Embedded Software

Thread synchronization

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Agenda

- Why synchronization - Shared data problem revisited
- Cases
  - Sharing data between threads
  - The Producer / Consumer problem
  - Park-A-Lot 2000
- Types of synchronization methods

The shared data problem revisited

The shared data problem revisited

```c
unsigned int shared;
void taskfunc()
{
   for(;;)
   {
    shared++;                // Increment i, then wait
    sleep(ONE_SECOND);       // 1 second
   }
}

int main()
{
   shared = 0;
   createThread(taskFunc);  // Start two identical threads
   createThread(taskFunc);  // that run the same function
   for(;;) sleep(ONE_SECOND);     // 1 second
}
```

The shared data problem revisited

- Let’s zoom in:

Program

```
while(true)
{
   shared++;
   sleep(ONE_SECOND);
}
```

Pseudo-machine instructions

```
LOAD R1, shared
INC R1
STORE shared, R1
```

Task 1

```
LOAD R1, shared
INC R1
STORE shared, R1
```

Task 2

```
LOAD R1, shared
INC R1
STORE shared, R1
```

The Challenge

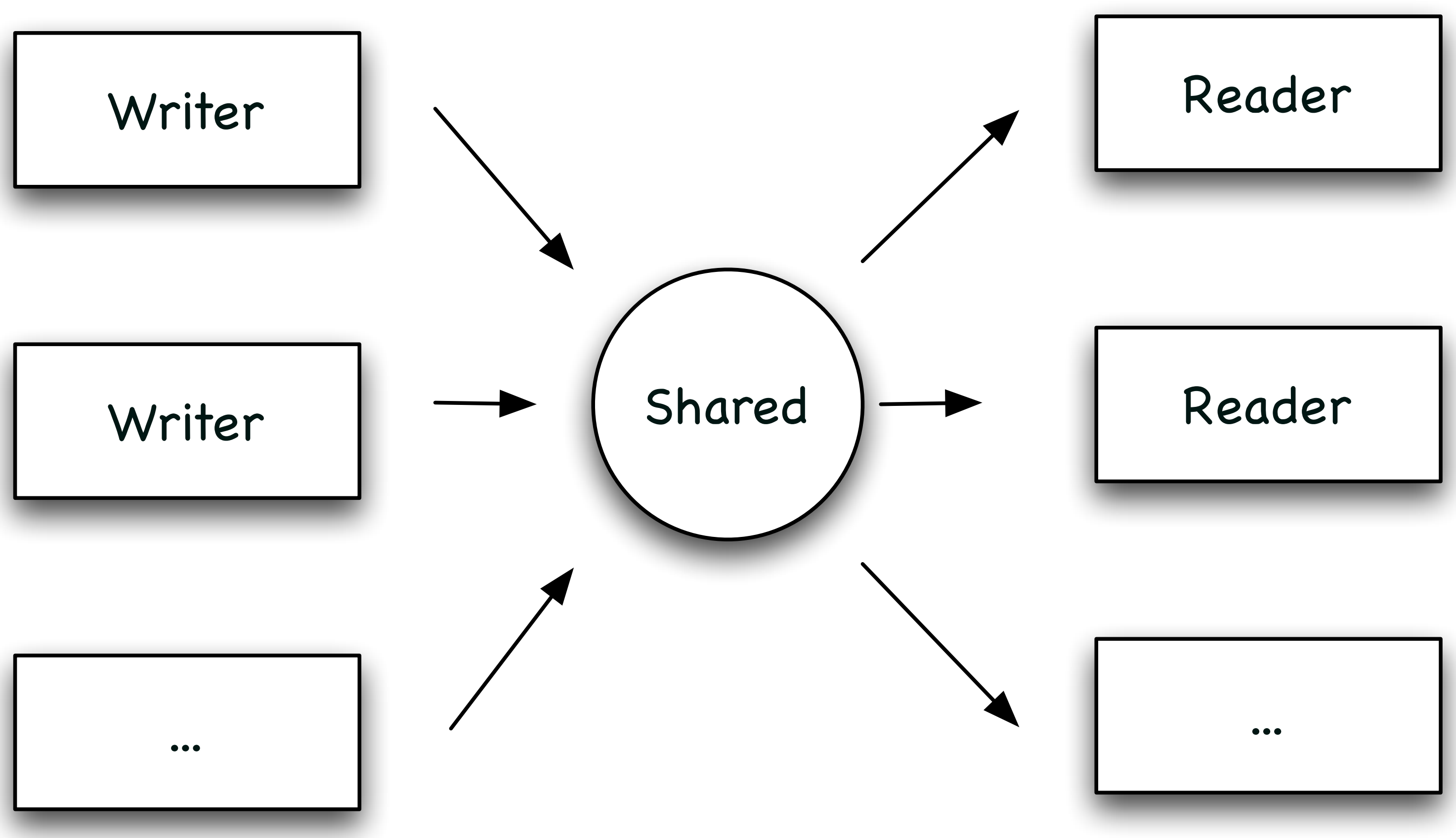
- We need a way to ensure that access to **shared** is mutually exclusive
  - When T_1 is using **shared**, T_2 must be denied access
  - When T_2 is using **shared**, T_1 must be denied access

