Sistemas Distribuídos

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Example: Game

- Generic problem: Waiting for an event in a different thread
- Wait for at least Min players before joining the game:

```
void joinTheGame() {
    ready++;
    while (ready < Min)
            ;
}
```

Example: Game

- Wait for at least Min and at most Max players before joining the game:

```
void joinTheGame() {
    ready++;
    while (ready < Min || playing >= Max)
        ;
    playing++;                          // leaving
}
```

Race: ready = ready + 1

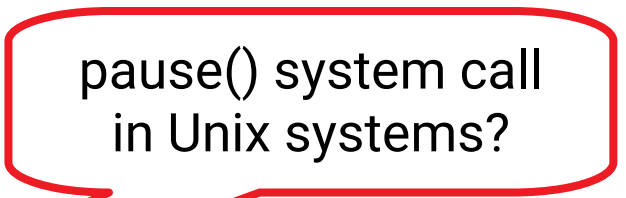
Busy waiting

Race: playing = playing + 1

How many problems with this code?

Waiting for an event

- Assuming we can ask the OS to suspend and wakeup threads, we solve busy waiting

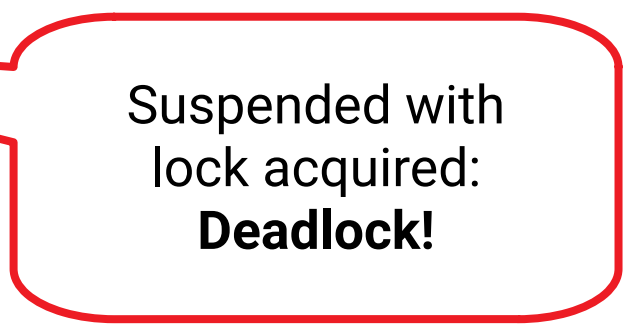



```
void joinTheGame() {
    ready++;
    if (ready < Min || playing >= Max)
            suspendMe();
    playing++;              // playing-- when leaving
    wakeAllOthers();  // also on leaving the game
}
```

Waiting for an event: 1st attempt

- Add locking:

```
void joinTheGame() {
    l.lock();
    ready++;
    if (ready < Min || playing >= Max)
        suspendMe();
    playing++;
    wakeAllOthers();
    l.unlock();
}
```



Waiting for an event: 2nd attempt

- Unlock while suspended:

```
void joinTheGame() {
    l.lock();
    ready++;
    if (ready < Min || playing >= Max) {
        l.unlock();
        suspendMe();
        l.lock();
    }
    playing++;
    wakeAllOthers();
    l.unlock();
}
```

Unlock to sleep

Relock to update other variables

Waiting for an event: 2nd attempt

- Player 1:
  - lock
  - ready++;
  - not enough ready, enter “if”
  - unlock

    (between unlock and suspend)

  - suspended…
    possibly forever...
- Player 2:
  - lock…

    … acquired
  - ready++;
  - enough ready, skip “if”
  - wake suspended
  - unlock

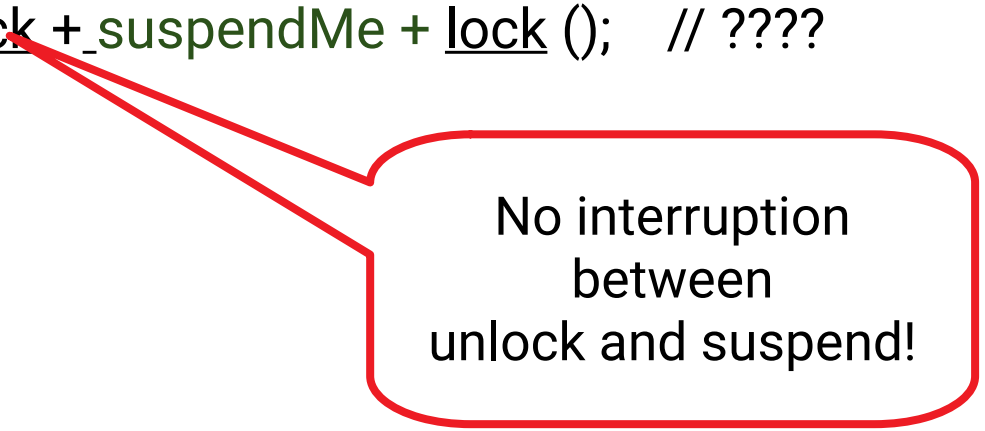
Waiting for events

- Inefficient if the waiting thread is busy polling the condition
- Leads to race conditions / deadlocks if the thread is suspended by the operating system

