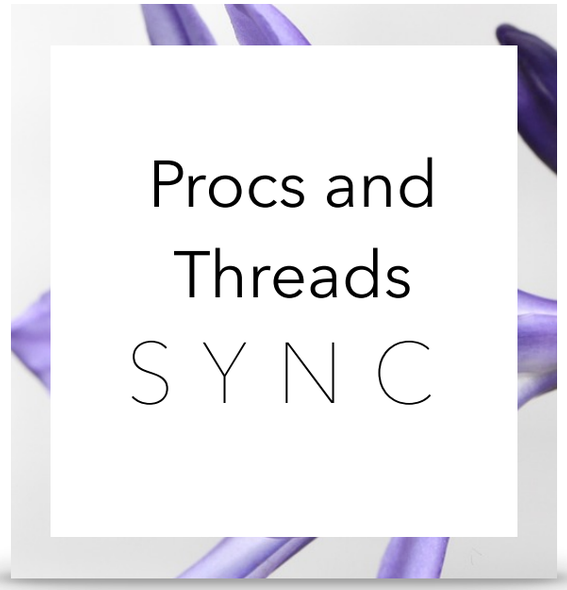
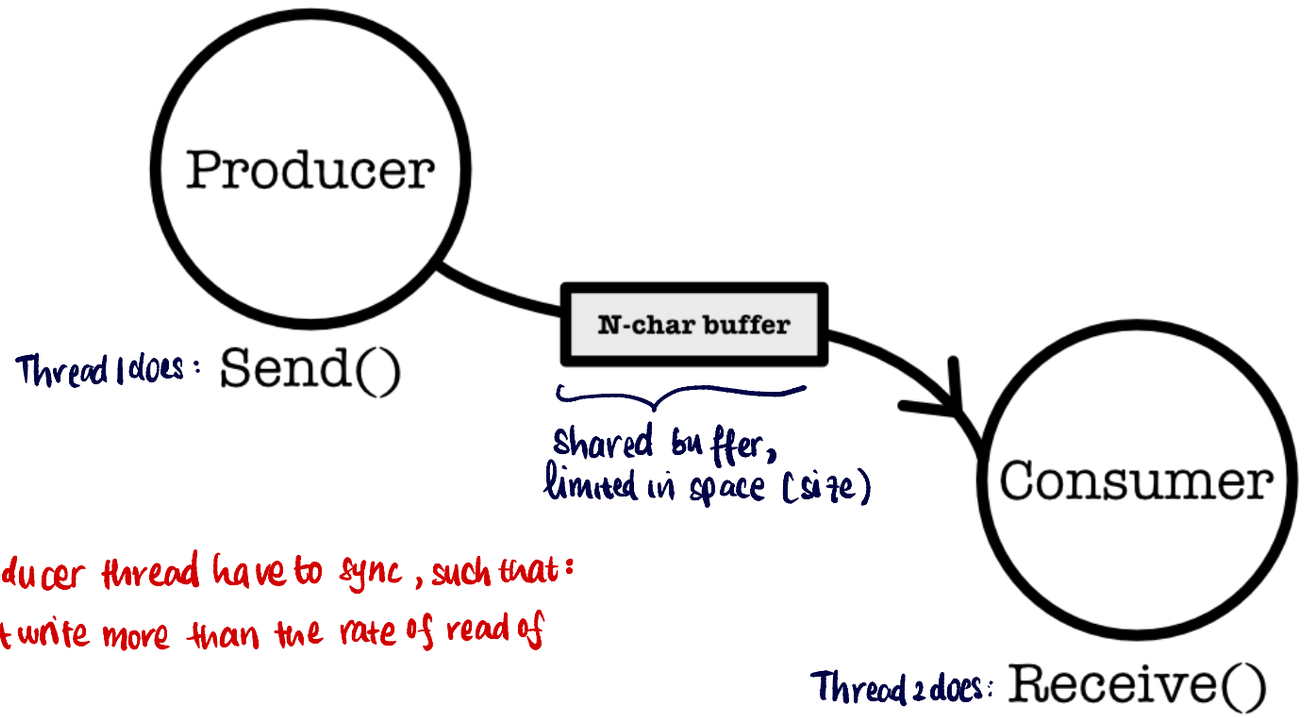


