Locks and semaphores

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KTH

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recap, what's the problem

```
  :
#include <pthread.h>

volatile int count = 0;

void *hello(void *arg) {
  for(int i = 0; i < 10; i++) {
    count++;
  }
}

int main() {
  pthread_t p1, p2;

  pthread_create(&p1, NULL, hello, NULL);
  pthread_create(&p2, NULL, hello, NULL);
    :
}
```

Peterson's algorithm

```
int request[2] = {0,0};
int turn = 0;

int lock(int id) {

  request[id] = 1;
  int other = 1-id;
  turn = other;

  while(request[other] == 1 && turn == other) {}; // spin

  return 1;
}

void release(int id) {
  request[id] = 0;
}
```

Total Store Order

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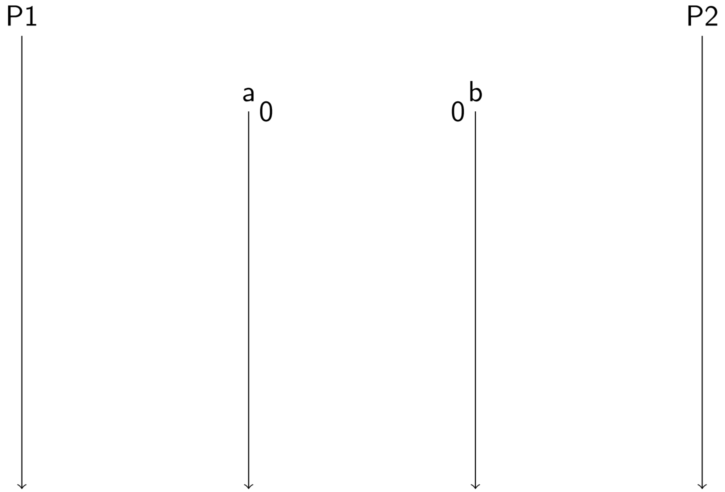

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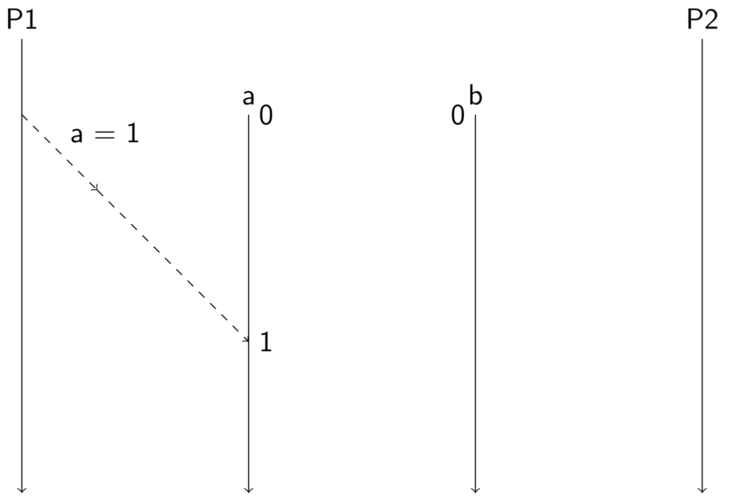

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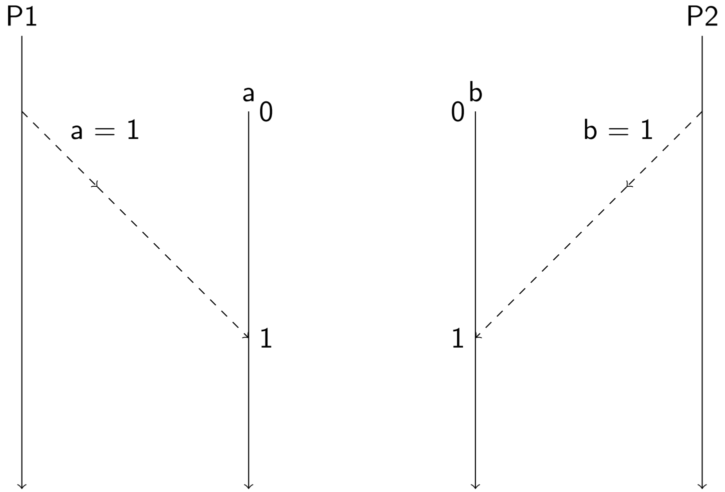

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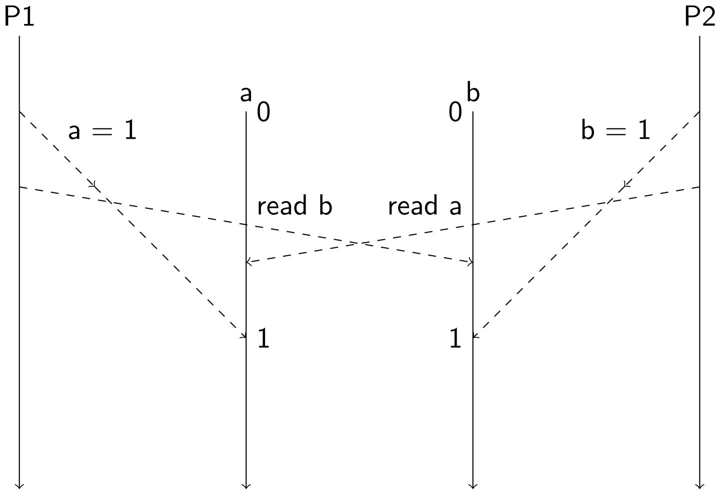

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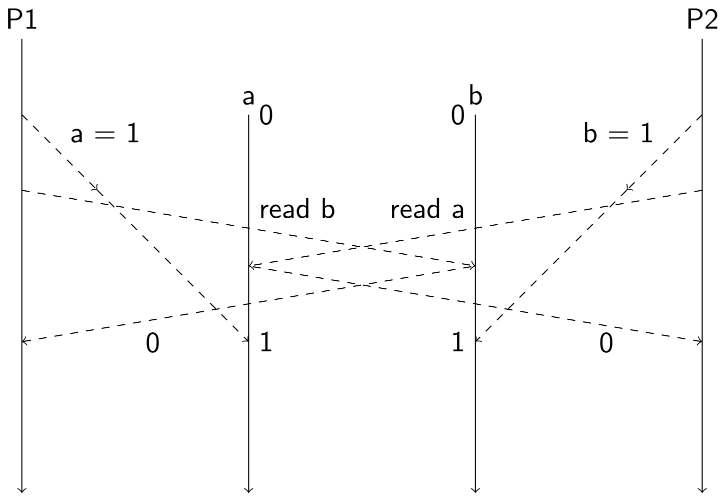

atomic memory operations

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- `test-and-set`: swap i.e. read and write to a memory location, the simplest primitive
- `fetch-and-add/and/xor/...` : update the value with a given operation, more flexible
- `compare-and-swap` : if the memory location contains a specific value then swap

try to lock by swap

```
int try(int *lock) {
    return __sync_val_compare_and_swap(lock, 0, 1);
}
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```
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movq     %rsp, %rbp
movq     %rdi, -8(%rbp)
movq     -8(%rbp), %rdx
movl     $0, %eax
movl     $1, %ecx
lock cmpxchgl    %ecx, (%rdx)
popq     %rbp
ret
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ret
```