Waiting for an event: 3nd attempt

- Would need something like this:

```
void joinTheGame() {
    l.lock();
    ready++;
    if (ready < Min || playing >= Max) {

                    l. unlock + suspendMe + lock ();    // ????

    }
    playing++;
    wakeAllOthers();
    l.unlock();
}
```



Condition Variables

- Atomically suspends the thread and releases the lock:

  Lock l = new ReentrantLock();

  Condition c = l.newCondition();

  c.await(); *// atomically unlocks l and suspends,*
  // relocks l on wakeup

- Waking up suspended threads:
  - c.signalAll(); *// all threads*
  - c.signal(); *// one thread*

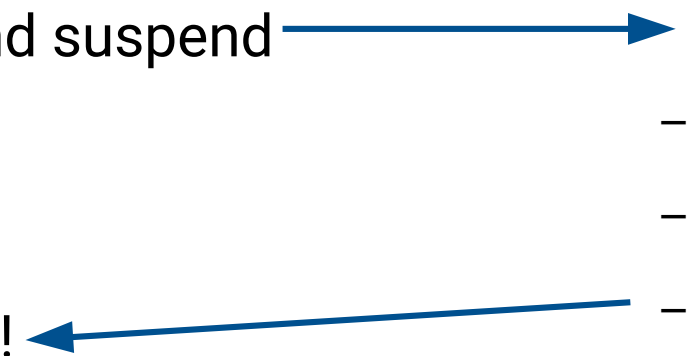
Waiting for an event: 3rd attempt

- Atomically unlock and suspend
- Relock when waking up

```
void joinTheGame() {
    l.lock();
    ready++;
    if (ready < Min || playing >= Max)
            c.await();
    playing++;
    c.signalAll();
    l.unlock();
}
```

Waiting for an event: 3rd attempt

- Player i < Min:
  - lock
  - ready++;
  - not enough ready, enter “if”
  - unlock and suspend
    ...
    ...
  - wakes up!
    (relock)
  - continues!
- Player i = Min:
  - lock…
    … acquired
  - ready++;
  - enough ready, skip “if”
  - wake suspended
  - unlock

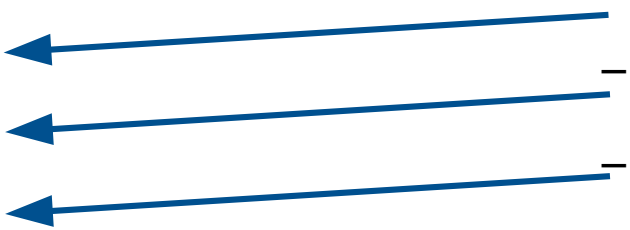


Waiting for an event: 3rd attempt

- Players i < Min:
  - lock
  - ready++;
  - not enough ready, enter “if”
  - unlock and suspend

    ...
  - waking up...
  - finally wakes up and gets lock!
  - playing++

- Players Min <= j < Min+Max:
  - player joins (playing++ = 1)
  - ...
  - player joins (playing++ = Max)



Playing > Max!

Waiting for an event: 4th version

- Must always use “while” loop:

```
void joinTheGame() {
    l.lock();
    ready++;
    while (ready < Min || playing >= Max) {
            c.await();
    }
    playing++;
    c.signalAll();
    l.unlock();
}
```

Can also wake up without signal being called! (“Spurious wakeup”)

Signaling an event

```
void joinTheGame() {
    l.lock();
    ready++;
    while (ready < Min ||
              playing >= Max) {
        c.await();
    }
    ...
    l.unlock();
}
```

```
void joinTheGame() {
    l.lock();
    ....
    playing++;
    c.signalAll();
    l.unlock();
}
void leaveTheGam
    l.lock();
    playing--;
    c.signal();
    l.unlock();
}
```

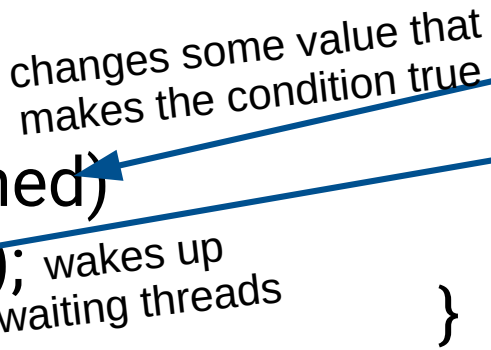
>1 or not all interested

At most any 1 interested

Waiting for an event: General case

```
Lock l = new ReentrantLock();
Condition c = l.newCondition();

void waitForEvent() {
    l.lock();
    ...
    while(!happened)
        c.await();
    ...
    l.unlock();
}
```

```
void event() {
    l.lock();
    ... // change state
    c.signal() or c.signalAll();
    l.unlock();
}
```



