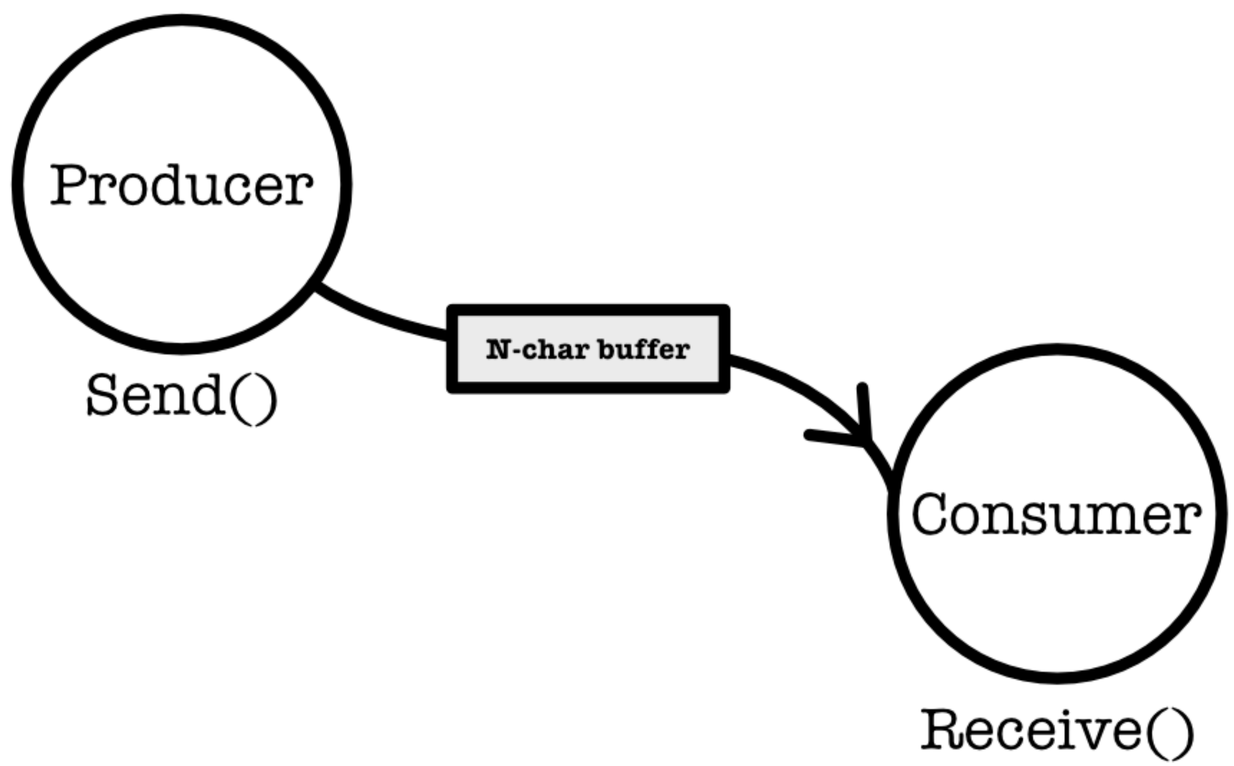
Procs and Threads
SYNC

50.005 CSE

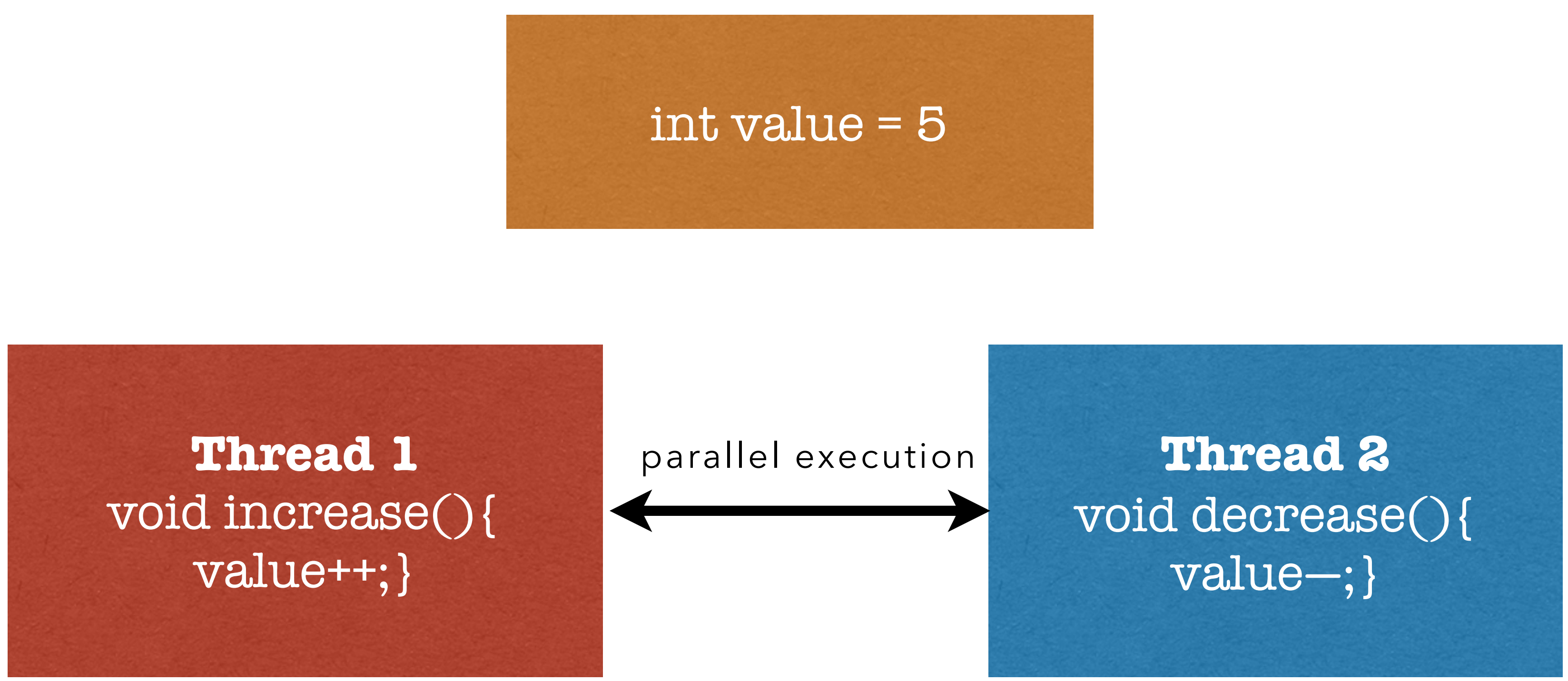
Natalie Agus
Information Systems Technology and Design
SUTD

MOTIVATION



THE RACE CONDITION

Behaviour of a system where its output is dependent on the sequence or timing of **uncontrollable** events



Possible outputs: value is 4, value is 5, and value is 6, depending on order of execution by scheduler.

Count ++ and count - - are **not** atomic in machine language. If they are somehow atomic by hardware implementation (atomic : implemented in **one** clock cycle), then race condition would not have surfaced.

CRITICAL SECTION

Count ++

```
LD(count, Rx)
ADDC(Rx, 1)
ST(Rx, count)
```

Count --

```
LD(count, Rx)
SUBC(Rx, 1)
ST(Rx, count)
```

These have to be uninterruptible

Rules of critical sections:

- **Mutual exclusion:**
    - preventing race condition
- **Has progress**:
    - if no thread / process in CS, then
    - select process in queue that can enter CS as soon as possible
- **Bounded waiting**:
    - each CS has finite length
    - there's max number of times other thread / processes are allowed to "cut" queue