Cases

Case - Ensuring shared data integrity

Case - Ensuring shared data integrity

- Multiple thread entities read/write to a common data structure (maybe as simple as a single variable)
  - ***Classic problem***



Case - Ensuring shared data integrity

- Problem
  - Common *shared* variable
- Solution “a mutex”

```
unsigned int shared;
Mutex m = MUTEX_INITIALIZER;


void threadFunc()
{
   for(;;)
   {
    lock(m);
    shared++;                 // Increment i...
    unlock(m);
    sleep(ONE_SECOND);        // ...then wait 1 second
   }
}

main()
{
   createThread(threadFunc);  // Start two identical threads
   createThread(threadFunc);  // that run the same function
   for(;;) sleep(100);
}
```

The mutex

Take the mutex
(or block if needed)

Release the mutex

Mutexes

- Mutexes are used to enforce MUTual EXclusion
- Mutexes are owned by one thread at a time - only the "***taker***" can release!
- Two operations on a mutex:
  - **lock(m)**
  - **unlock(m)**

```
lock(Mutex m)
{
   wait until m==1, then m=0;   // ATOMIC operation
}
```

If m=0, calling thread is **BLOCKED** until m==1
If m==1, calling thread proceeds

```
unlock(Mutex m)
{
   m=1;   // ATOMIC operation
}
```

Now m==1 so a **BLOCKED** thread is made **READY**

Case - Ensuring shared data integrity

- Problem
  - Common *shared* variable
- Solution "a semaphore"

```
unsigned int shared;
SEM_ID s;



void threadFunc()
{
   for(;;)
   {
    take(s);
    shared++;                  // Increment i...
    release(s);
    sleep(ONE_SECOND);         // ... then wait 1 second
   }
}

main()
{
  s = createSem(1);
   createThread(threadFunc);  // Start two identical threads
   createThread(threadFunc);  // that run the same function
   for(;;) sleep(100);
}
```

Take the semaphore (or block if needed)

Release the semaphore

Initializing the sem to 1

Semaphores

- Semaphores are used to enforce mutual exclusion or rather signaling
- Semaphores are NOT owned by one thread at a time - “***all***” can release!
- Two operations on a semaphore:
  - **take(s)** (A.K.A. get(s), pend(s), P(s), wait(s)…)
  - **release(s)** (A.K.A. give(s), post(s), V(s), signal(s)…)

```
take(Semaphore s)
{
   wait until s>0, then s=s-1;  // ATOMIC operation
}
```

If s=0, calling thread is **BLOCKED** until s>0
If s>0, calling thread proceeds

```
release(Semaphore s)
{
   s=s+1;  // ATOMIC operation
}
```

Now s>0 so a **BLOCKED** thread
is made **READY**

Mutexes & Semaphores: FAQ

- “Can more than one thread wait for a mutex/semaphore at a time?”
  - Yes. The threads are queued – see next slide

- “Which of the blocked threads are made ready?”
  - FIFO: The thread that has waited the longest
  - Priority: The highest-priority thread

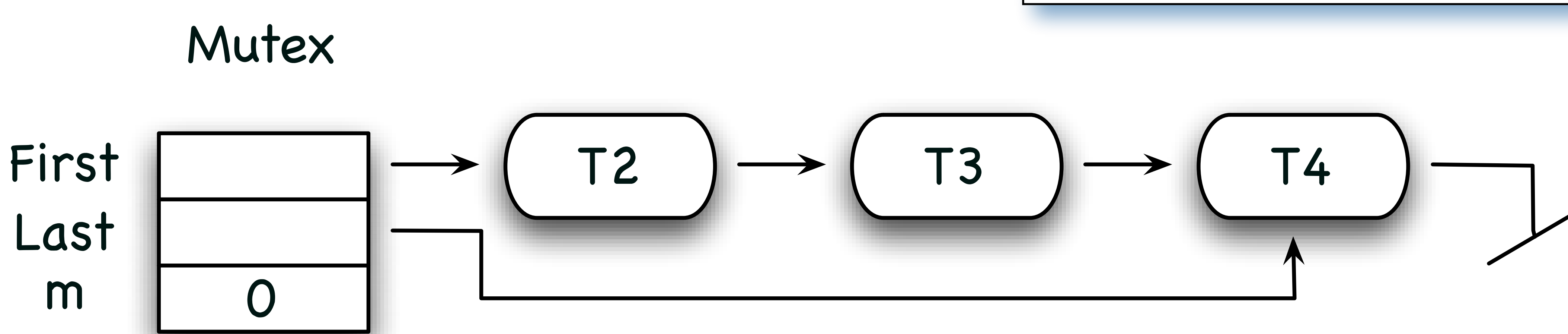
Mutexes & Semaphores: The queue

- Each mutex/semaphore is associated with a waiting queue (FIFO/priority)