Conclusions

- Condition variables for efficiently / correctly waiting for events in concurrent programs
- Use await() always within a “while” loop due to:
  - Races
  - Spurious wakeups

Example: Level crossing

(a.k.a. Readers-Writers Lock)

Image from: https://www.deccanherald.com/content/354607/dangerous-rail-crossings.html

RW lock: Identify conditions

- For a reader:

```
lock() {
    while(there is a writer)
            wait...
}
```

- For a writer:

```
lock() {
    while(there is anyone)
            wait...
}
```

RW lock: Identify conditions

- For a reader:

```
lock() {
    while(there is a writer)
            wait...
}
```

- For a writer:

```
lock() {
    while(there is anyone)
            wait...
}
```

- How to implement conditions? Add sufficient state:
  - int nr_readers
  - ~~int nr_writers~~ → boolean a_writer

RW lock: Add state

- For a reader:

```
lock() {
    while(there is a writer)
        wait…
    nr_readers++
}
unlock() {
    nr_readers--
}
```

- For a writer:

```
lock() {
    while(there is anyone)
        wait…
    a_writer = true
}
unlock() {
    a_writer = false
}
```

RW lock: Write conditions

- For a reader:

```
lock() {
    while(a_writer)
        wait…
    nr_readers++
}
unlock() {
    nr_readers--
}
```

- For a writer:

```
lock() {
    while(a_writer ||
            nr_readers>0)
        wait…
    a_writer = true
}
unlock() {
    a_writer = false
}
```

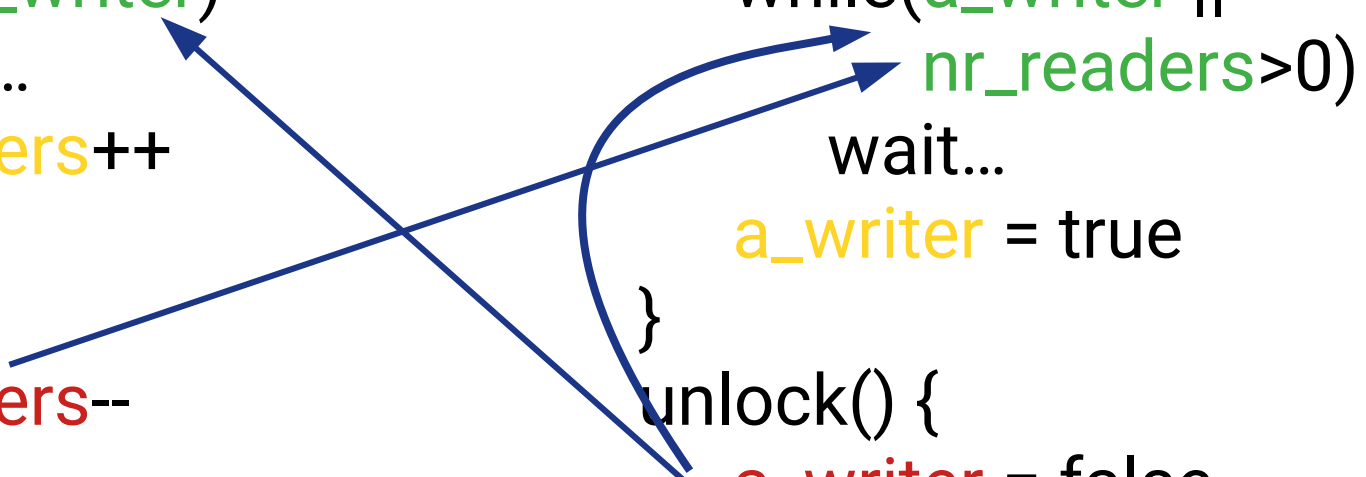
RW lock: Identify events

- For a reader:

```
lock() {
    while(a_writer)
        wait…
    nr_readers++
}
unlock() {
    nr_readers--
}
```

- For a writer:

```
lock() {
    while(a_writer ||
          nr_readers>0)
        wait…
    a_writer = true
}
unlock() {
    a_writer = false
}
```



RW lock: Implement events

- For a reader:

```
lock() {
    while(a_writer)
        c.await()
    nr_readers++
}
unlock() {
    nr_readers--
    c.signalAll()
}
```

- For a writer:

```
lock() {
    while(a_writer ||
            nr_readers>0)
            c.await()
    a_writer = true
}
unlock() {
    a_writer = false
    c.signalAll()
}
```

