操作系统原理

第七章：进程同步

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目录

Outline

Background

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- Solution to *producer and consumer problem* (Chapter 4) allows at most *(BSIZE - 1)* items in buffer at the same time.
  - A solution, where all *BSIZE* buffers are used is NOT simple.
  - Suppose that we modify the code by adding a variable *counter*.

Producer and consumer problem

Producer and consumer problem

- Shared-memory bounded-buffer

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- Shared-memory bounded-buffer

```
/* Shared variables */
#define BSIZE 10
struct item {
    ....
} buffer[BSIZE];
int in = 0, out = 0, counter = 0;
/*------------------------------------------------------------------*/
```

```
/*The producer loop*/
while(1) {
  /*produce an item*/
  while(counter == BSIZE)
    /*do nothing*/;
  buffer[in] = itemProduced;
  in = (in + 1) % BSIZE;
  counter++;
}
```

```
/*The consumer loop*/
while(1) {
  while(counter == 0)
    /*do nothing*/;
  itemConsumed = buffer[out];
  out = (out + 1) % BSIZE;
  counter--;
  /*consume the item*/
}
```

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  - We can show that the value of *counter* may be incorrect as follows.
- Note that the "*counter*++" and "*counter*−−" may be implemented in machine language as

```
; counter++
register1 = counter           ; load the counter to a register
register1 = register1 + 1     ; add
counter = register1           ; write back

; counter--
register2 = counter           ; load the counter to a register
register2 = register2 - 1     ; subtract
counter = register2           ; write back
```

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T_4	*counter*=register1		{*counter*=6}
T_5		*counter*=register2	{*counter*=4}

- The value of *counter* may be either 4 or 6, while the correct result should be 5.

Questions

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Race condition (1/2)

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- How do we avoid race condition?
  - Find some way to prohibit more than one process from reading and writing the shared data concurrently.
  - That is, the access must be *serialized* even if the processes attempt concurrent access.

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3. **Bounded waiting**: No process should have to wait forever to enter its critical section;

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2. **Progress**: No process running outside its critical section may block other processes trying to enter its critical section;
3. **Bounded waiting**: No process should have to wait forever to enter its critical section;
4. **Speed**: No assumptions may be made about speeds or the number of the CPUs.

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} while (1);
```

- In the following slides, we will try to construct several "entry section" and "exit section" to solve the race condition.

Questions

- Any questions?

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First try

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int turn = 0; // or 1
do {
  while(turn != i);   // entry section

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  turn = j;           // exit section

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```

- Does it satisfy all 4 requirements for a solution?

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- Does it satisfy all 4 requirements for a solution?
  - No, it breaks the **progress** requirement.

Second try

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```
bool flag[2] = {false, false};
do {
  // entry section
  flag[i] = true;
  while(flag[j]);

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  flag[i] = false; // exit section

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Second try

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bool flag[2] = {false, false};
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  flag[i] = false; // exit section

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```

- Does it satisfy all 4 requirements for a solution?
  - No, it breaks the **progress** requirement too.

Third try

Third try

```
int turn = 0; // or 1
bool flag[2] = {false, false};
do {
  // entry section
  flag[i] = true;
  turn = j;
  while(flag[j] && turn == j);

  CRITICAL SECTION

  flag[i] = false; // exit section

} while (1);
```

- Does it satisfy all 4 requirements for a solution?

Third try

```
int turn = 0; // or 1
bool flag[2] = {false, false};
do {
  // entry section
  flag[i] = true;
  turn = j;
  while(flag[j] && turn == j);

  CRITICAL SECTION

  flag[i] = false; // exit section

} while (1);
```

- Does it satisfy all 4 requirements for a solution?
  - Yes, it's a correct solution and is known as *Peterson's algorithm*.

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```
bool choosing[n] = {false, ..., false};
int number[n] = {0, ..., 0};
do {
  // entry section
  choosing[i] = true;
  number[i] = max(number[0], ..., number[n-1])+1;
  choosing[i] = false;
  for(j=0; j < n; j++) {
    while(choosing[j]);
    while((number[j]!=0)&&(number[j],j)<(number[i],i));
  }

  CRITICAL SECTION

  number[i] = 0; // exit section

} while (1);
```

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Disabling interrupts

- The CPU is only switched from process to process as a result of clock or other interrupts.
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- Disadvantages
  1. User processes should NOT be able to disable the interrupts;
  2. It's not feasible in a multiprocessor system.

