Semaphores & Monitors

Today

- Semaphores
- Monitors
- … and some other primitives

Next time

- Deadlocks

Semaphores

- A variable atomically manipulated by two operations – down (P) & up (V)
- Each semaphore has an associated queue of processes/threads
  - P/wait/down(sem)
    - If sem was "available" (>0), decrement sem & let thread continue
    - If sem was "unavailable" (<=0), place thread on associated queue; run some other thread

```
down(S):
   --Sem.value;
   if (Sem.value < 0){
      add this thread to Sem.L;
      block;
```

```
typedef struct {
   int value;
   struct thread *L;
} semaphore;
```

- Semaphores thus have history

Semaphores

- …
  - V/signal/up(sem)
    - If thread(s) are waiting on the associated queue, unblock one (place it on the ready queue)
    - If no threads are waiting, increment sem
      - The signal is "remembered" for next time up(sem) is called
    - Might as well let the "up-ing" thread continue execution

```
up(S):
  Sem.value++;
  if (Sem.value <= 0) {
     remove a process P from Sem.L;
     wakeup(P);
  }
```

```
typedef struct {
   int value;
   struct thread *L;
} semaphore;
```

- With multiple CPUs – lock semaphore with TSL
- *But then how's this different from previous busy-waiting?*

Semaphores

Operation	Value	Sem.L	CR
	1	{}	<>
P1 down	0	{}	P1
P2 down	-1	{P2}	P1
P3 down	-2	{P2,P3}	P1
P1 up	-1	{P3}	P2

```
down(Sem):
--Sem.value;
if (Sem.value < 0){
   add this thread to Sem.L;
   block;
}

up(Sem):
Sem.value++;
if (S.value <= 0) {
    remove a thread P from Sem.L;
    wakeup(P);
}
```

Semaphores

`empty = # available slots, full = 0, mutex = 1`

Producer

```
while (TRUE){
    item = produce_item();
    down(empty);
    down(mutex);
    insert_item(item);
    up(mutex);
    up(full);
}
```

Consumer

```
while (TRUE){
    down(full);
    down(mutex);
    item = remove_item();
    up(mutex);
    up(empty);
    consume_item(item);
}
```

- Semaphores and I/O devices

Mutexes

- Two different uses of semaphores
  - Synchronization – full & empty
  - Mutex – used for mutual exclusion

- Useful w/ thread packages
- Other possible operation

```
mutex_trylock()
```

```
mutex_lock:
    TSL REGISTER, MUTEX
    CMP REGISTER, #0
    JXE ok
    CALL thread_yield
    JMP mutex_lock
ok: RET

mutex_unlock:
   MOVE MUTEX, #0
   RET
```

Mutexes in Pthreads

Clearly missing a few definitions, including `main`

```
pthread_mutex_t mutex;
pthread_cond_t condc, condp;

void *producer(void *ptr)
{
   int i;

   for (i = 1; i <= MAX; i++) {
     pthread_mutex_lock(&mutex);
     while (buffer !=0) pthread_cond_wait(&condp, &mutex);
     buffer = i;
     ptread_cond_signal(&condc);    /* wakeup consumer */
     pthread_mutex_unlock(&mutex);
   }
   pthread_exit(0);
}

void *consumer(void *ptr)
{
   int i;

   for (i = 1; i <= MAX; i++) {
     pthread_mutex_lock(&mutex);
     while (buffer ==0) pthread_cond_wait(&condc, &mutex);
     buffer = 0;
     ptread_cond_signal(&condp);   /* wakeup producer */
     pthread_mutex_unlock(&mutex);
   }
   pthread_exit(0);
}
```

Problems with semaphores & mutex

- Solves most synchronization problems, but:
  - Semaphores are essentially shared global variables
    - Can be accessed from anywhere (bad software engineering)
  - No connection bet/ the semaphore & the data controlled by it
  - Used for both critical sections & for coordination (scheduling)
  - No control over their use, no guarantee of proper usage

Producer

```
while (TRUE){
   item = produc
   down(mutex);
   down(empty);
   insert_item(item);
   up(mutex);
   up(full);
}
```

