15-213 Recitation 14: Threads and Synchronization

18 April 2016

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Agenda

- Reminders
- Threads Revisited
- Synchronization

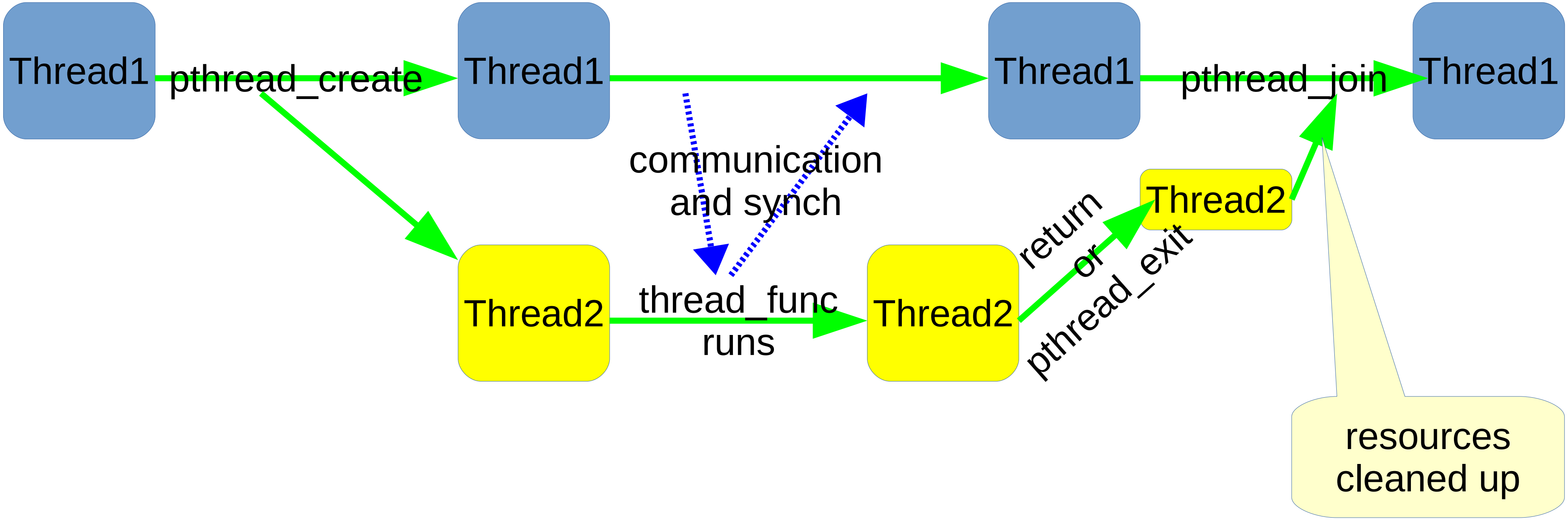
These aren't the only threads that can get tangled....

