TDDD36

Secure Mobile Systems

Systems Software

Lecture 2: Semaphores & Monitors

Simin Nadjm-Tehrani

Real-time Systems Laboratory

Department of Computer and Information Science
Linköping University

So far...

- Seen one method for dealing with mutual exclusion when sharing common resources: busy waiting

This lecture

- How can the mutual exclusion and synchronisation problems be solved with other constructs?
  - Semaphore and monitor
- What do we gain by using the support in OS or programming language?

Summary of early solutions

- Busy waiting solutions to mutual exclusion problems are:
  - Difficult to implement – consider n processes instead of 2 in solution from last lecture!
  - Wasteful for the CPU as a resource
- But...
  - They do not require any support
- Would be useful to have support from an operating system or a programming language

Semaphores

- A semaphore S is a non-negative integer variable on which only two operations **wait** and **signal** can be performed

```
wait(S)
  if S > 0 then S = S-1 else
  suspend the process calling wait(S)

signal(S)
  if some process P has been suspended by
  an earlier wait(S), then wake up P
  else S = S+1
```


Recall: two general problems

- Mutual exclusion

```
Process Pi
  {
  entry-protocol
       critical-section
  exit-protocol
  non-critical-section
  }
```

- Condition synchronisation
  - Ex: Compute the interest when all transactions have been processed

Using a semaphore ...

- Let's use a semaphore with the following implementation for solving mutual exclusion

```
wait(S)
  if S > 0 then S = S-1 else
  suspend the process calling wait(S)

signal(S)
  if some process P has been suspended by
  an earlier wait(S), then wake up P
  else S = S+1
```


Mutual exclusion

```
var mex: semaphore;
(* initially 1 *)
process Pi;
  loop
     wait(mex);
     critical_section;
     signal(mex);
     non_critical_section;
  end
end Pi;
```


Food for thought

Questions:

- How does the program behave with initial value 0 for the semaphore?
- If there are two processes, what is the maximum value of mex?
- If there are n processes?

Counting semaphores

- When more than one instance of a resource is available, e.g. print servers
- Processes can use up to max available but no more
- The semaphore can be initialised to provide access for n processes

Recall: two general problems

- Mutual exclusion

```
Process Pi
  {
  entry-protocol
       critical-section
  exit-protocol
  non-critical-section
  }
```

- Condition synchronisation
  - Ex: Compute the interest when all transactions have been processed

Condition synchronisation

```
var condition:semaphore;
(* initially 0*)

process P1; (* waiting process *)
...
wait(condition)
...
end P1;
process P2; (* signalling process *)
...
signal(condition)
...
end P2;
```

Semaphore implementations

- Wait and Signal are implemented as atomic operations
- Semaphore variable is always initialised as non-negative

But

- Which process to wake up among all suspended ones is not specified

Atomicity: alternatives

- For programmer wait and signal are atomic (indivisible) operations
- In the supporting environment, atomicity has to be assured by:
  - allowing only one wait/signal to operate on a semaphore at any one time e.g. by
    - disabling interrupts during execution
    - busy waiting on entry to semaphore ☺
    - hardware support (e.g. test-and-set operations) for locking before wait/signal

Spin locks

- The original definitions of wait & signal just used a version of busy waiting to implement the semaphore:

```
wait(s): while s ≤ 0 do nothing;
         s = s-1
signal(s): s = s+1
```


Semaphore implementations

- Wait and Signal are implemented as atomic operations
- Semaphore is always initialised as non-negative

But

- Which process to wake up among all suspended ones is not specified

Different implementations

```
process P1;
...
wait(s)
...
signal(s)
...
end;
```

```
process P2;
...
wait(s)
...
signal(s)
...
end;
```

```
process P3;
...
wait(s)
...
signal(s)
...
end;
```

One queue/semaphore at run-time:

Semaphores vs. Busy waiting

- For long critical sections, semaphores more efficient in using CPU
- Better code organisation, less errors?

- What about problems with deadlock and starvation?
- We will come back to these …

Example

```
process A                process B
while (true){            while (true) {
  print(A)                 print(T)
  print(K)                 print(C)
 }                          }
```

Insert semaphores so that a sequence of “TACK”s is printed out.