This is using GCC extensions to C, similar extensions available in all compilers.

```
int lock(int *lock) {

  while(try(lock) != 0) {}

  return 1;
}
```

a spin-lock

```
int lock(int *lock) {

  while(try(lock) != 0) {}

  return 1;
}

void release(int *lock) {
  *lock = 0;
}
```

finally - we're in control

```
int global = 0;

int count = 0;

void *hello(void *name) {
  for(int i = 0; i < 10; i++) {
    lock(&global);
    count++;
    release(&global);
  }
}
```

try using `taskset -c 1 ./spin 10000`

spin locks

spin locks

A film by Mike Leigh the director of 'Secrets and Lies' and 'Vera Drake'
HAPPY-GO-LUCKY
Sally Hawkins Eddie Marsan Alexis Zegerman
"Vastly entertaining and very funny"
"Fresh and funny, joyful and life - affirming"
"A joy to behold" ★★★★★
"A delight"
(Winner Best Actress)

avoid spinning

We need to talk to the operating system.

avoid spinning

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```
void lock(int *lock) {

  while(try(lock) != 0) {
    sched_yield();   // in Linux
  }

}
```

Wham - .....

For how long should we sleep?

Wham - .....

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Wham - .....

For how long should we sleep?

We would like to be woken up as the lock is released - before you go-go.

a detour in Sun Solaris

```
void lock(lock_t *m) {

  while(try(m->guard) != 0) {};

  if(m->flag == 0) {
    m->flag = 1;
    m->guard = 0;
  } else {
    queue_add(m->queue, gettid());
    m->guard = 0;
    park();
 }
```

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    park();
 }
```

```
void unlock(lock_t *m) {

  while(try(m->guard) != 0) {};

  if(empty(m->queue)) {
    m->flag = 0;
  } else {
    unpark(dequeue(m->queue));
  }
  m->guard = 0;
}
```

It's not easy to to get it right.

```
/* m->flag == 1 */
        :
queue_add(m->queue, gettid());
m->guard = 0;
park();
// when I wake up the flag is set
```

```
if(empty(m->queue)) {
  m->flag = 0;
} else {
  // don't reset the flag
  unpark(dequeue(m->queue));
}
```

it's not easy

It's not easy to to get it right.

```
/* m->flag == 1 */
      :
queue_add(m->queue, gettid());
setpark();
// if somone unparks now my park() is a noop
m->guard = 0;
park();
```

```
if(empty(m->queue)) {
  m->flag = 0;
} else {
  // don't reset the flag
  unpark(dequeue(m->queue));
}
```

back to Linux

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- futex_wait(mutex, val) : suspend on the `mutex` if its equal to `val`.
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In GCC you have to call them using a `syscall()`

