Semaphores

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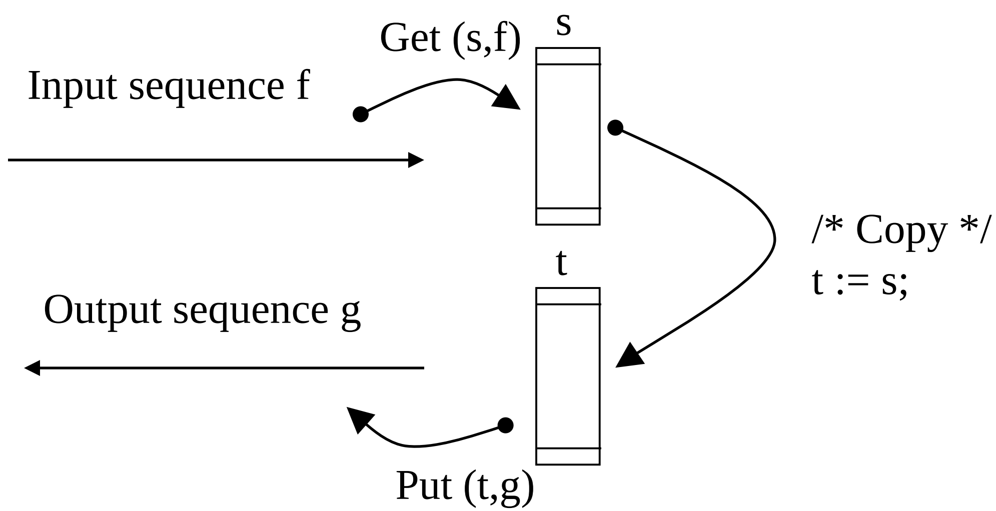
Concurrency: Double buffering

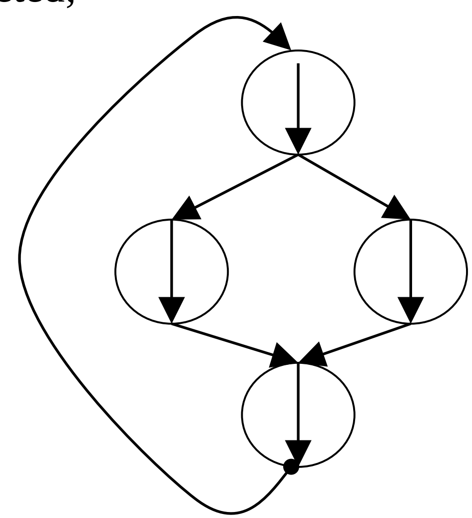
/* Fill s and empty t concurrently */




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

Specifies concurrent execution

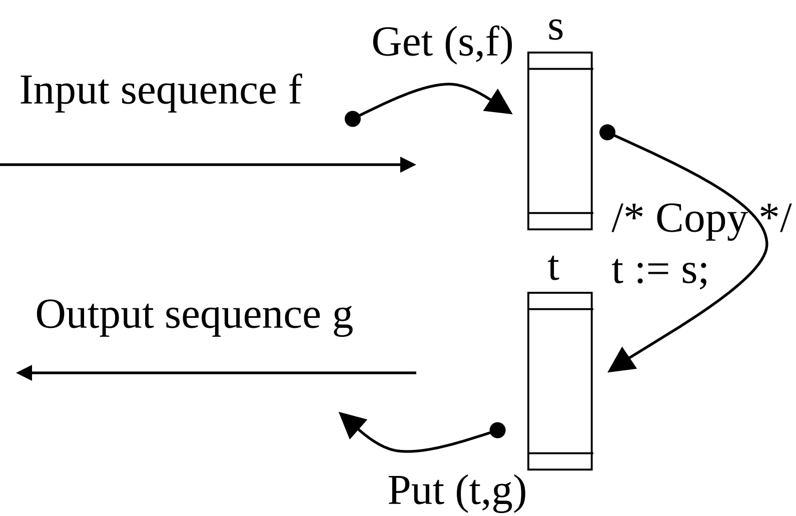
(Threads)



