Semaphores
(and Eventcounts)

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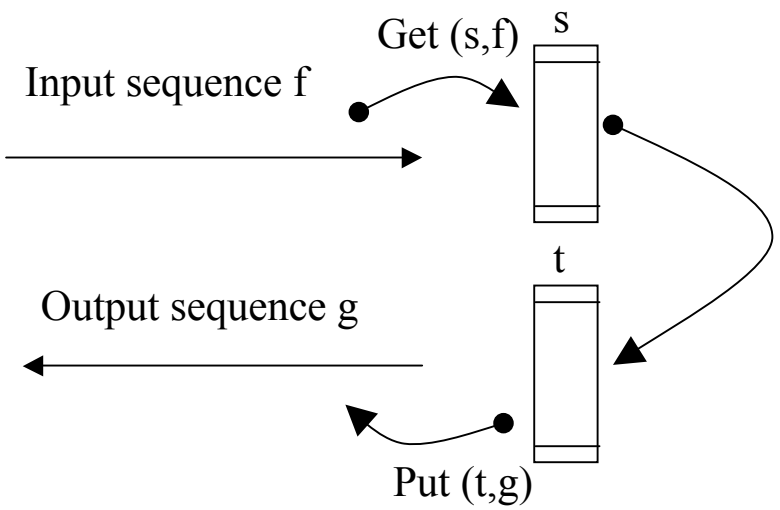
“The Wa” (Wawa) at Princeton

- See the “too much milk” problem last week
- Wawa
  - http://www.wawa.com/
  - http://www.absoluteastronomy.com/encyclopedia/w/wa/wawa_food_markets.htm
  - http://www.urinal.net/wawa/

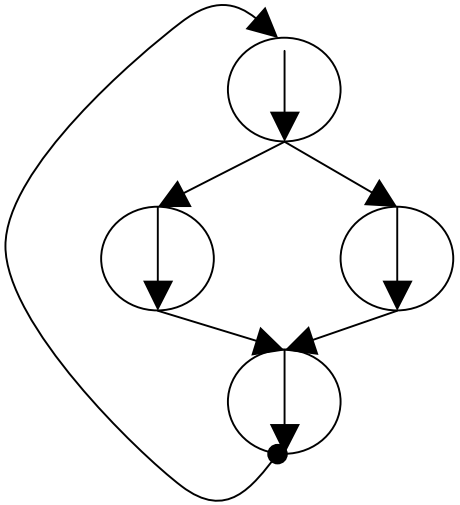
Concurrency: Double buffering




```
Get(s,f);
Repeat
        Copy;
        cobegin
                Put(t,g);
                Get(s,f);
        coend;
until completed;
```

Specifies concurrent execution

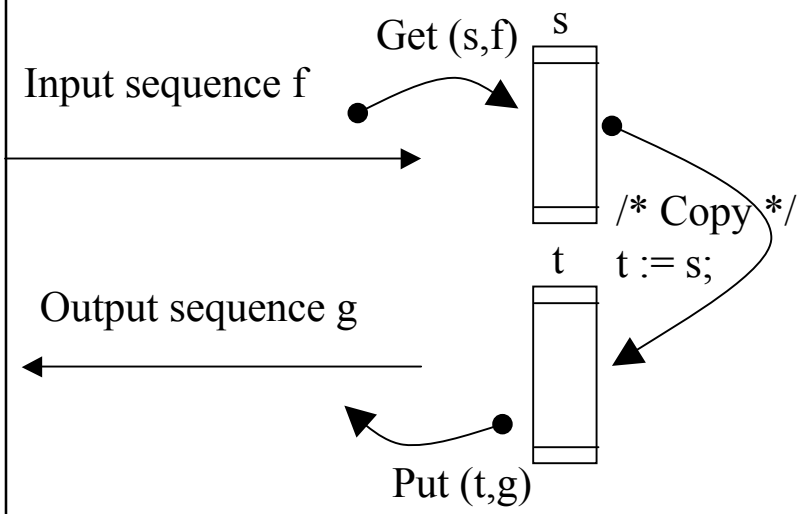
(Threads)



- **Put and Get** are disjunct
- … but not with regards to **Copy**!