RW lock: Add locks

```
void readLock() {
    l.lock();
    while(a_writer)
            c.await();
    nr_readers++;
    l.unlock();
}
void readUnlock() {
    l.lock();
    nr_readers--;
    c.signalAll();
    l.unlock();
}
```

```
void writeLock() {
    l.lock();
    while(a_writer ||
            nr_readers>0)
            c.await();
    a_writer = true;
    l.unlock();
}
void writeUnlock() {
    l.lock();
    a_writer = false;
    c.signalAll();
    l.unlock();
}
```

RW lock: Reduce wakeups

```
void readLock() {
    l.lock();
    while(a_writer)
            c.await();
    nr_readers++;
    l.unlock();
}
void readUnlock() {
    l.lock();
    nr_readers--;
    if (nr_readers==0) c.signal();
    l.unlock();
}
```

```
void writeLock() {
    l.lock();
    while(a_writer ||
            nr_readers>0)
            c.await();
    a_writer = true;
    l.unlock();
}
void writeUnlock() {
    l.lock();
    a_writer = false;
    c.signalAll();
    l.unlock();
}
```

RW lock: Fairness

- Will readers and writers eventually access the critical section?

RW lock: Identify conditions

- For a reader:

```
lock() {
    while(there is a writer
          inside or waiting)
        wait...
}
```

- For a writer:

```
lock() {
    while(there is anyone)
        wait...
}
```

- How to implement conditions? Add sufficient state:
  - int nr_readers
  - ~~int nr_writers~~ → boolean a_writer
  - int waiting

RW lock: Add state and conditions

- For a reader:

```
lock() {
    while(writer inside
            || waiting>0)
        wait…
    nr_readers++
}
unlock() {
    nr_readers--
}
```

- For a writer:

```
lock() {
    waiting++
    while(there is anyone)
            wait…
    a_writer = true
    waiting--
}
unlock() {
    a_writer = false
}
```

RW lock: Implement events

```
lock() {
    while(a_writer ||
            waiting > 0)
        c.await()
    nr_readers++
}
unlock() {
    nr_readers--
    c.signalAll()
}
```

signal?

```
lock() {
    waiting++
    while(a_writer ||
            nr_readers>0)
        c.await()
    a_writer = true
    waiting--
}
unlock() {
    a_writer = false
    c.signalAll()
}
```

No signal(). This makes it always false.

RW lock: Reduce wakeups

```
void readLock() {
    l.lock();
    while(a_writer ||
            waiting>0)
            c.await();
    nr_readers++;
    l.unlock();
}
void readUnlock() {
    l.lock();
    nr_readers--;
    if (nr_readers==0) c.signalAll();
    l.unlock();
}
```

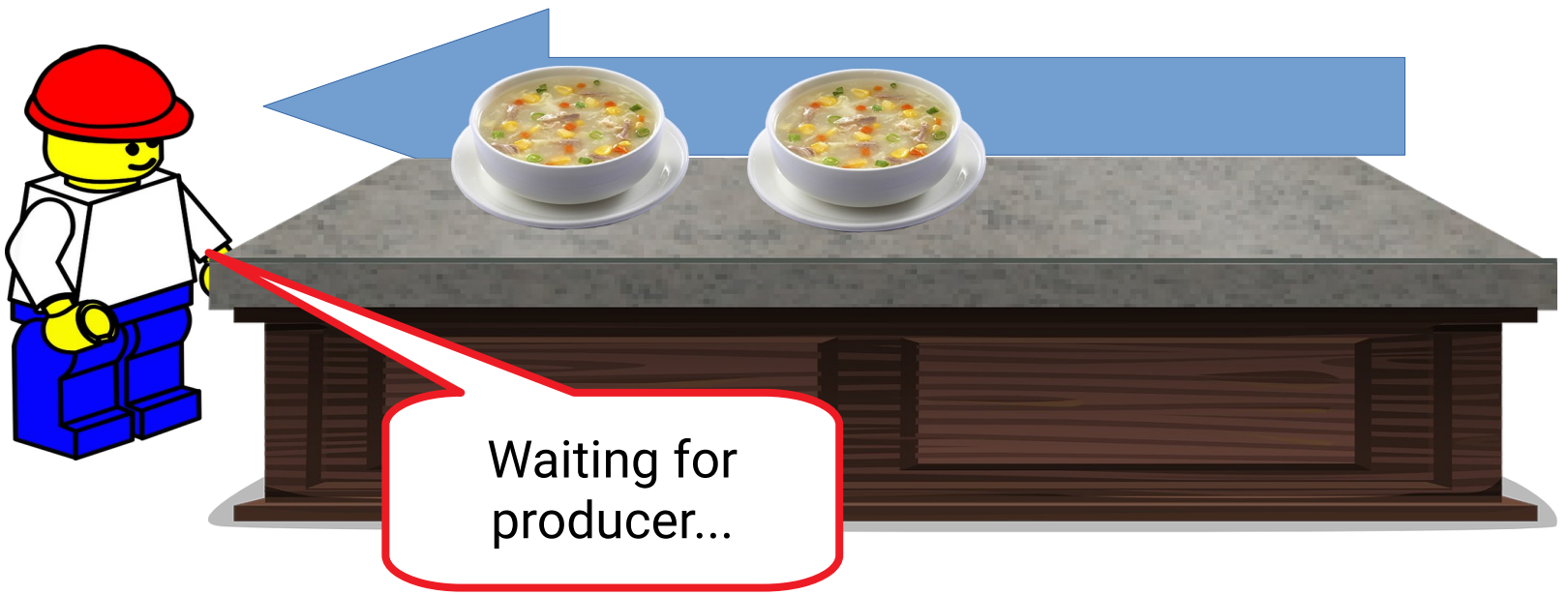
Cannot be optimized to c.signal()!

```
void writeLock() {
    l.lock();
    waiting++;
    while(a_writer ||
            nr_readers>0)
            c.await();
    a_writer = true;
    waiting--;
    l.unlock();
}
void writeUnlock() {
    l.lock();
    a_writer = false;
    c.signalAll();
    l.unlock();
}
```