- **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 */**

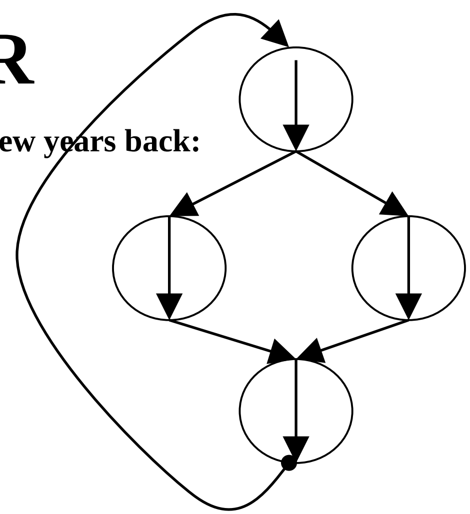
Proposed code:

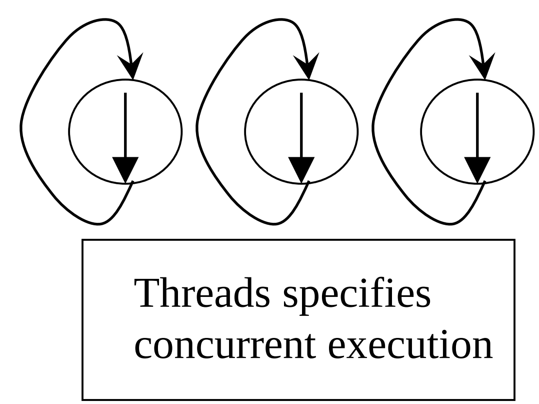
copy_thread:: *{acq(lock_t); acq(lock_s); **t=f;** rel(lock_s); rel(lock_t);**}**

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**
  - **And as Thomas once said at the beginning of the course a few years back: Ordnung Muss Sein!**





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

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

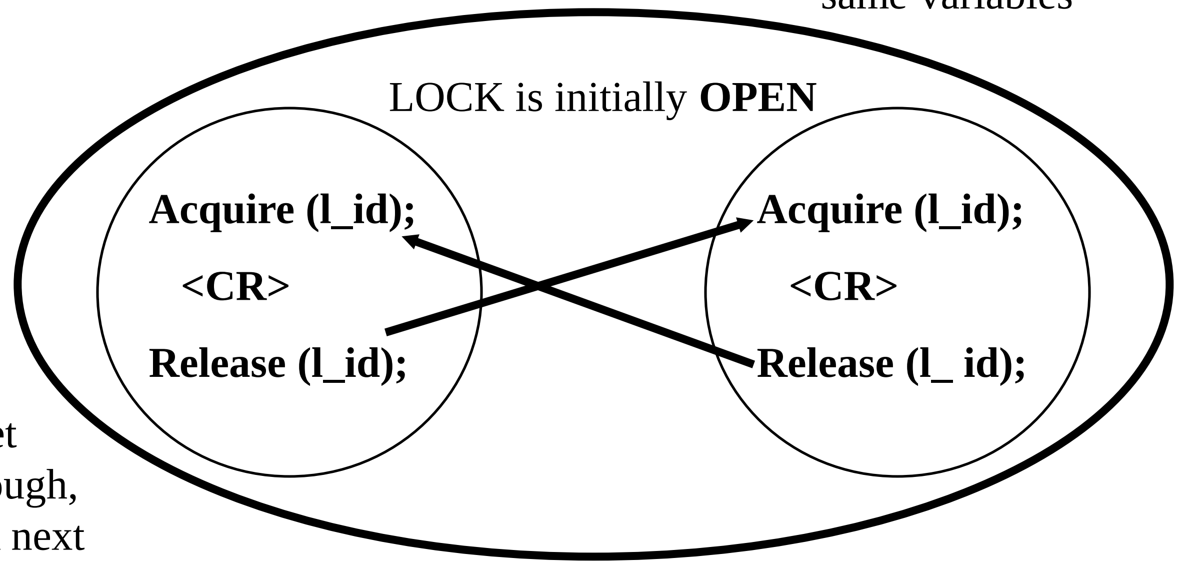
- UnBlock(lock)
  - Spin on lock.guard
  - Dequeue a TCB
  - Put TCB in ready_queue
  - Clear spin lock.guard