Concurrency: Double buffering

/* Fill s and empty t **concurrently**: OS Kernel will do preemptive scheduling of GET, COPY and PUT*/



Three threads executing concurrently:

{put_thread||get_thread||copy_thread} **/* Assume preemptive scheduling by kernel */**

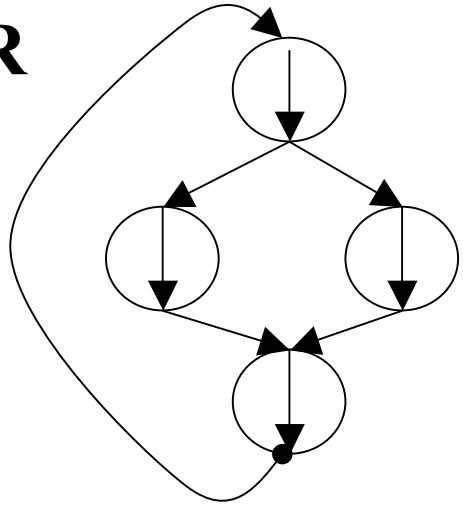
Proposed code:

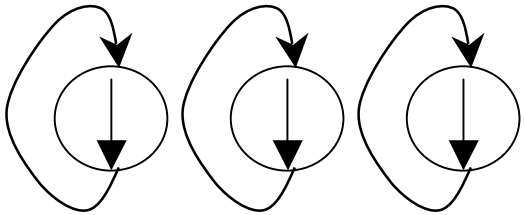
copy_thread:: *{acq(lock_t); acq(lock_s); **t=f;** rel(lock_s); rel(lock_t);**}**

get_thread:: *{ack(lock_s); **s=f;** rel(lock_s);**}**

put_thread:: *{ack(lock_t): **g=t;** rel(lock_t);**}**

- **Not bad, but NO ORDER**





Threads specifies concurrent execution

Protecting a Shared Variable

- Remember: we need a shared address space
  - threads inside a process share adr. Space
- Acquire(mutex); count++; Release(mutex);
- **(1) Acquire(mutex) system call**
  - User level library
    - **(2) Push parameters onto stack**
    - **(3) Trap to kernel (int instruction)**
  - Kernel level
    - Int handler
      - **(4) Verify valid pointer to mutex**
      - Jump to code for Acquire()
        - **(5) mutex closed: block caller: insert(current, mutex_queue)**
        - **(6) mutex open: get lock**
  - User level: **(7) execute count++**
- **(8) Release(mutex) system call**

Issues

- How “long” is the critical section?
- Competition for a mutex/lock
  - Uncontended = rarely in use by someone else
  - Contended = often used by someone else
  - Held = currently in use by someone
- Think about the results of these options
  - Spinning on low-cont. lock
  - Spinning on high-cont. lock
  - Blocking on low-cont. lock
  - Blocking on high-cont. lock

By the way …

- “test and set” works at both user and kernel level

Block/unblock syscalls

- Block
  - Sleep on token
- Unblock
  - Wakes up first sleeper
- By the way
  - Remember that “test and set” works both at user and kernel level

