2 wants to enter CS
req_2=TRUE and turn=P1;
req_1=TRUE so P2 waits in while loop
P2 continues after P1 executes max_end

Peterson Algorithm

- (*different scenarios cntd.*):
 - P1 and P2 want to enter CS at the same time
- ```

P1: P2:
req_1=TRUE; req_2=TRUE;
turn=P2; turn=P1;

⇒ order depends on which process assigns value to the
 turn variable first.

```

## Hardware Based Solutions

- with uninterruptable machine code instructions completed in one machine cycle
  - e.g.: `test_and_set`
- busy waiting used
- when a process exits CS, no mechanism to determine which other process enters next
  - indefinite waiting possible
- disabling interrupts
  - interferes with scheduling algorithm of operating system

## Hardware Based Solutions

```
test_and_set(a): cc ← a
 a ← TRUE
```

- with one machine instruction, contents of "a" copied into condition code register and "a" is assigned TRUE

```
mx_begin: test_and_set(busy);
 while (cc) {
 test_and_set(busy);
 }
mx_end: busy=FALSE;
```

busy: shared variable  
cc: local condition code

## Semaphores

- hardware and software based solution
- no busy waiting
- does not waste CPU time
- **semaphore** is a special variable
  - only access through using two special operations
  - special operations cannot be interrupted
  - operating system carries out special operations

## Semaphores

- s: semaphore variable
  - special operations:
    - P (wait): when entering CS: `mutex_begin`
    - V (signal): when leaving CS: `mutex_end`
- ```
P(s) :      V(s) :
if (s > 0)   if (anyone_waiting_on_s)
  s=s-1;      activate_next_in_line;
else         else
  wait_on_s;  s=s+1;
```

Semaphores

- take on integer values (≥ 0)
- created through a special system call
- assigned an initial value
- binary semaphore:
 - can be 0/1
 - used for CS
- counting semaphore:
 - can be integers ≥ 0

Example: Observer – Reporter

```
global shared variables:
counter: integer;
sem: semaphore;

process P1:      process P2:
  observe;      ...
  P(sem);        P(sem);
                counter++;      print(counter);
                V(sem);          counter=0;
                ....            V(sem);

main_program:
  sem=1; counter=0;
  activate(P1);
  activate(P2);
```

Example: Observer – Reporter

sample run:

```
P1: P(sem) ... sem=0;
P2: P(sem) ... sem=0 so P2 is suspended
P1: V(sem) ... P2 is waiting for sem; activate P2
P2: V(sem) ... no one waiting; sem=1
```

Synchronization with Semaphores

- a process may require an event to proceed – process is suspended
 - e.g. process waiting for input
 - another process detecting the occurrence of event wakes up suspended process
- ⇒ “suspend – wake-up” synchronization

Synchronization with Semaphores

- solution:

```
event: semaphore; event=0;
```

```
process P1:      process P2:
...              ...
P(event);        ...
...              V(event);
...              ...
```

- more than two processes may be synchronized

Semaphores

Initial value for semaphore:

- =1 for mutual exclusion
- =0 for synchronization

Semaphores

- possible deadlock scenario:

```
x, y: semaphore;
x=1; y=1;
```

```
process 1:  process 2:
...         ...
P(x);      P(y);
...         ...
P(y);      P(x);
...         ...
V(x);      V(y);
V(y);      V(x);
...         ...
```