Two Kinds of Synchronization

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

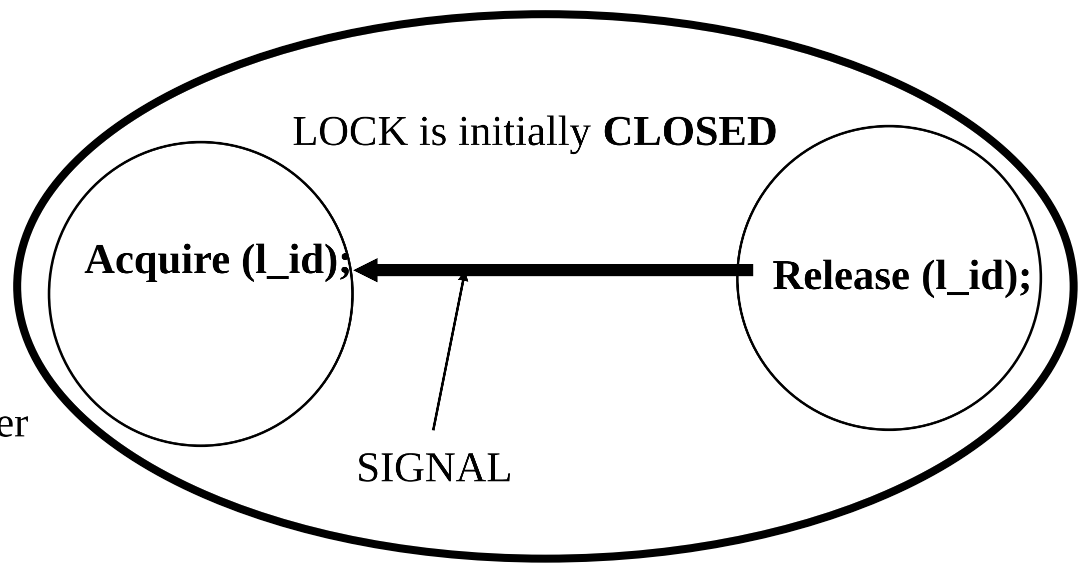
Process w/two threads

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)

Published as an appendix to the paper on the T.H.E. operating system

- “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);
}
```

MUTEX

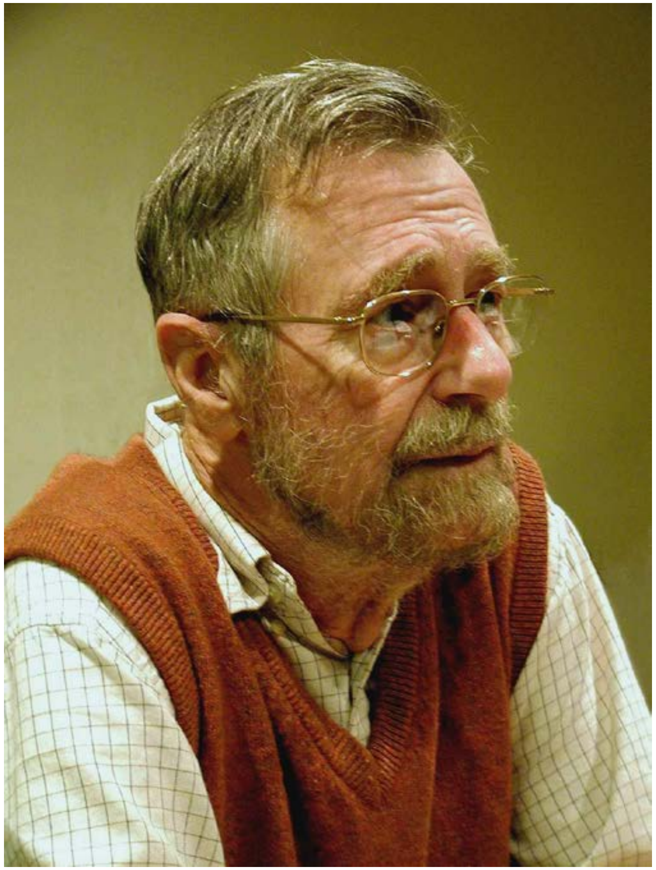
```
V(s) {
  if (++s <= 0)
    Unblock(s);
}
```

Can get negative s: counts number of waiting threads

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

An aside on Dijkstra

- Dutch, moved to UT/austin
- 1972 Turing Award Winner
- Go to statement considered harmful
- Homepage
- EDSAC Summer School



Semaphores can be used for …

- Mutual exclusion (solution of critical section problem). Binary semaphore
- Resources with multiple instances (e.g. buffer slots in producer/consumer problem. Counting semaphore
- Signaling events

Examples of classic synchronization problems

- Critical Section
- Producer/Consumer
- Reader/Writer
- Sleeping Barber
- Dining Philosophers

Semaphores w/Busy Wait

P(s):