Example: Soup counter

(a.k.a. Bounded Buffer)

Blocking consumer



Bounded buffer: blocking consumer

```
Lock l = new ReentrantLock();
Condition c = l.newCondition();
Queue<Object> q = …;

Object get() {
    l.lock();

    while(q.isEmpty())
        c.await();
    s = q.remove();
    l.unlock();
}
```

```
void put(Object s) {
    l.lock();
    q.add(s);
    c.signalAll();
    l.unlock();
}
```

changes some value that makes the condition true

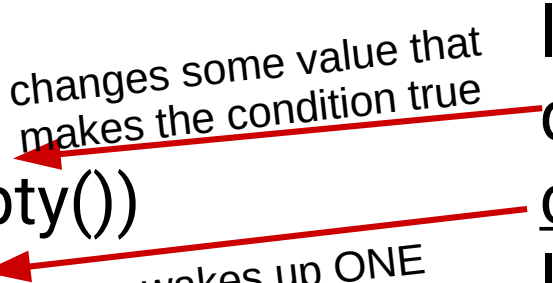
wakes up waiting threads

Why signal ALL if only one continues?

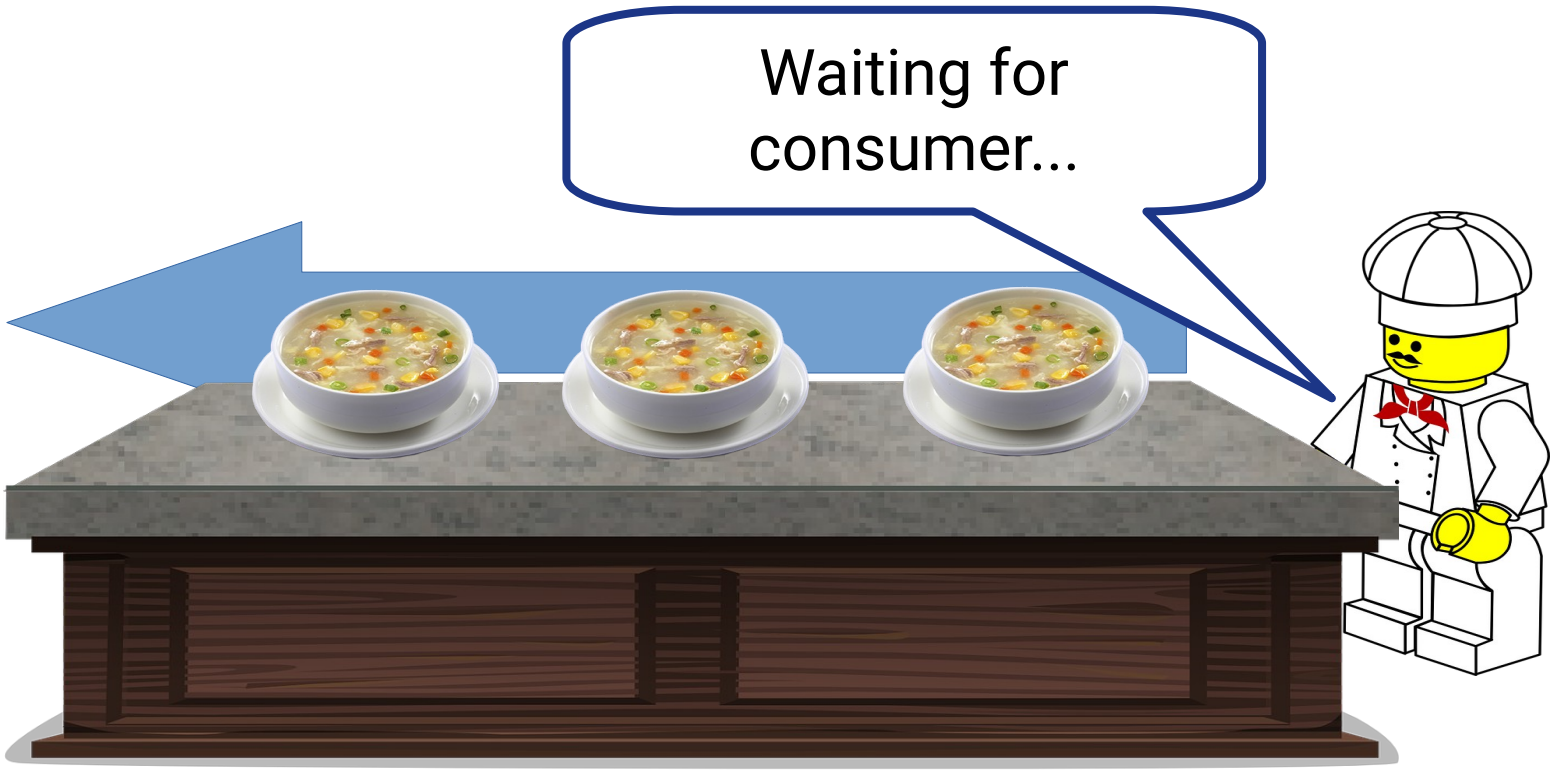
Bounded buffer: blocking consumer

```
Lock l = new ReentrantLock();
Condition c = l.newCondition();
Queue<Object> q = …;

Object get() {
    l.lock();

    while(q.isEmpty())
        c.await();
    s = q.remove();
    l.unlock();
}
```

```
void put(Object s) {
    l.lock();
    q.add(s);
    c.signal();