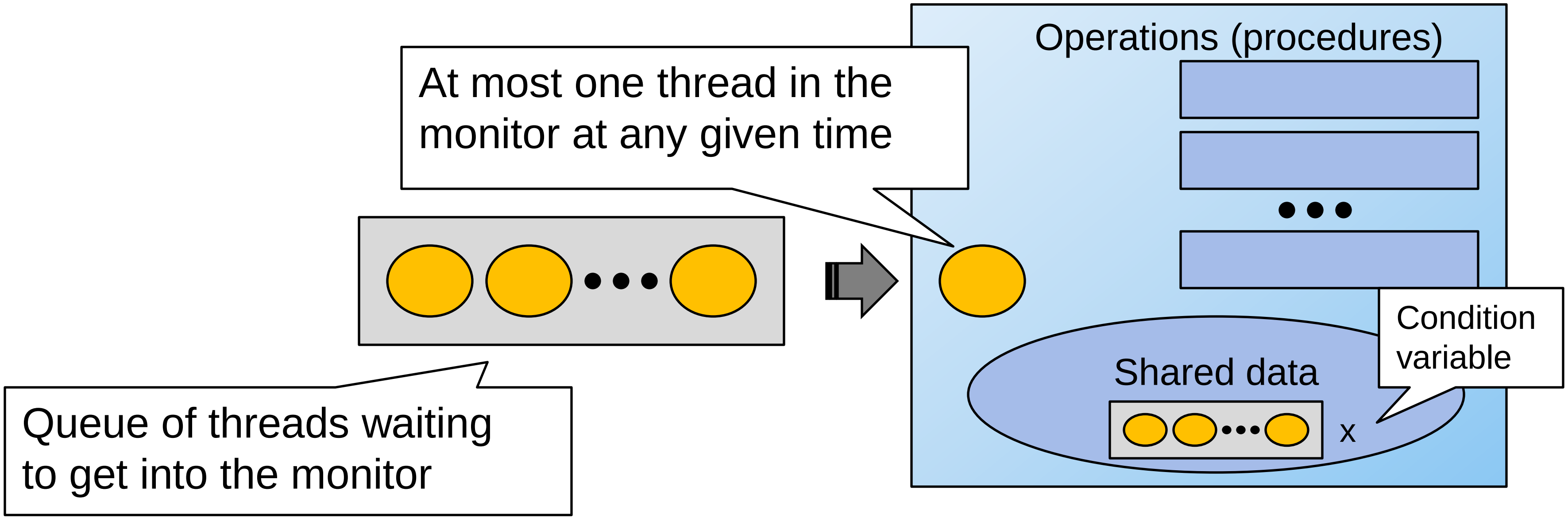
What happens if the buffer is full?

Consumer

```
while (TRUE){
   down(full);
   down(mutex);
   item = remove_item();
   up(mutex);
   up(empty);
   consume_item(item);
}
```

Monitors

- Monitors - higher level synchronization primitive
  - A programming language construct
    - Collection of procedures, variables and data structures
  - Monitor's internal data structures are private
- Monitors and mutual exclusion
  - Only one process active at a time - *how?*
  - Synchronization code is added by the compiler



Monitors

- Once inside a monitor, a thread may discover it can't continue, and
  - wants to wait, or
  - inform another one that some condition has been satisfied
- To enforce sequences of events – Condition variables
  - Can only be accessed from within the monitor
  - Two operations – `wait & signal`
  - A thread that waits "steps outside" the monitor (to a wait queue associated with that condition variable)
  - What happen after the signal?
    - Hoare – process awakened run, the other one is suspended
    - Brinch Hansen – process doing the signal must exit the monitor
    - *Third option? Process doing the signal continues to run (Mesa)*
  - `Wait` is not a counter – signal may get lost

Monitors in Java

```
public class ProducerConsumer {
      static final int N = 100;                     // constant giving the buffer size
      static producer p = new producer( );   // instantiate a new producer thread
      static consumer c = new consumer( );// instantiate a new consumer thread
      static our_monitor mon = new our_monitor( );  // instantiate a new monitor
      public static void main(String args[ ]) {
         p.start( );                                       // start the producer thread
         c.start( );                                       // start the consumer thread
      }
      static class producer extends Thread {
         public void run( )  {                          // run method contains the thread code
            int item;
            while (true) {                               // producer loop
               item = produce_item( );
               mon.insert(item);
            }
         }
         private int produce_item( ) { ... }    // actually produce
      }
      static class consumer extends Thread {
         public void run( )  {                          run method contains the thread code
            int item;
            while (true) {                               // consumer loop
               item = mon.remove( );
               consume_item (item);
            }
         }
         private void consume_item(int item) { ... }     // actually consume
      }
```

