Sistemi Operativi I

Corso di Laurea in Informatica

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SAPIENZA
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Process/Thread Synchronization

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Synchronization as a solution to the critical section problem

Part III: Process Synchronization

The Need for Synchronization: Example

Consider the following real-world scenario, involving 2 roommates: Bob and Carla

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5:20pm		Arrive home
5:25pm	Arrive at the grocery	Look in the fridge → No milk!

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5:50pm		Buy milk
6:05pm		Arrive home, put the milk in the fridge

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5:25pm	Arrive at the grocery	Look in the fridge → No milk!
5:30pm	Buy milk	Leave home for the grocery
5:45pm	Arrive home, put the milk in the fridge	Arrive at the grocery
5:50pm		Buy milk
6:05pm		Arrive home, put the milk in the fridge
6:05pm	Oh f*%#k!	Oh f*%#k!

The Need for Synchronization: Example

- In the example, Bob and Carla represents 2 processes/threads
- Theoretically, they should cooperate to achieve a common task (e.g., buying some milk)
- In practice, though, they might incur in unpleasant situations (e.g., buying too much milk!)

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- Theoretically, they should cooperate to achieve a common task (e.g., buying some milk)
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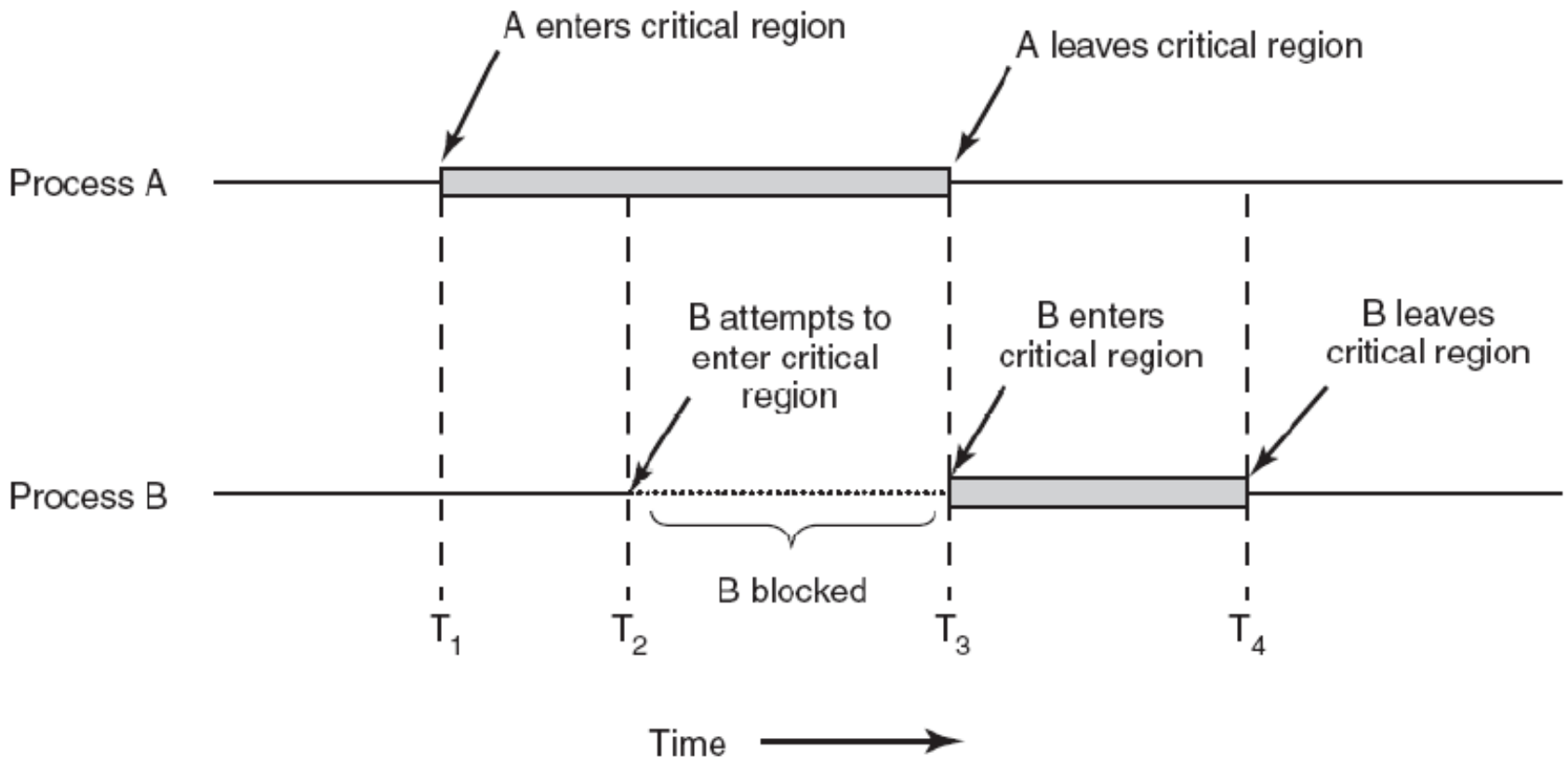
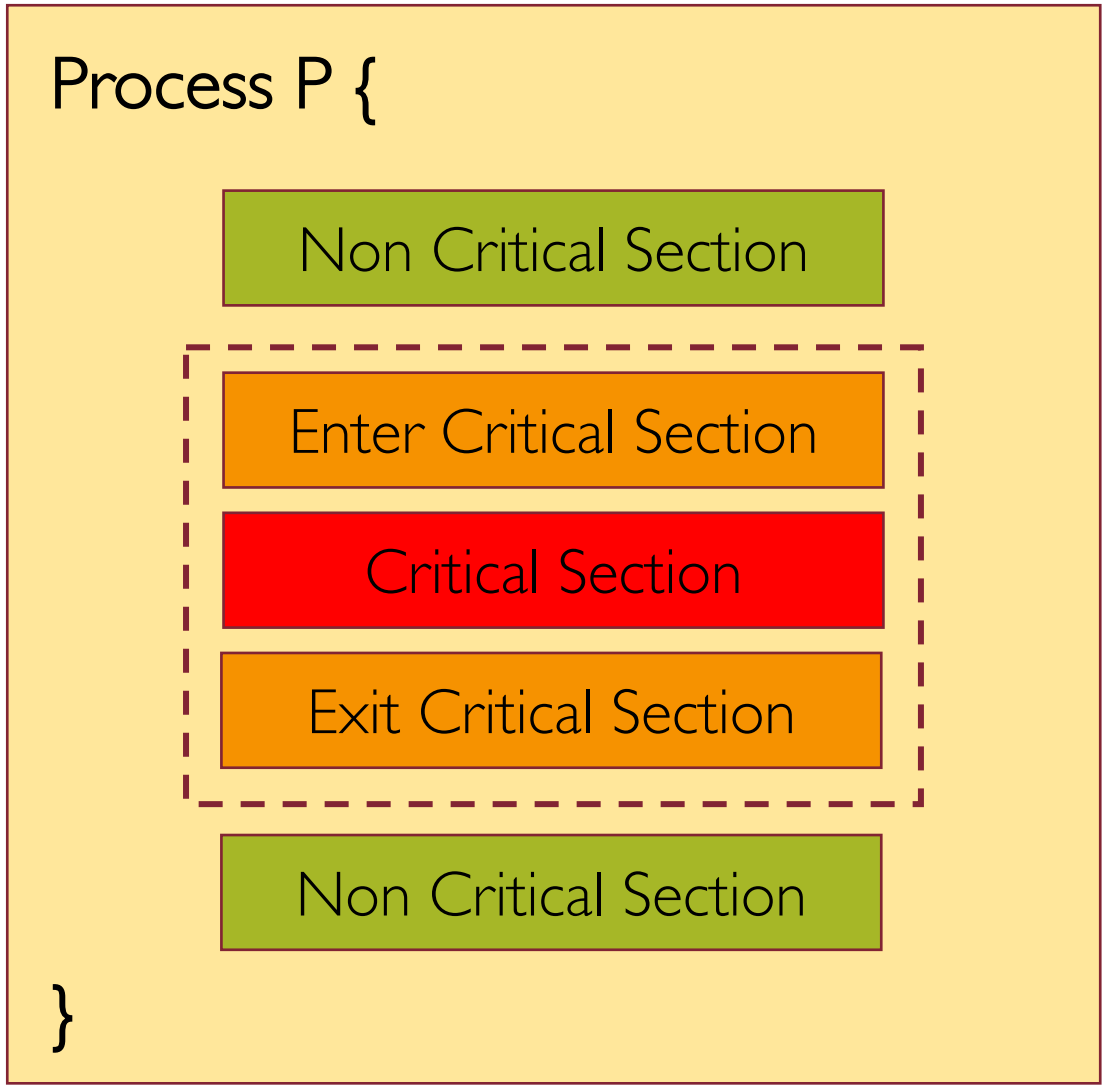
What kind of mechanisms do we need in order to get independent yet cooperating processes to communicate
and have a consistent view of the "world" (i.e., computational state)?