PETERSON'S SOLUTION

```
For process / thread i,
    while (true):
        flag[i] = true
        turn = j
        while (flag[j] && turn == j);

        //Critical section
        _______
        _______
        flag[i] = false

        //Remainder section
        _______
        _______
```

Busy waiting. If i (or j) can't enter CS immediately, it must be waiting at **while** loop

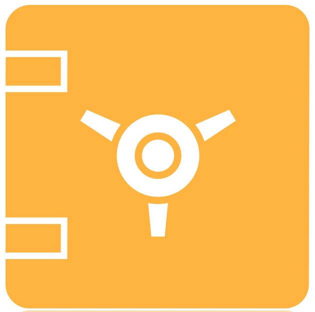
- One of the Critical section implementations
- Assume **LD** and **ST** are **atomic**
- i,j are processes / threads running in parallel
- Global vars:
  - bool flag[N] = {false}
  - int turn

SYNCHRONIZATION HARDWARE

Easy solution for supporting critical section, but less flexible

Disables interrupt

during critical sections



Atomic

hardware instructions, implemented in the system

getAndSet(), swap(), get(), set()

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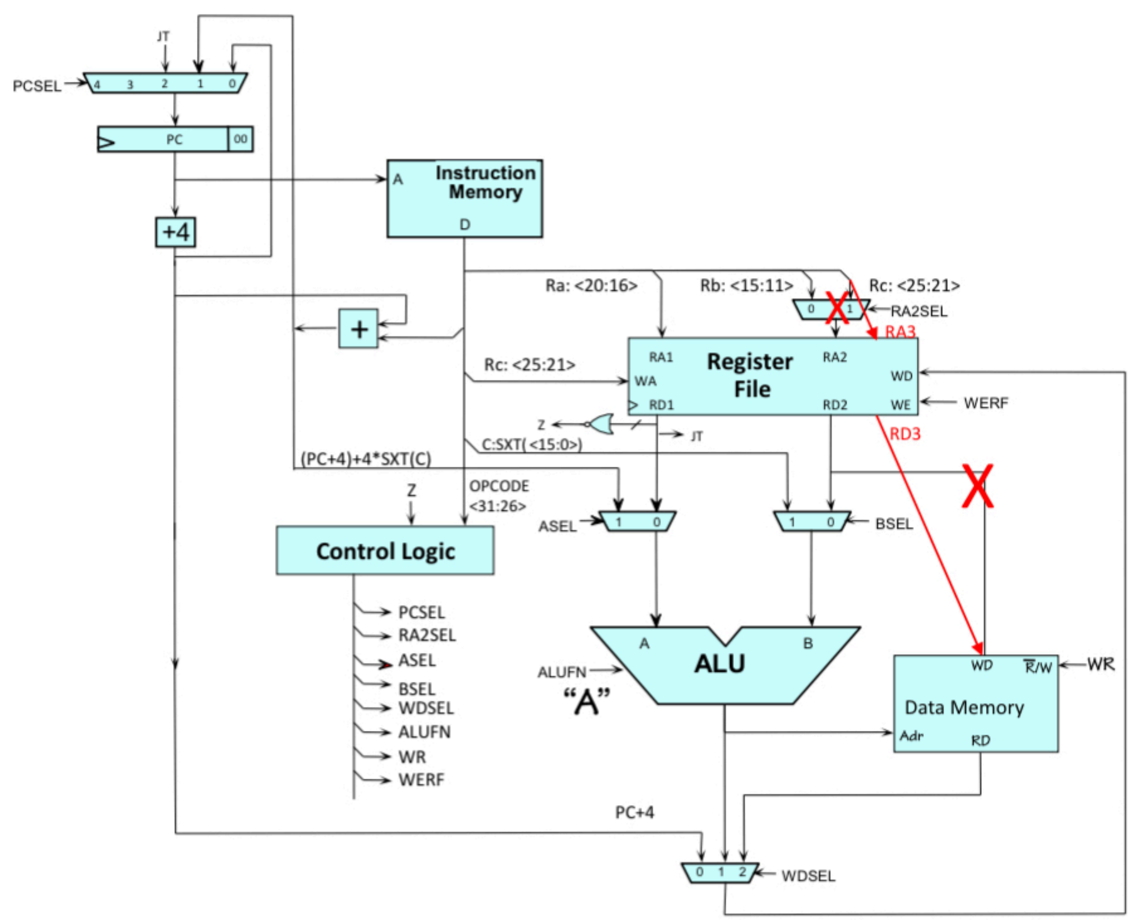
SYNCHRONIZATION HARDWARE