- When a thread takes a mutex:
  - m=0: the next incoming thread is added to the mutex's queue
  - m=1: running thread done, next thread activated

```
lock(Mutex m)
{
   wait until m==1, then m=0;
}
```

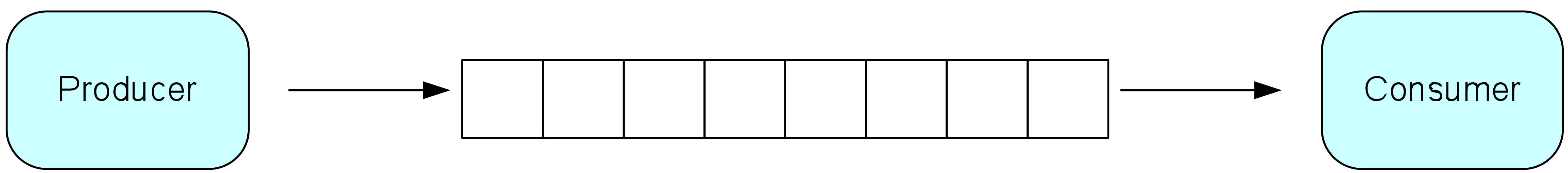
```
unlock(Mutex m)
{
   m=1;
}
```



The Producer-Consumer problem

The Producer-Consumer problem

- A producer produces elements and *puts* them in a ***buffer,*** from which the consumer *retrieves* an element at a time



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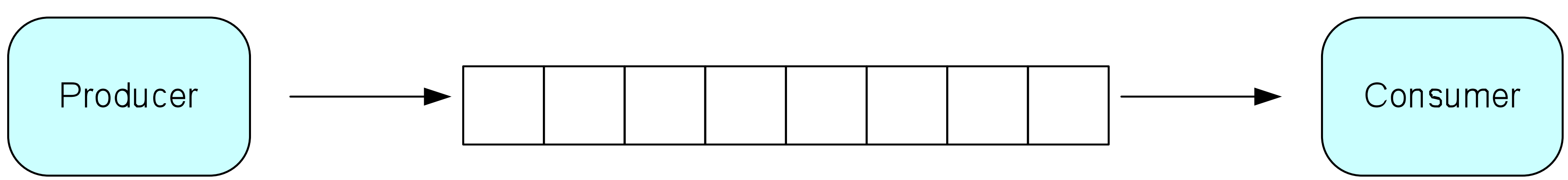
The producer-consumer problem

- What happens if…
  - The producer **put()**'s into a full buffer?
  - The consumer **get()**'s from an empty buffer?

- How can this be handled?
  - Checking **insert** and **remove** before insertion?
    - …and what if the buffer is full/empty? Sleep? How long?
  - Use 2 counting semaphores!



The producer-consumer problem

- ***Explain how to extend this implementation to use 2 counting semaphores to prevent buffer over/underrun***

```
template<typename T>
class Buffer
{
public:
   Buffer(size_t buffserSize) : buffer_(new T[bufferSize]),
   bufferSize_(bufferSize), insert_(0), remove_(0) { }

   void put(const T& x)  {
    buffer_[insert_] = x;
    insert_ = (insert+1)%bufferSize_;
   }

   T get() {
        T tmp = buffer_[remove_];
        remove_ = (remove_+1)%bufferSize_;
        return tmp;
   }

private:
   T* buffer_;
   size_t bufferSize_;
   CountingSemaphore emptySlotsLeft_;
   CountingSemaphore usedSlotsLeft_;
   size_t insert_;
   size_t remove_;
};
```

Implemented as ***circular buffer***
insert_ : Insertion pointer
remove_ : Remove pointer