Image: SilviaStoedter @ pixabay.com

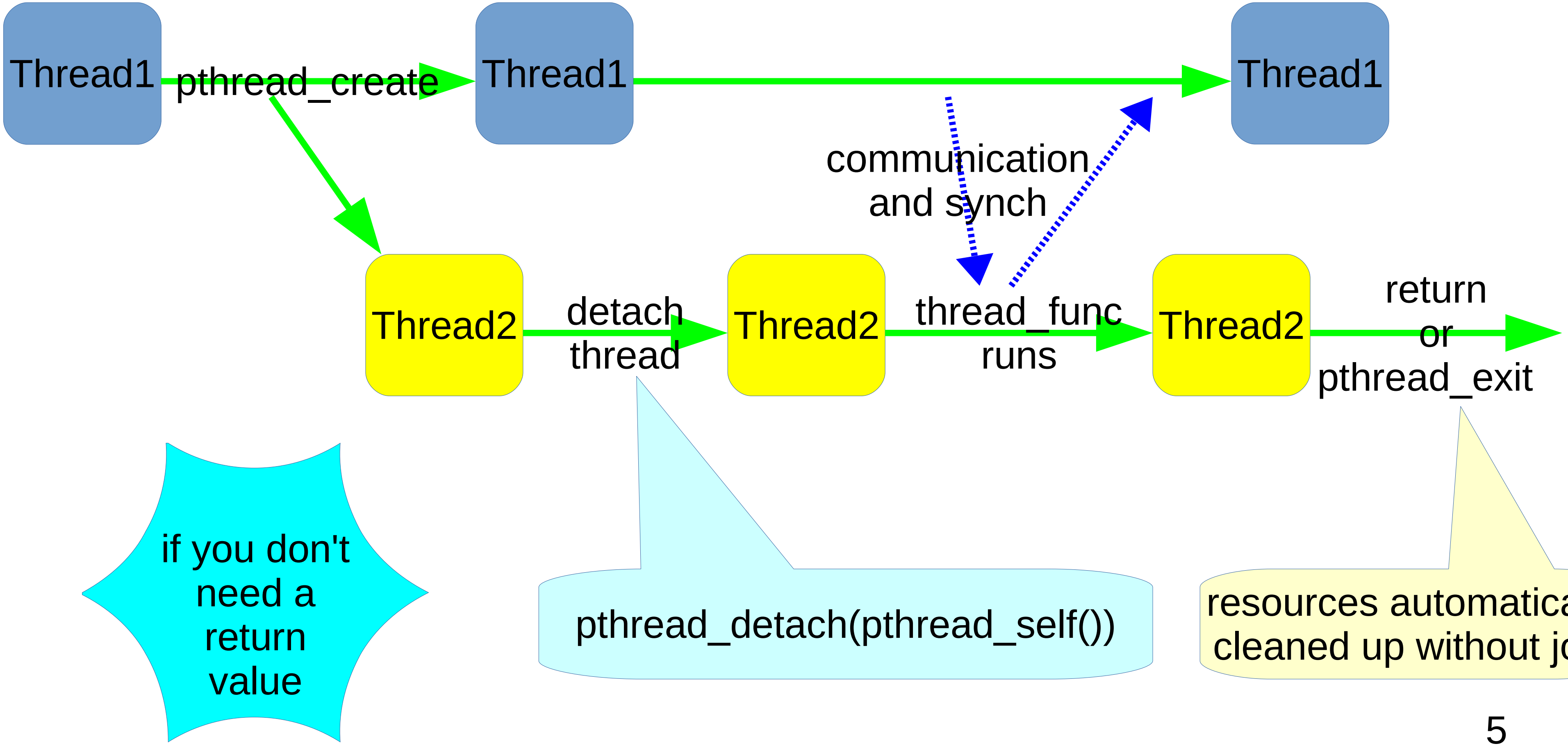
Reminders

- Proxylab is due a week from tomorrow
  - there are no grace days!
  - make your code robust against unexpected inputs

Thread Life Cycle



Thread Life Cycle



Using Threads

- Let's sum the elements of an array

Single-threaded

```
int *nums;

int sum_array(size_t n) {
   int sum = 0;
   // iterate over the elements of the array
   for (int i = 0; i < n; i++)
      sum += nums[i];
   return sum;
}
```

Using Threads: Summing an Array

Multi-threaded

```
// the main thread function – sum a section of the array
void *thread_fun(void *vargp) {
    int myid = *((int*)vargp);
    size_t start = myid * nelems_per_thread;
    size_t end = start + nelems_per_thread;
    size_t i;
    int sum = 0;
    for (i = start; i < end; i++)
        sum += nums[i];
    psum[myid] = sum;
    return NULL;
}
```

note: we're omitting a bunch of variable declarations

Using Threads: Summing an Array

```
int sum_array(int nelems) {
   int sum = 0;
   // figure out how big the sections should be
   nelems_per_thread = nelems / nthreads;
   // create threads
   for (i = 0; i < nthreads; i++) {
      myid[i] = i;
      Pthread_create(&tid[i], NULL, thread_fun, &myid[i]);
   }
   // wait for the threads to finish
   for (i = 0; i < nthreads; i++)
      Pthread_join(tid[i], NULL);
   // collect results
   for (i = 0; i < nthreads; i++)
      sum += psum[i];
   // add leftover elements
   for (e = nthreads * nelems_per_thread; e < nelems; e++)
      sum += nums[e];
   return sum;
```

why use an
array for myid?

Critical Sections and Shared Variables

```
volatile int total = 0;
void *incr(void *ptr) {
   for (int i = 0; i < *((int*)ptr); i++)
      total++;
   return NULL;
}

int main() {
   pthread_t tids[NTHREADS];
   int y = NINCR;
   for (int i = 0; i < NTHREADS; i++)
      Pthread_create(&tids[i], NULL, incr, &y);
   for (int i = 0; i < NTHREADS; i++)
      Pthread_join(tids[i], NULL);
   printf(“total is: %d\n”, total);
   return 0;
}
```

What will this program print?

Critical Sections and Shared Variables

```
volatile int total = 0;
void *incr(void *ptr) {
   for (int i = 0; i < *((int*)ptr); i++)
      total++;
   return NULL;
}

int main() {
   pthread_t tids[NTHREADS];
   int y = NINCR;
   for (int i = 0; i < NTHREADS; i++)
      Pthread_create(&tids[i], NULL, incr, &y);
   for (int i = 0; i < NTHREADS; i++)
      Pthread_join(tids[i], NULL);
   printf(“total is: %d\n”, total);
   return 0;
}
```

We have NTHREADS incrementing the total NINCR times each

but the total may be much less than NINCR*NTHREADS!

