Reminder

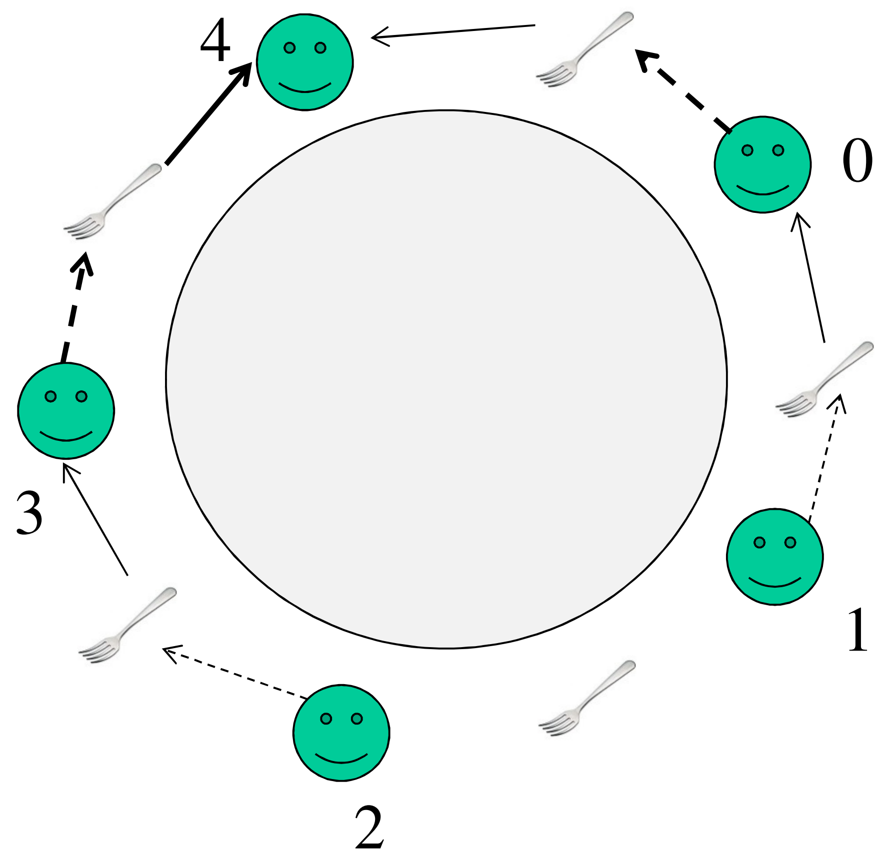
- HW1
  - On Carmen
  - Pseudo-code is ok
  - Due Wednesday, Sep. 14

- New office hour (starting from next week):
  - 2-3 pm Tuesdays

Another Solution?

- Even# takes left first
- Odd# takes right first

- Worst case scenario?



Semaphore: pros and cons

- Pros:
  - no waste of resources due to busy waiting
  - flexible resource management using an initial value > 1
- Cons:
  - processes using semaphores must be aware of each other and coordinate respective use of semaphores
  - insertion of P and V calls is tricky and prone to errors
  - correctness of program using semaphores can be very hard to verify
  - do not scale up well - i.e. impractical for large scale use

Group Discussion

- Linux kernel uses both spinning locks and semaphore-based mutex locks
  - Why? Any assumptions?

- In what scenarios the above assumptions would be broken?

Monitors: definition

- Monitors are abstract data types for encapsulating shared resources
- A monitor consists of:
  - shared objects and local variables,
  - a set of procedures
- Basic properties of the monitor
  - procedures are the only operations that can be performed on the resource and on the local variables
  - only one process at a time can be active (i.e. executing a procedure) within a monitor

Monitors: condition variables

- Condition variables are variables on which two operations are defined, *wait* and *signal*:
  - syntax: **<*variable*>.wait** and **<*variable*>.signal**
- They are used to delay and resume execution of processes calling monitor's procedures
- Condition variables are visible only from within monitor procedures

Semantics of *wait* and *signal*

- A queue is associated with each condition variable
  - ***<variable>*.queue** returns **true** if queue is not empty
- The ***<variable>*.wait** call suspends the calling process
  - calling process relinquishes control of the monitor
  - calling process is enqueued on the variable's queue
- The ***<variable>*.signal** call causes one waiting process to gain control of the monitor
  - the waiting process resumes execution from where it left (i.e. right after the wait statement)
  - the calling process is enqueued on the *urgent* queue
    - http://portal.acm.org/citation.cfm?id=355620.361161

Producer-Consumer problem

```
circular_pool: monitor
begin
    pool: array 0..N-1 of buffer;
    count, head, tail: int;
    nonemtpy, nonfull: condition;

Procedure extract(x)
begin
    if count = 0 then nonempty.wait;
    x:= pool[tail] ;
    tail := tail + 1 mod N;
    count := count - 1;
    nonfull.signal
end

Procedure insert(x)
begin
    if count = N then nonfull.wait;
    pool[head] := x;
    head := head + 1 mod N;
    count := count + 1;
    nonempty.signal
end

    count := 0
    head := 0; tail := 0;
end circular_pool
```

Readers-Writers: base version

procedure Read**;**
  begin
  <*read file*>
  end Read**;**

procedure Write;
  begin
  <*write file*>
  end Write**;**

Readers-Writers with concurrent reader access

```
procedure startRead
begin
        readers = readers+1;
end

<READ FILE>

procedure endRead
begin
        readers = readers -1;
        if (readers == 0) then
                writer.signal;
end
```

```
procedure writer
begin
        if (readers >0) then
                writer.wait;
<WRITE FILE>
writer.signal
end
```

- This solution works, but does not guarantee readers priority
  - hint: who is allowed into the monitor when a writer exits?