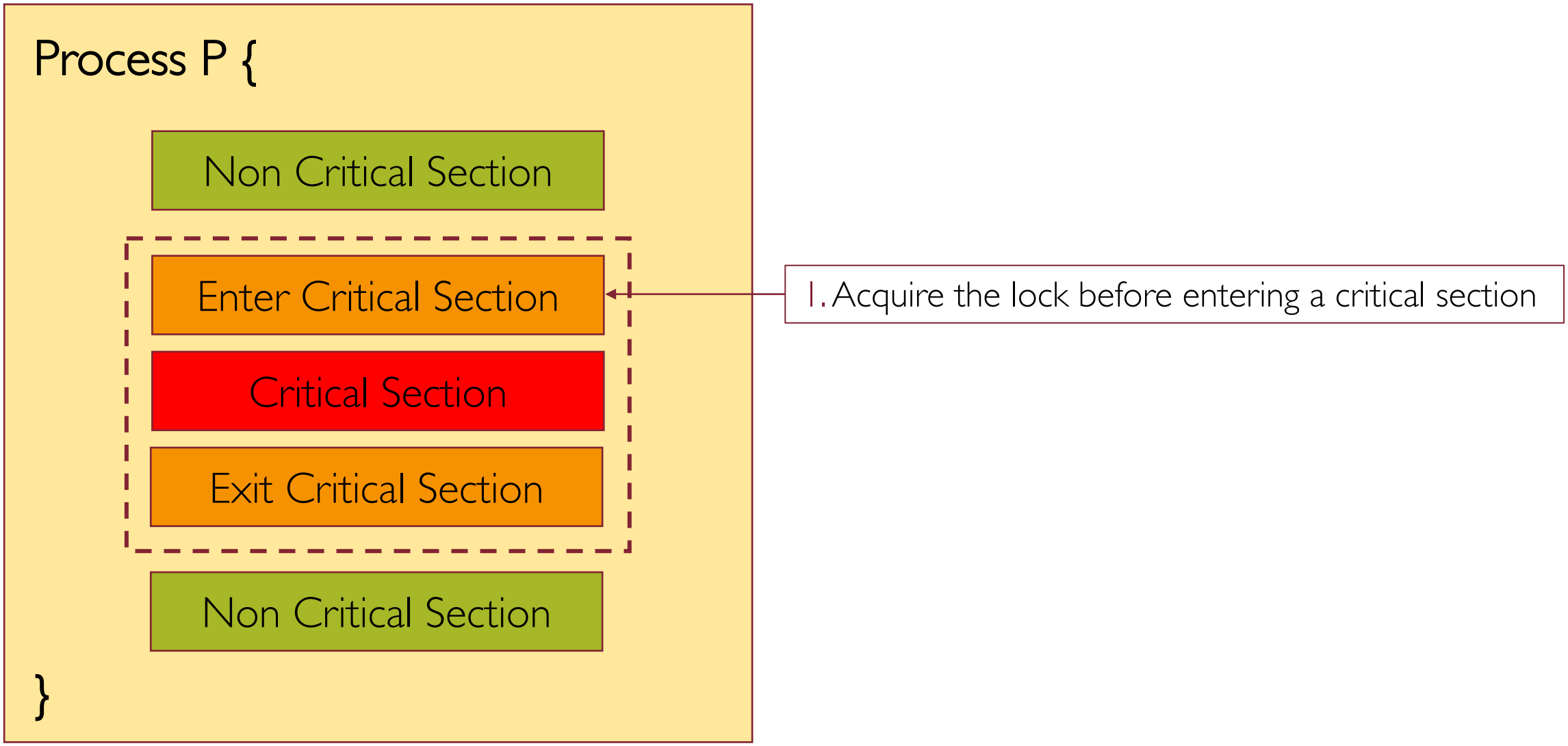
The Critical Section Problem



The Anatomy of a Critical Section