```
while (s <= 0) {};
s--;
```

V(s):

```
s++;
```

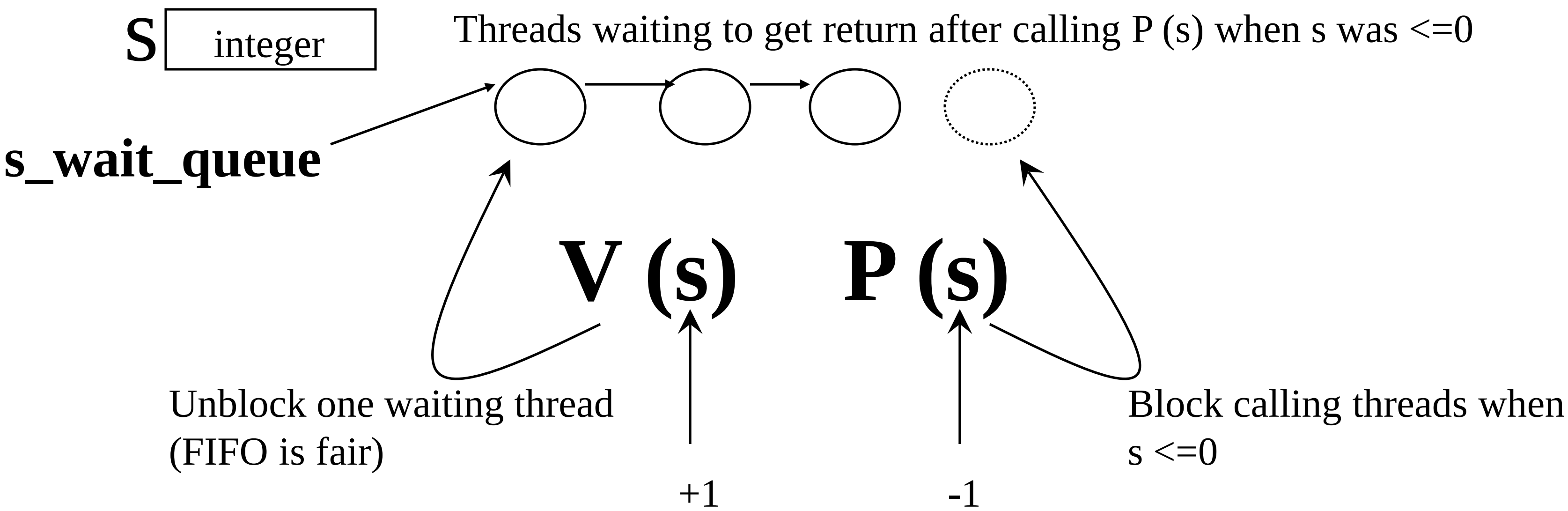
ATOMIC
(NB: mutex around while can create a problem…)

If spinning inside mutex V will not get in:

- *Must open mutex, say, between every iteration of while to make it possible for V to get in*
  - *Costly*
  - *Starvation possible*
    - *Of P's*
    - *Of V's*

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

The Structure of a Blocking Semaphore Implementation

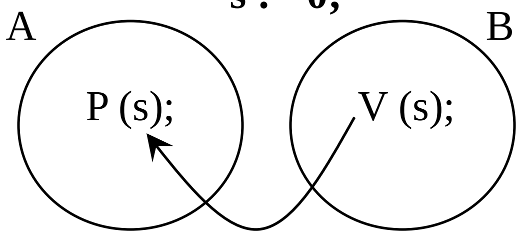


- Atomic: Disable interrupts
- Atomic: P() and V() as System calls
- Atomic: Entry-Exit protocols

Using Semaphores

“The Signal”

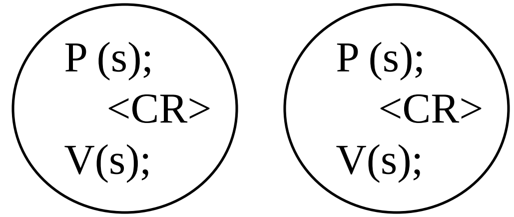
s := 0;



A blocks until B says V

s := 1;

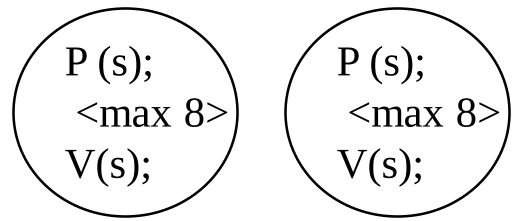
“The Mutex”



One thread gets in, next blocks until V is executed

s := 8;

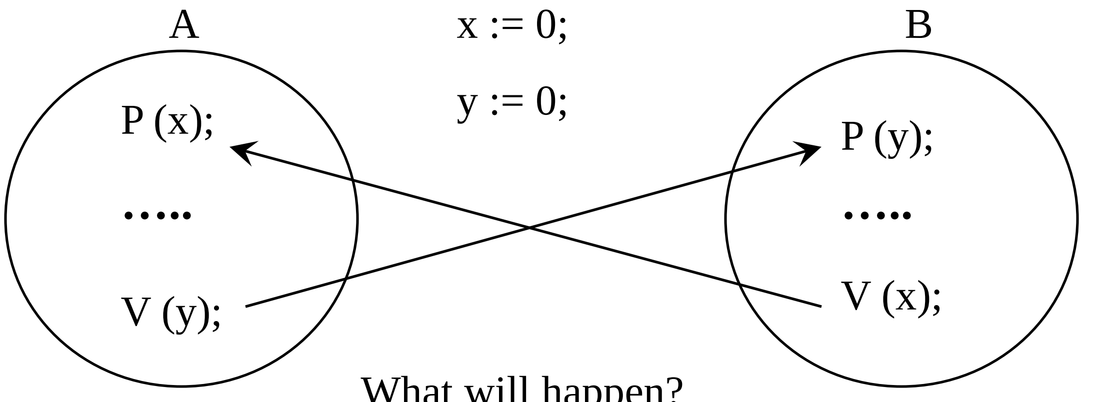
“The Team”



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

NB: remember to set the initial semaphore value!

Simple to debug?



What will happen?

THEY ARE FOREVER WAITING FOR EACH OTHERS SIGNAL

Semaphores w/Busy Wait

P: Passieren == to pass
P: Proberen == to test

Dutch words

V: Vrijmagen == to make free
V: Verhogen == to increment

P(s):