50.005 CSE

Natalie Agus
Information Systems Technology and Design
SUTD

MOTIVATION



* Consumer and producer thread have to sync, such that:
  1) producer doesn't write more than the rate of read of consumer
  2) consumer only attempts to read when the buffer has some content

THE RACE CONDITION

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

For eg: thread library scheduler or kernel process scheduler is out of the app developer's control

int value = 5

Thread 1
void increase(){
value++;}

parallel execution

Thread 2
void decrease(){
value—;}

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

OR, protected by critical sections. [But critical section does not necessarily imply uninterruptibility]

Note that critical section can be pre-empted – interrupted and resumed → ① by the same thread

② or, if a thread in Crit. section is interrupted it has to be "rolled" back to the state before entering the critical section. (more on this later)

Rules of critical sections:

meaning, what rules should be uphold if you code a library that supports "critical section".

and also all programming language libraries that support implementations of "critical sections" must uphold these rules as well.

- **Mutual exclusion:**
  - preventing race condition
- **Has progress**: → important! Otherwise if you just require mutex, a trivial solution will be to allow nobody to enter the Crit. Section, i.e: zero 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

does NOT work for multicore systems because setup of /reading shared variables in multicore system is complicated → each CPU has different cache. ↳ you must make them "see" the latest update, need kernel help.

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

This is where you would call the functions that are supposed to be your critical section
                //Critical section
                function_1 (arguments,...) etc
                _______
                _______
                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

there's only one "turn" variable

SYNCHRONIZATION HARDWARE

Easy solution for supporting critical section, but less flexible

Disables interrupt

during critical sections

although some people do implement crit. sections as uninterruptible using hardware (wiring and etc), this is almost impossible to do if your crit. section contains many lines of instructions

too many different permutation of types of code developers can write.

Atomic

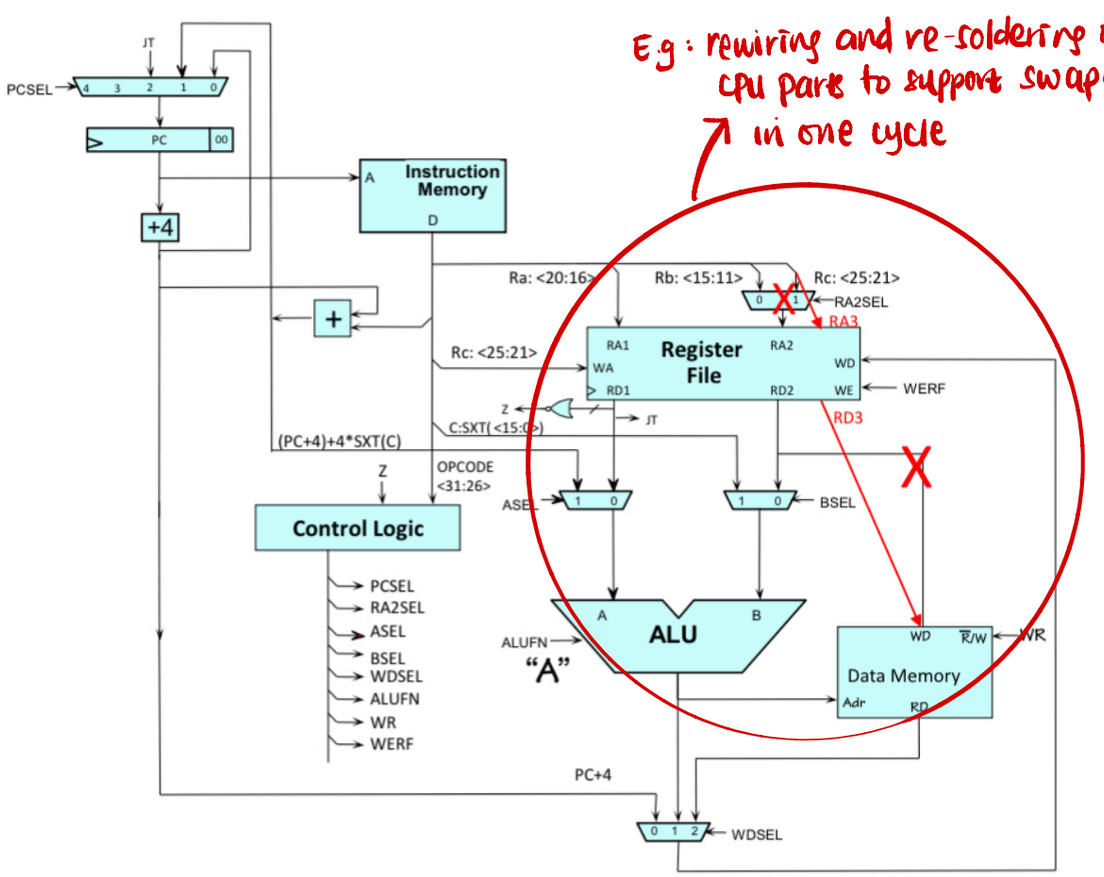
hardware instructions, implemented in the system