Critical Sections and Shared Variables

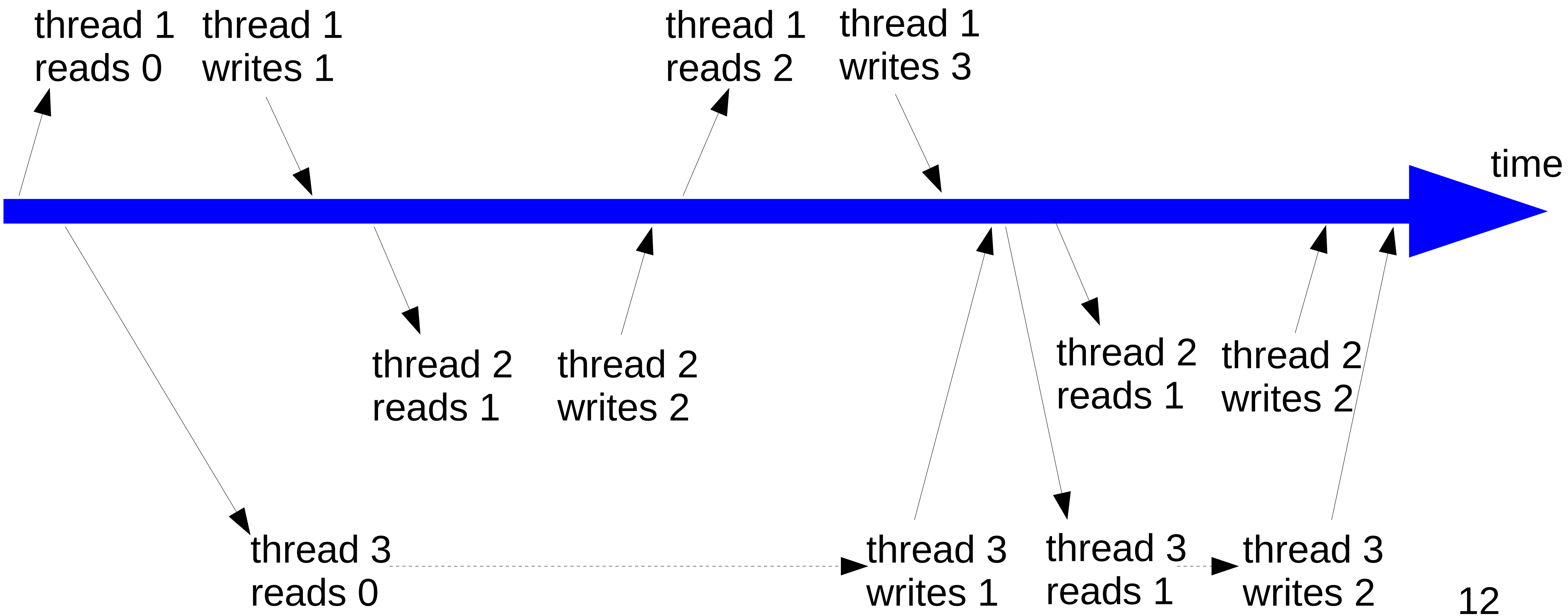
```
volatile int total = 0;
void *incr(void *ptr) {
   for (int i = 0; i < *((int*)ptr); i++)
      total++;
   return NULL;
}

int main() {
   pthread_t tids[NTHREADS];
   int y = NINCR;
   for (int i = 0; i < NTHREADS; i++)
      Pthread_create(&tids[i], NULL, incr, &y);
   for (int i = 0; i < NTHREADS; i++)
      Pthread_join(tids[i], NULL);
   printf(“total is: %d\n”, total);
   return 0;
}
```

Shared variable

critical section

What Happened?



Threads: Mutual Exclusion

- Need to prevent multiple threads from accessing the same resource at the same time
- In our `sum_array` example, we managed to avoid simultaneous access by giving each thread a separate section of the array
- In general, we'll need a way to temporarily stop a thread while another is accessing the resource it wants to use
    - we use a semaphore or mutex
    - trying to lock a mutex while it is already locked blocks the thread until it is unlocked by the other thread that had already locked it
    - the code between a pair of lock and unlock calls is a *critical section*.

Semaphores

- Special counters with an invariant: their value is never negative
- two *atomic* operations
  - `P(s)` tries to decrement the counter `s` (locking the resource), and puts the thread to sleep if the counter is already zero
  - `V(s)` increments the counter (freeing the resource) and wakes any thread that may be waiting on `s`
- Mutexes are a subclass of semaphores
  - their value is always either 0 or 1
  - often faster than semaphores because the binary value permits optimizations

Using Semaphores

- Limited resource
  - initialize count to total number of items available
  - decrement just before starting to use one of the items
  - increment when done using the item
- Producer-Consumer
  - initialize count to zero
  - producer generates a new item, then increments semaphore
  - consumer decrements semaphore, then retrieves item

Protecting Shared Resources with a Semaphore

- Suspend execution of thread until resource is “acquired”

```
volatile int total = 0;
sem_t sem;

void *incr(void *ptr) {
   for (int i = 0; i < *ptr; i++) {
      sem_wait(&sem);
      total++;    // CRITICAL SECTION
      sem_post(&sem);
   }
   return NULL;
}

int main() {
   ...
   sem_init(&sem,0,1);
```

remember to initialize the semaphore first!

Protecting Shared Resources with a Mutex

- Can use a mutex just like a semaphore initialized to 1

```
volatile int total = 0;
pthread_mutex_t M;

void *incr(void *ptr) {
   for (int i = 0; i < *ptr; i++) {
      pthread_mutex_lock(&M);
      total++;    // CRITICAL SECTION
      pthread_mutex_unlock(&M);
   }
   return NULL;
}

int main() {
   ...
   pthread_mutex_init(&M);
```

remember to initialize the mutex first!