TSL and SWAP (1/3)

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```
bool TSL(bool &target)
{
  bool rv = target;
  target = true;
  return rv;
}
```

```
void SWAP(bool &a, bool &b)
{
  bool temp = a;
  a = b;
  b= temp;
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  bool temp = a;
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  b= temp;
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- Bear in mind that TSL and SWAP are executed *atomically*, that is, as one uninterruptible unit.

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```
bool lock = false;
do {
  // entry section
  while(TSL(lock))
    ;

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  // exit section
  lock = false;

} while (1);
```

```
bool lock=false;
do {
  // entry section
  bool key = true;
  while(key == true)
    SWAP(lock, key);

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  // exit section
  lock = false;

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- But these two algorithms do NOT satisfy the **bounded-waiting** requirement.

TSL and SWAP (3/3)

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- A correct solution using TSL

TSL and SWAP (3/3)

- A correct solution using TSL

```
bool lock = false, waiting[n] = {false, ..., false};
do {
  // entry section
  waiting[i] = true;  bool key = true;
  while(waiting[i] && key)
    key = TSL(lock);
  waiting[i] = false;

  CRITICAL SECTION

  // exit section
  int j = (i + 1) % n;
  while((j != i) && !waiting[j])
    j = (j+1) % n;
  if(j == i)      lock = false;
  else            waiting[j] = false;

} while (1);
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- This type of solution is also called a *spinlock*.
  - Because the process "spins" while waiting on a lock.
  - The spinlocks are **only** useful in multiprocessor systems.
    - Because no context switch is required if the locks are expected to be held for short times.

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  - It's invented by *Edsger Dijkstra* and first used in the *THE* operating system.
- What's the semaphore?
  - A semaphore S is an integer variable that, apart from initialization, is accessed **only** through two standard **atomic** operations: $P(down)$ and $V(up)$.

Implementation (1/2)

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```
typedef struct {
  int value;

  /*processes blocked by this semaphore*/
  struct PCB *L;
} semaphore;
```

```
void P(semaphore *S) {
 S->value--;
 if(S->value < 0) {
  Add (curproc) to S->L;

  (curproc)->state=WAITING;
  scheduler();
 }
}
```

```
void V(semaphore *S) {
  S->value++;
  if(S->value <= 0) {
    Remove a proc (A) from S->L;

    (A)->state=READY; //Wakeup (A)

  }
}
```

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        2. Spinlocks in multi-processor systems.

Application programming interface

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  - A data object is to be shared among several concurrent processes.
    - Some of them (*readers*) may want **only** to read the data object, while others (*writers*) may want to update the data object.
  - Multiple readers may read the data object simultaneously, but the writers must have exclusive access to the data object.

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  - A data object is to be shared among several concurrent processes.
    - Some of them (*readers*) may want **only** to read the data object, while others (*writers*) may want to update the data object.
  - Multiple readers may read the data object simultaneously, but the writers must have exclusive access to the data object.
- The dining-philosophers problem

Classic problems of synchronization

- The producer and consumer problem
  - Explained in the chapter “Process Management”.
- The readers-writers problem
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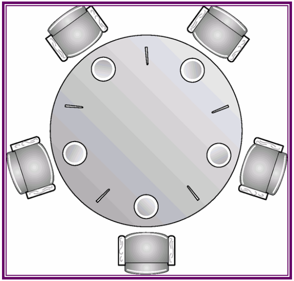

The producer and consumer problem (1/2)

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- A semaphore *mutex* is used to protect the critical section when accessing the buffer.
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  - *empty* is initialized to the value *BSIZE*;
  - *full* is initialized to the value 0.