a futex lock

```
void lock(volatile int *lock) {
  while(try(lock) != 0) {
    // time to sleep ...
    futex_wait(lock, 1);
  }
}
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void unlock(volatile int *lock) {
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  *lock = 0;
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Not very efficient - we want to avoid calling `futex_wake()` *if no one is waiting.*

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The lock procedure is platform specific, normally implemented as a combination of spinning and yield.

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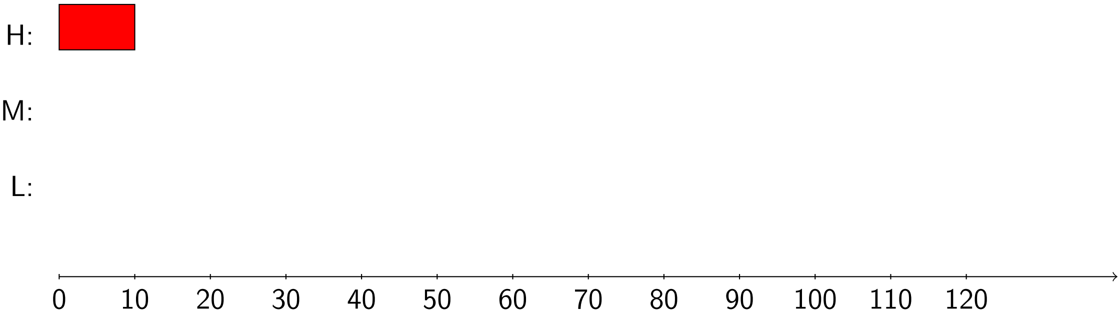
- Livelock: we're moving around in circles, all threads think that they are doing progress but we're stuck in a loop.
- Starvation: we're making progress but some threads are stuck waiting.
- Unfairness: we're making progress but some threads are given more of the resources.

Assume we have a fixed priority scheduler, three processes with high (H), medium (M) and low (L) priority and one critical resource.



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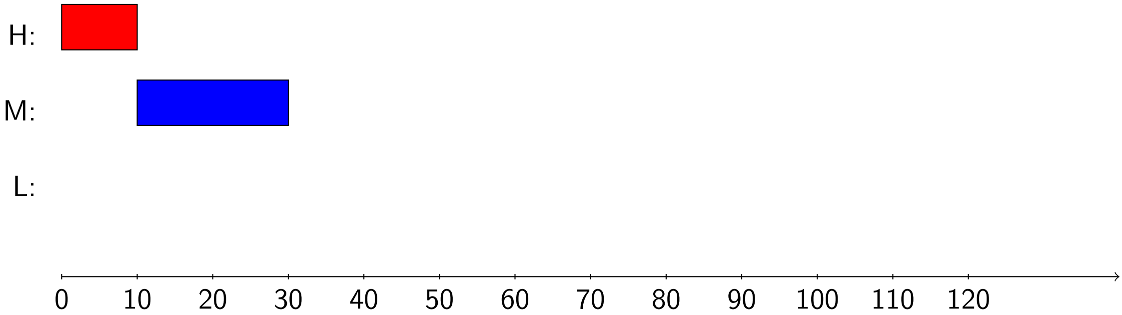

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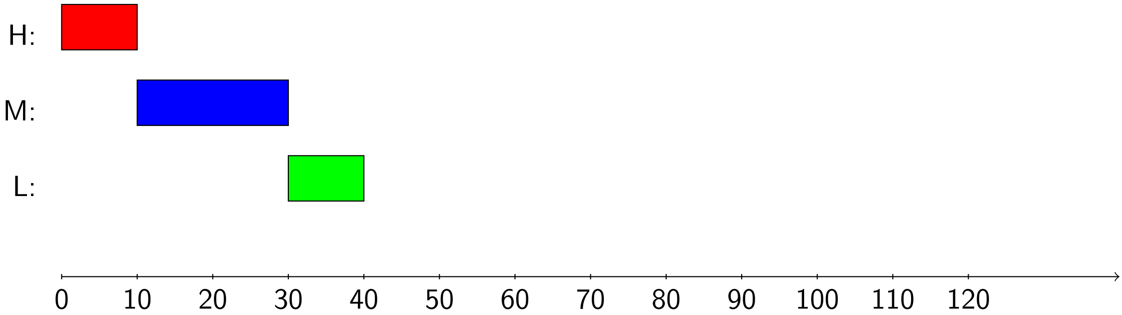

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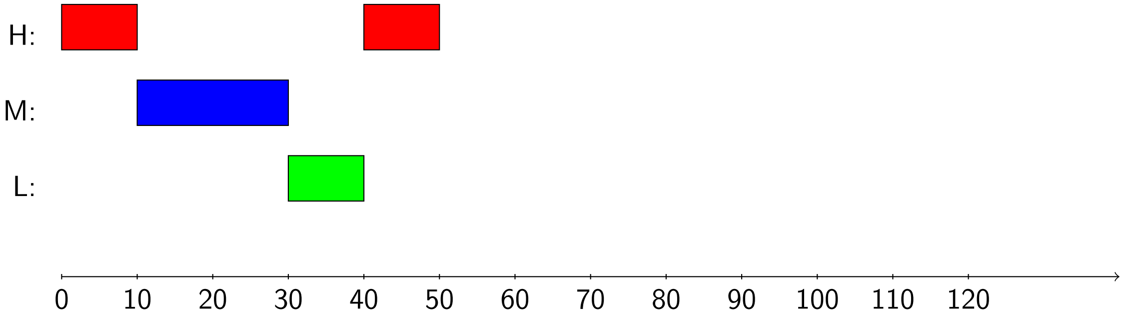

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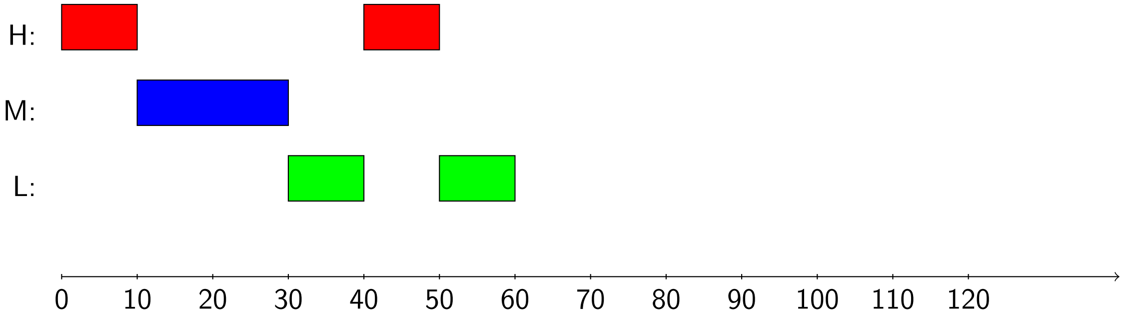

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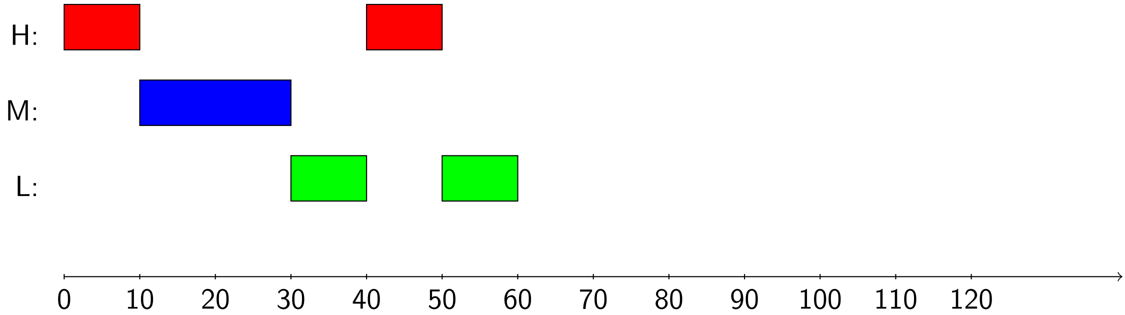

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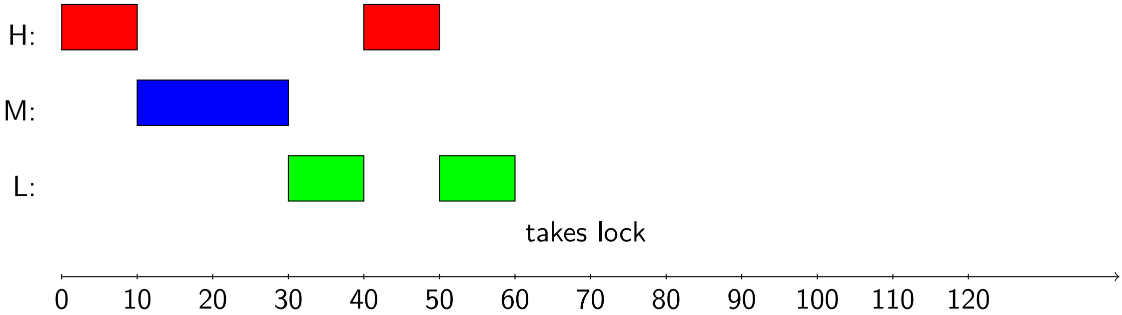

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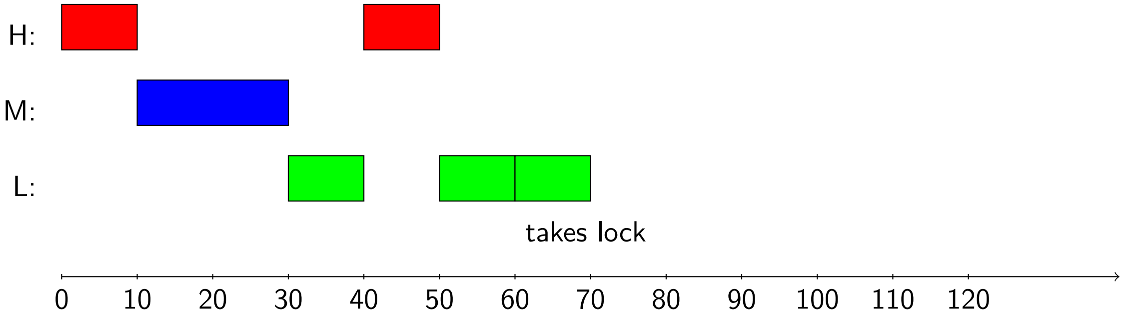

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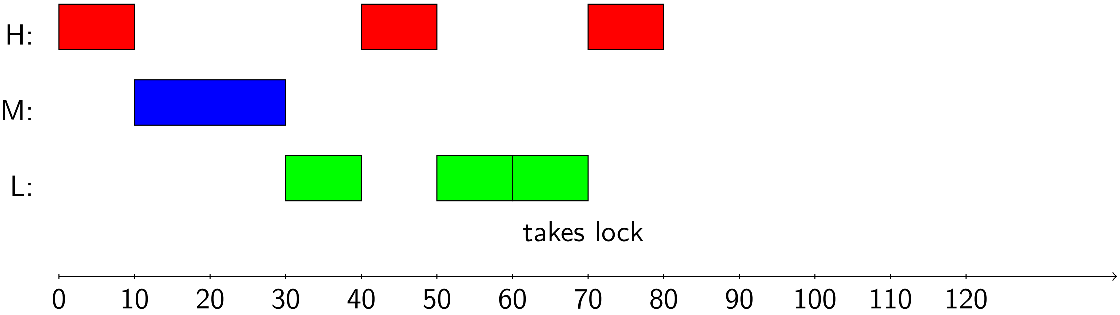

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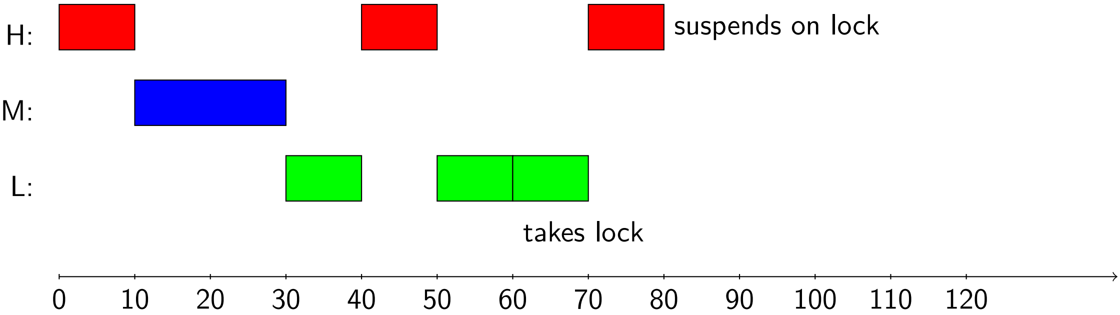

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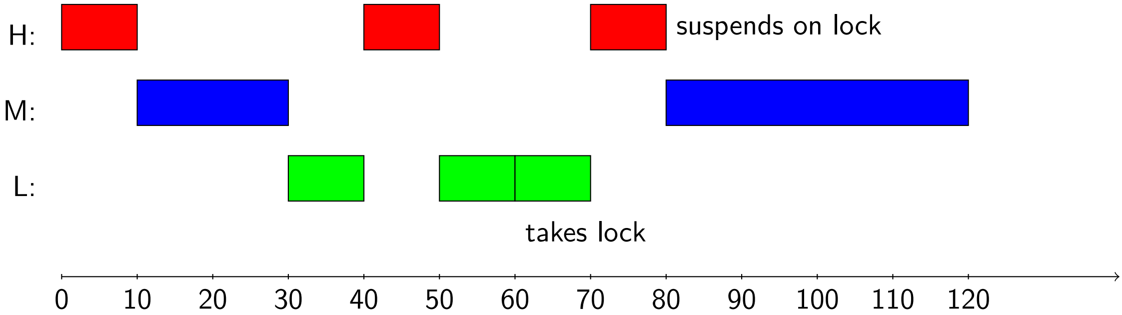
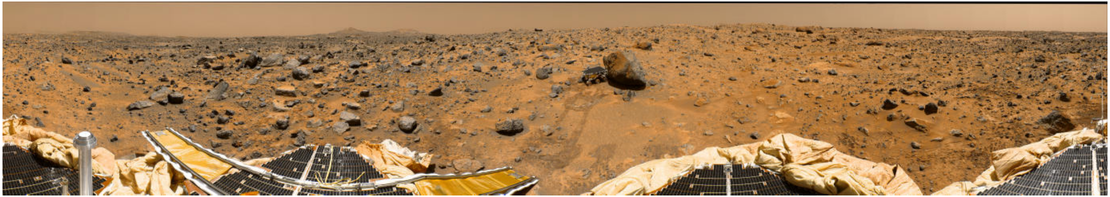


Mars Pathfinder and Priority Inversion



Some examples

- concurrent counter
- a list
- a queue

the concurrent counter