Problem Solved?

- Sort of...
- Locks in threads are *slow*.
  - they involve OS calls and *uncached* memory accesses
- Only one instance of the critical section can run at once
  - your eight-core CPU effectively becomes a single-core CPU

Other Solutions

- avoid shared modifiable memory if at all possible
  - (shared read-only memory is OK)
- use a more sophisticated thread synchronization model
  - reader/writer
  - producer-consumer

Problem: Deadlock

- What's about to happen?

Process 1

```
pthread_mutex_lock(&A);
...
pthread_mutex_lock(&B);
```

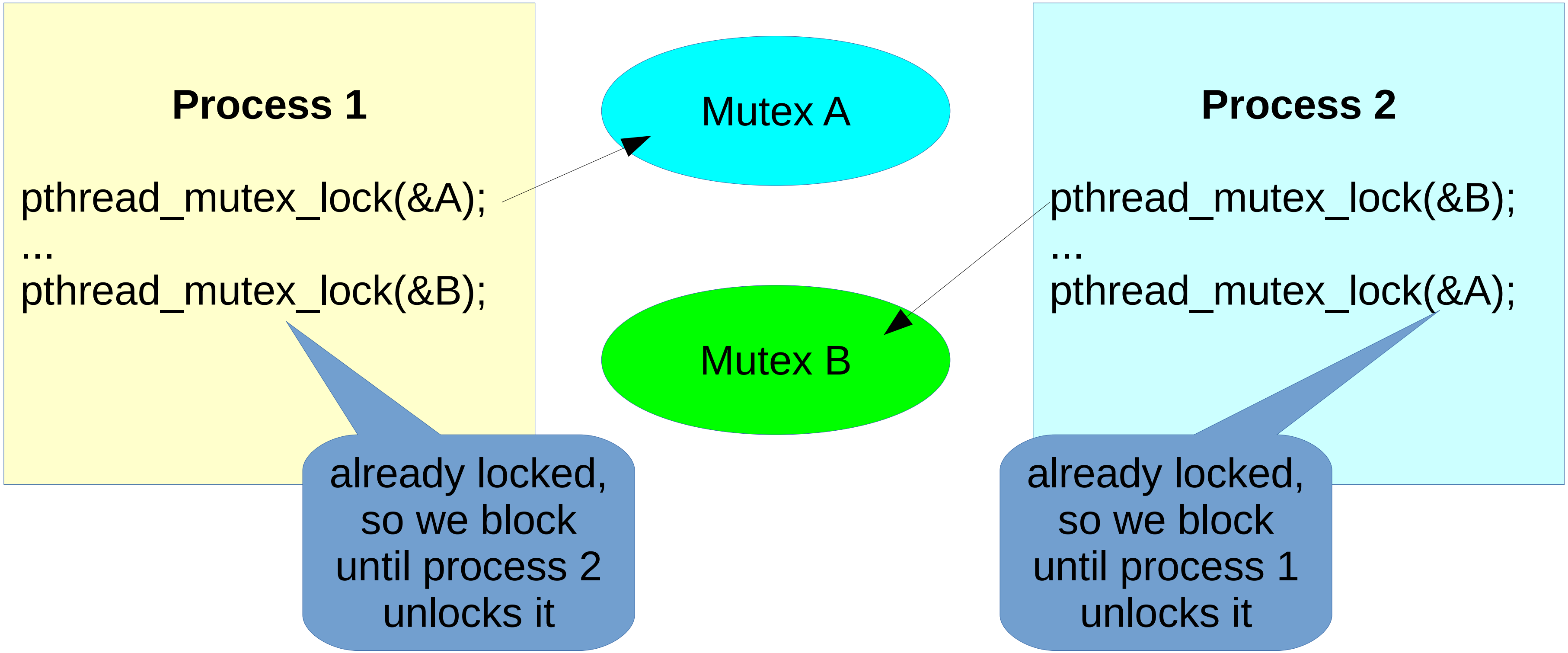
Mutex A

Mutex B

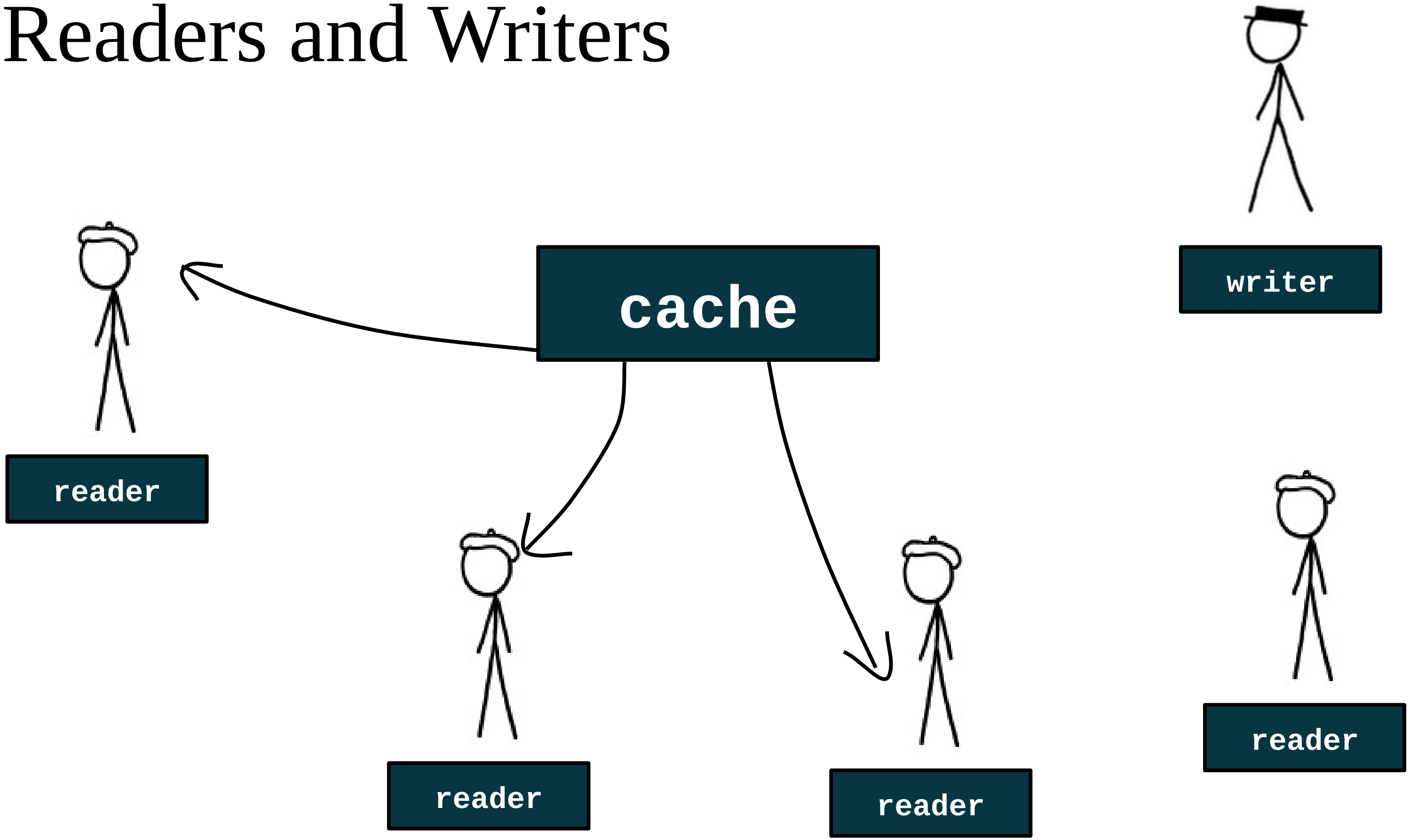
Process 2

```
pthread_mutex_lock(&B);
...
pthread_mutex_lock(&A);
```