Locking Critical Section



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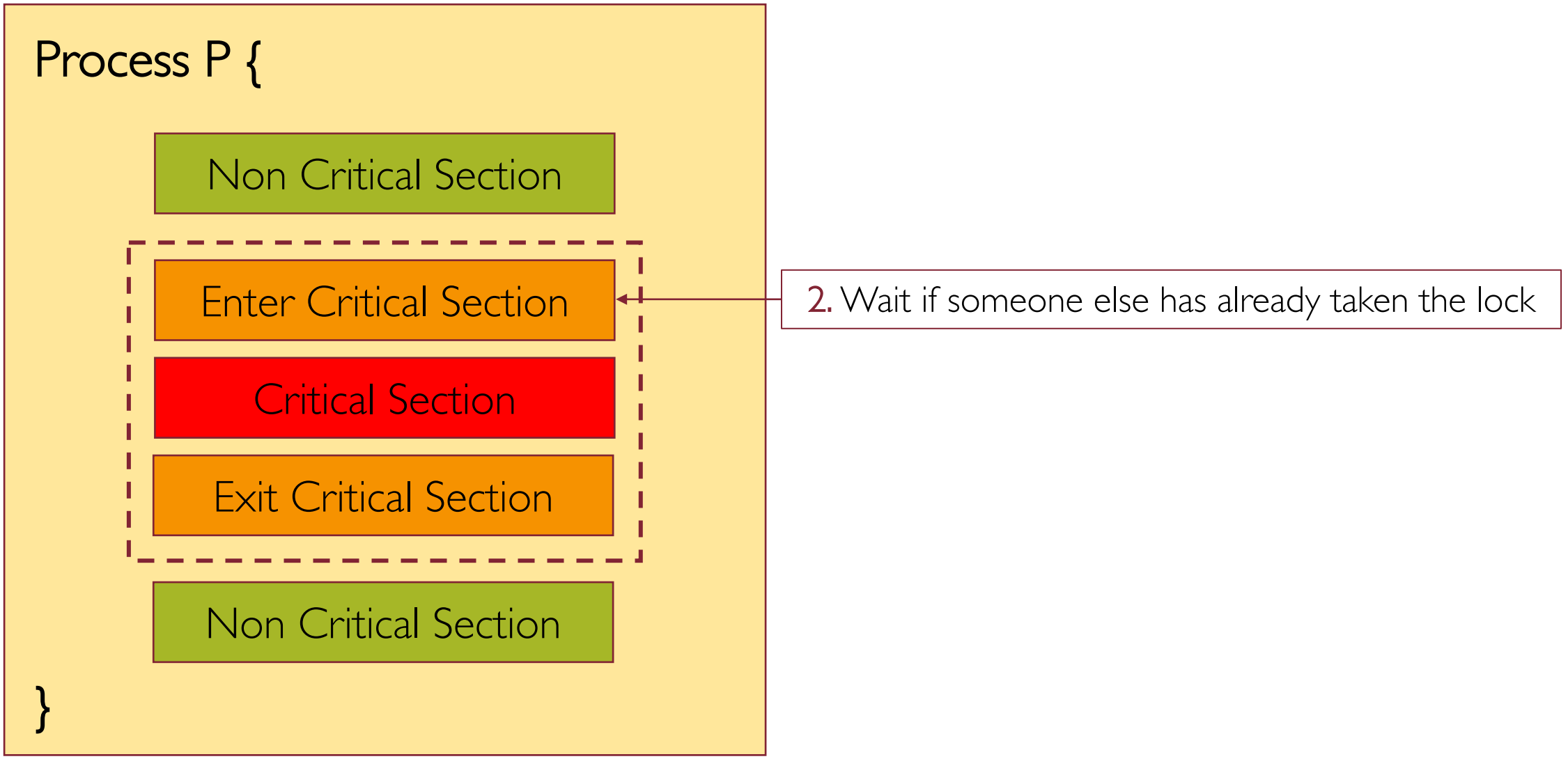

