Semaphores

Semaphore Types
Simple Synchronization
Synch./Coordination
Problems…

Types of Semaphores….

Recall the "implementation" of a semaphore.

We can modify our semaphore implementation to prevent s.count from becoming negative. s.count can then be of type unsigned integer!!

Also, the modified version will ease the definition of two different types of semaphores:

- binary semaphores
- general counting semaphores

```
type semaphore…

typdef struct{
unsigned int count;
list_of_processes queue;

} semaphore;
```

```
P(s):     if s.count ≥ 1 then s.count --
else block(s)
```

where block(s) places the process on s.queue and invokes the process scheduler.

```
V(s):     if s.queue is non-empty then
      wakeup(s);
else s.count ++;
```

where wakeup(s) removes a process from s.queue and places it into the ready list.

binary vs. counting

The type of semaphore can generally be determined by inspecting the definition.

For a binary semaphore, the values are restricted to 0 and 1 (i.e.,s.count is binary).

A counting semaphore can take on any integer value v≥0; i.e., s.count can be used to reflect the number of available resources

- Semaphores used to provide mutual exclusions are generally defined as binary semaphores:
  - typical definitions:
  - semaphore mutex = 1;
  - semaphore mutex = 0;
- Note: do not confuse counting semaphores that are initialized to 1 with a binary semaphore. There is a difference → s.count is bounded to an max. value of 1.
- The exact type is often implicit in the type of use (eg. mutex)

simple synchronization

Counting semaphores are used to manage limited resources and corresponding access to them.

Binary semaphores are usually used to facilitate mutual exclusion; i.e., only a single process is allowed to access the CS.

Notation found in the literature may vary:

- P(s) == wait(s) == down(s)
- V(s) == signal(s) == up(s)

Note: Implementation of queuing determines if starvation of waiting processes can occur!!

Example: Mutex with Semaphores:

```
semaphore mutex =1;

process p_i:

while(1){
    P(mutex);
    access CS;
    V(mutex);
    do the rest of the prog.
}
```

What would happen if mutex was initialized to 0?

Classical Problems

The study of Process synchronization and coordination has led to a number of problem types:

- Mutual Exclusion problem
- Producer/Consumer problem
- Readers/Writers problem

We have already seen solutions to the MUTEX problem.

To demonstrate the Producer/Consumer problem, we consider the famous bounded buffer problem. First, a simple version:

- Let buffer B consist of *n* empty buffer slots;
- Let *e* be a counting semaphore that keeps track of how many empty slots are left in B.
- Let *f* be a counting semaphore that keeps track of how many full slots there are in B.
- Last but not least we use a binary semaphore *b* to provide mutex.
- The semaphores are initialized as:
  - e = n (why ??)
  - f = 0 (why ??)
  - b = 1 (why ??)

..bounded buffer problem

```
Bounded Buffer Solution:

semaphore e = n, f = 0, b = 1;
cobegin
  producer: while(1){
    produce next element;
1:              P(e);
2:              P(b);
    add element to B;
3:              V(b);
4:              V(f);   }
//
  consumer: while(1){
5:               P(f);
6:               P(b);
     remove element from B;
7:               V(b);
8:               V(e);
     consume the element;  }
coend;
```

- A few things to consider:
  - Will this solution work for multiple consumers and producers?
  - Does it matter in which order we call P(e)-P(b) and P(f)-P(b)
  - Can we swap just lines 1&2 ??
  - Can we swap just lines 7&8 ??
  - Does it matter how buffer B is being implemented?

The readers/writers problem

One of the most studied problems in process synch. is the readers/writers problem.

Let R = {$r_1..r_m$} a set of processes that read from a database. Let W = {$w_1..w_k$} be the set of processes that write values to the same database.

The system is subject to the following constraints:

1. Readers and writers can never access the database simultaneously;
1. Only a single writer at a time is allowed in the database;
1. Multiple readers may access the database simultaneously;

We can distinguish 3 versions of the R/W problem:

1. Weak Reader Priority
2. Strong Reader Priority
3. Writer Priority

For the weak reader priority, an arriving writer waits until there are no more active readers.

Strong reader priority meets the constraints of weak reader priority, with the addition that a waiting reader has priority over a waiting writer.

For writer priority, an arriving reader waits until there are no more active or waiting writers.