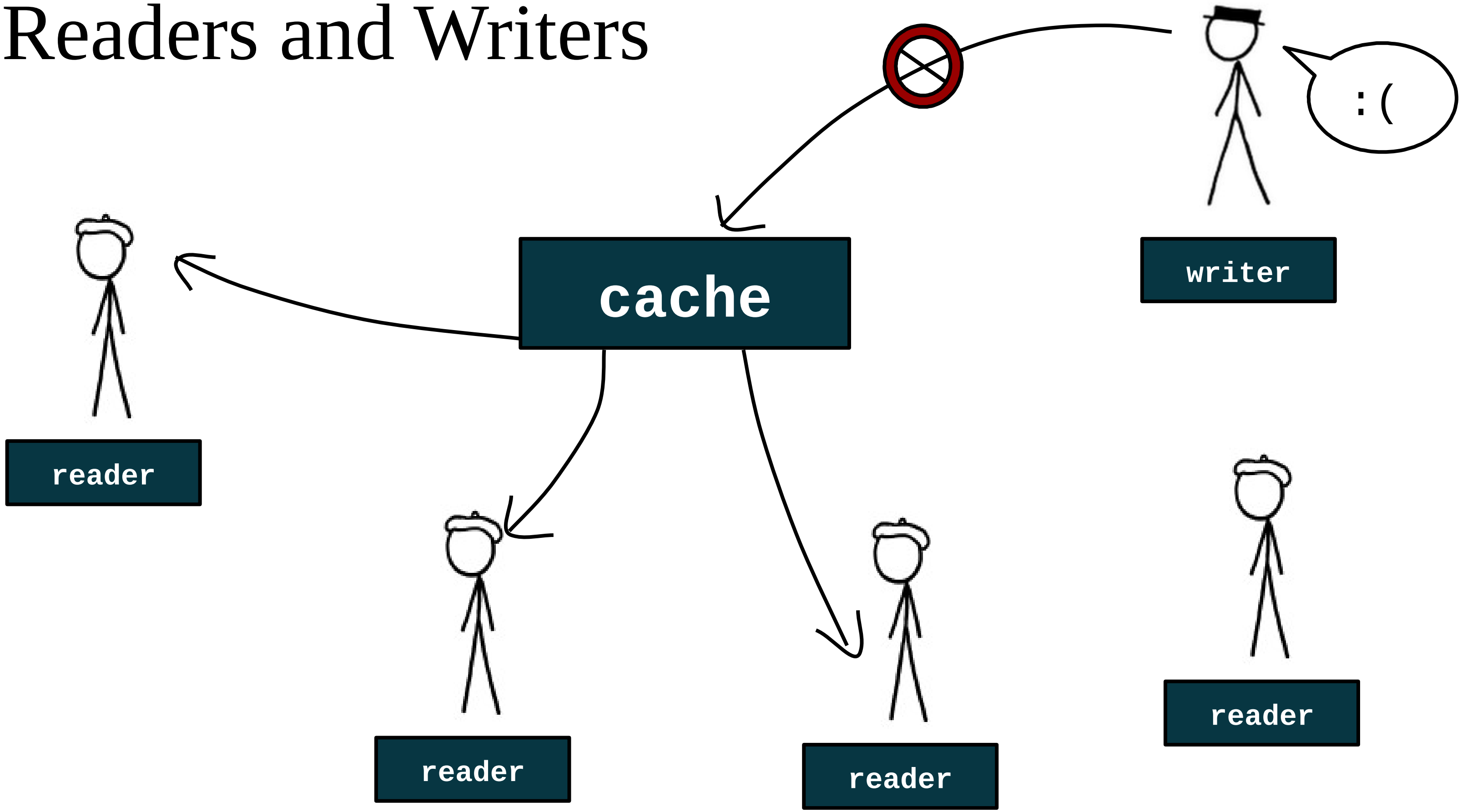
Problem: Deadlock



Readers and Writers