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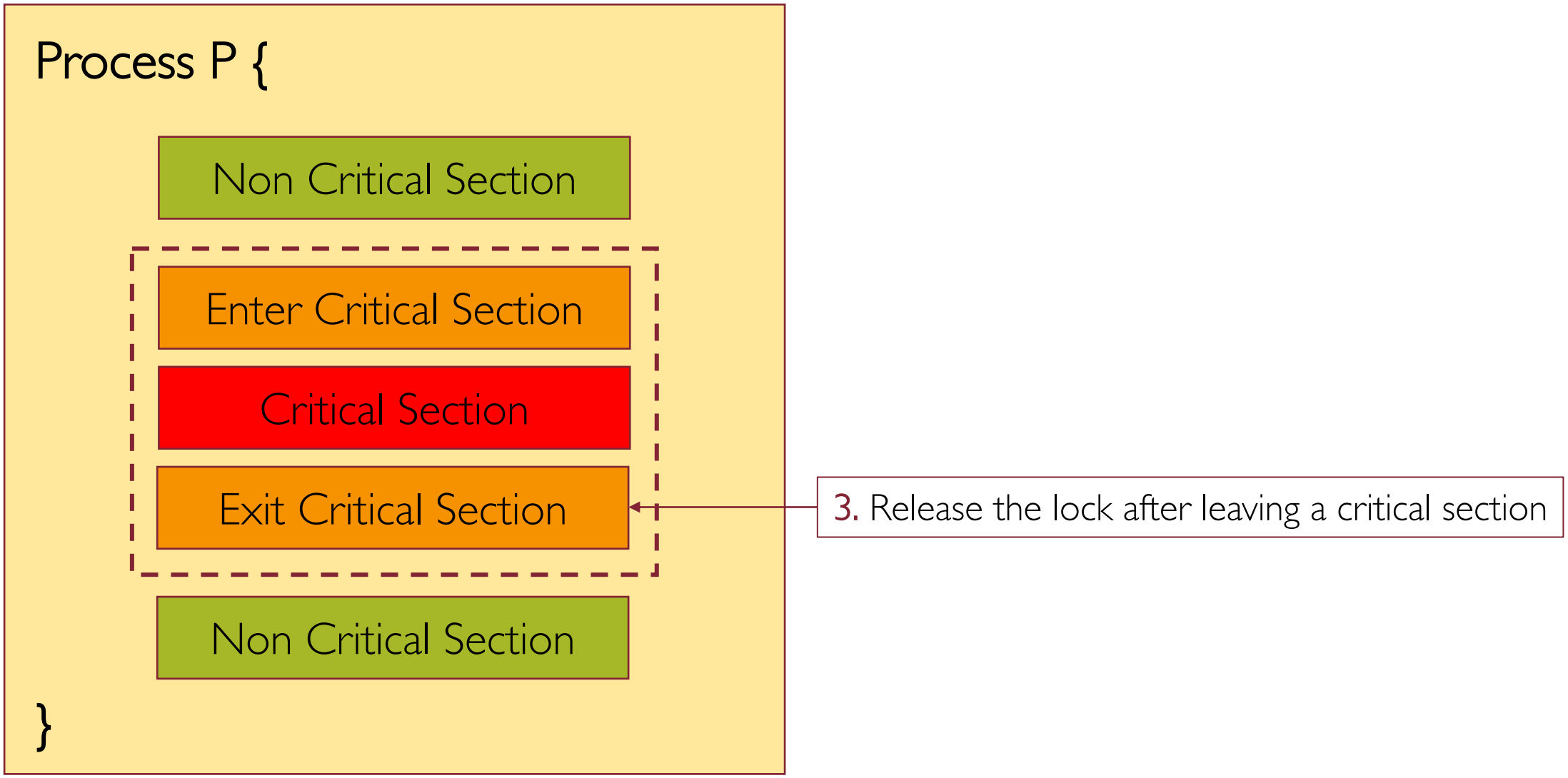