get() and set(), swap()

done in a single clock cycle. Limited flexibility too. You definitely cannot merge so many lines of instructions in a single cycle.

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!

SYNCHRONIZATION PROBLEMS

Two types : ① Mutex and ② Condition Syncrhonization

- 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
———————
———————
———————
```

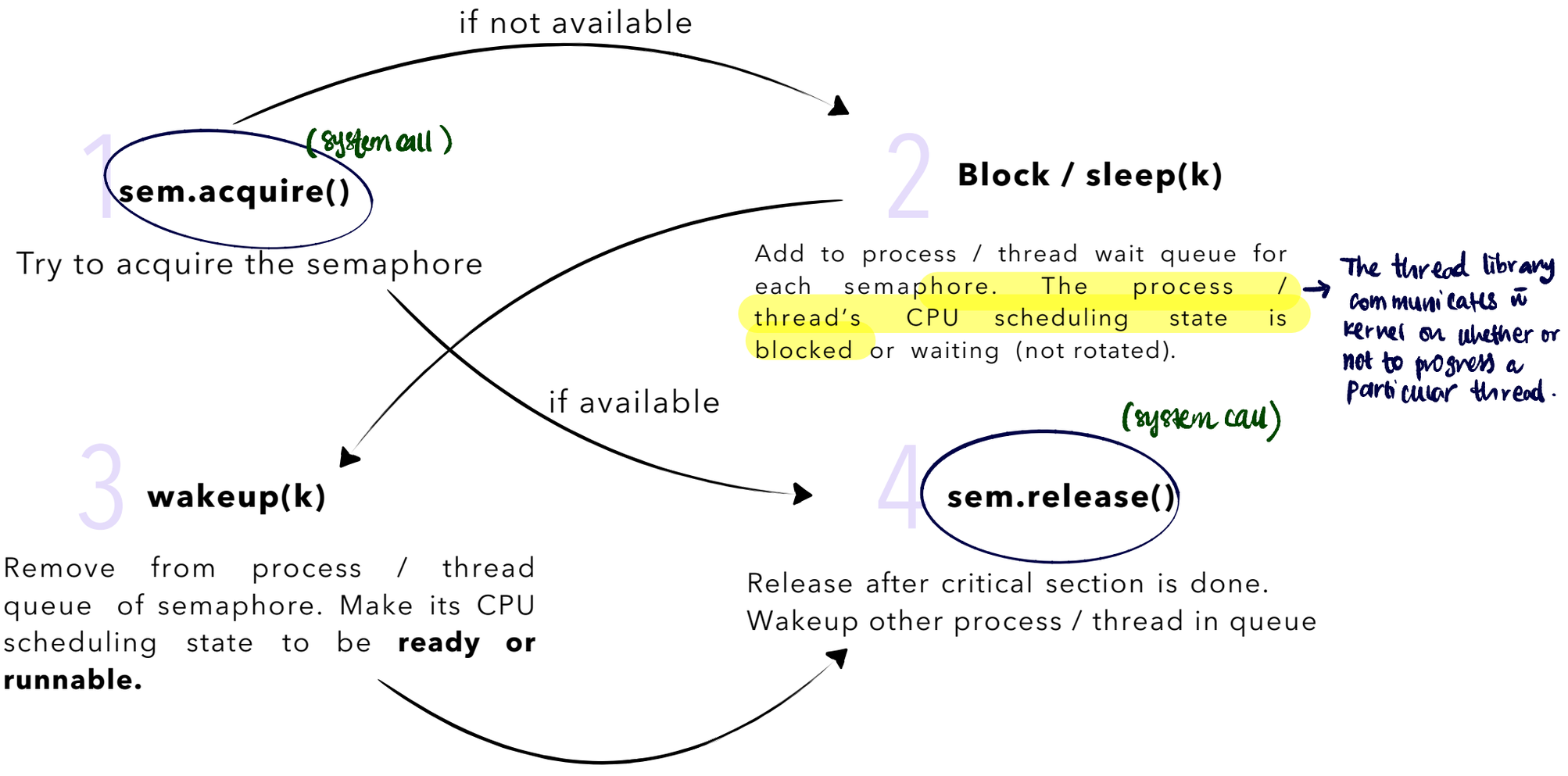
maintained and stored by kernel in UNIX systems

- 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



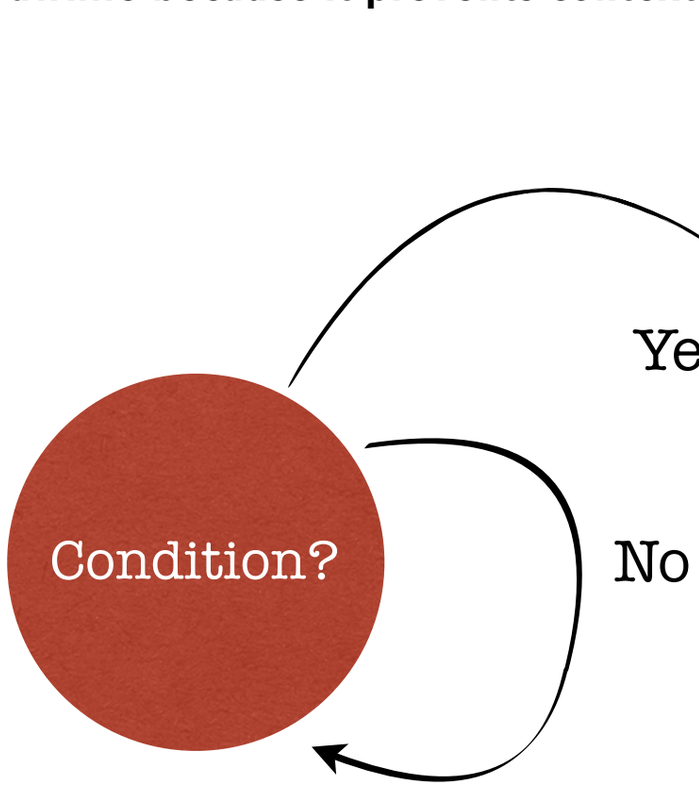