Readers and Writers



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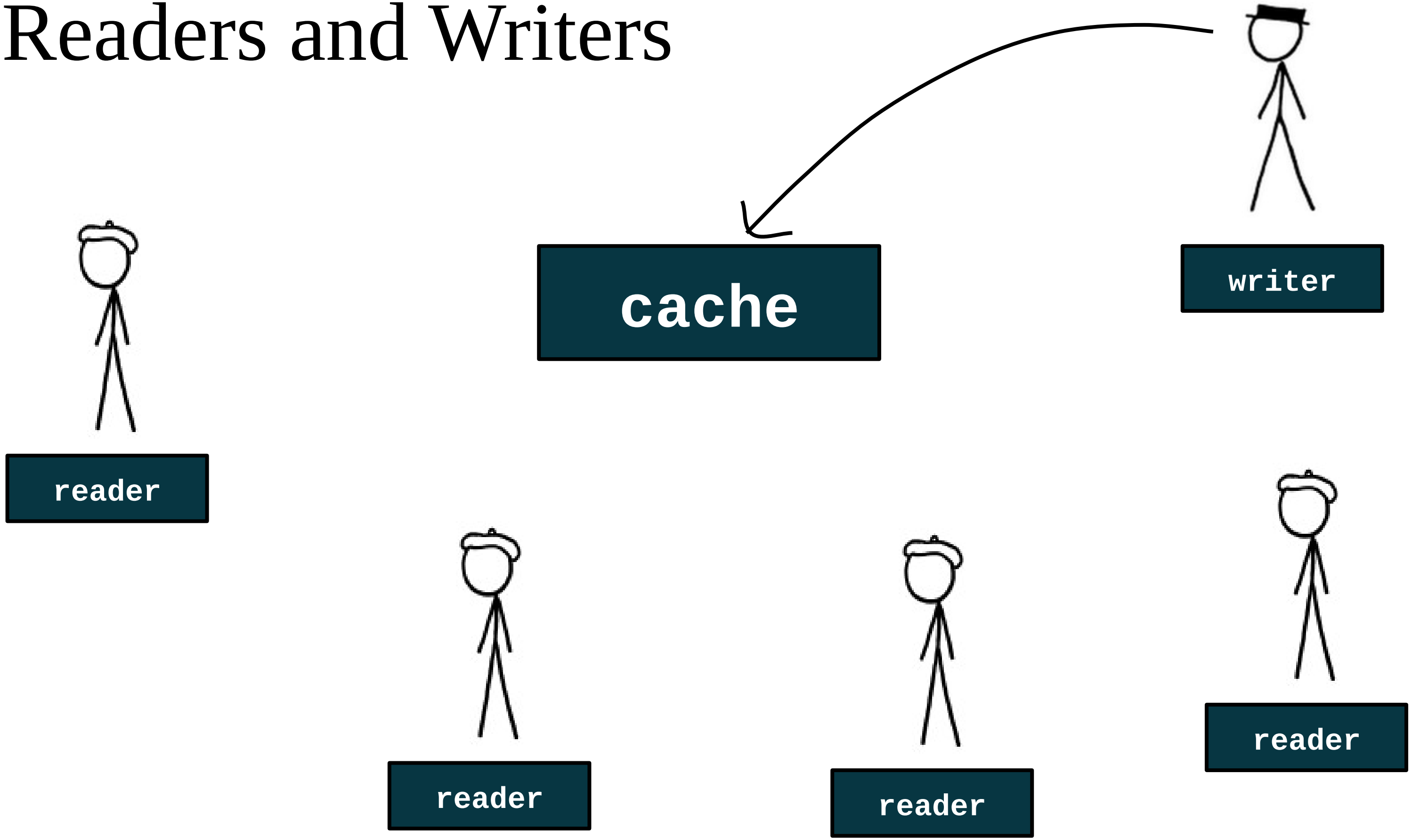