The producer and consumer problem (2/2)

The producer and consumer problem (2/2)

```
/*The producer loop*/
do {
    ...
    produce an item;
    ...
   P(&empty);
   P(&mutex);
    ...
   add the item to buffer;
    ...
   V(&mutex);
   V(&full);
} while(1);
```

The producer and consumer problem (2/2)

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do {
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   produce an item;
   ...
   P(&empty);
   P(&mutex);
   ...
   add the item to buffer;
   ...
   V(&mutex);
   V(&full);
} while(1);
```

```
/*The consumer loop*/
do {
   P(&full);
   P(&mutex);
   ...
   remove an item from buffer;
   ...
   V(&mutex);
   V(&empty);
   ...
   consume the item;
   ...
} while(1);
```

Questions

- Any questions?

The readers-writers problem (1/2)

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  - *mutex* is initialized to the value 1.

The readers-writers problem (2/2)

The readers-writers problem (2/2)

```
/*The writer loop*/
do {
    P(&wrt);
     ...
     writing is performed
     ...
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} while(1);
```

The readers-writers problem (2/2)

```
/*The writer loop*/
do {
    P(&wrt);
    ...
    writing is performed
    ...
    V(&wrt);
} while(1);
```

```
/*The reader loop*/
do {
    P(&mutex);
    readcount++;
    if(readcount == 1)
      P(&wrt);
    V(&mutex);
    ...
    reading is performed
    ...
    P(&mutex);
    readcount--;
    if(readcount == 0)
      V(&wrt);
    V(&mutex);
} while(1);
```

Questions

- Any questions?

The dining-philosopher problem (1/3)

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```
semaphore chopstick[5] = {1, ..., 1};
/*philosopher i*/
do {
    ...
    thinking
    ...
   P(&chopstick[i]);
   P(&chopstick[(i + 1) % 5]);
    ...
    eating
    ...
   V(&chopstick[(i + 1) % 5]);
   V(&chopstick[i]);
} while(1);
```

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   ...
   eating
   ...
  V(&chopstick[(i + 1) % 5]);
  V(&chopstick[i]);
} while(1);
```

- Is this a correct solution?
  - No.

The dining-philosophers problem (2/3)

The dining-philosophers problem (2/3)

```
#define N          5
#define LEFT       ((i-1) % N)
#define RIGHT      ((i+1) % N)

enum {THINKING, HUNGRY, EATING} state[N];
semaphore mutex = 1; /*used to protect the 'state'*/

semaphore s[N] = {0, ..., 0};

               void philosopher(int i)
               {
                 while(1) {
                   think();
                   take_forks(i);
                   eat();
                   put_forks(i);
                 }
               }
```

The dining-philosophers problem (3/3)

The dining-philosophers problem (3/3)

```c
void test(int i)
{
   if(state[i] == HUNGRY &&
      state[LEFT] != EATING &&
      state[RIGHT] != EATING) {
     state[i] = EATING;
     V(&s[i]);
   }
}
```

The dining-philosophers problem (3/3)

```
void test(int i)
{
  if(state[i] == HUNGRY &&
     state[LEFT] != EATING &&
     state[RIGHT] != EATING) {
    state[i] = EATING;
    V(&s[i]);
  }
}
```

```
void take_forks(int i)
{
  P(&mutex);
  state[i] = HUNGRY;
  test(i);
  V(&mutex);
  P(&s[i]);
}
```

