Sistemi Operativi I

Corso di Laurea in Informatica

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SAPIENZA
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Synchronization as a solution to the critical section problem

Part III:
Process Synchronization

The Need for Synchronization

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5:20pm		Gets home

The Need for Synchronization

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Time	Bob	Carla
5:00pm	Gets home	
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5:10pm	Leaves home for the grocery	
5:20pm		Gets home
5:25pm	Gets at the grocery	Looks in the fridge → No milk!

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5:50pm		Buys milk
6:05pm		Gets home, puts the milk in the fridge

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5:45pm	Gets home, puts the milk in the fridge	Gets at the grocery
5:50pm		Buys milk
6:05pm		Gets home, puts the milk in the fridge
6:05pm	Oh f*%#k!	Oh f*%#k!

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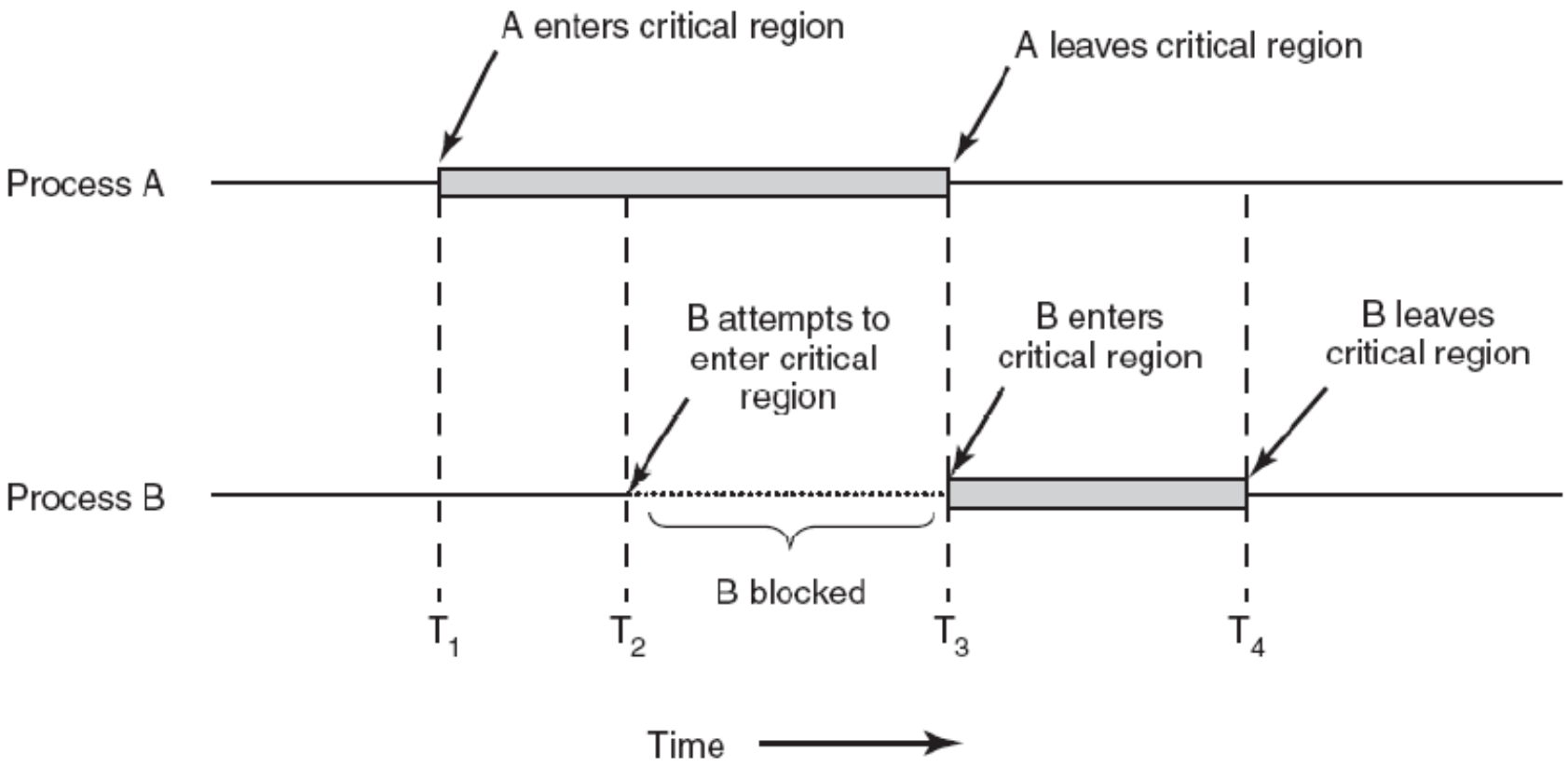
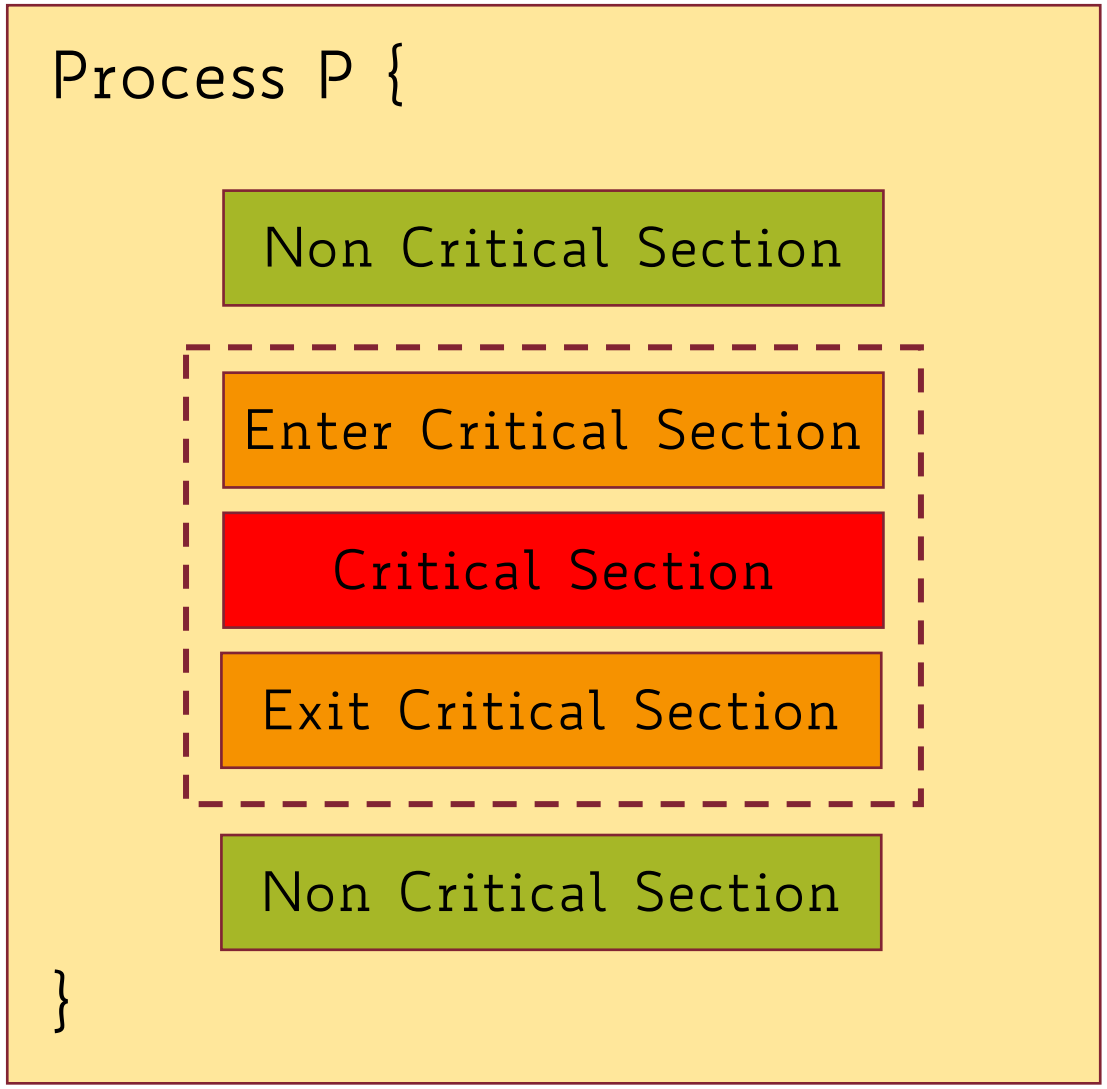
- Theoretically, they should cooperate to achieve a common task (e.g., buying some milk)
- In practice, though, they might incur in unpleasant situations (e.g., buying too much milk!)