```
struct counter_t {
  int val;
}

void incr(struct counter_t *c) {
  c->val++;
}
```

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struct counter_t {
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  c->val++;
}
```

```
struct counter_t {
  int val;
  pthread_mutex_t lock;
}

void incr(struct counter_t *c) {
  pthread_lock(c->lock);
  c->val++;
  pthread_unlock(c->lock);
}
```

Do the right thing

Doing the right thing often has a price.

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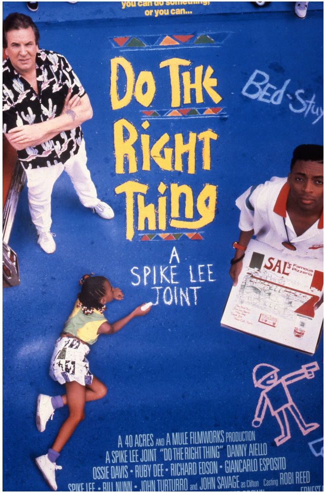
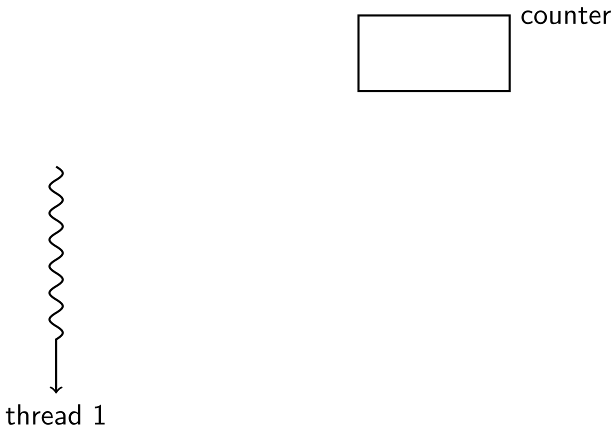


sloppy counter



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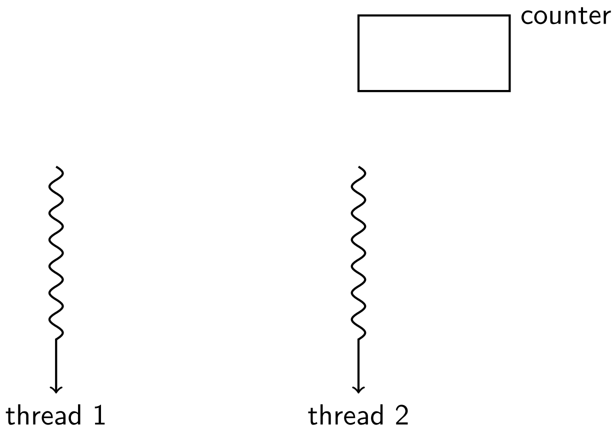

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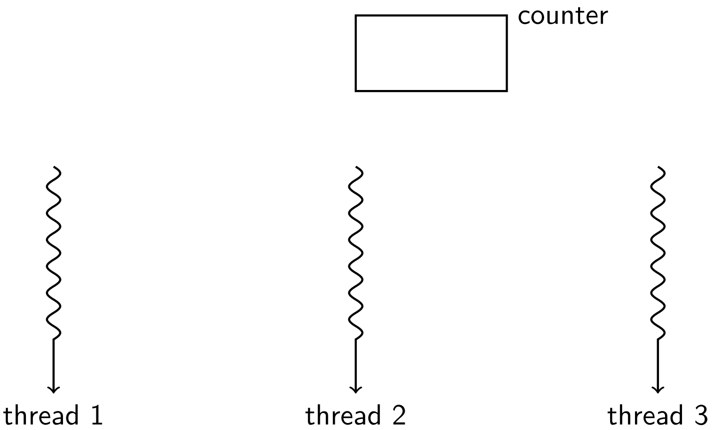

