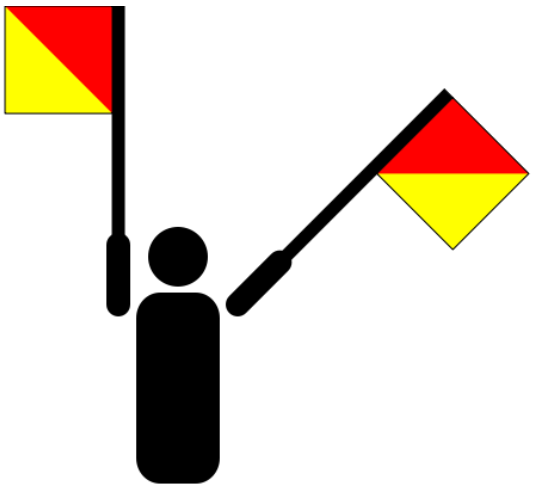
Too Few Chairs

Threads A, B, C, ...

```
1  wait until chairs > 0;
2  chairs--;
3  print("I'm working!");
4  chairs++;
```


Semaphores



Too Few Chairs with Semaphores

```
sem = new Semaphore(NUM_CHAIRS);
```

Threads A, B, C, ...

```
1  sem.wait();
2  print("I'm working!");
3  sem.signal();
```


Too Much Milk with Semaphores

```
sem = new Semaphore(1);
```

Threads A, B

```
1  sem.wait();
2  if (noMilk) {
3     buy milk;
4  }
5  sem.signal();
```

Implementing Semaphores

```
class Semaphore {

  public:
    void Wait();
    void Signal();

  private:
    int value;
    Queue Q;

}

Semaphore(int val) {
   value = val;
   Q = empty;
}
```

```
void Wait() {
   value--;
   if (value < 0) {
      add curThread to Q;
      put curThread to sleep;
   }
}

void Signal() {
   value++;
   if (value <= 0){
      remove T from Q;
      put T on ready queue;
   }
}
```

Must be atomic (interrupts or Test&Set)!

Producer/Consumer with Semaphores

```
class ProducerConsumer {
   public:
     void Produce();
     void Consume();
   private:
     Items buffer;
     // control buffer access
     Semaphore mutex;
     // count of free slots
     Semaphore empty;
     // count of used slots
     Semaphore full;
}

ProducerConsumer(int N) {
     mutex.value = 1;
     empty.value = N;
     full.value  = 0;
     buffer = new buffer[N];
}
```

```
void Produce() {
   <produce item>
   empty.Wait(); // one fewer slot, or wait
   mutex.Wait(); // get access to buffer
   <add item to buffer>
   mutex.Signal(); // release buffer
   full.Signal(); // one more used slot
}


void Consume() {
   full.Wait(); // wait until there's an item
   mutex.Wait(); // get access to buffer
   <remove item from buffer>
   mutex.Signal(); // release buffer
   empty.Signal(); // one more free slot
   <use item>
}
```

Locks and Semaphores Summary

- Synchronization difficult without OS help
- Primitives: Locks, Semaphores
- Disable interrupts or test&set
  - Hardware support!
- Semaphores generalize locks
  - Binary semaphores
  - Counting semaphores
  - Scheduling constraints