Implementing Block and Unblock

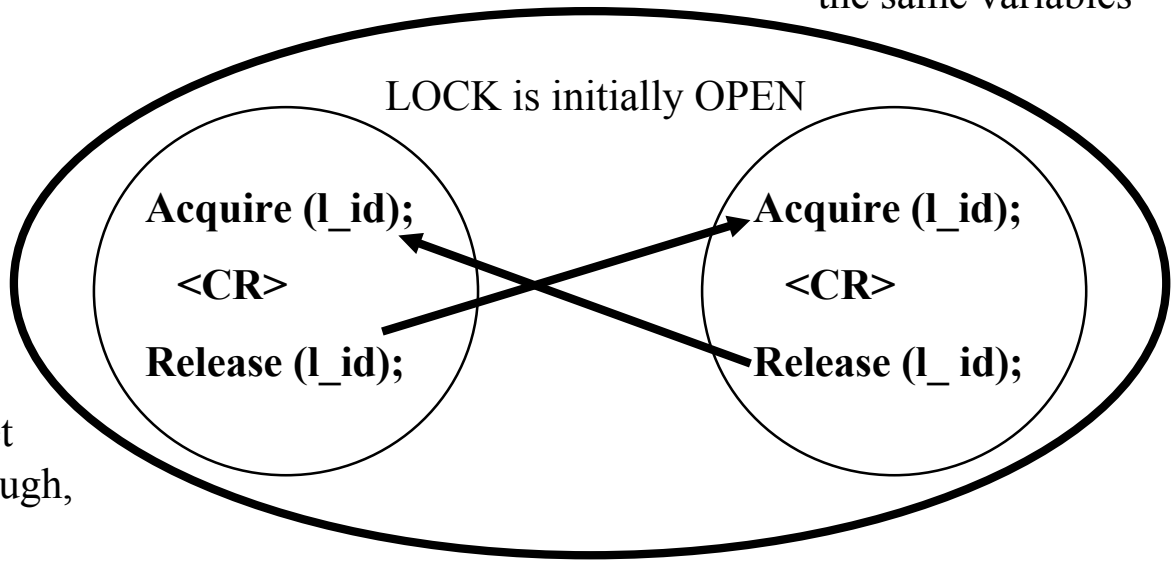
- Block (lock)
  - Spin on lock.guard
  - Save context to TCB
  - Enqueue TCB
  - Clear spin lock.guard
  - goto scheduler

- UnBlock(lock)
  - Spin on lock.guard
  - Dequeue a TCB
  - Put TCB in ready_queue
  - Clear spin lock.guard

Two Kinds of Synchronization

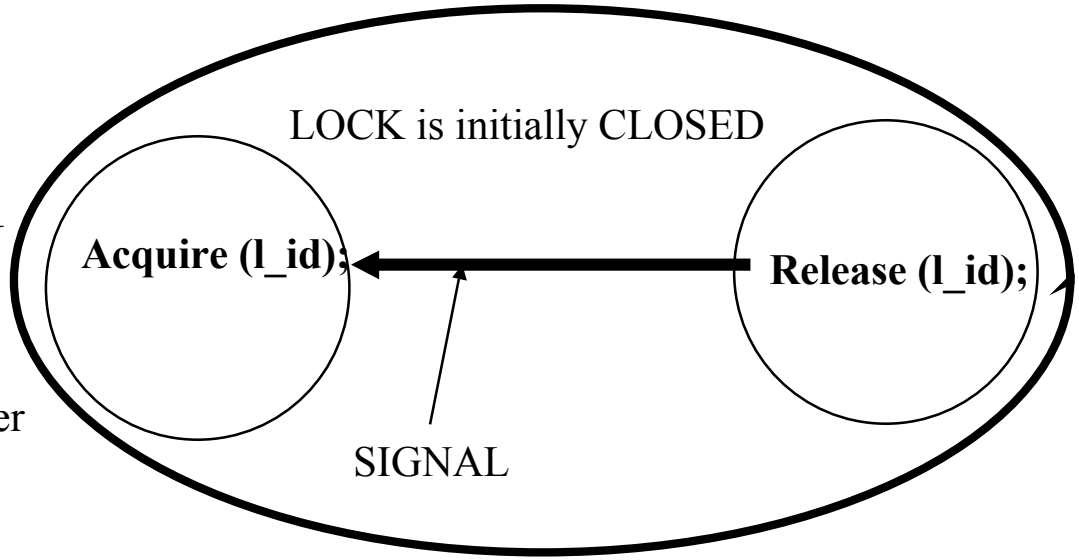
Threads inside one process: Shared address space. They can access the same variables

Process w/two threads



MUTEX

Acquire will let first caller through, and then block next until Release



CONDITION SYNCHRONIZATION

Acquire will block first caller until Release

Think about ...