What mechanism do we need to get independent yet cooperating processes to communicate with each other and have a consistent view of the "world" (i.e., computational state)?

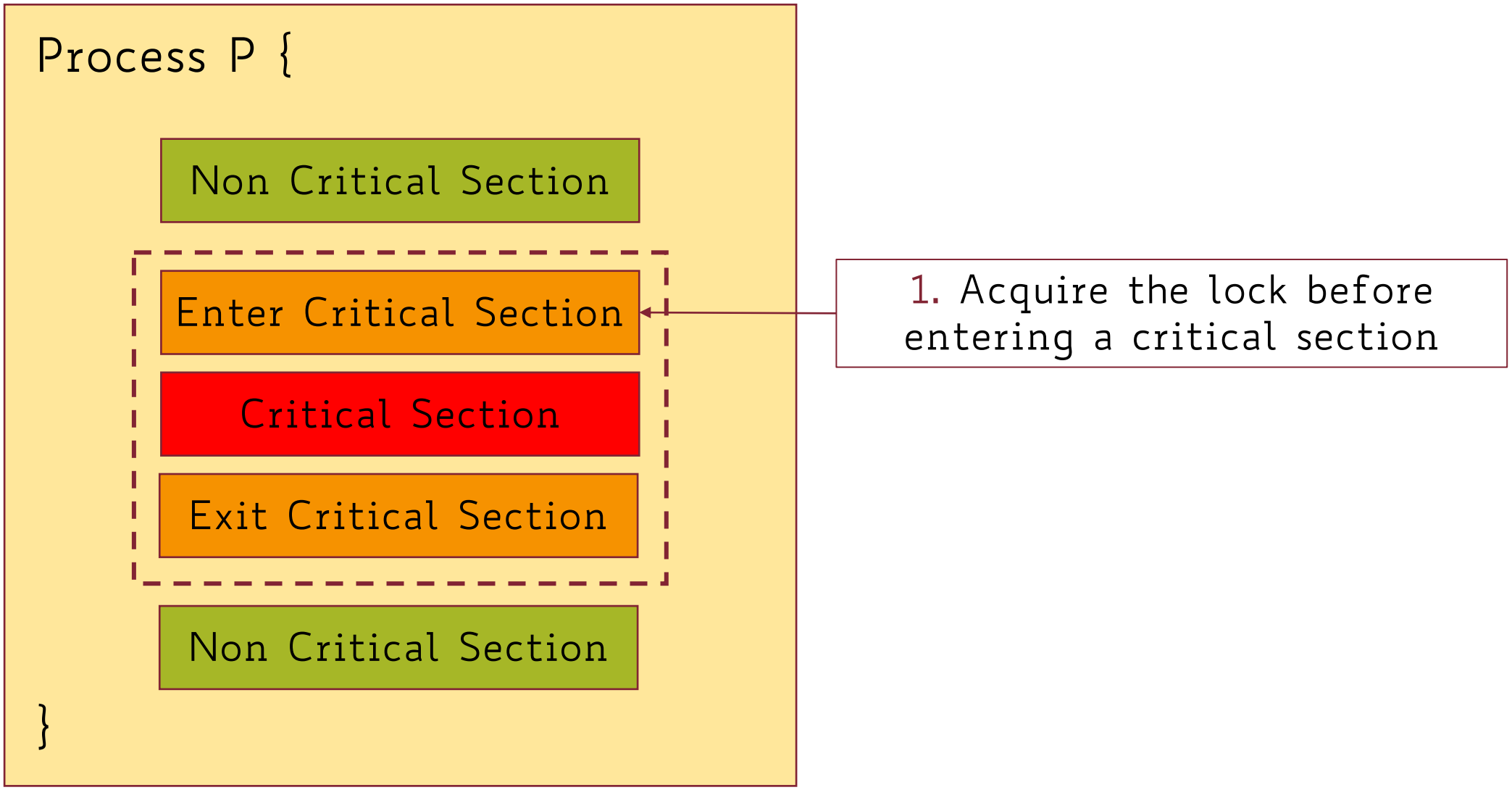