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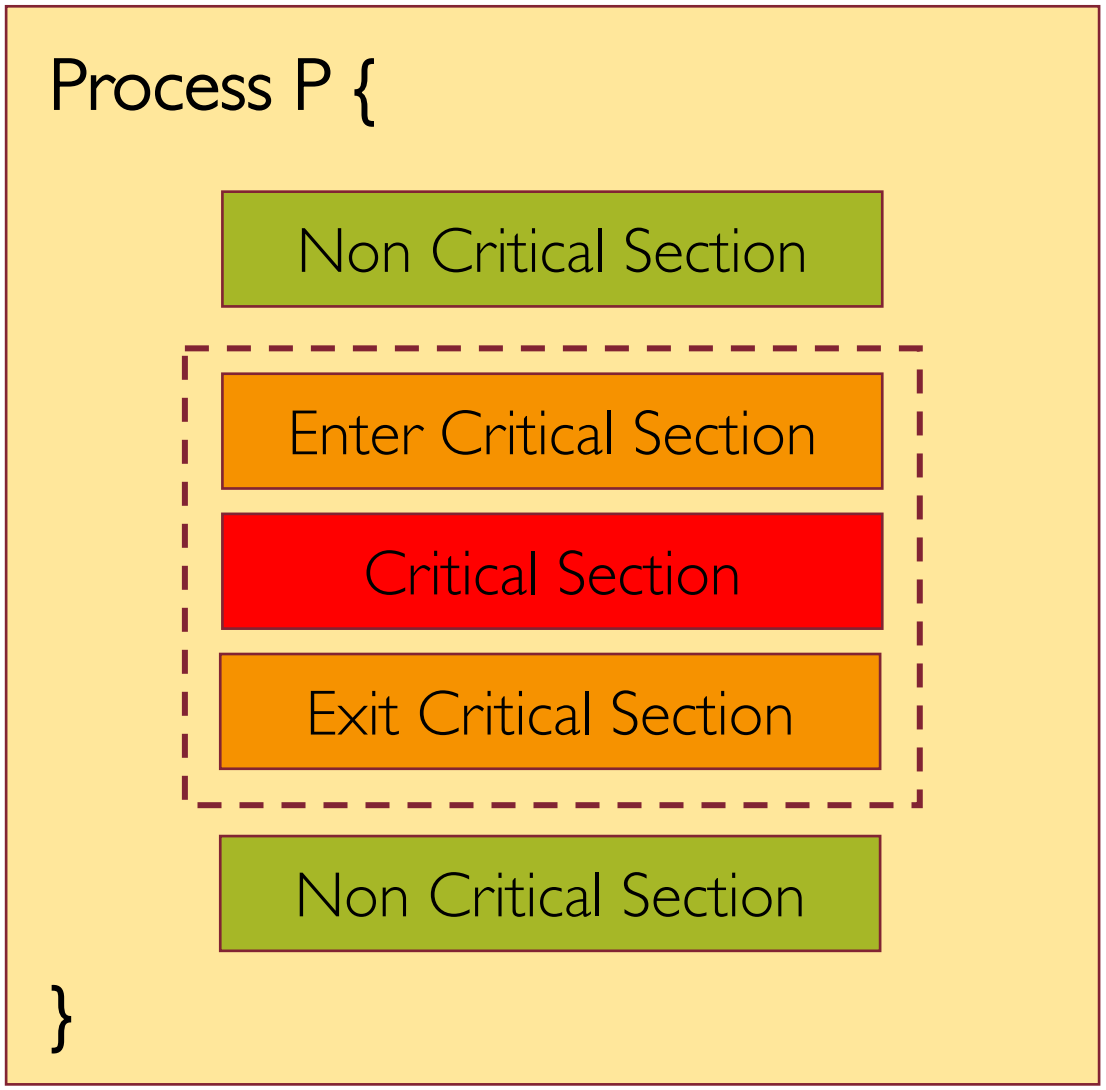

All synchronization involves waiting!