```
void put_forks(int i)
{
  P(&mutex);
  state[i] = THINKING;
  test(LEFT);
  test(RIGHT);
  V(&mutex);
}
```

Questions

- Any questions?

Binary semaphore

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- A *binary semaphore* is a semaphore with an integer value range only between 0 and 1.
  - It can be simpler to implement than a counting semaphore on some hardware architectures.
- A counting semaphore can be implemented using binary semaphores.

Implementation of binary semaphore

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typedef struct {
  bool flag;

  /*processes blocked by this binary-semaphore*/
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```

```
void bP(binary-semaphore *bS) {
  if(bS->flag == true)
    bS->flag = false;
  else {
    Add (curproc) to bS->L;

    (curproc)->state=WAITING;
    scheduler();
  }
}
```

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    scheduler();
  }
}
```

```
void bV(binary-semaphore *bS) {
  if(bS->L is empty)
    bS->flag = true;
  else {
    Remove a proc (A) from bS->L;

    (A)->state=READY; //Wakeup (A)
  }
}
```

Implementation of binary semaphore

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  }
}
```

- The *bP* and *bV* must be executed **atomically**.

Implement counting semaphore using binary semaphore

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```
typedef struct {
  int value;

  binary-semaphore bS1 = true,   /*protect 'value'*/
                   bS2 = false;  /*synchronization*/
} semaphore;
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  binary-semaphore bS1 = true,   /*protect 'value'*/
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} semaphore;
```

```
void P(semaphore *S)
{
  bP(&S->bS1);
  S->value--;
  if(S->value < 0) {
    bV(&S->bS1);
    bP(&S->bS2);
  } else
    bV(&S->bS1);
}
```

Implement counting semaphore using binary semaphore

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void P(semaphore *S)
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    bP(&S->bS2);
  } else
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}
```

```c
void V(semaphore *S)
{
  bP(&S->bS1);
  S->value++;
  if(S->value <= 0)
    bV(&S->bS2);
  bV(&S->bS1);
}
```

Implement counting semaphore using binary semaphore

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  int value;

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} semaphore;
```

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{
  bP(&S->bS1);
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    bV(&S->bS1);
    bP(&S->bS2);
  } else
    bV(&S->bS1);
}
```

```
void V(semaphore *S)
{
  bP(&S->bS1);
  S->value++;
  if(S->value <= 0)
    bV(&S->bS2);
  bV(&S->bS1);
}
```

- This implementation of P and V may **not** be executed **atomically**.

Questions

- Any questions?

Deadlock and starvation (1/2)

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```

```
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   P(&mutex);
   ...
   remove an item from buffer;
   ...
   V(&mutex);
   V(&empty);
   ...
   consume the item;
   ...
} while(1);
```

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  - A situation where processes wait indefinitely within the semaphore.
  - For example, the previous solution to the 'readers-writers' problem may result in starvation.
  - The starvation can be avoided by using a FCFS resource allocation policy.

Questions

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Outline

High-level language synchronization constructs

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High-level language synchronization constructs

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    - *Monitors*.
        - It's suggested by Brinch-Hansen in 1973.
    - And many others...

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  - Monitors have an important property that makes them useful for achieving mutual exclusion: *only one process can be active in a monitor at any instant*.

```
monitor producer−consumer {
  int i;
  condition c;