Easy solution for synchronization, but less flexible



	OP	OPC	LD	ST	JMP	BEQ	BNE	LDR	STX
ALUFN	F(op)	F(op)	"+"	"+"	--	--	--	"A"	"+"
WERF	1	1	1	0	1	1	1	1	0
BSEL	0	1	1	1	--	--	--	--	0
WDSEL	1	1	2	--	0	0	0	2	0
WR	0	0	0	1	0	0	0	0	1
RA2SEL	0	--	--	1	--	--	--	--	0
PCSEL	0	0	0	0	2	Z?1:0	Z?0:1	0	0
ASEL	0	0	0	0	--	--	--	1	0

How could we add an instruction

`STX(R2,R0,R1)`

as a short-cut for

`ADD(R1,R0,R0)`
`ST(R2,0,R0)` ?

Register-transfer language expression:
Mem[Reg[Ra] + Reg[Rb]] ← Reg[Rc]
`STX(Rc,Rb,Ra)`

Must amend data path & register file!
Register file needs another RA/RD port!
Could eliminate RA2SEL mux!

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SYNCHRONIZATION PROBLEMS

Mutex and Condition Synchronization

- Critical section is a section where only **one thread at a time** can access : **mutual exclusion**
- Some CS must be uninterruptible, some might not. Do not confuse CS with uninterruptible instructions.
- Mutual exclusion is not the only synchronization problem
- Sometimes, **you want a MAX of T threads that can access a section at the same time or asynchronously,** instead of just 1 thread at a time.
- This is called **condition synchronization**

SEMAPHORE

```
Semaphore sem = new Semaphore(x);
sem.acquire();
//Critical section
———————
———————
———————
sem.release();
//Remainder section
———————
———————
———————
```

- Another one of the Critical section implementation
- int state variable value (sem)
- Two **atomic** operations: acquire() and release()

SOLVES TWO SYNCHRONIZATION PROBLEMS:

- **Mutex**: if binary semaphore, x = 1
- **Condition synchronization**: if counting semaphore, x > 1

NO BUSY WAITING

if not available

1 **sem.acquire()**

Try to acquire the semaphore

2 **Block / sleep(k)**

Add to process / thread wait queue for each semaphore. The process / thread's CPU scheduling state is blocked or waiting (not rotated).

if available

3 **wakeup(k)**

Remove from process / thread queue of semaphore. Make its CPU scheduling state to be **ready or runnable.**