- Mutual exclusion using Acquire - Release:
  - Easy to forget one of them
  - Difficult to debug. must check all threads for correct use: “Acquire-CR-Release”
  - No help from the compiler?
    - It does not understand that we mean to say MUTEX
    - But could
      - check to see if we always match them “left-right”
      - associating a variable with a Mutex, and never allow access to the variable outside of CR

Semaphores (Dijkstra, 1965)

- "Down(s)"/"Wait(s)"/"P(s)"
  - Atomic
  - DELAY (block, or busy wait) if not positive
  - Decrement semaphore value by 1

- "Up(s)","Signal(s)", "V(s)"
  - Atomic
  - Increment semaphore by 1
  - Wake up a waiting thread *if any*

```
P(s) {
  if (--s < 0)
    Block(s);
}
```

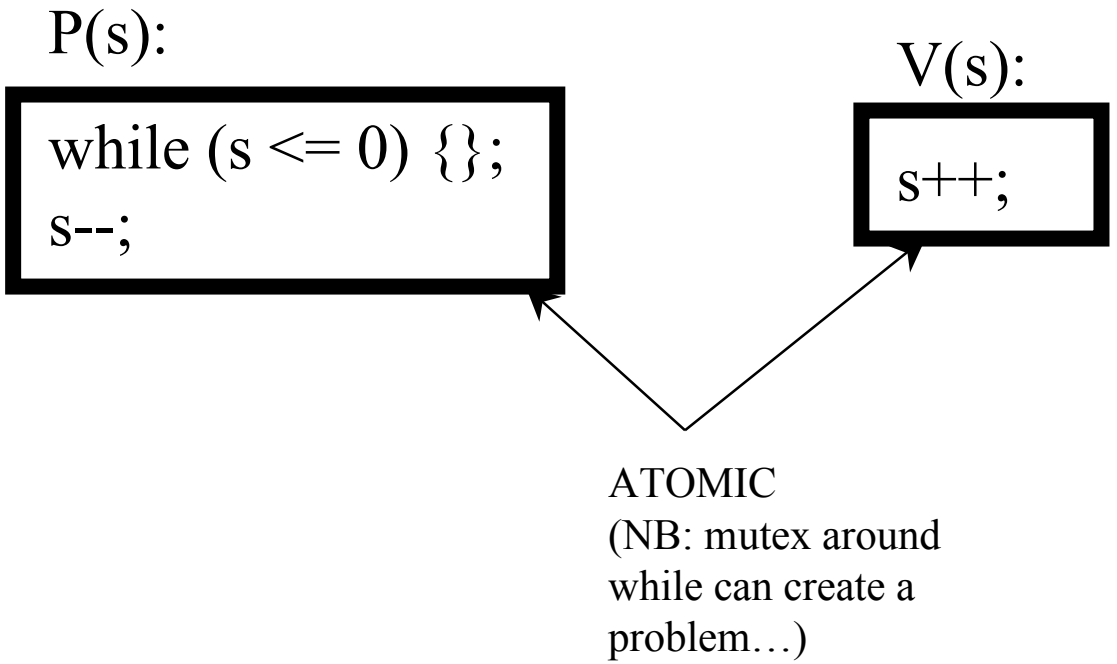
```
V(s) {
  if (++s <= 0)
    Unblock(s);
}
```