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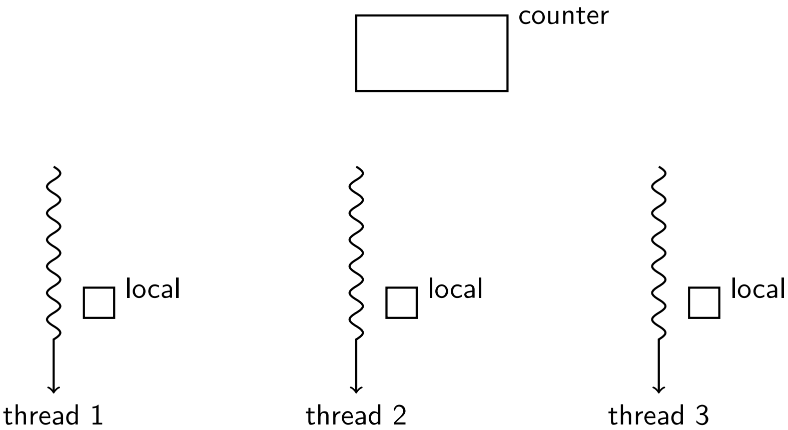

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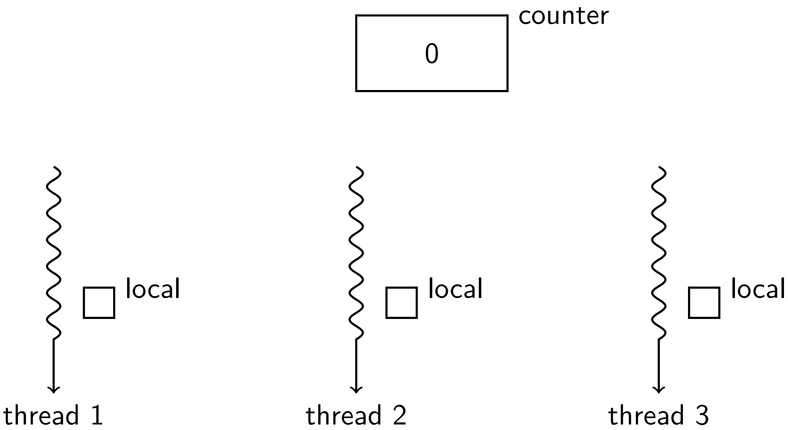

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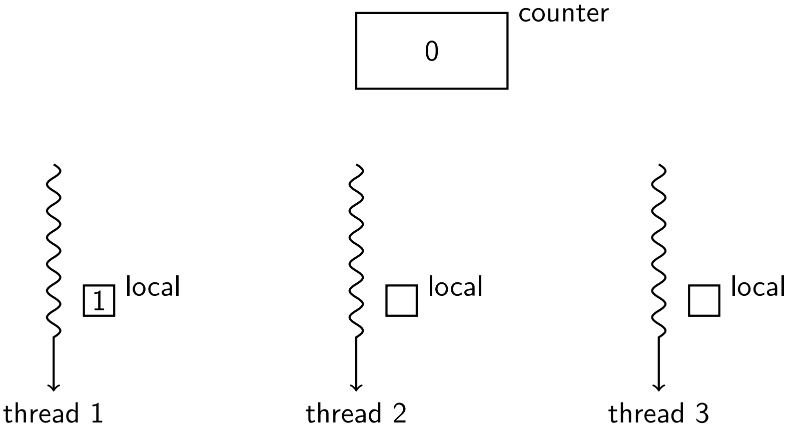

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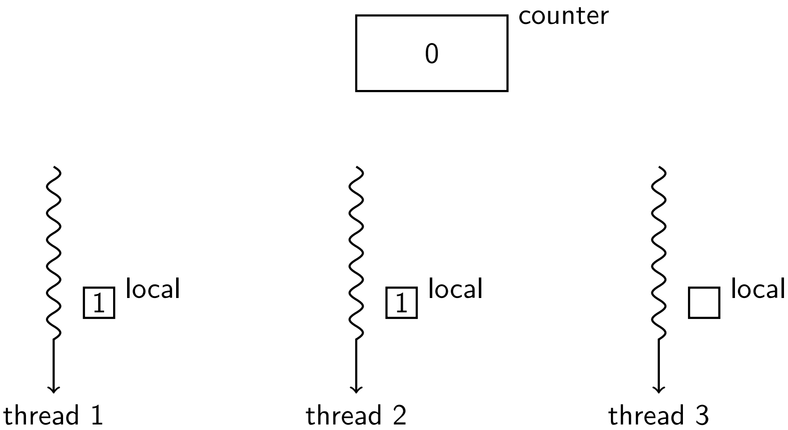

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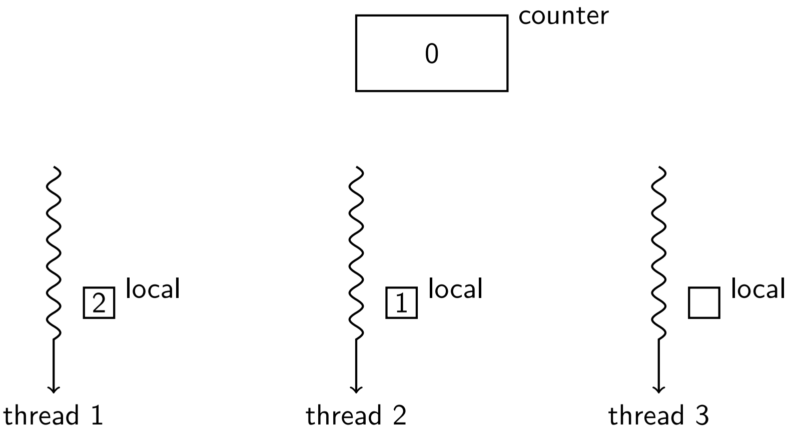

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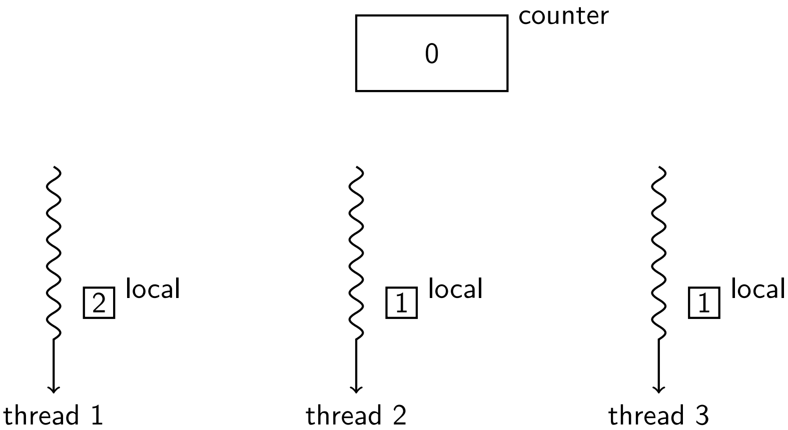