    l.unlock();
}
```



Blocking producer



Bounded buffer: blocking producer

```
Lock l = new ReentrantLock();
Condition c = l.newCondition();
Queue<Object> q = …;

Object get() {
    l.lock();
    s = q.remove();
    c.signal();
    l.unlock();
}
```

```
void put(Object s) {
    l.lock();

    while(q.size()>=Max)
            c.await()
    q.add(s);
    l.unlock();
}
```

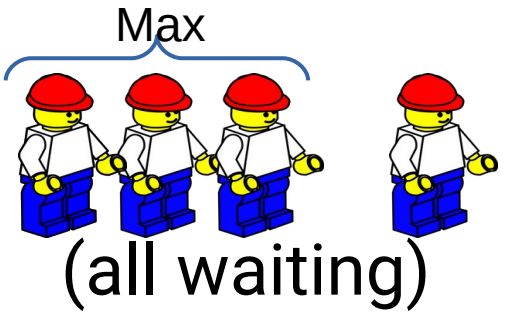
Bounded buffer: blocking both

```
Lock l = new ReentrantLock();
Condition c = l.newCondition();
Queue<Object> q = …;

Object get() {
    l.lock();
    while(q.isEmpty())
        c.await();
    s = q.remove();
    c.signal();
    l.unlock();
}

void put(Object s) {
    l.lock();
    while(q.size()>=Max)
        c.await()
    q.add(s);
    c.signal();
    l.unlock();
}
```

?

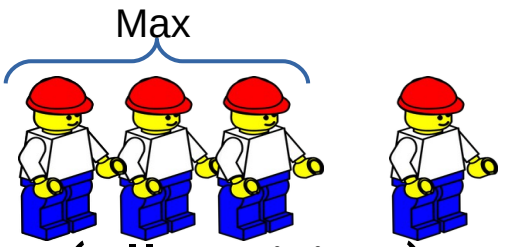
Is it possible to have producers and consiumers blocked at the same time?