MUTEX

Can get negative s: counts number of waiting threads

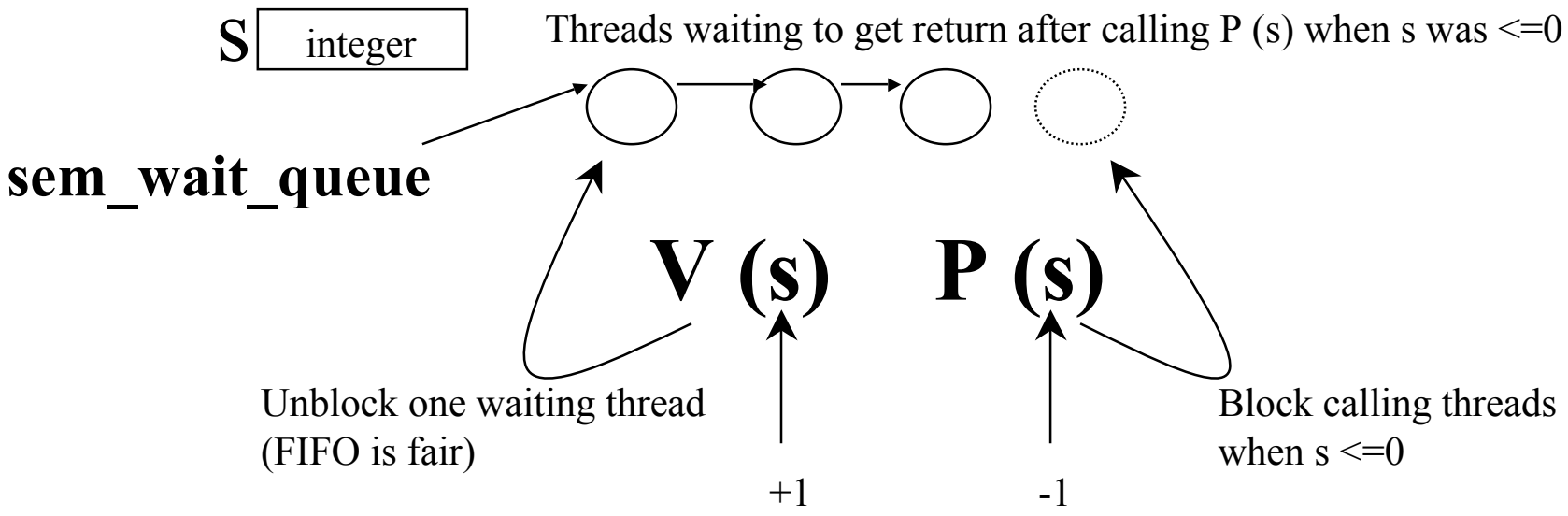
s is NOT accessible through other means than calling P and V

Semaphores w/Busy Wait



- Starvation possible (in theory)?
- Does it matter in practise?

The Structure of a Semaphore

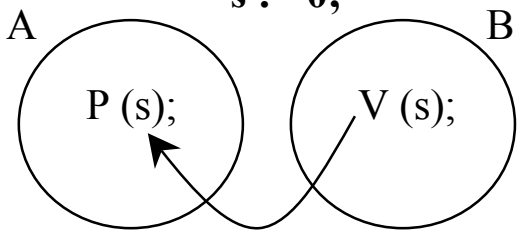


- Atomic: Disable interrupts
- Atomic: P() and V() as System calls
- Atomic: Entry-Exit protocols

Using Semaphores

"The Signal"

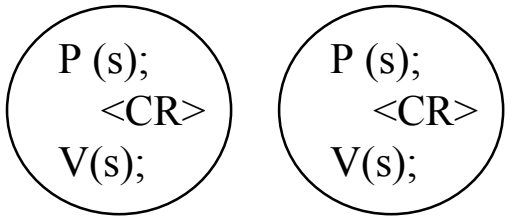
s := 0;



A blocks until B says V

"The Mutex"

s := 1;

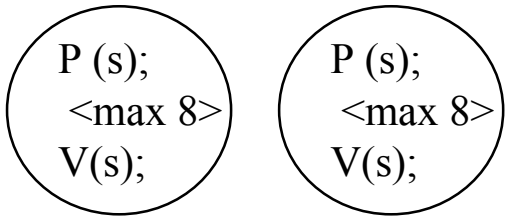


One thread gets in, next blocks until V is executed

NB: remember to set the initial semaphore value!