```
while (s <= 0) {};
s--;
```

V(s):

```
s++;
```

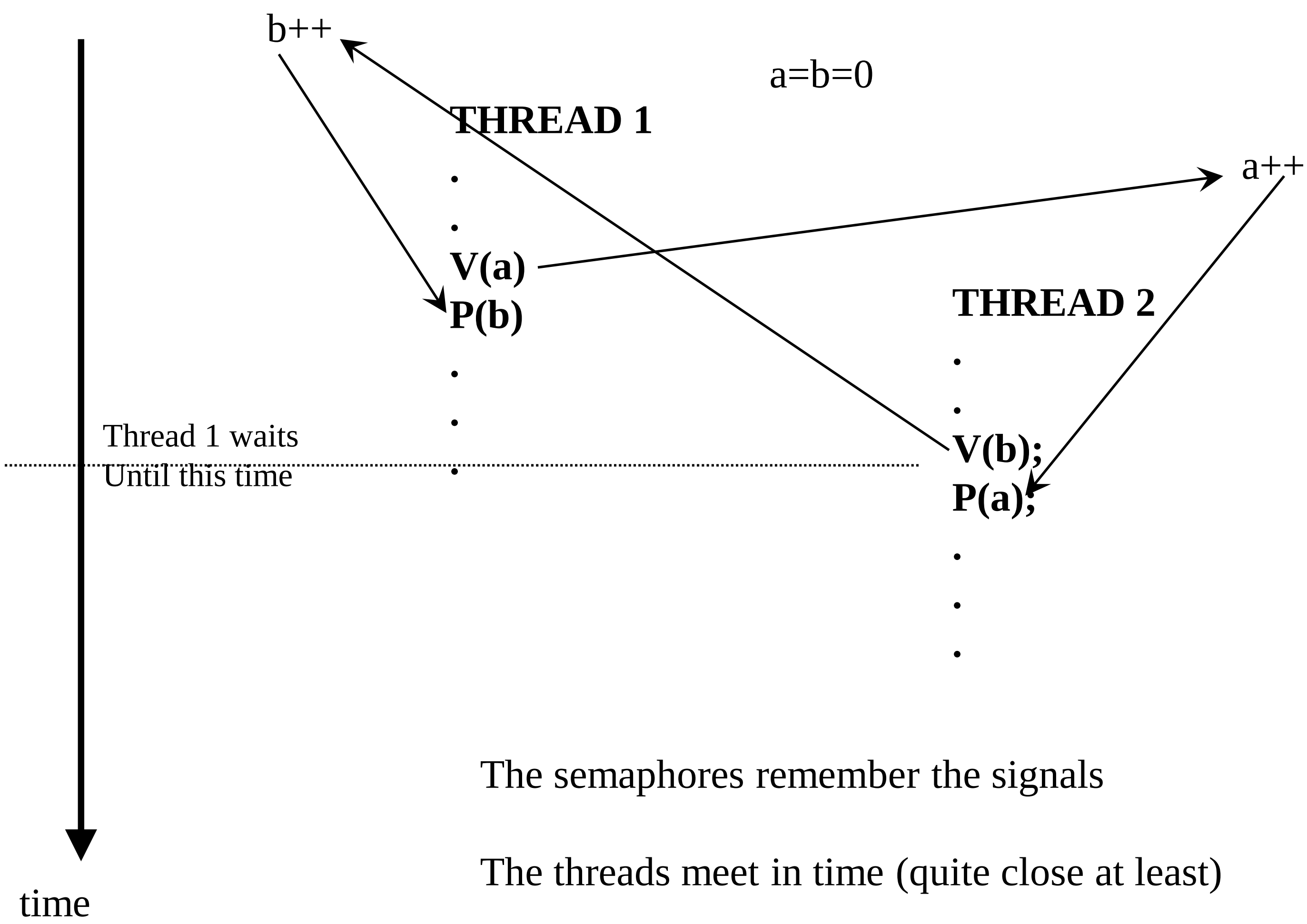
mutex

P == wait == down, V == signal == up

Why so many names?

- •Down, up: what the ops *do*
- •Wait, signal: what the ops are *used for*
- •P, V: the original names by Dijkstra

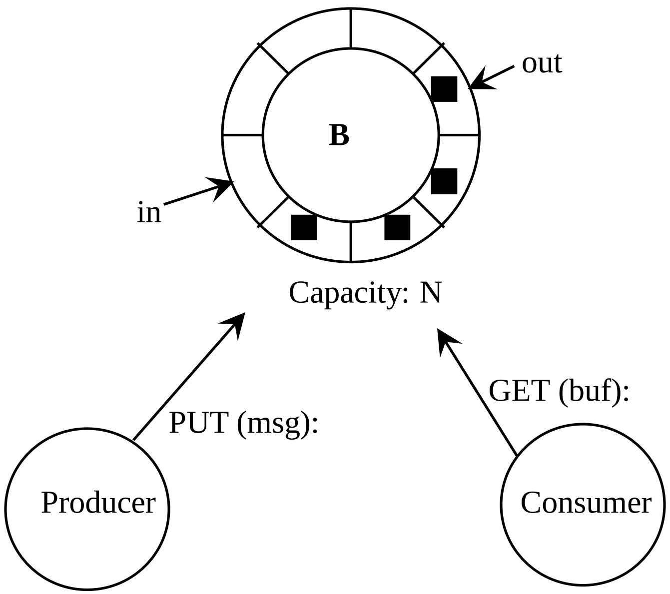
Rendezvous between two threads



The semaphores remember the signals

The threads meet in time (quite close at least)

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

Semaphores w/Busy Wait

P(s):

```
while (s <= 0) {};
s--;
```

V(s):

```
s++;
```

MUTEX

If P **spinning inside mutex then** V **will not get in**

- •Must *open mutex*, say, between every iteration of while to make it possible for V to get in
  - •Costly
    - •Every 10th iteration?
      - •latency
  - •Starvation possible, Lady Luck may ignore some threads
    - •Of P’s
    - •Of V’s

Hard life…

- Implementing the P and V of semaphores
  - If WAIT is done by blocking
    - Expensive
    - Must open mutex
      - But no logical issues since we now have a waiting queue and will not get starvation
  - If done by spinning
    - Must open mutex during spin to let V in
      - Starvation of P’s and V’s possible
        - May not be a problem in practise
- What can a poor (perhaps somewhat theoretical oriented) Computer Scientist do?
  - Research (“I can do better”)
  - Publish (So other people can say “I can do better”)

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

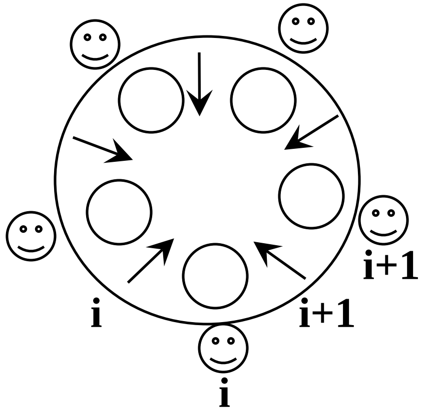
Hsieh’s Solution (1989)

