Interprocess Communication

Types of Interaction

- between concurrent processes
  - resource sharing
  - communication
  - synchronization

Levels of Interaction

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

Resource Sharing

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

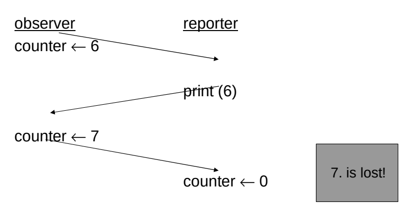
Example

- 2 processes: Observer and Reporter
- `counter` shared variable

```
observer:
while TRUE {
     observe;
     counter ++;
}
```

```
reporter:
while TRUE {
     print_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
  - outcome depends on order and running speed of processes
  - may be different for different runs

Example – Possible Errors

P1:
```
while TRUE
   k=k+1;
```

P2:
```
while TRUE
   k=k+1;
```

`k=0` (intial value)

what about the values of k depending on the order of **P1** and **P2** executions?

SOLUTION: mutual exclusion

Sharing

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

Synchronization

- 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: only one process can execute a CS for a resource at a time

Example

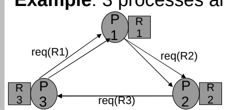
P1:
```
while TRUE {
   <non-CS>
   mx_begin
       <CS ops>
   mx_end
   <non-CS>
}
```

P2:
```
while TRUE {
   <non-CS>
   mx_begin
       <CS ops>
   mx_end
   <non-CS>
}
```

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`
  - any processes in its CS which have not 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 CS to proceed
  - if not leave mark (empty)

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 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*

```
         global 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*

- use 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
  - simpler

Peterson Algorithm

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

P1:

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

mx_end: req_1 = 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
- is assigned an initial value
- binary semaphore:
  - can be 0/1
  - used for CS
- counting semaphore:
  - can be integers >=0

Example: Observer – Reporter

```
global variables:
  counter: integer;
  sem: semaphore;
process observer:          process reporter:
  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 occurence 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);
 ...               ...
```

Pay attention to the order of P and V!