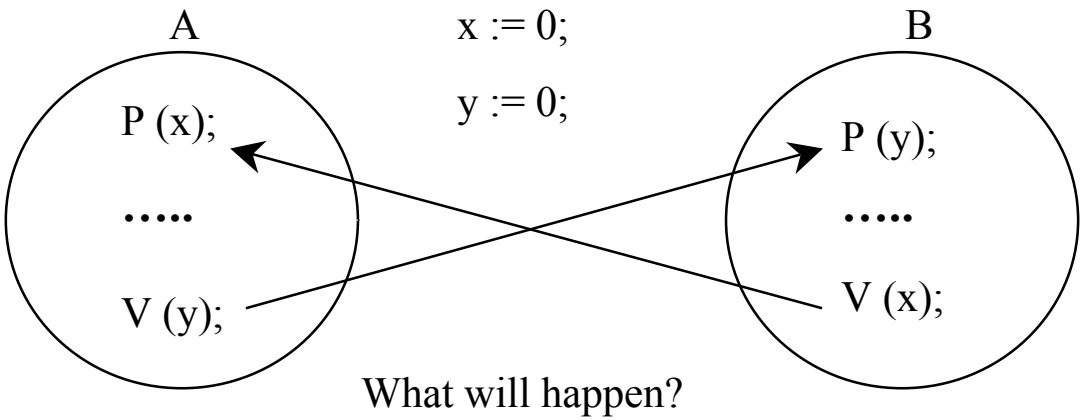
"The Team"

s := 8;



Up to 8 threads can pass P, the ninth will block until V is said by one of the eight already in there

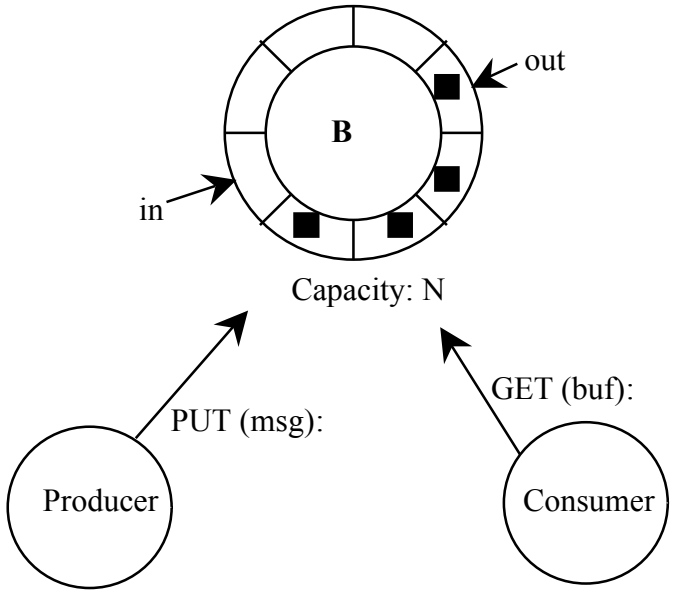
Simple to debug?



What will happen?

THEY ARE FOREVER WAITING FOR EACH OTHERS SIGNAL

Bounded Buffer using Semaphores



Rules for the buffer B:

- No Get when empty
- No Put when full
- B shared, so must have mutex between Put and Get

Use one semaphore for *each condition* we must wait for to become TRUE:

- B empty: nonempty:=0;
- B full: nonfull:=N
- B mutex: mutex:=1;

PUT (msg):
P(nonfull);
P(mutex);
<insert>
V(mutex);
V(nonempty);

GET (buf):
P(nonempty);
P(mutex);
<remove>
V(mutex);
V(nonfull);

- Is Mutex needed when only 1 P and 1 C?
- PUT at one end, GET at other end

Implementing Semaphores w/mutex

```
P(s) {
  Acquire(s.mutex);
  if (--s.value < 0) {
    Release(s.mutex);
    Acquire(s.delay);
  } else
    Release(s.mutex);
}
```

```
V(s) {
  Acquire(s.mutex);
  if (++s.value <= 0)
    Release(s.delay);
  Release(s.mutex);
}
```

- Kotulski (1988)
  - Two processes call P(s) (s.value is initialized to 0) and preempted after Release(s.mutex)
  - Two other processes call V(s)

Hemmendinger's solution (1988)

```
P(s) {
  Acquire(s.mutex);
  if (--s.value < 0) {
    Release(s.mutex);
    Acquire(s.delay);
  }
  Release(s.mutex);
}
```

```
V(s) {
  Acquire(s.mutex);
  if (++s.value <= 0)
    Release(s.delay);
  else
    Release(s.mutex);
}
```

- The idea is not to release s.mutex and turn it over individually to the waiting process
- P and V are executing in locksteps