```
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

Dining Philosophers

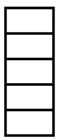


- Each: need 2 forks to eat
- 5 philosophers: 10 forks
- 5 forks: 2 can eat concurrently

Things to observe:

- A fork can only be used by one at a time
- No deadlock, please
- No starving, please
- Concurrent eating, please

s



s(i): One semaphore per fork to be used in **mutex** style P-V

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

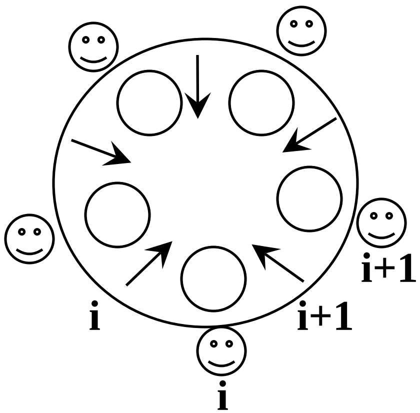
P(s(i));
P(s(i+1));
eat;
V(s(i+1));
V(s(i));

T_i

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

T_i

Dining Philosophers

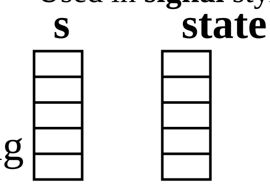


To avoid starvation they could look after each other:

•**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

One semaphore per philosopher
Used in **signal** style



•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);
```

Trouble: **starvation** pattern possible:
2&4 at table, 1&3 hungry
2 gets up, 1 sits down
4 gets up, 3 sits down
3 gets up, 4 sits down
1 gets up, 2 sits down
Ad infinitum => Phil 0 will starve

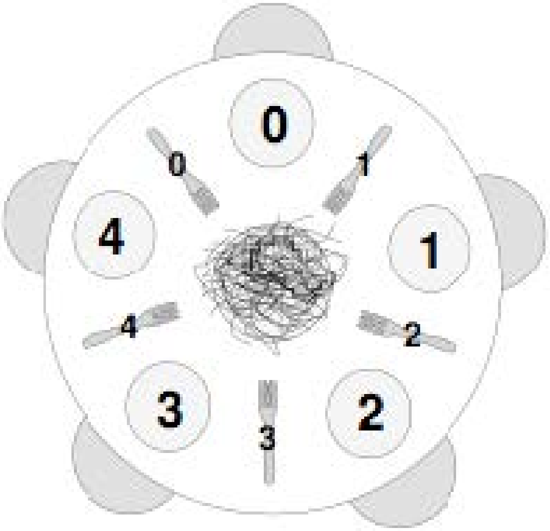
Last solution has a problem

Trouble in Tanenbaums solution:

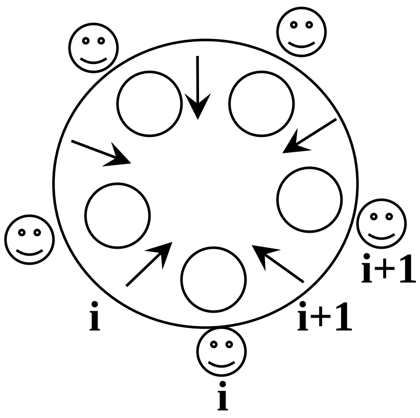
starvation pattern possible:

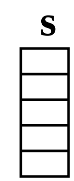
2&4 at table, 1&3 hungry
2 gets up, 1 sits down
4 gets up, 3 sits down
3 gets up, 4 sits down
1 gets up, 2 sits down

Ad infinitum => Phil 0 will starve



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));
```

Some Links

- Wikipedia: *Semaphore*
- Alan B. Downey: *The Little Book of Semaphores*
  Book
- Creature Mann: Santa and his Helpers: *Video*
- Udacity: Mutual Execution vs Synchronization: *Video*
- Jouni Leppäjärvi: *Master's Thesis*