ON ACQUIRE() AND RELEASE()

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

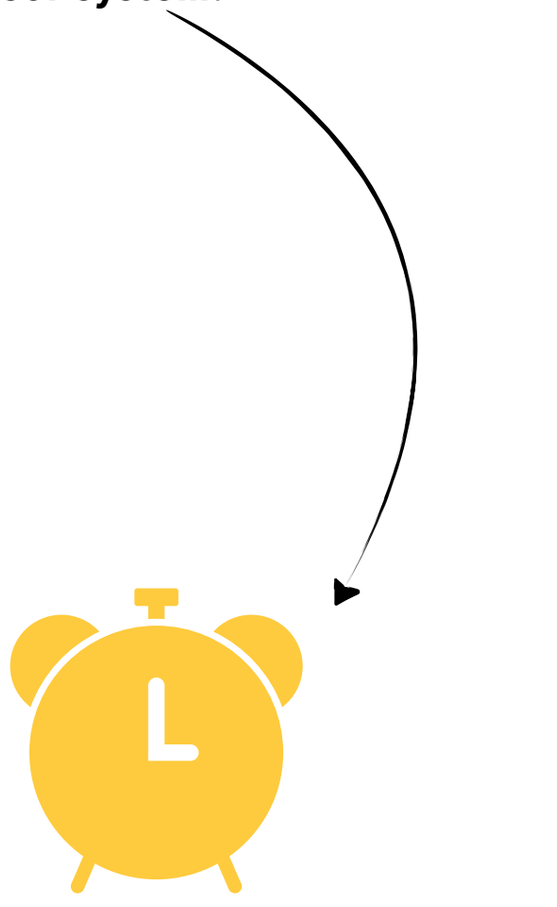
- This is a *circular* need → semaphore needed for CS, CS needed for semaphore's acquire and release
- Possible solutions:
  - Implement acquire() and release() using solutions that involve busy waiting, i.e: Peterson solution
  - Implement using hardware solution
  - Implement using software solution: system call that's uninterruptible, however **this doesn't work in multiprocessor system**
- 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
}
```