The Critical Section Problem



The Anatomy of a Critical Section



Locking Critical Section



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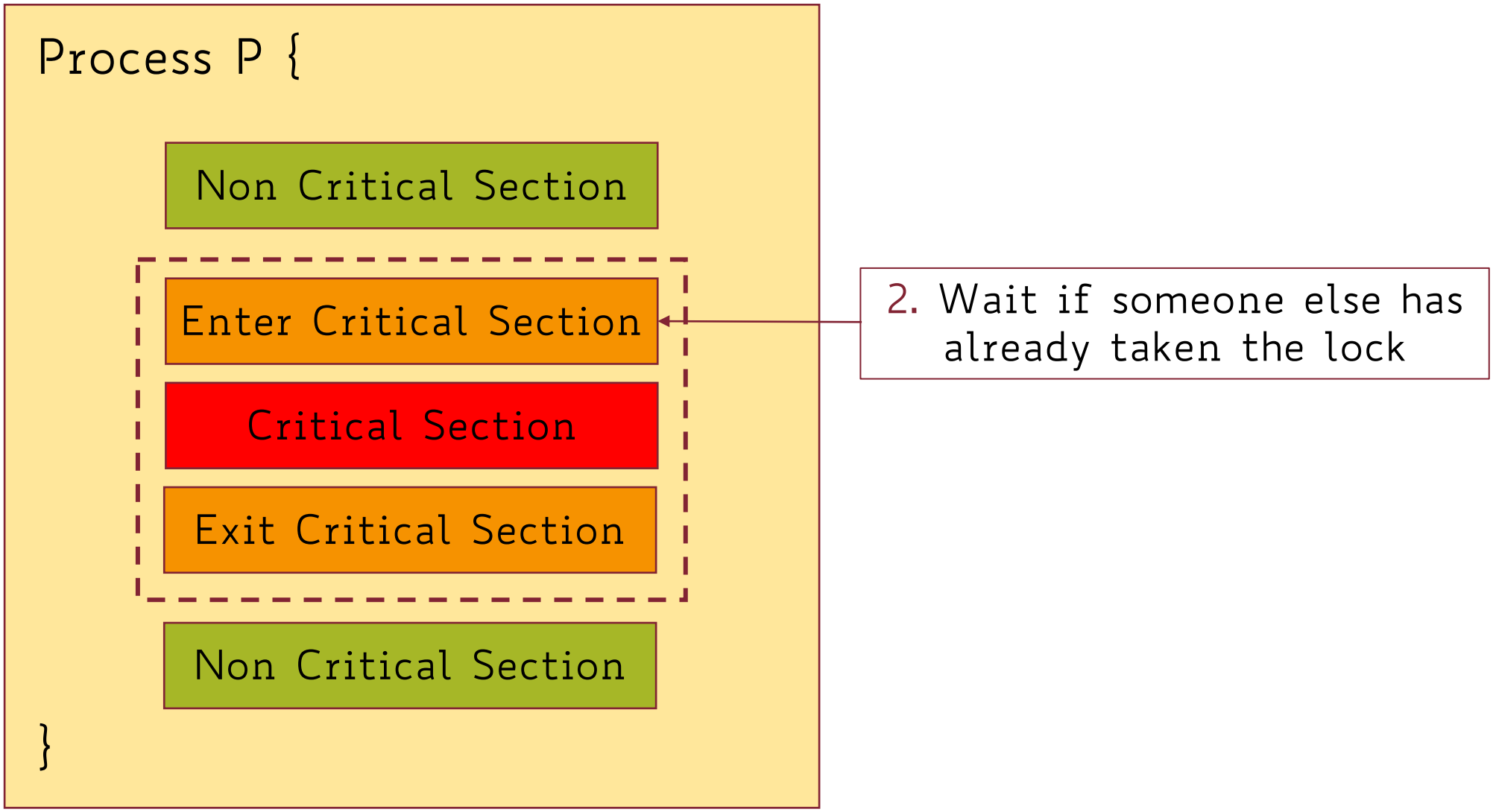