Weak Reader Priority

Semaphore Solution for Weak Reader Priority:

```
shared var
 int nreaders = 0;
 semaphore: rmutex, wmutex = 1;

writer_i:

 while(1){
   … // progr. outside the DB;

  P(wmutex);

    write data to the DB;

  V(wmutex);

 }
```

```
reader_i:

 while(1){
   … // prog. outside the DB;

   P(rmutex);
   if (nreaders == 0){
       nreaders++;
       P(wmutex);
   }
   else nreaders++;

   V(rmutex);
    read the DB;
    P(rmutex);
    nreaders--;
    if (nreaders == 0)
      V((wmutex);
    V(rmutex)
 }
```

…weak reader discussion

- What are the things to be noted in the weak reader solution:

1. multiple readers can enter the database.
1. only the first reader blocks arriving writers (P(wmutex)).
1. The last reader unblocks waiting writers and enables arriving writers to enter the DB (V(wmutex))

1. we need to maintain a counter that keeps track of the number of readers that are in the DB.
1. does nreaders also count waiting readers?
1. why is this a weak reader priority solution??
1. What do you suggest to change to make it a strong reader priority?

Strong Reader Priority…

Semaphore Solution for
Strong Reader Priority:

```
shared var
  int nreaders = 0;
  semaphore: rmutex, wmutex, srmutex = 1;

writer_i:

  while(1){
    … // progr. outside the DB;

    P(srmutex);
    P(wmutex);

      write data to the DB;

    V(wmutex);
    V(srmutex);
  }
```

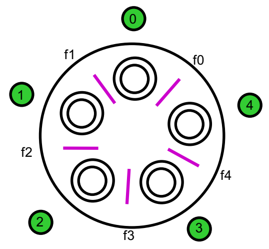
```
reader_i:

  while(1){
    … // prog. outside the DB;

    P(rmutex);
    if (nreaders == 0){
        nreaders++;
        P(wmutex);
    }
    else nreaders++;

    V(rmutex);
     read the DB;
     P(rmutex);
     nreaders--;
     if (nreaders == 0)
       V((wmutex);
     V(rmutex)
  }
```

…strong reader discussion

- When the first reader enters the DB, nreader > 0.
- All subsequent readers, i.e., those waiting on rmutex and those arriving can enter while nreaders > 0;
- The first arriving writer is blocked on wmutex while nreaders > 0.
- subsequent writers are blocked on srmutex.
- Arriving readers are blocked on wmutex while a writer is active.
- subsequent readers will wait on rmutex.
- A departing writer will signal wmutex, thereby unblocking the first reader.
- It will also signal srmutex, thereby unblocking a writer, which will then wait on wmutex.

..dinner-time: Dining Philosophers

5 philosophers, p_i ($1 \leq I < 5$), sit at a round table with a bowl of spaghetti in the center. In front of each philosopher is a plate. To the left and the right of the plate is one fork. In order to eat, a philosopher need to use 2 forks. (see picture)



Philosophers mostly think but at unspecified times they get hungry and wish to eat.
To do that, philosopher p_i must pick up forks f_i and $f_{(i+1)\%5}$.

The problem: develop a fork acquisition protocol that is:
1. deadlock free
2. fair
3. maximally concurrent

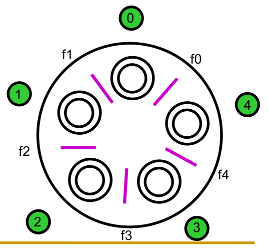
..dining philosophers…

We can abstract the problem by the following code:

```
p(i):{
  while(1){
    think(i);
    grab_forks(i);
    eat(i);
    return_forks(i);
  }
}
```

a naïve semaphore solution:

```
grab_forks(i):
  P(f[i]); P(f[(i + 1)%5]);

return_forks(i):
 V(f[i]); V(f[(i + 1)%5]);
```



The key is in the implementation of *grab_forks(i),* as it determines if p_i is allowed to eat.

…food for thought…

- What's wrong with the naïve solution?? → *DEADLOCK !!*
- How can this happen? Analyze!
- One way to break a circular wait is to implement a global counter (counting semaphore) that will limit the number philosophers to grab a fork to n-1.
- How does this help?
- Another way to break a circular wait is to implement one philosopher (i.e., p_1) to ask for the right fork before asking for the left. All others are asking for the left fork first.
- However, this solution violates the concurrency requirement as with one eating others might be blocked.
- How?? Let's analyze

another thought….

- We decide to divide the philosophers in an even and an odd group (aren't they all).
  - the even group picks up left before right fork
  - the odd group picks up right before left fork
- We still need to worry about starvation of individual philosophers.
- With regular semaphores, there is not much we can do, and the solutions are never satisfactory.
- We will revisit the dining philosophers later, with new coordination mechanisms.
- Examples:
  - AND synchronization
  - Monitors
- Think about why the dining philosopher problem is so important and what it contributes to research in process synchronization!