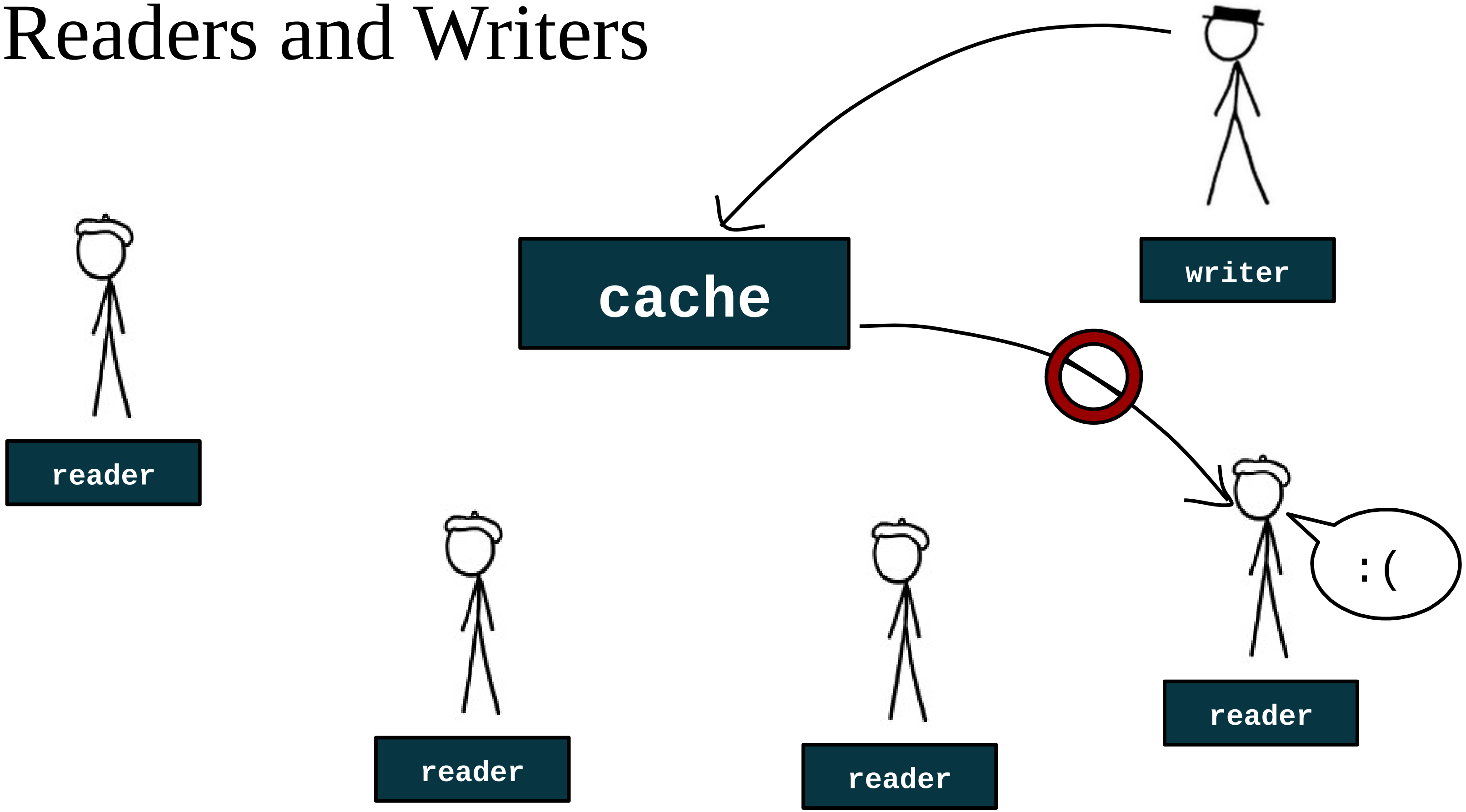
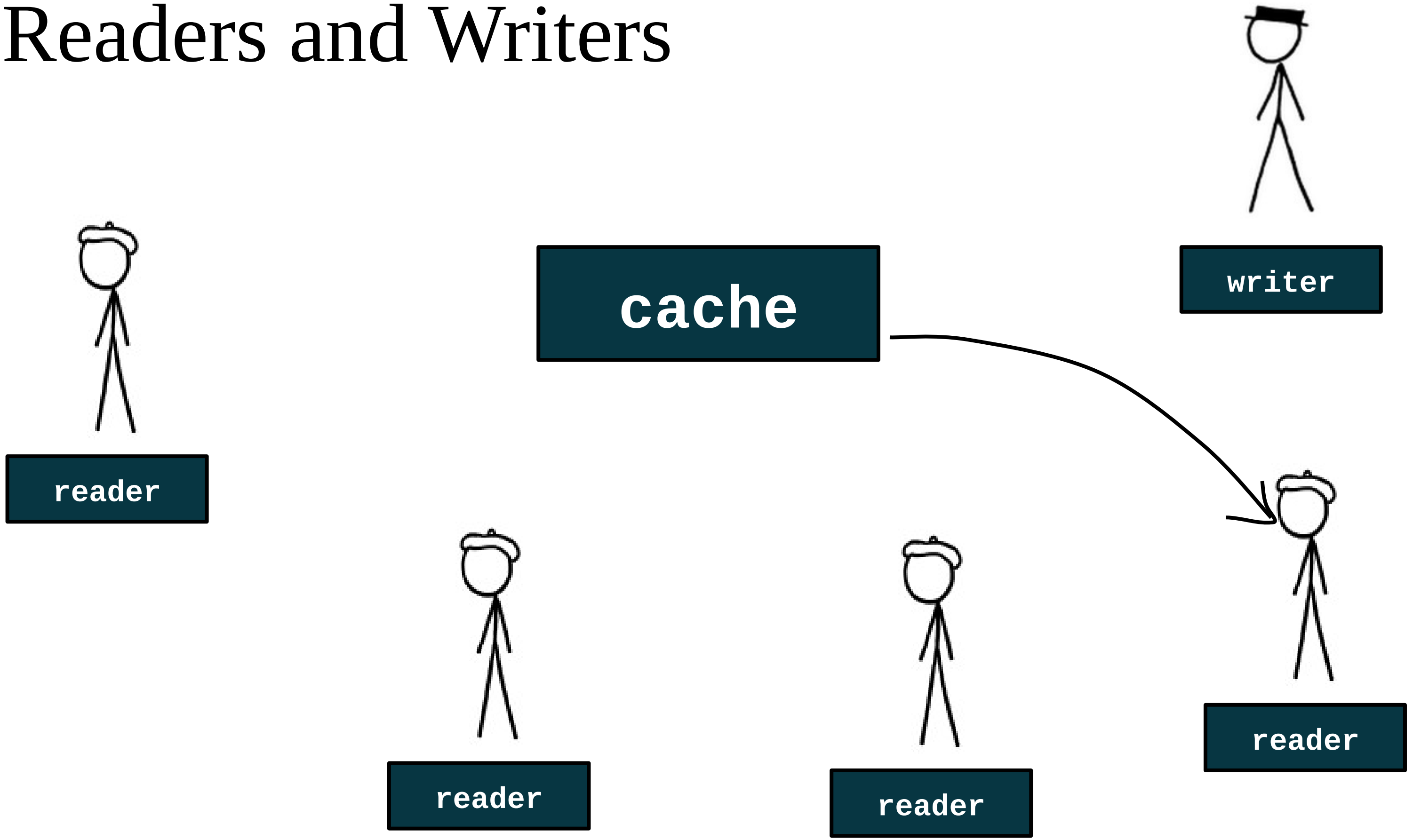