Only ***one*** producer & ***one*** consumer

Simplified construction
Possible exceptions are NOT handled

The producer-consumer problem

```
template<typename T>
class Buffer
{
public:
    Buffer(size_t bufferSize) : buffer_(new T[bufferSize]), bufferSize_(bufferSize),
        insert_(0), remove_(0)
    {
     emptySlotsLeftSem_ = createCountingSem(bufferSize_);
     usedSlotsLeftSem_ = createCountingSem(0);
    }

    void put(const T& x)  {
     take(emptySlotsLeftSem_);
     buffer_[insert_] = x;
     insert_ = (insert_+1)%bufferSize_;
     release(usedSlotsLeftSem_);
    }

    T get()  {
     take(usedSlotsLeftSem_);
          T tmp = buffer_[remove_];
     remove_ = (remove_+1)%bufferSize_;
     release(emptySlotsLeftSem_);
    }

private:
    T* buffer_;
    size_t bufferSize_;
    SEM_ID emptySlotsLeftSem_;
    SEM_ID usedSlotsLeftSem_;
    size_t insert_;
    size_t remove_;
};
```

Semaphores are init with size bufferSize_

The producer thread will automatically block if buffer is full on **put()**

The consumer thread will be automatically blocked if buffer is empty on **get()**

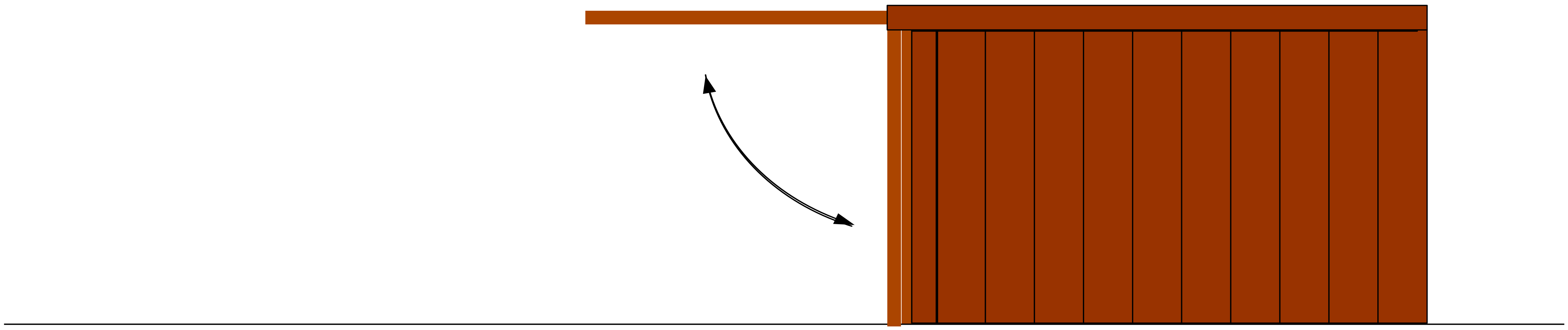
Both consumer and producer threads will be **automatically unblocked** if data is ready or buffer not full any longer