  void produce()
  {
    ...
  }

  void consume()
  {
    ...
  }
}
```

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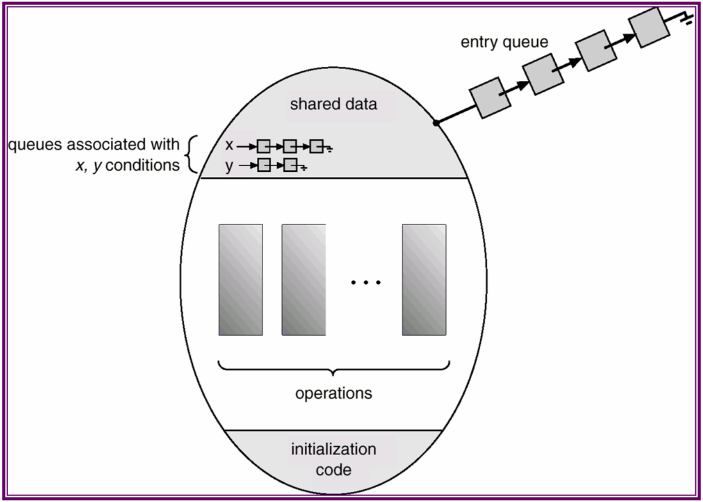
        - *c.wait();* - means that the process invoking it will be suspended until another process invokes
        - *c.signal();*
    - Note that if no process is suspended, then the *signal* operation has no effect.

Monitor with condition variables

Monitor with condition variables



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  - Mesa-style (Mesa is a programming language): letting P run and suspending Q.

Monitor solution to the dining-philosopher problem

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```
monitor dp {
  enum {THINKING, HUNGRY, EATING} state[N];
  condition c[N];

  void take_forks(int i) {
    state[i] = HUNGRY;
    test(i);
    if(state[i] != EATING)
      c[i].wait();
  }

  void test(int i) {
    if(state[i] == HUNGRY &&
       state[LEFT] != EATING &&
       state[RIGHT] != EATING) {
      state[i] = EATING;
      c[i].signal();
    }
  }
  void init() {
    for(int i = 0; i < N; i++)
      state[i] = THINKING;
  }
}
```

```
void put_forks(int i) {
  state[i] = THINKING;
  test(LEFT);
  test(RIGHT);
}
```

Questions

- Any questions?

Language support

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  - By adding the keyword *synchronized* to a method declaration, Java guarantees that once any thread has started executing that method, no other thread will be allowed to start executing any other *synchronized* method in that class.

Language support

- The monitor constructs must be supported by the programming language to be useful.
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- Example: Java (Mesa-style monitor with only one condition variable)
  - By adding the keyword *synchronized* to a method declaration, Java guarantees that once any thread has started executing that method, no other thread will be allowed to start executing any other *synchronized* method in that class.
  - And Java provides two operations: *wait* and *notify* to block and wakeup the thread.

Questions

- Any questions?

Outline

Relationship of semaphore and monitor

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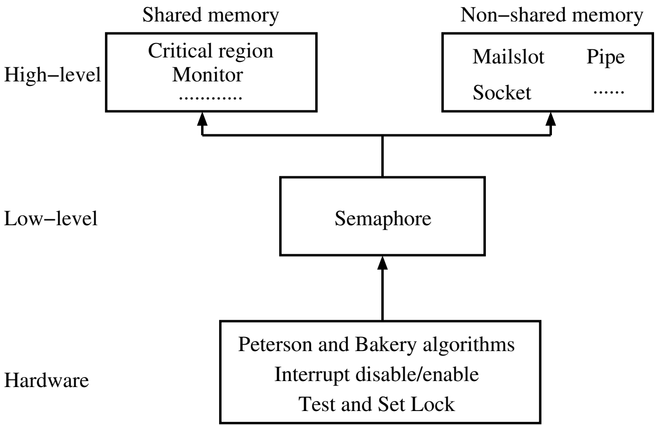

Implement semaphore using monitor

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```
monitor semaphore {
  int value;
  condition c;

  void P() {
    value--;
    if(value < 0)
      c.wait();
  }

  void V() {
    value++;
    if(value <= 0)
      c.signal();
  }
}
```

Implement monitor using semaphore

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semaphore mutex = 1, next = 0;
int next_count = 0;

// for each condition variable x
semaphore x_sem = 1;
int x_count = 0;
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// Mutual exclusion
// within a monitor
P(&mutex);
...
body of F;
...
if(next_count > 0)
  V(&next);
else
  V(&mutex);
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// x.wait()
x_count++;
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else
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  V(&next);
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x_count--;
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```
// x.signal()
if(x_count > 0) {
   next_count++;
  V(&x_sem);
  P(&next);
   next_count--;
}
```

Questions

- Any questions?