Bounded buffer

- 

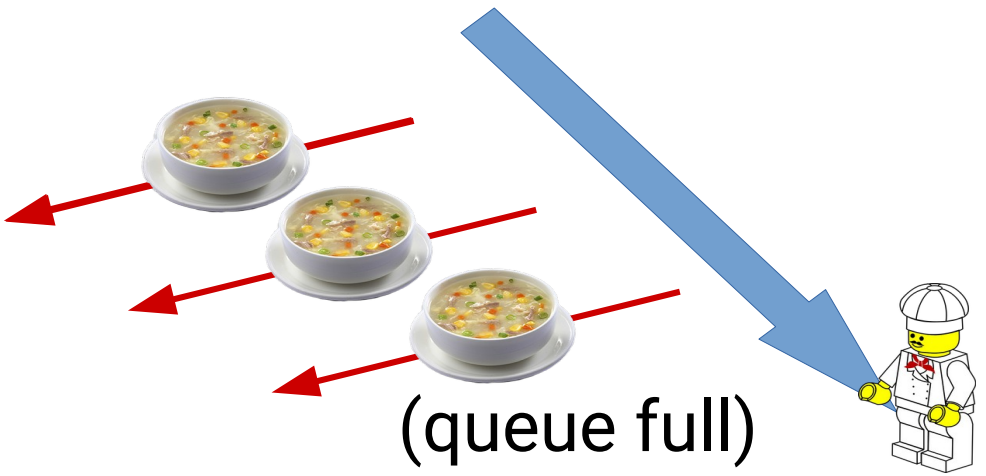
- Buffer of size Max
- More than Max consumers waiting…
- All producers busy elsewhere….

Bounded buffer

- 

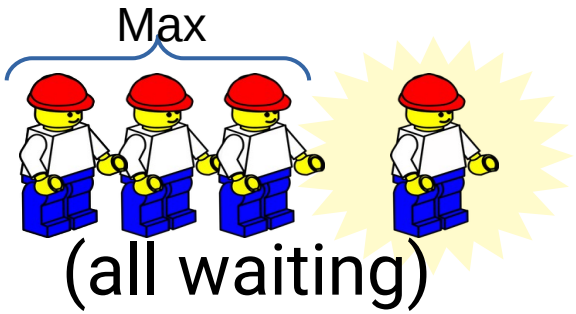
(all waiting)

(3 waiting)
(2 waiting)
(1 waiting)

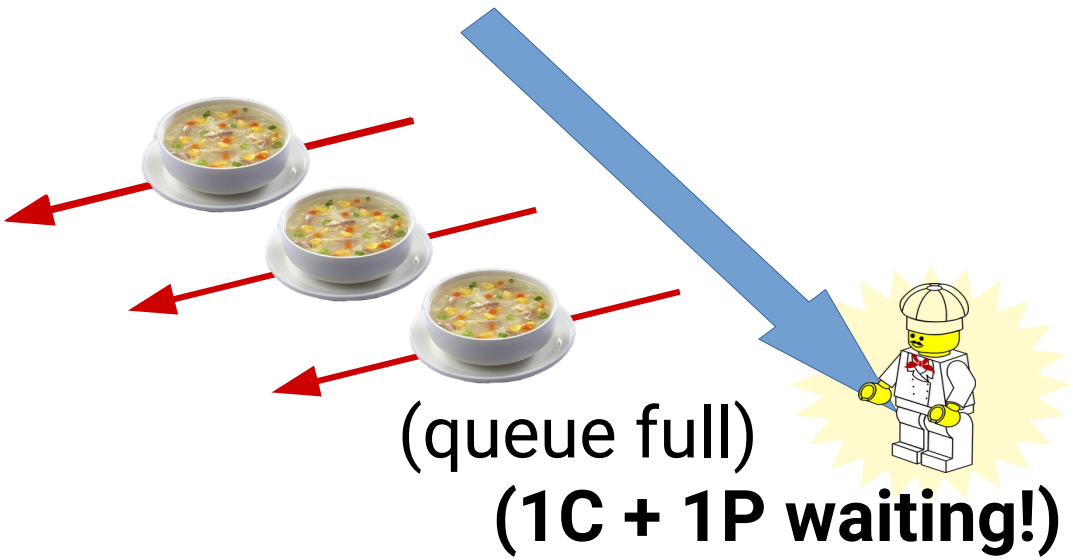

(queue full)

- Producer tries to put more than Max and blocks

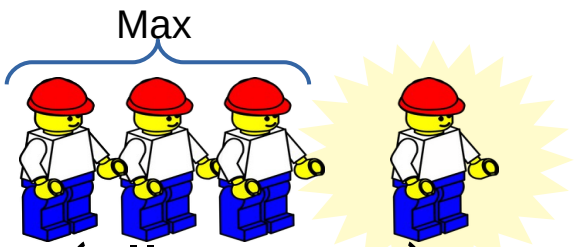
Bounded buffer

- 

(3 waiting)
(2 waiting)
(1 waiting)