Student solution

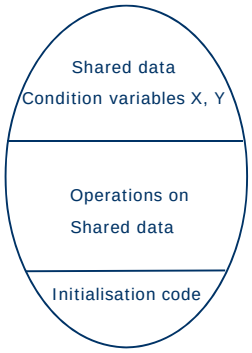
```
var S: semaphore (* initially 1 *)
var Z: semaphore (* initially 1 *)
process A                process B
while (true){            while (true) {
 wait(S);                 wait(S);
  print(A);                print(T);
 signal(S);               wait(Z);
 wait(Z);                 signal(S);
  print(K);                print(C);
 signal(Z)                signal(Z)
}                        }
```


What is a monitor?

- A programming abstraction consisting of:
  - A data structure on which programmer can define operations – which can only be run one at a time
  - Condition variables for synchronisation
- Encapsulates shared data that several processes can operate upon
- All access is with mutual exclusion
- Pre object-orientation!

[Hoare 74]

Overview



Condition variables

- Declared as special synchronisation variables:
  Condition X;
- With two designated operations:

wait(X): suspend the calling process

signal(X): if there are suspended processes on this variable, wake one up

Example: Bounded buffer

```
(* in some language that supports monitors *)

monitor BoundedBuffer;
Buf: array [0..SizeOfBuffer] of integer;
Base, Top: integer;
Count: integer;
NotFull, NotEmpty: condition;
operation Append(E: integer);
...
end Append;
operation Take(var E: integer);
...
end Take;
begin
<initialize> (* set Base,Top,Count to 0 *)
end BoundedBuffer;
```

Operation Append

```
operation Append (E: integer);
begin
if Count == SizeOfBuffer + 1 then
wait(NotFull);
Buff[Top] = E;
Top = (Top + 1) mod SizeOfBuffer;
Count = Count + 1;
signal(NotEmpty)
end Append;
```


Operation Take

```
operation Take (var E: integer);
begin
if Count == 0 then
wait(NotEmpty);
E = Buff[Base];
Base = (Base + 1) mod SizeOfBuffer;
Count = Count - 1;
signal(NotFull)
end Take;
```


Producer-Consumer problem

```
process Producer;
var Element:
  integer;
begin
  loop
  Produce(Element);
  Append(Element)
  end
end Producer;
```

```
process Consumer;
var Element:
  integer;
begin
  loop
  Take(Element);
  Consume(Element)
  end
end Consumer;
```

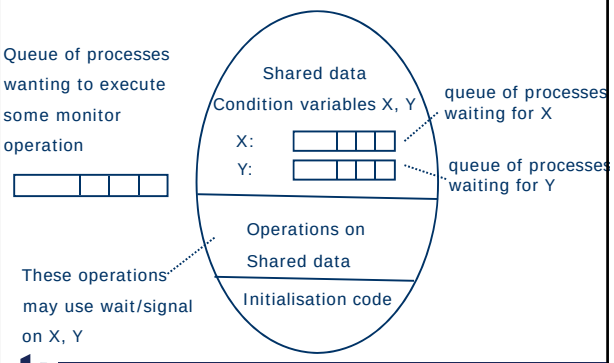

Observations

- Programmer uses **wait** and **signal** inside the code that defines the operations on the shared data structure

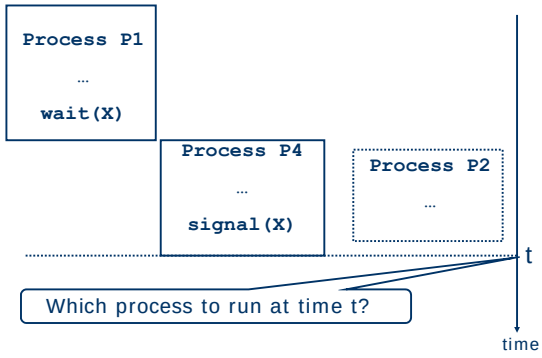
Note:

- The condition variable has no values assigned to it
- The queue associated with each variable is the main synchronisation mechanism
- Different semantics from semaphore operations for **wait** and **signal**

Process queues



How does it work?



Options

- Original Hoare monitor: let the woken up process (P1) continue

What if there are several processes waiting on X?

- Pragmatic solution (Java): let the signalling process continue, and wake up P1 once P4 is suspended/exits

P1 has to check for condition X when woken up!

Summary

- Monitors have the same power as semaphores but are at a higher level of abstraction
  - Exercise: Try implementing producer-consumer solution with semaphores!
- Monitor has two different mechanisms for handling synchronisation and for data communication
- Mutually exclusive access to data automatic, but matching waits and signals still a problem!

Questions?