Slide 1

Software solution: Peterson's algorithm

P_0:

```
...
flag[0] = true;
turn = 1;
while (flag[1]
         && turn == 1)
  /* do nothing */;
<critical section>
flag[0] = false;
...
```

P_1:

```
...
flag[1] = true;
turn = 0;
while (flag[0]
         && turn == 0)
  /* do nothing */;
<critical section>
flag[1] = false;
...
```

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Peterson's algorithm:

- ➜ implements mutual exclusion
- ➜ not widely used:
  - ✘ burns CPU cycles
  - ✘ can be extended to work for n processes, but overhead increases
  - ✘ cannot be extended to work for an unknown number of processes

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HARDWARE APPROACHES TO MUTUAL EXCLUSION

- ➜ How can the hardware help us to implement mutual exclusion?

Interrupt disabling:

- ➜ Useful on uniprocessor systems only
- ➜ Prevents preemption

```
...
<disable interrupts/signals>
<critical section>
<enable interrupts/signals>
...
```

Example: OS/161

```
spl = splhigh();
<critical section>
splx(spl);
```

➨ useful within OS, not appropriate for user processes

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SPECIAL MACHINE INSTRUCTIONS

- ➜ Software approaches exploit a property guaranteed by the hardware:

  each memory access is **atomic**

- ➜ Problems occured as we sometimes would like a number of memory accesses to be atomic
- ➜ Could the hardware provide complex atomic operations that help us?

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Test and set:

```
atomic bool testset (int i)
{
  if (0 == i) {
    i = 1;
    return true;
  } else
    return false;
}
```

Exchange:

```
atomic void exchange (int register,
                      int memory)
{
  int tmp;
  tmp      = memory;
  memory   = register;
  register = tmp;
}
```

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Mutual exclusion with test-and-set:

```
int bolt = 0;
void proc (int i) {
  for (;;) {
    while (!testset (bolt))
      /* do nothing */;
    <critical section>
    bolt = 0;
    <remainder>
  }
}

void main () {
  bolt = 0;
  parbegin (proc (1), proc (2), ..., proc (N));
}
```


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Advantages of special machine instructions:

- ✔ Applicable to any number of processes on either a single processor or multiple processors sharing main memory
- ✔ Simple and therefore easy to verify

Disadvantages of special machine instructions:

- ✘ Busy-waiting consumes processor time
- ✘ Starvation is possible when a process leaves a critical section and more than one process is waiting.
- ✘ Deadlock
  - If a low priority process has the critical region and a higher priority process requires access, the higher priority process will obtain the processor to wait for the critical region

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SEMAPHORES

- ➜ Dijkstra (1965) introduced the concept of a semaphore in his study of cooperating sequential processes
- ➜ Semaphores are variables that are used to signal the status of shared resources to processes

How does that work?

- ➜ If a resource is not available, the corresponding semaphore blocks any process waiting for the resource
- ➜ Blocked processes are put into a process queue maintained by the semaphore (avoids busy waiting!)
- ➜ When a process releases a resource, it signals this by means of the semaphore
- ➜ Signalling resumes a blocked process if there is any
- ➜ Wait and signal operations cannot be interrupted
- ➜ Complex coordination can be specified by multiple semaphores

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How are semaphores implemented?

➜ A semaphore is a variable `s` consisting of
  - an integer value `count` and
  - a process queue `queue`

➜ Initially, `count` is set to a nonnegative value and `queue` is empty

➜ There are two operations that a process `current` can apply:

`wait(s)`: Decrement `count`; if `count` becomes negative, put `current` into `queue`

`signal(s)`: Increment `count`; if `count` is not positive, unblock a process from `queue`

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```
typedef struct {
  int     count;
  queue_t queue;
} semaphore;

void wait (semaphore s) {
  s.count--;
  if (s.count < 0) {
    <place current in s.queue>
    <block current>
  }
}
void signal (semaphore s) {
  s.count++;
  if (s.count <= 0)
    <remove a process P from s.queue>
    <place P on ready list>
}
```


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There are various flavours of semaphores:

➜ Counting semaphores versus binary semaphores:
  - In a counting semaphore, `count` can take arbitrary integer values
  - In a binary semaphore, `count` can only be 0 or 1
  - Counting semaphores can be implemented in terms of binary semaphores (how?)

➜ Strong semaphores versus weak semaphores:
  - In a strong semaphore, `queue` adheres to the FIFO policy
  - In a weak semaphore, any process may be taken from `queue`
  - Strong semaphores can be implemented in terms of weak semaphores (how?)

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MUTUAL EXCLUSION

Implementation of mutual exclusion with semaphores:

```
semaphore s;
 s.count = 1;
 s.queue = empty_queue ();

void proc (int i) {
  for (;;) {
    wait (s);
    <critical section>
    signal (s);
    <remainder>
  }
}
void main () {
  parbegin (proc (1), proc (2), ..., proc (n));}
```

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Mutex:

- A semaphore that allows only one process in a critical section is often called a mutex
- There exist various flavours, such as, read-write mutexes and read-write-update mutexes
- Given exchange or test-and-set are available, easy to implement in user-level:
  1. test-and-set lock
  2. if succesful, return
  3. if not, yield current thread, repeat

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SEMAPHORES IN OS/161

- defined in `src/kern/thread/synch.c` and `src/kern/include/synch.h`
- operations are called:
  - `P` (proberen: try), instead of `wait`
  - `V` (verhogen: increase), instead of `signal`
- definition of data type `semaphore`