Synchronization: Goals

- Any synchronization solution to the critical section problem must satisfy 3 properties:
  - Mutual Exclusion → only one process/thread can be in its critical section at a time!

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Synchronization: Goals

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  - Mutual Exclusion → only one process/thread can be in its critical section at a time!
  - Liveness → If no process is in its critical section, and one or more want to execute it then any one of these must be able to get into its critical section
  - Bounded Waiting → A process requesting entry into its critical section will get a turn eventually, and there is a limit on how many others get to go first

Synchronization: Goals

- In the milk example:
  - Ensuring mutual exclusion means no more milk than what is needed will be bought (i.e., only one between Bob and Carla will buy milk if needed)

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  - Ensuring liveness means that someone should buy some milk (i.e., the option where both Bob and Carla do not do anything is surely safe but undesirable)
  - Ensuring bounding waiting means that eventually Bob and Carla will enter their critical section

Too Much Milk: Solution 1

Use a note

```
# Thread Bob

if (!milk and !note):
    leave_note()
    buy_milk()
    remove_note()
```

```
# Thread Carla

if (!milk and !note):
    leave_note()
    buy_milk()
    remove_note()
```

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Does this solution work?

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Does this solution work regardless of the scheduling?

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# Thread Carla

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    buy_milk()
    remove_note()
```

Does this solution work regardless of the scheduling?

No! mutual exclusion can be violated

Too Much Milk: Solution 2

Use 2 (labeled) notes

```
# Thread Bob

leave_note(Bob)

if (!note(Carla)):
    if (!milk):
        buy_milk()

remove_note()
```

```
# Thread Carla

leave_note(Carla)

if (!note(Bob)):
    if (!milk):
        buy_milk()

remove_note()
```

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Use 2 (labeled) notes

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```
# Thread Carla

leave_note(Carla)

if (!note(Bob)):
    if (!milk):
        buy_milk()

remove_note()
```

Does this solution work regardless of the scheduling?

No! Liveness propery can be violated

Too Much Milk: Solution 3

Use 2 (labeled) notes… more cleverly

```
# Thread Bob

leave_note(Bob)

while (note(Carla)):
    do_nothing()
if (!milk):
    buy_milk()

remove_note()
```

```
# Thread Carla

leave_note(Carla)

if (!note(Bob)):
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remove_note()
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remove_note()
```

Does this solution work regardless of the scheduling?

Yes!

Too Much Milk: Solution 3

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# Thread Bob

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while (note(Carla)):
    do_nothing()
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```

Y: →

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Case 1: no note from Bob

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Case 1: no note from Bob

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Thread Bob must be executing different code

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Carla will buy milk only if needed

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Case 2: Bob has left a note

Too Much Milk: Solution 3

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So has Carla, therefore Bob will be waiting (loop)

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Carla will remove his note and Bob will buy milk if needed

Too Much Milk: Solution 3

X: →

```
# Thread Bob

leave_note(Bob)

while (note(Carla)):
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if (!milk):
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Case 2: Carla has left a note

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if (!note(Bob)):
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X:

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while (note(Carla)):
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remove_note()
```

Case 2: Carla has left a note

Bob will wait doing nothing until Carla removes her note

```
# Thread Carla

leave_note(Carla)

if (!note(Bob)):
    if (!milk):
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remove_note()
```

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This solution assumes loads and stores being atomic (i.e., non-interruptable)

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We need to have appropriate "tools" (i.e., primitive constructs)
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- Locks → At each time, only one process holds a lock, executes its critical section, and finally releases the lock
- Semaphores → A generalization of locks
- Monitors → To connect shared data to synchronization primitives

Require some HW support and waiting

Locks

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- Rules for using a lock:
  - Always acquire the lock before accessing shared data
  - Always release the lock after finishing with shared data
  - Lock must be initially free
- Only one process/thread can acquire the lock, others will wait!