Simplified construction
Possible exceptions are NOT handled

Case - Park-a-lot 2000

Case - Park-a-lot 2000

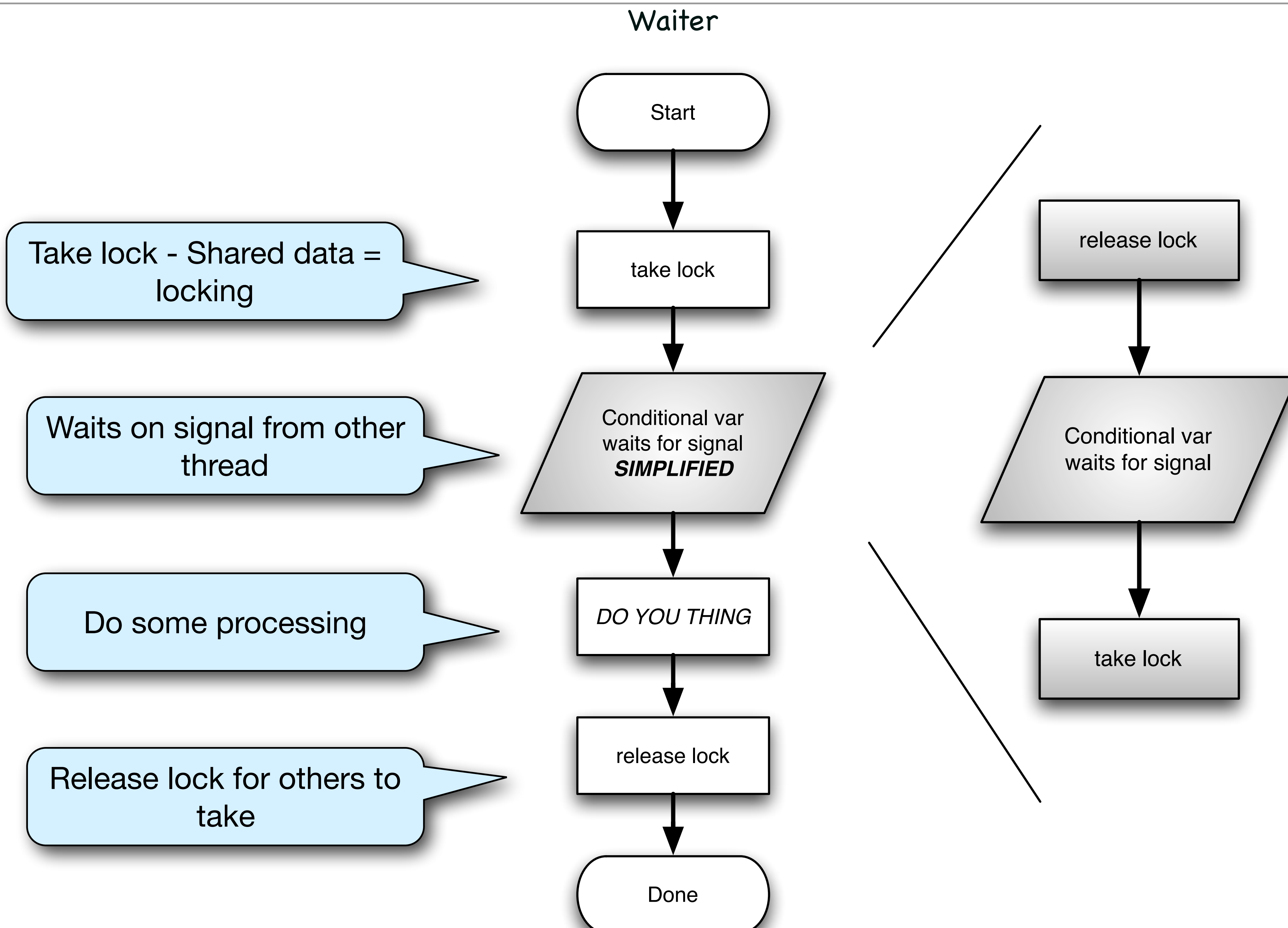
- Example: Park-a-lot 2000: An automated car parking system
  - One thread steers the car
  - Another thread steers the garage door opener
- ***Coordination how?***



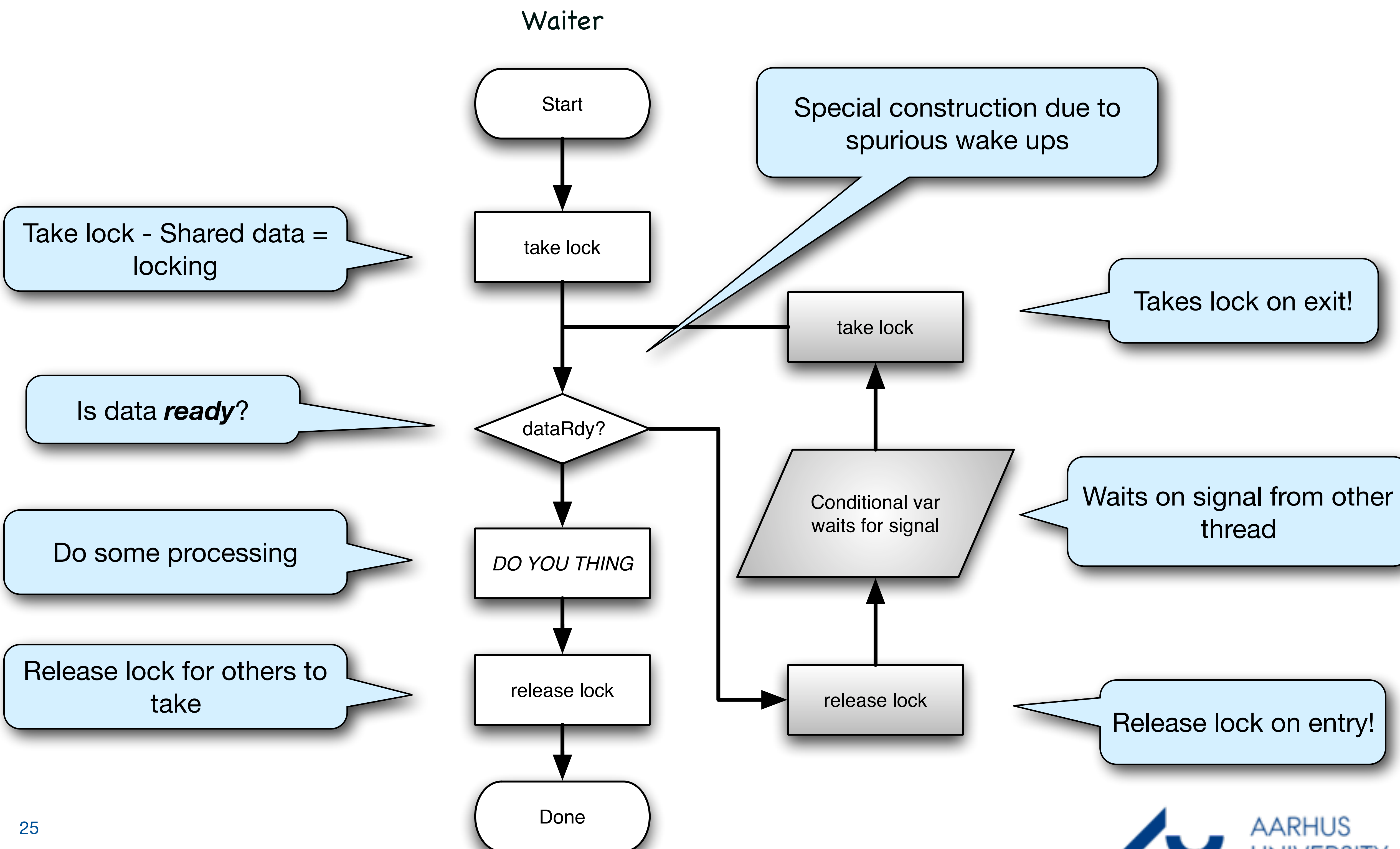
Signaling mechanism - Which?