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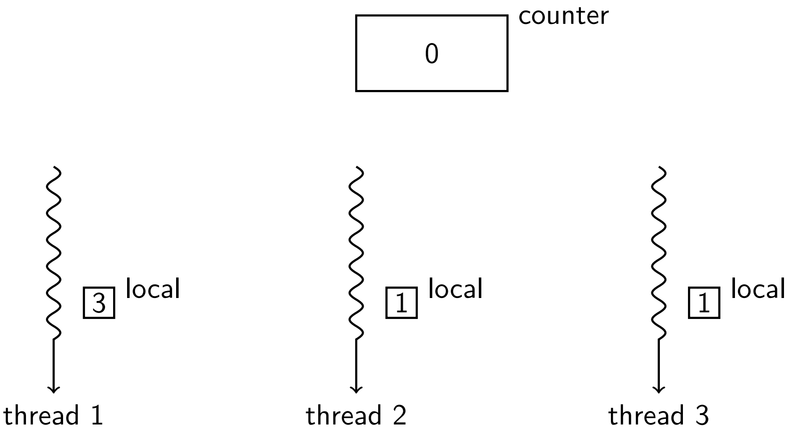

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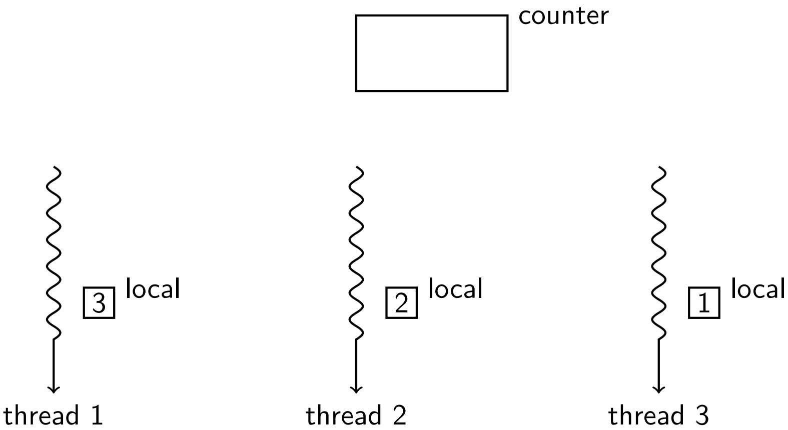

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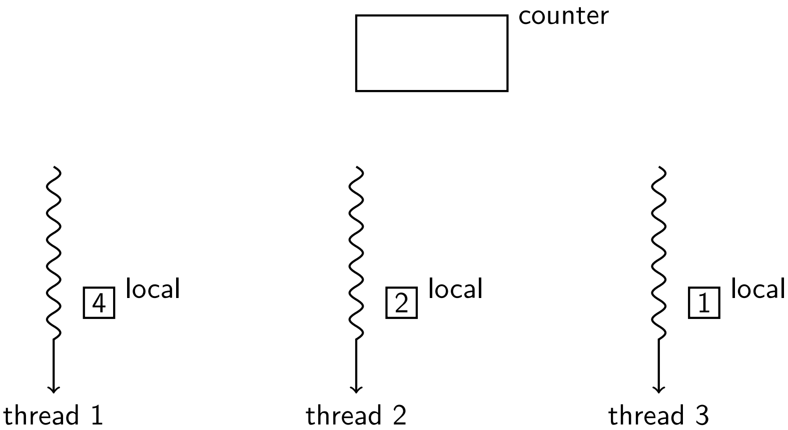

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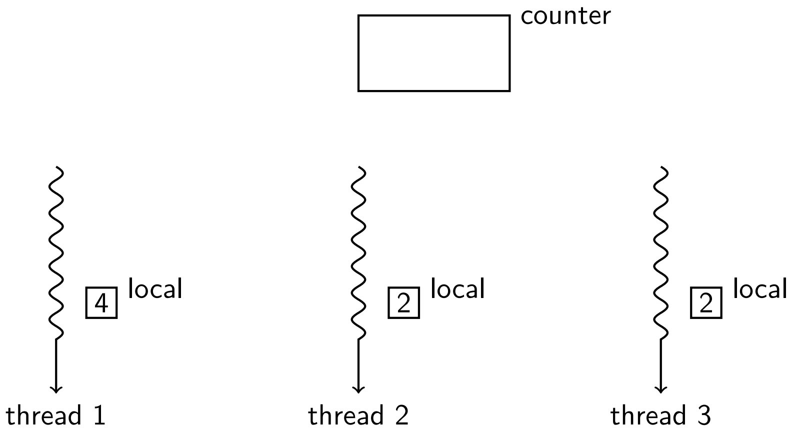

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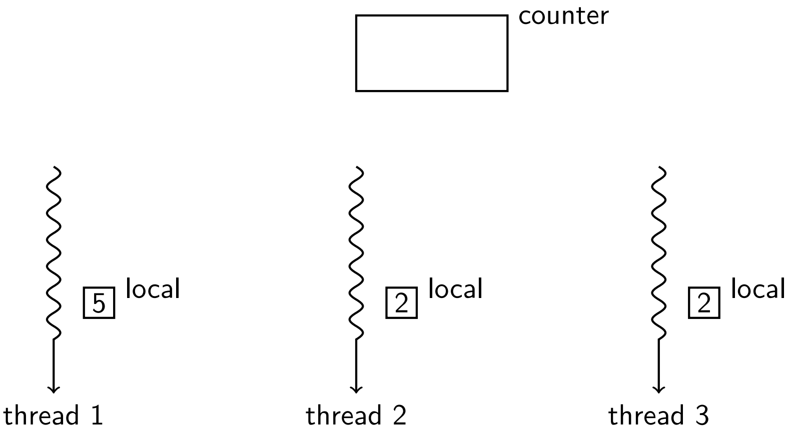

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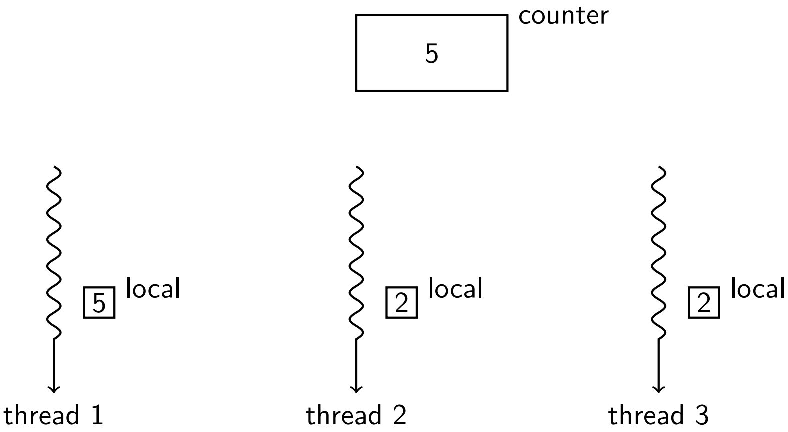