Readers and Writers



Readers and Writers



Starvation

- If there are many readers, they may keep writers from acquiring the resource because someone is always reading
  - the writer is being **starved** of the resource
- Important to minimize the amount of time you hold a lock

Read(ers)-Write(r) Lock

- allows a single writer *xor* multiple concurrent readers
- ```
  int pthread_rwlock_init(pthread_rwlock *lock,
                          const pthread_rwlockattr_t *attr);
  ```
- `int pthread_rwlock_rdlock(pthread_rwlock *lock);`
  - lock for reading; blocks if someone is currently (attempting to) write
- `int pthread_rwlock_wrlock(pthread_rwlock *lock);`
  - lock for writing; blocks until all current users finish
- `int pthread_rwlock_unlock(pthread_rwlock *lock);`
- `int pthread_rwlock_destroy(pthread_rwlock *lock);`
  ```

Problem: Livelock

- Much like deadlock, but the processes/threads spin indefinitely instead of hanging
- Think of two people trying to get past each other in a hallway
  - both move the same way
  - then both move the other way at the same time
  - awkward dance continues…
- Often the result of attempting to compensate for potential deadlock
  - spinning on a trylock() to avoid hanging on a lock()

Which Lock Do I Use?

- Consider **what** is shared and what type of **access** is desired
  - only one thread at a time allowed
    - ?
  - more than one instance of a shared resource is available
    - ?
  - multiple threads can read concurrently, but only one may write at a time
    - ?

Which Lock Do I Use?

- Consider **what** is shared and what type of **access** is desired
  - only one thread at a time allowed
    - **mutex** example: global count variable
  - more than one instance of a shared resource is available
    - **semaphore** example: multiple free slots in a shared buffer
  - multiple threads can read concurrently, but only one may write at a time
    - **readers-writer lock** example: lookup from global list, web-proxy cache