- We need Conditionals... But How?
  - Fundamental point is that we have a
    - Receiver/Waiter who waits on a conditional variable
    - Sender/Indicator who signals this particular conditional variable at some point

We need Conditionals... - Receiver/Waiter



We need Conditionals... - Receiver/Waiter



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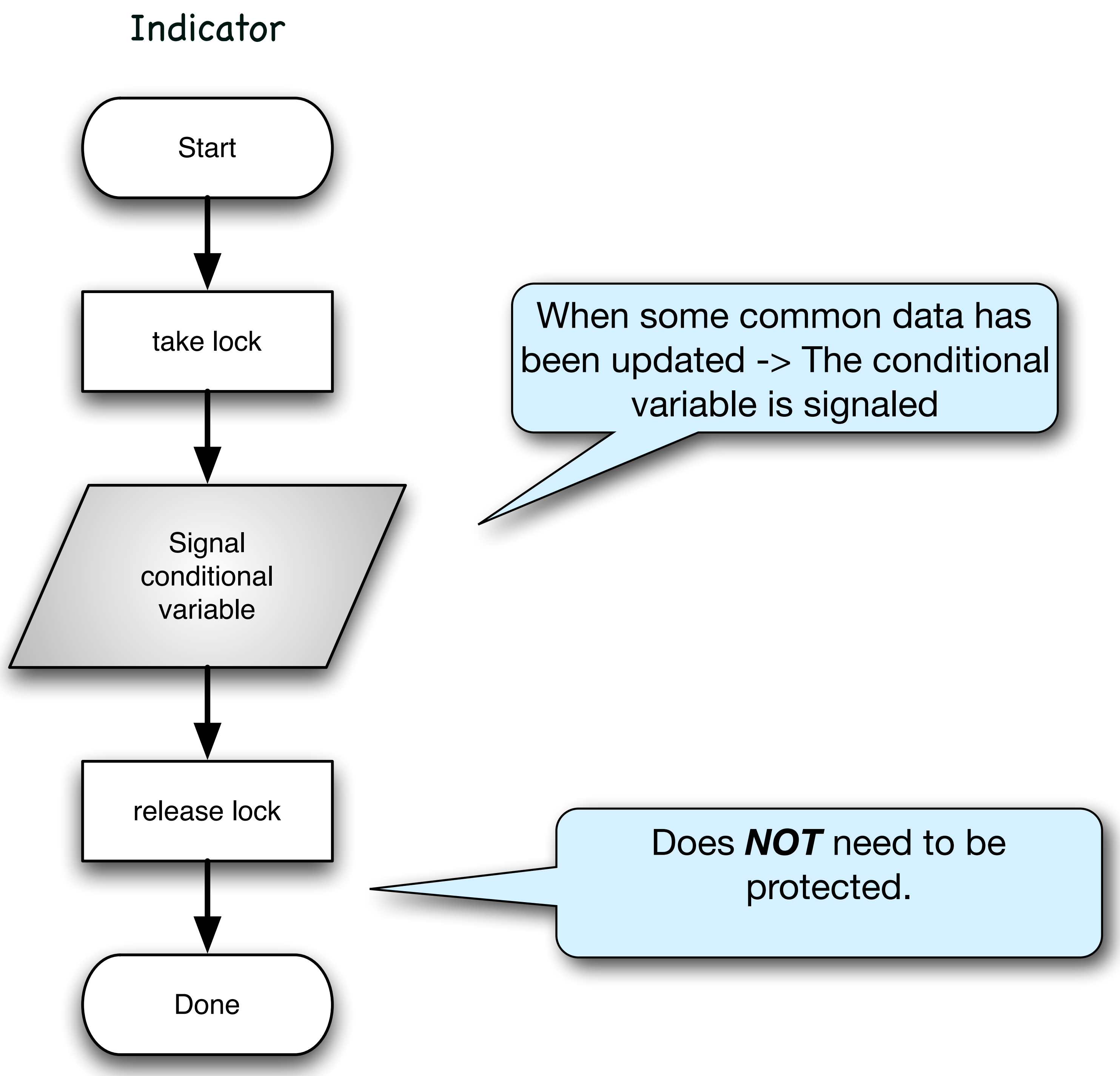
We need Conditionals... - Sender/Indicator