4 **sem.release()**

Release after critical section is done. Wakeup other process / thread in queue

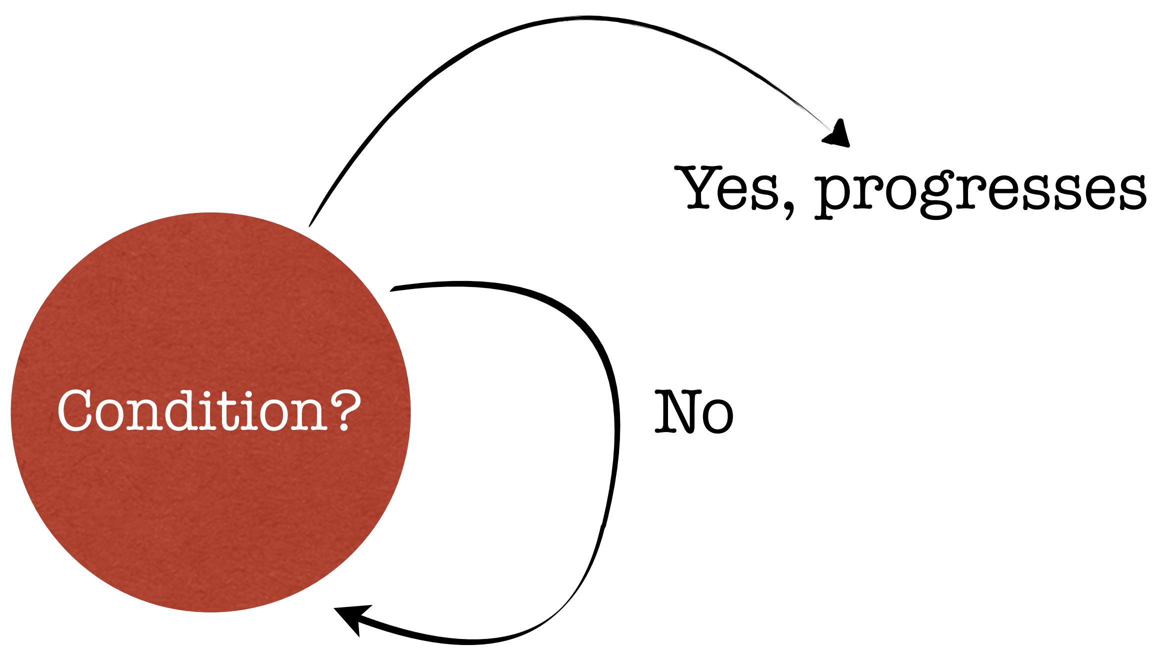
ON ACQUIRE() AND RELEASE()

Semaphore is required to execute critical sections, but semaphore's acquire() and release() itself is a critical section

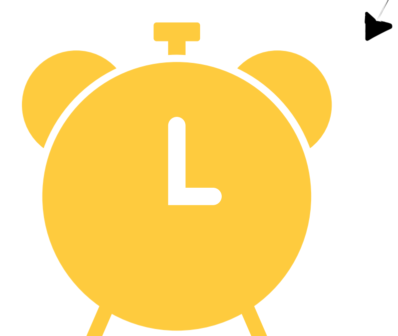
- This is a *circular* need
- Possible solutions:
  - Implement acquire() and release() using solutions that involve busy waiting, i.e: Peterson solution
  - Implement using hardware solution : getAndSet()
- Hence, busy wait on acquire() and release() alone, no busy wait on other critical section because semaphore is used

WHY BUSY WAITING IS BAD?

It is bad when it takes a long time. Otherwise, it might be beneficial if we only busy wait for awhile because it prevents context switch at times in multiprocessor system.



Repeat check,
Wastes CPU cycle: **spinlock**



But generally we do not know for sure how long a critical section will take, just that it is **bounded**

JAVA SOLUTION TO SYNCHRO PROBLEMS

Two possible ways to synchronize methods of objects accessible by multiple threads. **Satisfies both cases of synchro problems: mutex and condition synchronization**

1. **Method synchronization:**

```
public synchronized returnType methodName(args)
{
    //Critical section here, can try wait() then notify() if needed for
    condition synchronization
}
```

