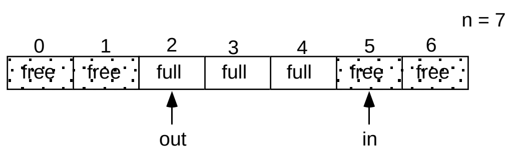
The Producer-Consumer Problem (Review from Lecture 07)

- One thread is a producer of information; another is a consumer of that information
  - They share a bounded circular buffer
  - Processes — OS must support shared memory between processes
  - Threads — all memory is shared

```
var buffer:  array[0..n-1] of items;     /* circular array */
in = 0
out = 0
```



```
/* producer */                         /* consumer */
repeat forever                         repeat forever
    …                                      while (in == out)
    produce item nextp                         do nothing
    …                                      nextc = buffer[out]
    while (in+1 mod n == out)              out = out+1 mod n
        do nothing                         …
    buffer[in] = nextp                     consume item nextc
    in = in+1 mod n                        …
end repeat                             end repeat
```

Too Much Milk!

Time	You	Your Roommate
3:00	Arrive home	
3:05	Look in fridge, no milk	
3:10	Leave for grocery	
3:15		Arrive home
3:20	Arrive at grocery	Look in fridge, no milk
3:25	Buy milk, leave	Leave for grocery
3:30		
3:35	Arrive home	Arrive at grocery
3:36	Put milk in fridge	
3:40		Buy milk, leave
3:45		
3:50		Arrive home
3:51		Put milk in fridge

3:51 Oh, no! ***Too much milk!!***

- The problem here is that the lines:

  "Look in fridge, no milk"

  through

  "Put milk in fridge"

  are not an **atomic** operation

Another Example

```
Thread A                  Thread B

i = 0                     i = 0
while (i < 10)            while (i > –10)
    i = i + 1                 i = i – 1
print "A wins"            print "B wins"
```

- Assumptions:
  - Memory load and store are atomic
  - Increment and decrement are not atomic
- Questions:
  - Who wins?
  - Is it guaranteed that someone wins?
  - What if both threads have their own CPU, running concurrently at exactly the same speed? Is it guaranteed that it goes on forever?
  - What if they are sharing a CPU?

Critical Section & Mutual Exclusion

- *Critical section* (*region*) — code that only one thread can execute at a time (e.g., code that modifies shared data)
- *Mutual exclusion* — ensures that only one thread does a particular activity at a time — all other threads are *excluded* from doing that activity
  - More formally, if process P_i is executing in its critical section, then no other processes can be executing in their critical sections
- *Lock* — mechanism that prevents another thread from doing something:
  - *Lock* before entering a critical section
  - *Unlock* when leaving a critical section
  - Thread wanting to enter a locked critical section must **wait** until it's unlocked

Enforcing Mutual Exclusion

- Methods to enforce mutual exclusion
  - Up to user — threads have to explicitly coordinate with each other
  - Up to OS — support for mutual exclusion
  - Up to hardware —architectural support
- Solution must make *progress* — if no process is executing in its critical section, and there exist some processes that wish to enter their critical section, then the selection of the processes that will enter the critical section next cannot be postponed indefinitely
  - Avoid *starvation* — if a thread starts trying to gain access to the critical section, then it should eventually succeed
  - Avoid *deadlock* — if **some** threads are trying to enter their critical sections, then **one** of them must eventually succeed

Algorithm 1

- Informal description:
  - Igloo with blackboard inside
    - Only one person (thread) can fit in the igloo at a time
    - In the igloo is a blackboard, which is large enough to hold only one value
  - A thread that wants to execute the critical section enters the igloo, and examines the blackboard
    - If its number is not on the blackboard, it leaves the igloo, goes outside, and runs laps around the igloo
      - After a while, it goes back inside, and checks the blackboard again
      - This “busy waiting” continues until eventually its number is on the blackboard
    - If its number is on the blackboard, it leaves the igloo and goes on to the critical section
    - When it returns from the critical section, it enters the igloo, and writes the other thread’s number on the blackboard

Algorithm 1 (cont.)

- Code:

```
t1 ( )   {
    while (true)   {
        while (turn != 1)
            ;     /* do nothing */
        … critical section of code …
        turn = 2;
        … other non-critical code …
    }
}

t2 ( )   {
    while (true)   {
        while (turn != 2)
            ;     /* do nothing */
        … critical section of code …
        turn = 1;
        … other non-critical code …
    }
}
```

Algorithm 2a

- Informal description:
  - Each thread has its own igloo
    - A thread can examine and alter its own blackboard
    - A thread can examine, but not alter, the other thread’s blackboard
    - “true” on blackboard = that thread is in the critical section
  - A thread that wants to execute the critical section enters the other thread’s igloo, and examines the blackboard
    - It looks for “false” on that blackboard, indicating that the other thread is not in the critical section
      - When that happens, it goes back to its own igloo, and writes “true” on its own blackboard, and then goes on to the critical section
    - When it returns from the critical section, it enters the igloo, and writes “false” on the blackboard

Algorithm 2a (cont.)

- Code:

```
t1 ( )   {
     while (true)   {
          while (t2_in_crit == true)
               ;     /* do nothing */
          t1_in_crit = true;
          … critical section of code …
          t1_in_crit = false;
          … other non-critical code …
     }
}

t2 ( )   {
     while (true)   {
          while (t1_in_crit == true)
               ;     /* do nothing */
          t2_in_crit = true;
          … critical section of code …
          t2_in_crit = false;
          … other non-critical code …
     }
}
```

Algorithm 2b

- Code:

```
t1 ( )   {
     while (true)   {
          t1_in_crit = true;
          while (t2_in_crit == true)
               ;     /* do nothing */
          … critical section of code …
          t1_in_crit = false;
          … other non-critical code …
     }
}

t2 ( )   {
     while (true)   {
          t2_in_crit = true;
          while (t1_in_crit == true)
               ;     /* do nothing */
          … critical section of code …
          t2_in_crit = false;
          … other non-critical code …
     }
}
```