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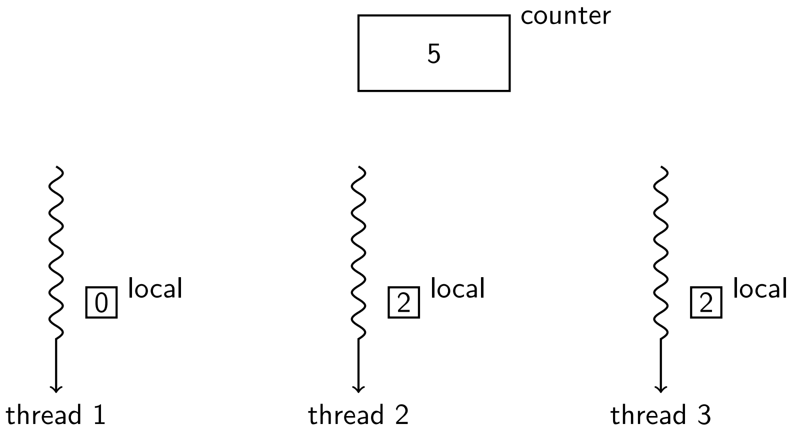

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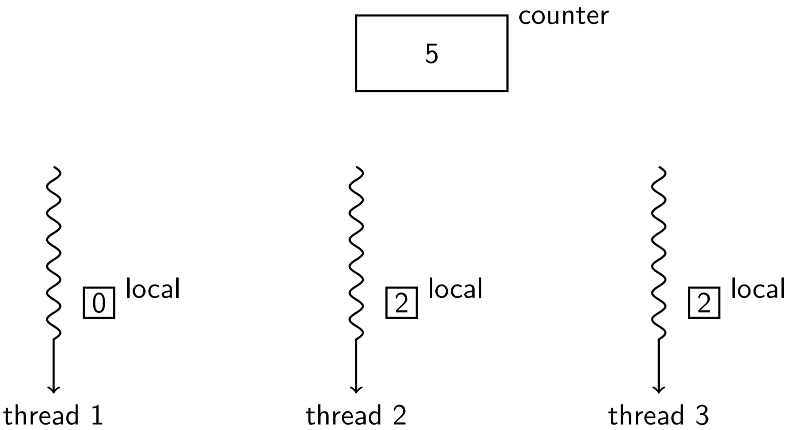

Sloppy vs Speed - do the right thing.

how about a list

Simple solution: protect the list with one lock.

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- concurrent updating: .... hmm, how would you solve it?

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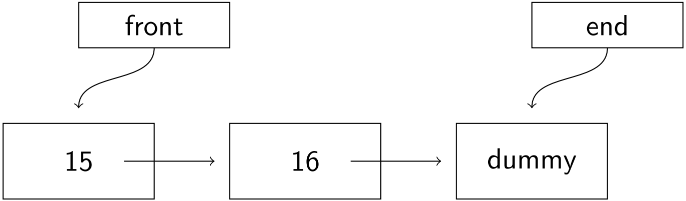

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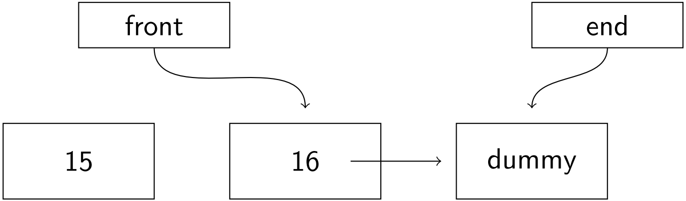

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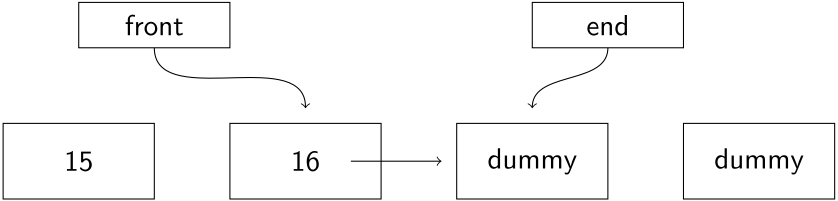

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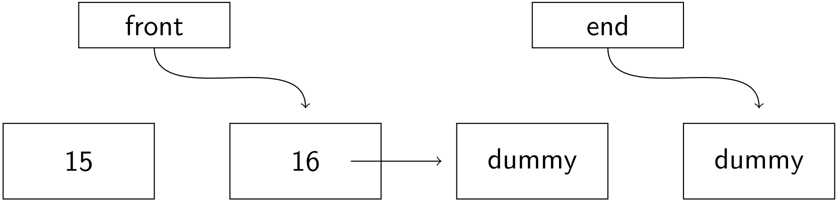

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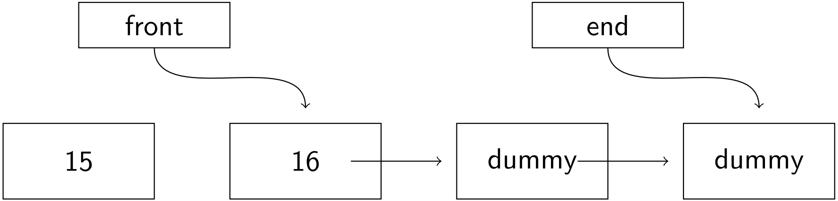

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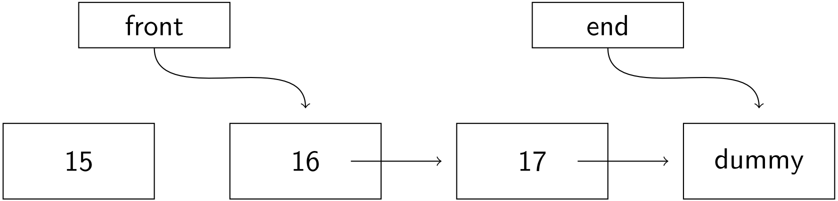

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How are things done in for example the JVM or Erlang?

beyond locks

The locks that we have seen are all right:

- We can take a lock and prevent others from obtaining the lock.

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- We can take a lock and prevent others from obtaining the lock.
- If someone holds the lock we will suspend execution.
- When the lock is released we will wake up and try to grab the lock again.

We would like to suspend and only be woken up if a specified condition holds true.

the queue revisited

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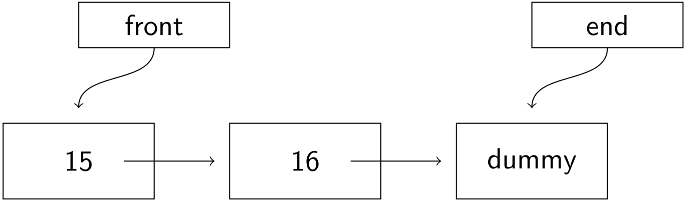

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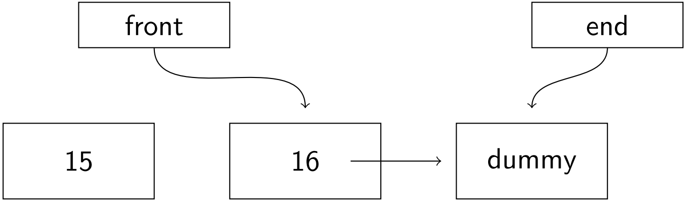