Conditionals - How do you code it?

```
Mutex m;
Conditional c;
```

```
void theWaiter()
{
   lock(m);

   while (!what_we_are_waiting_for)
   {
      condWait(c, m);
   }

   unlock(m);
}
```

```
void theIndicator()
{
   lock(m);
   // Do something...
   // unlock(m) - is okay
   what_we_are_waiting_for = true;
   condSignal(c);
   unlock(m);
}
```

Park-a-lot 2000 - Feeble attempt

- Our first attempt:

- “hope”…another word system engineers don’t like!

```
carDriverThread()
{
   driveUpToGarageDoor()
   sleep(GARAGE_DOOR_OPEN_TIME);
   // Let’s hope the door is open!
   driveIntoGarage();
}
```

```
garageDoorControllerThread()
{
   openGarageDoor()
   sleep(CAR_ENTER_GARAGE_TIME);
   // Let’s hope the car is in!
   closeGarageDoor();
}
```

- We need to be sure that…
  - The door is open before we move the car (car sync with garage door)
  - The car is in before we close the door (garage door sync with car)

Park-a-lot 2000

- Our second attempt: Two-way synchronization

```
carDriverThread()
{
   driveUpToGarageDoor();
   lock(mut);
   carWaiting = true;
   condSignal(entry);
   while(!garageDoorOpen)
     condWait(entry, mut);
   driveIntoGarage();
   carWaiting = false;
   condSignal(entry);
   unlock(mut);
}
```

```
garageDoorControllerThread()
{
   lock(mut);
   while(!carWaiting)
     condWait(entry, mut);
   openGarageDoor();
   garageDoorOpen = true;
   condSignal(entry);
   while(carWaiting)
     condWait(entry, mut);
   closeGarageDoor();
   garageDoorOpen = false;
   unlock(mut);
}
```

- This works!
  - 2-way synchronization
  - All waits are matched with signals

Types of synchronization methods

Types of synchronization methods

- Generally, there are three different types of semaphores for three different purposes:

  - Mutex: s=0 or s=1, belongs to one thread at a time
  - Conditionals Signaling facility used with a mutex
  - *Read/writable locks* *Multiple readers - Exclusive writer*

  - Counting semaphore: s ≥ 0, shared among threads
  - Binary semaphore: s=0 or s=1, shared among threads

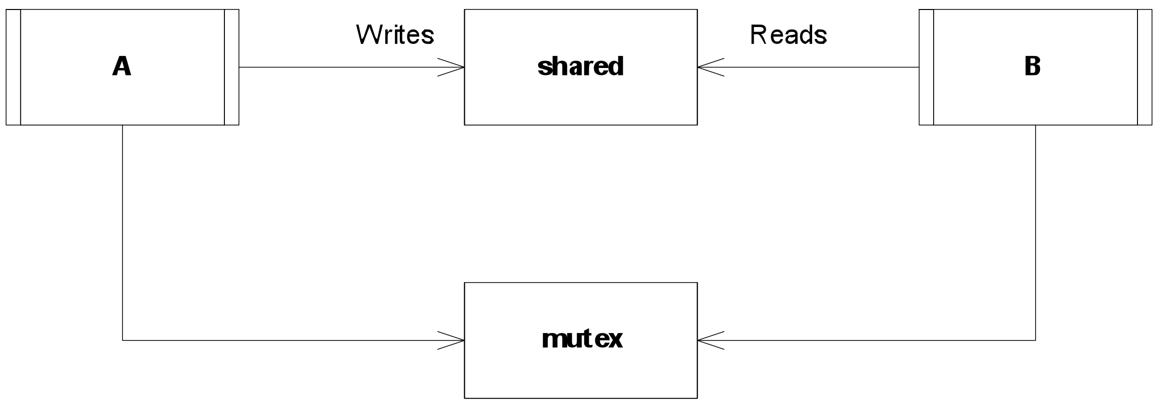
POSIX Synchronization mechanisms (Not all included)