Readers-Writers solution with readers' priority

```
procedure startRead;
    begin
        if busy then OKtoread.wait;
        readcount := readcount + 1;
        OKtoread.signal;
    end startRead;

procedure endRead;
    begin
        readcount := readcount - 1;
        if readcount = 0
                then OKtowrite.signal;
    end endRead;

procedure startWrite;
    begin
        if busy OR readcount ≠ 0
            then OKtowrite.wait;
        busy := true;
    end startWrite;

procedure endWrite;
    begin
        busy := false;
        if OKtoread.queue
            then OKtoread.signal
            else OKtowrite.signal;
    end endWrite;
```

Readers-Writers solution with readers' priority

```
procedure startRead;
    begin
        if busy then OKtoread.wait;
        readcount := readcount + 1;
        OKtoread.signal;
    end startRead;

procedure endRead;
    begin
        readcount := readcount - 1;
        if readcount = 0
                then OKtowrite.signal;
    end endRead;

procedure startWrite;
    begin
        if busy OR readcount ≠ 0
            then OKtowrite.wait;
        busy := true;
    end startWrite;

procedure endWrite;
    begin
        busy := false;
        if OKtoread.queue
            then OKtoread.signal
            else OKtowrite.signal;
    end endWrite;
```

wait with priority

- An enhanced version of the **wait** operation accepts an optional priority argument:
  - syntax: ***<variable>*.wait** <*parameter*>
  - the smaller the value of the parameter, the higher the priority
- When the variable is signaled, the process with the highest priority in the queue will be activated
  - the base wait implementation may use a First-In-First-Out (FIFO) discipline

Example: Smallest job first

```
procedure startPrint;
begin
    if NOT printerIsBusy
        then jobAvailable.wait;
    printer-file := buffer;
end startPrint;

<print printer-file>

procedure endPrint;
begin
    printerIsBusy := false;
    OKtoprint.signal;
end endPrint;
```

```
procedure enqueueJob(file);
begin
    if printerIsBusy
        then OKtoprint.wait sizeof(file);
    printerIsBusy := true;
    buffer := file;
    jobAvailable.signal
end;
```

Monitors: pros and cons

- Pros:
  - encapsulation provides automatic serialization
  - flexibility in blocking and unblocking process execution within monitor procedures
- Cons
  - lack of concurrency if monitor encapsulates shared resources
  - possibility of deadlock with nested monitor calls

Lessons learned

- Encapsulation of critical section of code is desirable
  - provides automatic mutual exclusion
  - single copy of code, single point of synchronization
  - however would be nice to have some form of controlled concurrency
- Blocking/unblocking of processes is powerful tool
  - basic ingredient are named queues, enqueue and dequeue operations
  - enqueue and dequeue operations usually subject to condition

Other existing mechanisms to handle concurrency

- Path Expressions
  - abstraction designed to describe the list of all possible legal executions of operations on shared resource
- Communicating Sequential Processes (CSP)
  - the exchange of messages as synchronization points between sequential processes
- ADA tasks
  - language constructs for the message passing
- One thing in common
  - None in practical use currently (though ADA was a popular language in 80s and 90s)

Multi-threaded programming in Java

- Java allows a program to specify multiple threads of execution
- Provides instructions to ensure mutual exclusion, and selective blocking/unblocking of threads

What is a thread in Java ?

- A thread is a program-counter and a stack
- All threads share the same memory space
- A running thread can
  - Yield
  - Sleep
  - Wait for I/O or notification
  - Be pre-empted
- A key feature: Synchronized methods
  - Allow an exclusive lock, e.g., in an update method

Basic Syntax

- Build a thread by extending the class java.lang.Thread
- Must have a public void run() method – it is executed at the start of the thread, and when it finishes, the thread finishes
- Synchronized statements
  - Synchronized (obj) { block }
  - Obtains a lock on obj before executing block, releases lock after executing block
- Wait() gives up lock and suspends the thread
- Notifyall() resumes all threads waiting on object, resumed tasks must reacquire lock before continuing

Producer Consumer Example

```
Public class ProducerConsumer  {
  private boolean ready ;
  private Object obj ;
  public ProducerConsumer() {
    ready = false   ;
  }
  public ProducerConsumer (Object  o)  {
    obj  = o ;
    ready = true ;
  }
```

```
Synchronized  Object consume() {
  while (!ready) wait() ;
  ready = false   ;
  notifyAll()   ;
  return obj   ;
}
Synchronized void produce (object o)
{
  while (ready) wait() ;
  obj = o ;
  ready = true ;
  notifyAll() ;
}
}
```