```
 struct semaphore {
         char *        name;
         volatile int count;
 };
struct semaphore* sem_create (const char *name, int initial_count);
void              P          (struct semaphore *);
void              V          (struct semaphore *);
void              sem_destroy(struct semaphore *);
```

- where is the queue??

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```
void  P(struct semaphore *sem) {
  int spl;
  assert(sem != NULL);

  /* May not block in an interrupt handler.
   * For robustness, always check, even if we can actually
   * complete the P without blocking. */
  assert(in_interrupt==0);

  spl = splhigh();
  while (sem->count==0) {
   thread_sleep(sem); }
  assert(sem->count>0);
  sem->count--;
  splx(spl);
}
```

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```
void V(struct semaphore *sem) {
  int spl;
  assert(sem != NULL);
  spl = splhigh();
  sem->count++;
  assert(sem->count>0);
  thread_wakeup(sem);
  splx(spl);
}
```

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Mutexes in OS/161

```
struct lock {
        char * name;
        struct thread  *volatile holder;
};

struct lock *lock_create    (const char *name);
void         lock_acquire   (struct lock *);
void         lock_release   (struct lock *);
int          lock_do_i_hold (struct lock *);
void         lock_destroy   (struct lock *);
```

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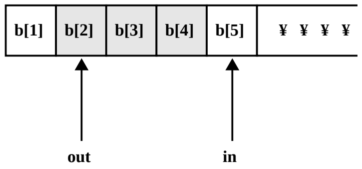
Producer/Consumer Problem

- ➜ One or more producers are generating data and placing these in a buffer
- ➜ A single consumer is taking items out of the buffer one at time
- ➜ Only one producer or consumer may access the buffer at any one time



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```
int    in, out;
elem_t b[];

producer:
  for (;;) {
    <produce item v>
    b[in] = v;
    in++;
  }

consumer:
for (;;) {
  while (in <= out)
    /* do nothing */;
  w = b[out];
  out++;
  <consume item w>
}
```

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```
semaphore n = init_sem (0);  /* number of items in buffer  */
semaphore s = init_sem (1);  /* access to critical section */

void producer () {
  for (;;) {
    v = produce ();
    wait (s);
    append (v);
    signal (s); signal (n);
}  }

void consumer () {
  for (;;) {
    wait (n); wait (s);
    w = take ();
    signal (s);
    consume (w);
}  }
```

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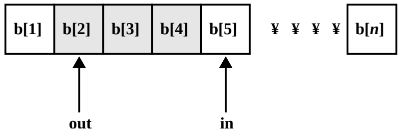
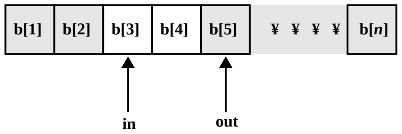
Producer with Circular Buffer





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Monitors

- ➜ A monitor is a software module implementing mutual exclusion
- ➜ Monitors are easier to program than semaphores
- ➜ Natively supported by a number of programming languages: Concurrent Pascal, Modula-(23) & Java
- ➜ Chief characteristics:
  - Local data variables are accessible only by the monitor (not externally)
  - Process enters monitor by invoking one of its procedures
  - Only one process may be executing in the monitor at a time
- ➜ Main problem: provides less control; coarse grain

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```
int    in, out;
elem_t b[];
```

Producer:

```
for (;;) {
  <produce item v>
  while ((in + 1) % n == out)
    /* do nothing */;
  b[in] = v;
  in = (in + 1) % n;
}
```

Consumer:

```
for (;;) {
  while (in == out)
    /* do nothing */;
  w = b[out];
  out = (out + 1) % n;
  <consume item w>
}
```

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Synchronisation in a monitor:

`cwait (c)`: Suspend `current` on condition `c` (opens monitor to other processes)

`csignal (c)`: Resume execution of a processes suspended on condition `c` (ignored if no such process)

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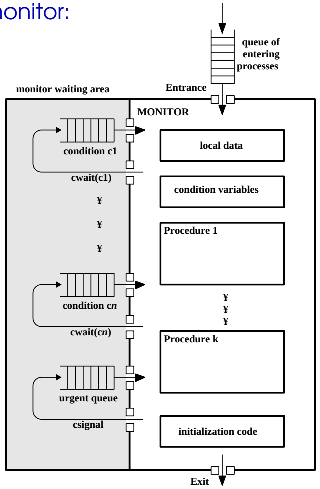
Structure of a monitor:



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Producer/consumer using a monitor:

```
char        buffer[N];
int         nextin = 0, nextout = 0, count = 0;
condition_t not_full, not_empty;
```

```
void append (char c) {
  if (N == count)
    cwait (not_full);
  buffer[nextin] = c;
  nextin = (nextin + 1) % N;
  count++;
  csignal (not_empty);
}
```

```
void take (char c) {
  if (0 == count)
    cwait (not_empty);
  x = buffer[nextout];
  nextout = (nextout + 1) % N;
  count--;
  csignal (not_full);
}
```


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MONITORS IN JAVA

Resources or critical sections can be protected using the `synchronized` keyword:

```
synchronized (<expression>) {
    <statements>
}
```

- ➜ *<expression>* must evaluate to an object or array
- ➜ thread only proceeds after obtaining the lock of the object
- ➜ `synchronized` can be applied to a method: entire method is a critical section