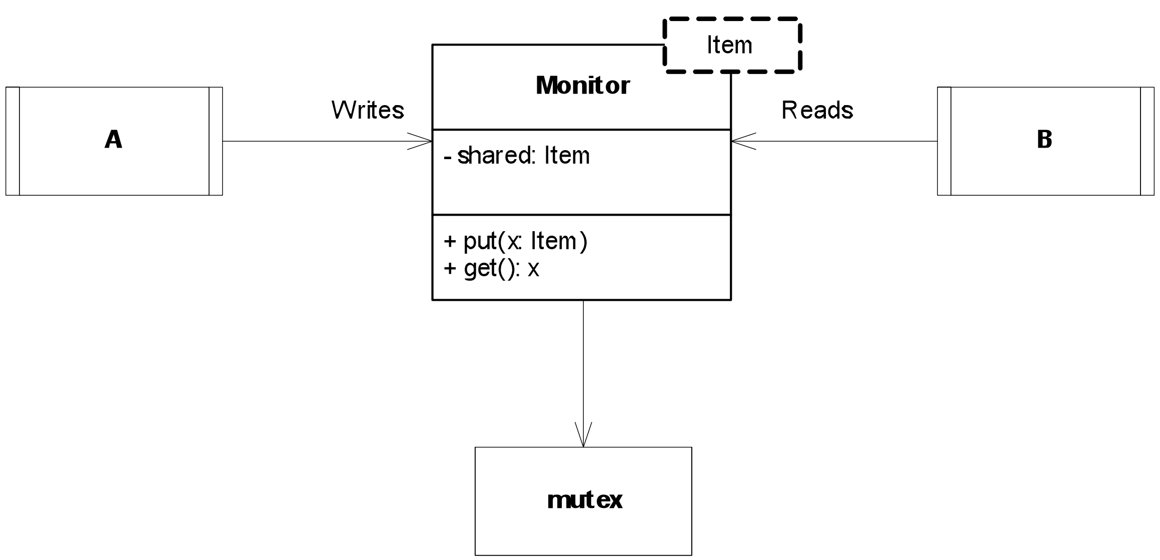
```c
#include<pthread.h>

int pthread_mutex_init(pthread_mutex_t* mutex, pthread_mutex_attr_t *mutexattr);
int pthread_mutex_lock(pthread_mutex_t* mutex);
int pthread_mutex_unlock(pthread_mutex_t* mutex);
int pthread_mutex_destroy(pthread_mutex_t* mutex);

int pthread_rwlock_init(pthread_rwlock_t* mutex, pthread_rwlockattr_t *mutexattr);
int pthread_rwlock_rdlock(pthread_rwlock_t* mutex);
int pthread_rwlock_wrlock(pthread_rwlock_t* mutex);
int pthread_rwlock_unlock(pthread_rwlock_t* mutex);
int pthread_rwlock_destroy(pthread_rwlock_t* mutex);

int pthread_cond_init(pthread_cond_t *cond, const pthread_condattr_t *attr);
int pthread_cond_wait(pthread_cond_t *cond, pthread_mutex_t *mutex);
int pthread_cond_signal(pthread_cond_t *cond);
int pthread_cond_broadcast(pthread_cond_t *cond);
int pthread_cond_destroy(pthread_cond_t *cond)
```

```c
#include<semaphore.h>

int sem_init(sem_t* sem,         // Semaphore ID
         int pshared,            // Unsupported. Set to 0
         unsigned int value  // Initial value , >=0
         );

int sem_destroy( sem_t* sem);// Semaphore ID to destroy
int sem_wait(sem_t* sem);            // Wait for sem
int sem_post(sem_t* sem);            // Post (signal) sem
```

Aids / Tools

The Monitor





- Monitor: A template class
  - When accessed, the Monitor
    1. takes mutex,
    2. accesses shared,
    3. releases mutex
  - Responsibility for mutual exclusion: Programmer → monitor
- Any drawbacks/consequences?
  - Complete copy of shared returned – takes time
  - Exception between lock() and unlock()?

The Scoped Locking idiom

- A idiom pattern to ensure proper mutex clean-up, even on errors
- The idea: Create an object that automatically takes and releases a mutex at proper times – how?
  - lock() → constructor
  - unlock() → destructor
- ***How does this ensure clean-up?***
  - ***Generalized idiom called RAII - Learn IT!!!***

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