Monitors in Java

```
static class our_monitor {                          // this is a monitor
    private int buffer[ ] = new int[N];
    private int count = 0, lo = 0, hi = 0; // counters and indices
    public synchronized void insert(int val) {
        if (count == N) go_to_sleep( );     // if the buffer is full, go to sleep
        buffer [hi] = val;                  // insert an item into the buffer
        hi = (hi + 1) % N;                  // slot to place next item in
        count = count + 1;                  // one more item in the buffer now
        if (count == 1) notify( );          // if consumer was sleeping, wake it up
    }
    public synchronized int remove( ) {
        int val;
        if (count == 0) go_to_sleep( );     // if the buffer is empty, go to sleep
        val = buffer [lo];                  // fetch an item from the buffer
        lo = (lo + 1) % N;                  // slot to fetch next item from
        count = count – 1;                  // one few items in the buffer
        if (count == N – 1) notify( );      // if producer was sleeping, wake it up
        return val;
    }
   private void go_to_sleep( ) { try{wait( );} catch(InterruptedException exc) {};}
 }
}
```

Message passing

- IPC in distributed systems
- Message passing

```
send(dest, &msg)
recv(src, &msg)
```

- Design issues
  – Lost messages: acks
  – Duplicates: sequence #s
  – Naming processes
  – Performance
  – …

Producer-consumer with message passing

```
#define N 100     /* num. of slots in
   buffer */

void producer(void)
{
   int item; message m;

   while(TRUE) {
      item = produce_item();
      receive(consumer, &m);
      build_message(&m, item);
      send(consumer, &m);
    }
}
```

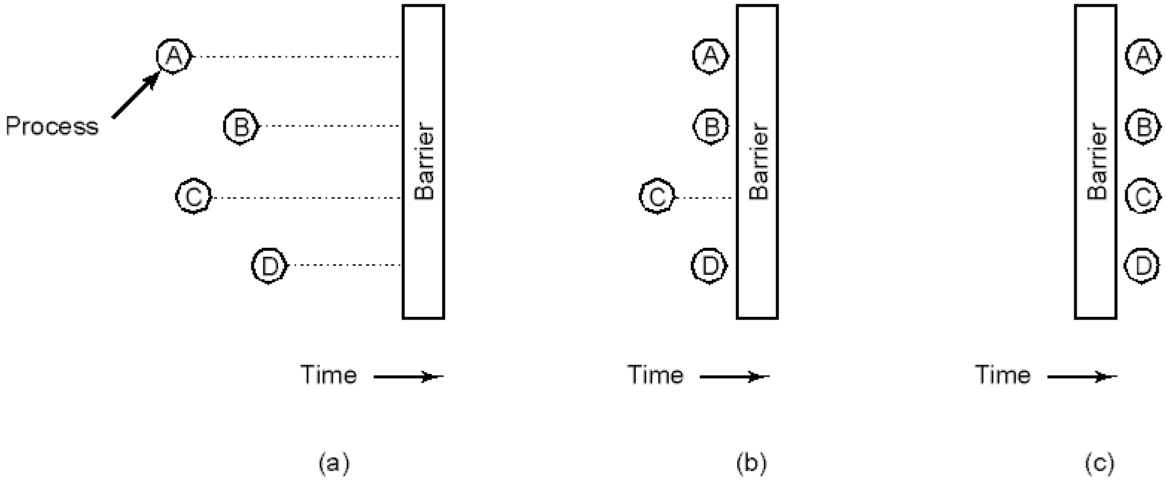
```
void consumer(void)
{
   int item, i; message m;

   for(i = 0; i < N; i++)
         send(producer, &m);

   while(TRUE) {
       receive(producer, &m);
       item = extract_item(&m);
       send(producer, &m);
       consume_item(item);
     }
}
```

Barriers

- To synchronize groups of processes
- Type of applications
  - Execution divided in phases
  - Process cannot go into new phase until all can
- e.g. Temperature propagation in a material



Coming up

- Deadlocks

  How deadlock arise and what you can do about them