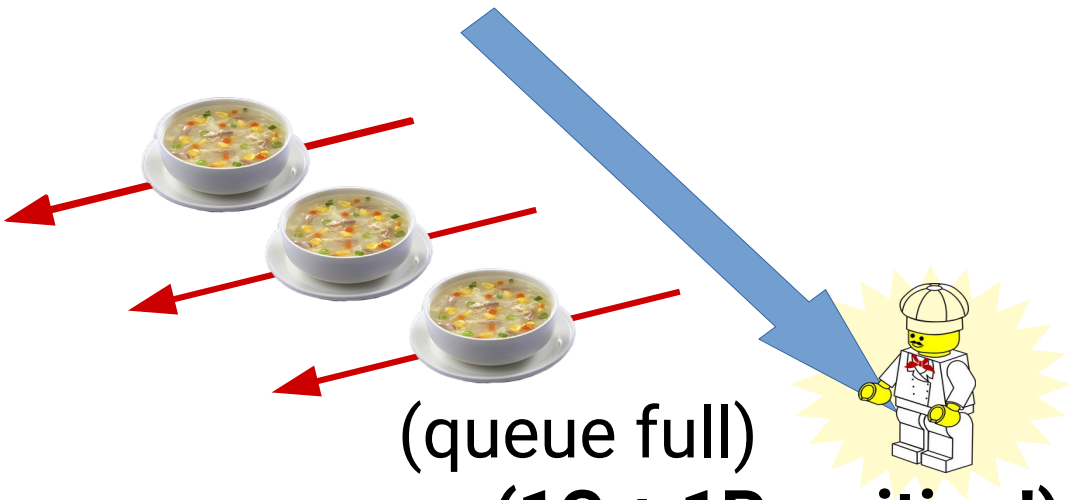


Bounded buffer

- 

(all waiting)

(3 waiting)
(2 waiting)
(1 waiting)


(queue full)
(1C + 1P waiting!)

-  signal() wakes **Consumer** or Producer?

Deadlock

Bounded buffer

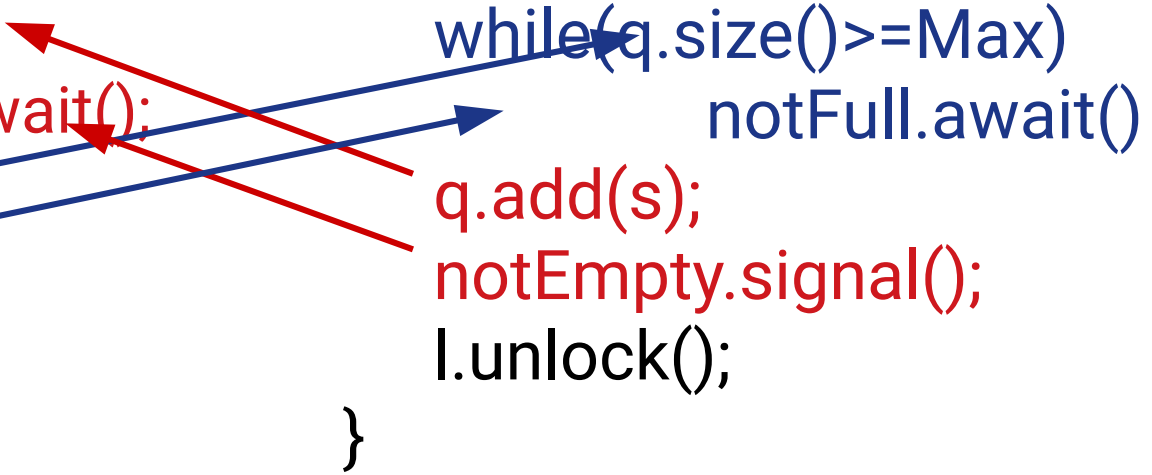
- This is a general problem with different conditions and the same condition variable
- Workaround: Use signalAll()
  - Inefficient (“thundering herd”)
  - This was the only solution with Java “synchronized” monitors (with notifyAll())

Bounded buffer: 2 condition variables

```
Lock l = new ReentrantLock();
Condition notEmpty = l.newCondition();
Condition notFull = l.newCondition();
Queue<Object> q = …;
```

```
Object get() {
    l.lock();
    while(q.isEmpty())
        notEmpty.await();
    q.remove();
    notFull.signal();
    l.unlock();
}
```

```
void put(Object s) {
    l.lock();
    while(q.size()>=Max)
        notFull.await()
    q.add(s);
    notEmpty.signal();
    l.unlock();
}
```



Summary

- Using multiple condition variables for the same lock reduces the need to use signalAll()
- But… not easy to be sure!!!

- “Bounded buffer” is an important building block for concurrent programs:
  - Unix *pipes*
  - *Sockets* in distributed programs