Too Much Milk: Solution Using Locks

Use lock primitives

```
# Thread Bob

Lock.acquire()

if (!milk):
    buy_milk()

Lock.release()
```

```
# Thread Carla

Lock.acquire()

if (!milk):
    buy_milk()

Lock.release()
```

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Q: How do we make **`acquire()`** and **`release()`** atomic?

HW Support for Synchronization

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High-level atomic operations (SW)	lock, monitor, semaphore, send/receive
Low-level atomic operations (HW)	disabling interrupts, atomic instructions (test&set)

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  - external events → interrupts (e.g., time slice) cause the scheduler to take over the currently running thread

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- If we think about it, the reason why we care of synchronization is because context switches may occur unexpectedly
- The CPU scheduler takes control due to 2 possible situations:
  - internal events → the current thread voluntarily relinquishes control of the CPU (e.g., via an I/O system call)
  - external events → interrupts (e.g., time slice) cause the scheduler to take over the currently running thread

We want to prevent the CPU scheduler to take control while an **`acquire()`** operation is ongoing

Implementing Locks: Disabling Interrupts

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We cover all the possible cases where the current thread might loose control of the CPU, either voluntarily (due to internal events) or involuntarily (due to external events)

Implementing Locks: Disabling Interrupts

```
Class Lock {
  public void acquire(Thread t);
  public void release();
  private int value; // 0=FREE, 1=BUSY
  private Queue q;

  Lock() {
    // lock is initially FREE
    this.value = 0;
    this.q = null;
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```

```
public void acquire(Thread t) {
  disable_interrupts();
  if(this.value) { // lock is held by someone
    q.push(t); // add t to waiting queue
    t.sleep(); // put t to sleep
  }
  else {
    this.value = 1;
  }
  enable_interrupts();
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public void release() {
  disable_interrupts();
  if(!q.is_empty()) {
    t = q.pop(); // extract a waiting thread from q
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We need both **acquire** and **release** being implemented as system calls

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Why?

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HW Support for Synchronization

Implementing high-level synchronization primitives requires low-level hardware support

High-level atomic operations (SW)	lock, monitor, semaphore, send/receive
Low-level atomic operations (HW)	disabling interrupts, atomic instructions (test&set)

Implementing Locks: Atomic Instructions

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  - On a uniprocessor → straightforward to implement adding a new instruction
  - On a multiprocessor → the processor issuing the instruction must also be able to invalidate any copies of the value other processes may have in their cache
- Examples:
  - **`test&set`** (most architectures) → reads a value, writes **`1`** back to memory
  - **`exchange`** (x86) → swaps values between register and memory

Implementing Locks: `test&set`

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Case 1: if lock is free (`value = 0`) `test&set(value)` will read 0, set it to 1 and return 0

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Case 1: if lock is free (`value = 0`) `test&set(value)` will read 0, set it to 1 and return 0

The lock is now busy, the boolean expression in the while guard is false and **`acquire`** terminates

Implementing Locks: `test&set`

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public void acquire() {
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```

```
public void release() {
  this.value = 0;
}
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Case 2: if lock is busy (`value = 1`) `test&set(value)` will read 1, set it to 1 and return 1

The lock is still busy, the boolean expression in the while guard is true and **`acquire`** continues to loop until **`release`** executes

Atomic Instructions: Any Issue?

```
public void acquire() {
  while(test&set(this.value) == 1) {
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```

- What's wrong with the above implementation?

Atomic Instructions: Any Issue?

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Atomic Instructions: Any Issue?

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```

who is going to take the lock once released?

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  - What is the CPU doing?
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Disabling Interrupts vs. Atomic Instructions

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Disabling Interrupts vs. Atomic Instructions

- 2 main problems with disabling interrupts:
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  - unfeasible with mulitprocessor architectures
- 2 main problems with atomic instructions:
  - busy waiting
  - unfairness as there is no queue where threads wait for the lock to be released

Improving `test&set` To Reduce Busy Waiting

Can we implement locks with `test&set` without any busy-waiting?

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```

No, but we can minimize busy-waiting time by atomically checking the lock value and giving up the CPU if the lock is busy

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```

We can't totally get rid of busy-waiting but we can make it independent on how long is the critical section delimited by **`acquire`** and **`release`**

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