Kearn's Solution (1988)

```
P(s) {
  Acquire(s.mutex);
  if (--s.value < 0) {
    Release(s.mutex);
    Acquire(s.delay);
    Acquire(s.mutex);
    if (--s.wakecount > 0)
      Release(s.delay);
  }
  Release(s.mutex);
}
```

```
V(s) {
  Acquire(s.mutex);
  if (++s.value <= 0) {
    s.wakecount++;
    Release(s.delay);
  }
  Release(s.mutex);
}
```

Two Release(s.delay) calls are also possible

Hemmendinger's Correction (1989)

```
P(s) {
  Acquire(s.mutex);
  if (--s.value < 0) {
    Release(s.mutex);
    Acquire(s.delay);
    Acquire(s.mutex);
    if (--s.wakecount > 0)
      Release(s.delay);
  }
  Release(s.mutex);
}
```

```
V(s) {
  Acquire(s.mutex);
  if (++s.value <= 0) {
    s.wakecount++;
    if (s.wakecount == 1)
      Release(s.delay);
  }
  Release(s.mutex);
}
```

Correct but a complex solution

Hsieh's Solution (1989)

```
P(s) {
  Acquire(s.delay);
  Acquire(s.mutex);
  if (--s.value > 0)
    Release(s.delay);
  Release(s.mutex);
}
```

```
V(s) {
  Acquire(s.mutex);
  if (++s.value == 1)
      Release(s.delay);
  Release(s.mutex);
}
```

- Use Acquire(s.delay) to block processes
- Correct but still a constrained implementation

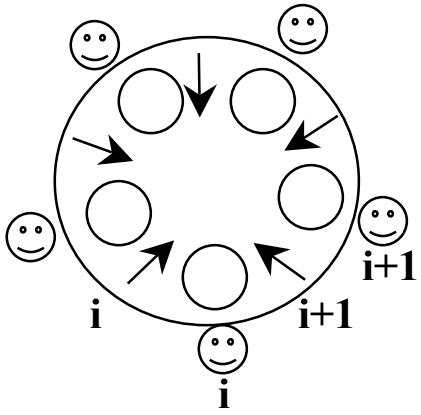
Implementing Semaphores w/Eventcount

```
P(S) {
  int t;
  t = Ticket(S.T);
  Await(S.ec, t - S.value);
}
```

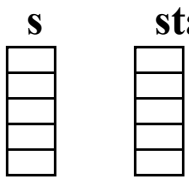
```
V(S) {
  Advance(S.ec);
}
```

- Semaphore S has
  - Ticket data structure S.T
  - Eventcount S.ec
  - Value S.value
- Does this work?
- Can we use Semaphores to implement eventcount?

Dining Philosophers



- Each: 2 forks to eat
- 5 philosophers: 10 forks to let all eat concurrently
- 5 forks: 2 can eat concurrently



- Free

Mutex on whole table:
- *1 can eat at a time*

```
P(mutex);
eat;
V(mutex);
```

T_i

Get L; Get R;
- *Deadlock possible*

S(i) = 1 initially

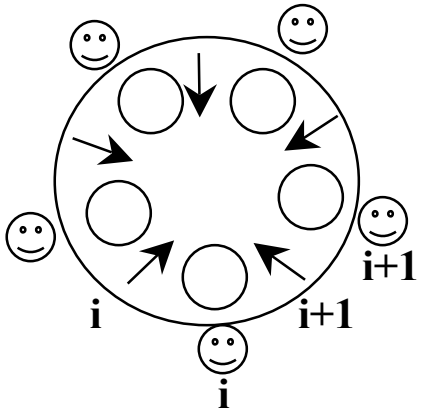
```
P(s(i));
P(s(i+1));
eat;
V(s(i+1));
V(s(i));
```

T_i

Get L; Get R if free else Put L;
- *Starvation possible*

T_i

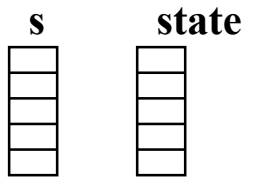
Dining Philosophers



To avoid starvation they could look after each other:

•**Entry**: If L and R is not eating I can

•**Exit**: If L (R) wants to eat and L.L (R.R) is not eating I start him eating



•Thinking

•Eating

•Want

S(i) = 0 initially

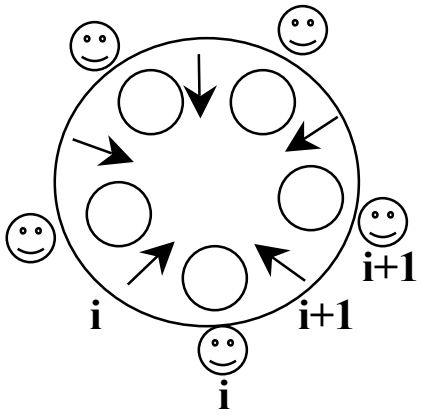
T_i

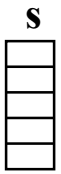
```
While (1) {
   <think>
   ENTRY;
      <eat>
   EXIT;
}
```

```
P(mutex);
   state(i):=Want;
   if (state(i-1) !=Eating AND state(i+1) != Eating)
   {/*Safe to eat*/
      state(i):=Eating;
      V(s(i));  /*Because  */    }
V(mutex);
P(s(i)); /*Init was 0!! I or neighbor must say V(i) to myself!*/
```

```
P(mutex);
   state(i):=Thinking;
   if (state(i-1)=Want AND state(i-2) !=Eating)
   {
      state(i-1):=Eating;
      V(s(i-1));  /*Start Left neighbor*/
   }
/*Analogue for Right neighbor*/
V(mutex);
```

Dining Philosophers





S(i) = 1
initially

Can we in a simple way do better than this one?

Get L; Get R;
•Deadlock possible

```
P(s(i));
   P(s(i+1));
      eat;
   V(s(i+1));
V(s(i));
```

•Non-symmetric solution. Still quite elegant

•Remove the danger of circular waiting (deadlock)

•T1-T4: Get L; Get R;

•T5: Get R; Get L;

T_1, T_2, T_3, T_4:

```
P(s(i)):
   P(s(i+1));
      <eat>
   V(s(i+1));
V(s(i));
```

T_5

```
P(s(1));
   P(s(5));
      <eat>
   V(s(5));
V(s((1));
```

Event Count (Reed 1977)

- **`Init( ec )`**
  - Set the eventcount to 0
- **`Read( ec )`**
  - Return the value of eventcount **`ec`**
- **`Advance( ec )`**
  - Atomically increment **`ec`** by 1
- **`Await( ec, v )`**
  - Wait until the expression **`ec >= v is TRUE`**

Bounded Buffer with Event Count

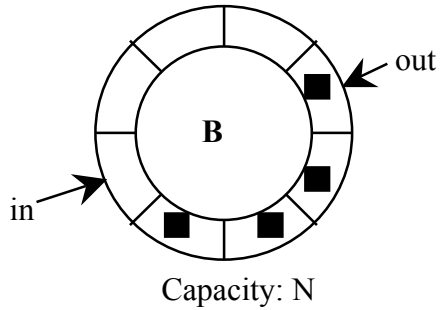
in=out=0;

```
producer() {
  int next = 0;

  while (1) {
    produce an item
    next++;
    await(out, next - N);
    put the item in buffer;
    advance(in);
  }
}
```

```
consumer() {
  int next = 0;

  while ( 1 ) {
    next++;
    await(in, next);
    take an item from buffer;
    advance(out);
    consume the item;
  }
}
```



- Does this work for more than one producer and consumer?
  - No, we will get multiple events happening, need a sequencer

Sequencers

- Ticket(T) returns an ascending integer number, starting at 0
  - Atomic op
  - Just like an automatic ticket machine
- Multi-producer code

```
producer() {
        int t;
        while (1) {
                produce item;
                t=ticket(T);
                await(in, t);                   /* sync w/producers */
                await(out, t-N+1);              /* sync w/consumers */
                buffer[t%N]=item;
                advance(in);
        }
}
```

- What about the consumer?