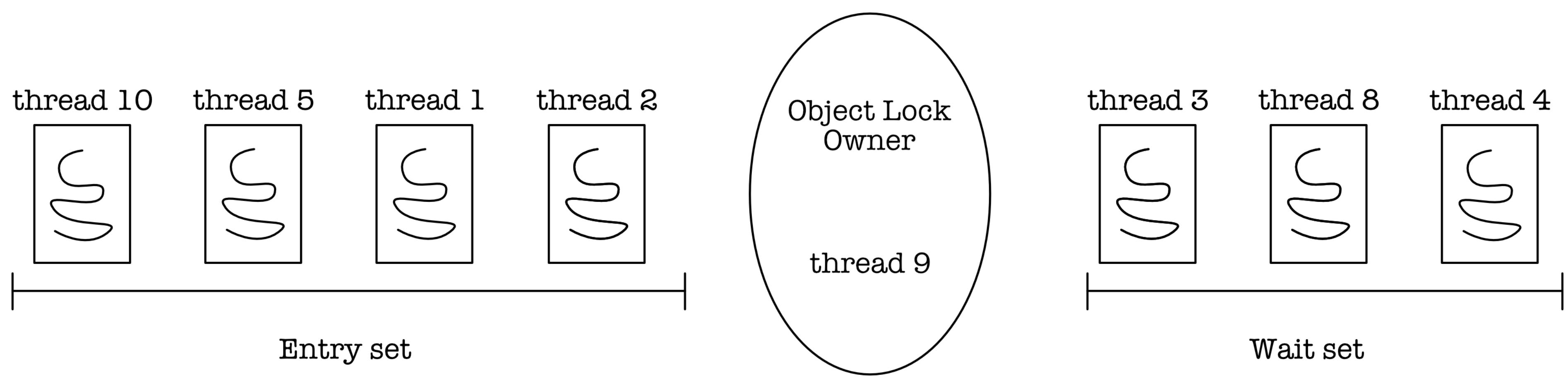
2. **Block synchronization:**

```
Object mutexLock = new Object();
   public returnType methodName(args){
        synchronized(mutexLock) {
          //Critical section here
        }

        //Remainder section
   }
```

ENTRY AND WAIT SET

These sets are **per object, meaning each object only has ONE lock.** Each object can have many synchronized *methods*. These methods share **one** lock.



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Four Java Thread library methods to highlight: notify(), notifyAll(), yield(), wait()

```
public synchronized returnType
methodName(args)
{
        //Critical section here
}
```

When Java threads in entry set try to enter **synchronized method / block,** the thread library will test whether the lock is free (try to acquire lock).

If yes, enter CS, if no, remain in entry set.

1. **Notify()** : wakes up / pick **any** arbitrary thread from wait set to entry set.
2. **NotifyAll()** : wakes up / pick **all** thread in wait set to entry set, good for condition synchronization

Both of the above are called by a thread that's existing CS.

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Four Java Thread library methods to highlight: notify(), notifyAll(), yield(), wait()

```
Object mutexLock = new Object();

  public returnType methodName(args){
      synchronized(mutexLock) {
        while(someCondition != True)
            Thread.wait();
        //Critical section here
        notify()
      }

      //Remainder section
  }
```

3. Yield() : gives up time to CPU scheduler but doesn't give up lock **(dangerous)**

4. Wait() : Thread releases object lock, gives up time to CPU scheduler, state changed to blocked / waiting, **goes to wait set.**

Called by thread who enters synchronized method successfully but cannot progress due to some other condition, e.g: waiting I/O, dependency on other thread's output, etc

JAVA NAMED CONDITION VARIABLE

For multiple conditions in ONE object

Lock lock = new **ReentrantLock**()
Condition lockCondition =
lock.newCondition()

Lock.lock()

To wait for specific condition:
lockCondition.await()

To signal specific thread waiting for this condition:
lockCondition.signal()

Lock.unlock()

```
/**
 * myNumber is the number of the thread
 * that wishes to do some work
 */
public void doWork(int myNumber) {
   lock.lock();

   try {
      /**
       * If it's not my turn, then wait
       * until I'm signaled
       */
      if (myNumber != turn)
         condVars[myNumber].await();

      // Do some work for awhile . . .

      /**
       * Finished working. Now indicate to the
       * next waiting thread that it is their
       * turn to do some work.
       */

      turn = (turn + 1) % 5;
      condVars[turn].signal();
   }
   catch (InterruptedException ie) { }
   finally {
      lock.unlock();
   }
}
```