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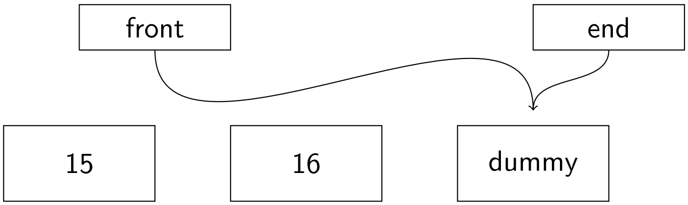

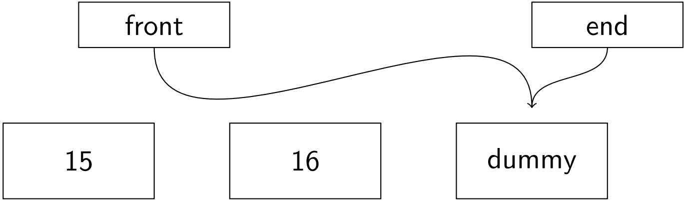

What do we do now?

conditional variables

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Introducing pthread conditional variables:

- `pthread_cond_t` : the data structure of a conditional variable

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The exact declarations are slightly more complicated, check the man pages.

the producer/consumer

A single element buffer, multiple consumers, multiple producers.

```
int buffer;
int count  = 0;
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```
void put(int value) {
  assert(count == 0);
  count = 1;
  buffer = value;
}
```

```
int get() {
  assert(count == 1);
  count = 0;
  return buffer;
}
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  count = 0;
  return buffer;
}
```

Let's try to make this work.

this will not work

```
void produce(int val) {
    put(val);
}
```

```
int consume() {
    int val = get();
    return val;
}
```

add a mutex and cond variable

```
pthread_cond_t cond;
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pthread_cond_t cond;
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produce(int val) {
  pthread_mutex_lock(&mutex);
  if(count == 1)
    pthread_cond_wait(&cond, &mutex);
  put(val);
  pthread_cond_signal(&cond);
  pthread_mutex_unlock(&mutex);
}
```

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  if(count == 0)
    pthread_cond_wait(&cond, &mutex);
  int val = get();
  pthread_cond_signal(&cond);
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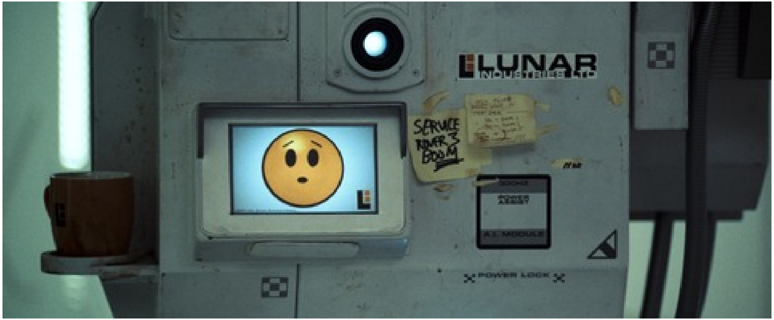
  return val;
}
```

When does this work, when does it not work?

If you're signaled to wake up - it might take some time before you do wake up.



better

```
pthread_cond_t filled, empty;
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```
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  pthread_mutex_lock(&mutex);
  while(count == 1)
    pthread_cond_wait(&empty, &mutex);
  :
  pthread_cond_signal(&filled);
  :
}
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int consume() {
  pthread_mutex_lock(&mutex);
  while(count == 0)
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  :
  pthread_cond_signal(&empty);
  :
}
```

a larger buffer

```
int buffer[MAX];
int *getp = 0;
in  *putp = 0;
int count  = 0;
```

```
void put(int value) {
  assert(count < MAX);
  buffer[putp] = value;
  putp = putp + 1 % MAX;
  count++;
}
```

```
int get() {
  assert(count > 0);
  int val = buffer[getp];
  getp = getp + 1 % MAX
  count--
  return val;
}
```

final touch

```
produce(int val) {
  :
  while(count == MAX)
    pthread_cond_wait(&empty, &mutex);
  :
}
```

final touch

```
produce(int val) {
  :
  while(count == MAX)
    pthread_cond_wait(&empty, &mutex);
  :
}



int consume() {
   :
  while(count == 0)
    pthread_cond_wait(&filled, &mutex);
   :
}
```

final touch

```
produce(int val) {
  :
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  :
}



int consume() {
   :
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   :
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```

Can we allow a producer to add an entry while another removes an entry?

Where are we now?

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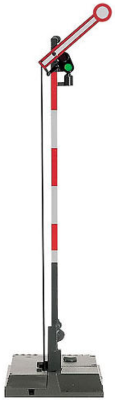
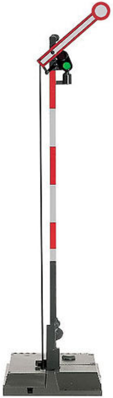
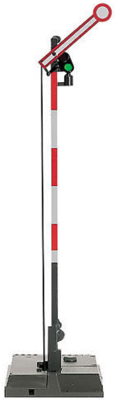
Is there more?





Properties of a semaphore:



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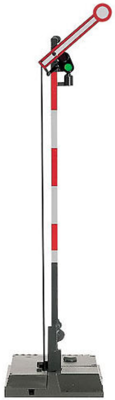
Semaphores



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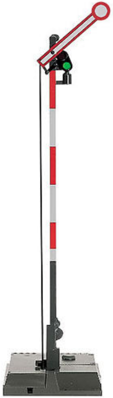

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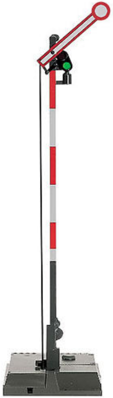

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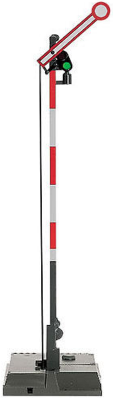

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A semaphore is a counter of resources.

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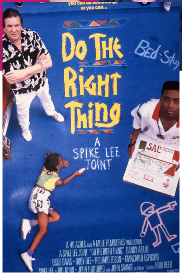
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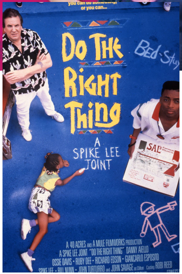
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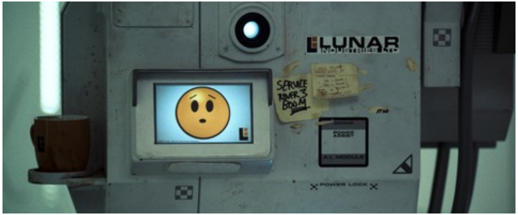
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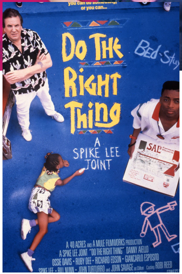
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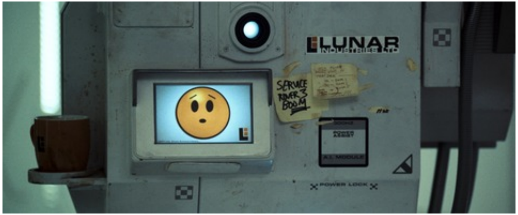
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