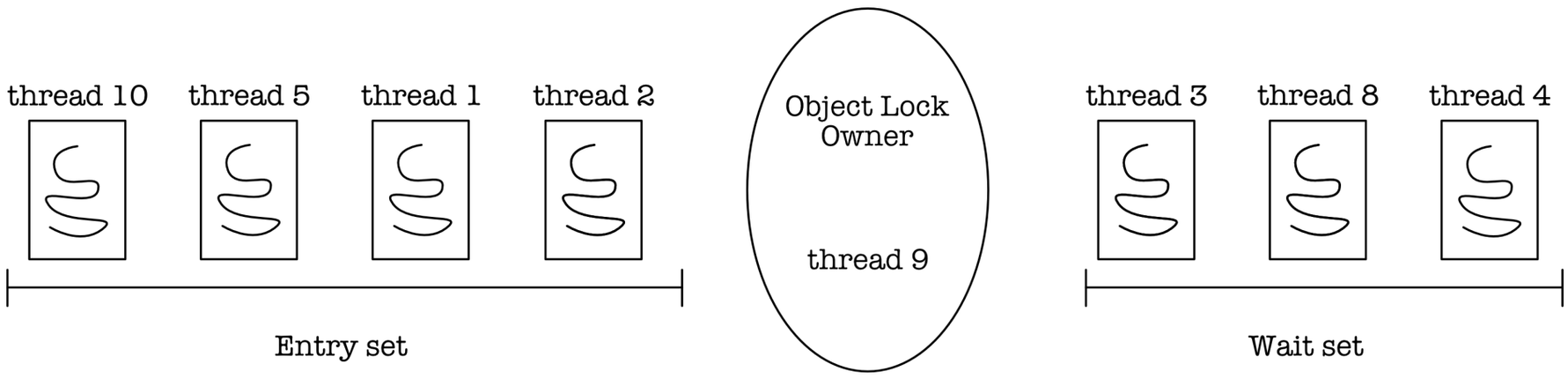
2. **Block synchronization:**

```
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.



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

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

      //Remainder section
}
```

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.

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.** *relies on the fact that other threads will eventually call notify() to wake you up.*

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 waiti
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();
  }
}
```

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  catch (InterruptedException ie) { }
  finally {
    lock.unlock();
  }
}
```

Filter algorithm : peterson's for > 2 threads

level = array of N int

last_to_enter = array of N int

The algo : for thread i :

try to acquire lock

```
for k in range (0, N):
    level[i] = k
    last_to_enter[k] = i
    while (last_to_enter[k] == i and there exists j ≠ i such
           that level[j] >= k);

// critical section
```

Wait until there's no more threads with higher level than me.