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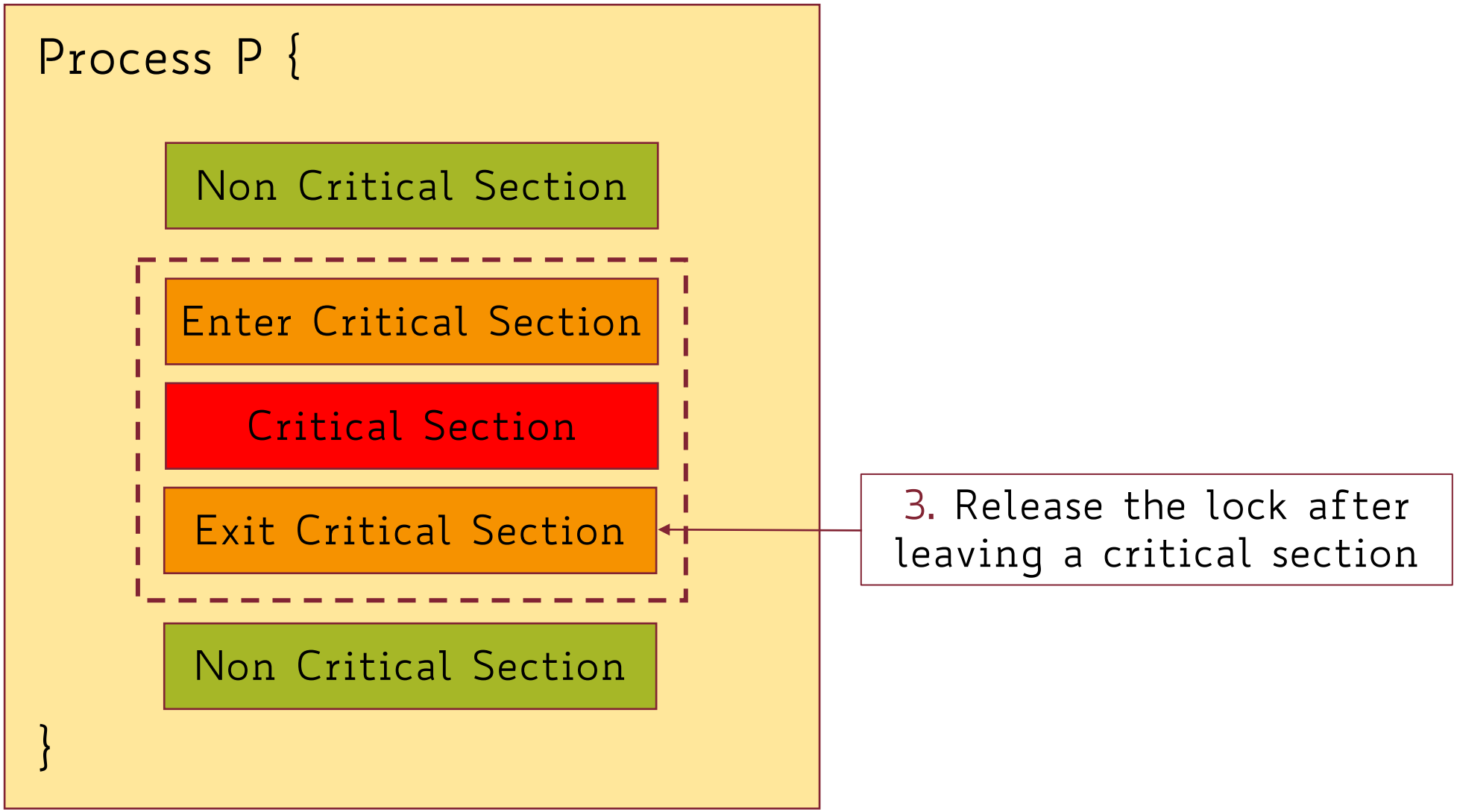

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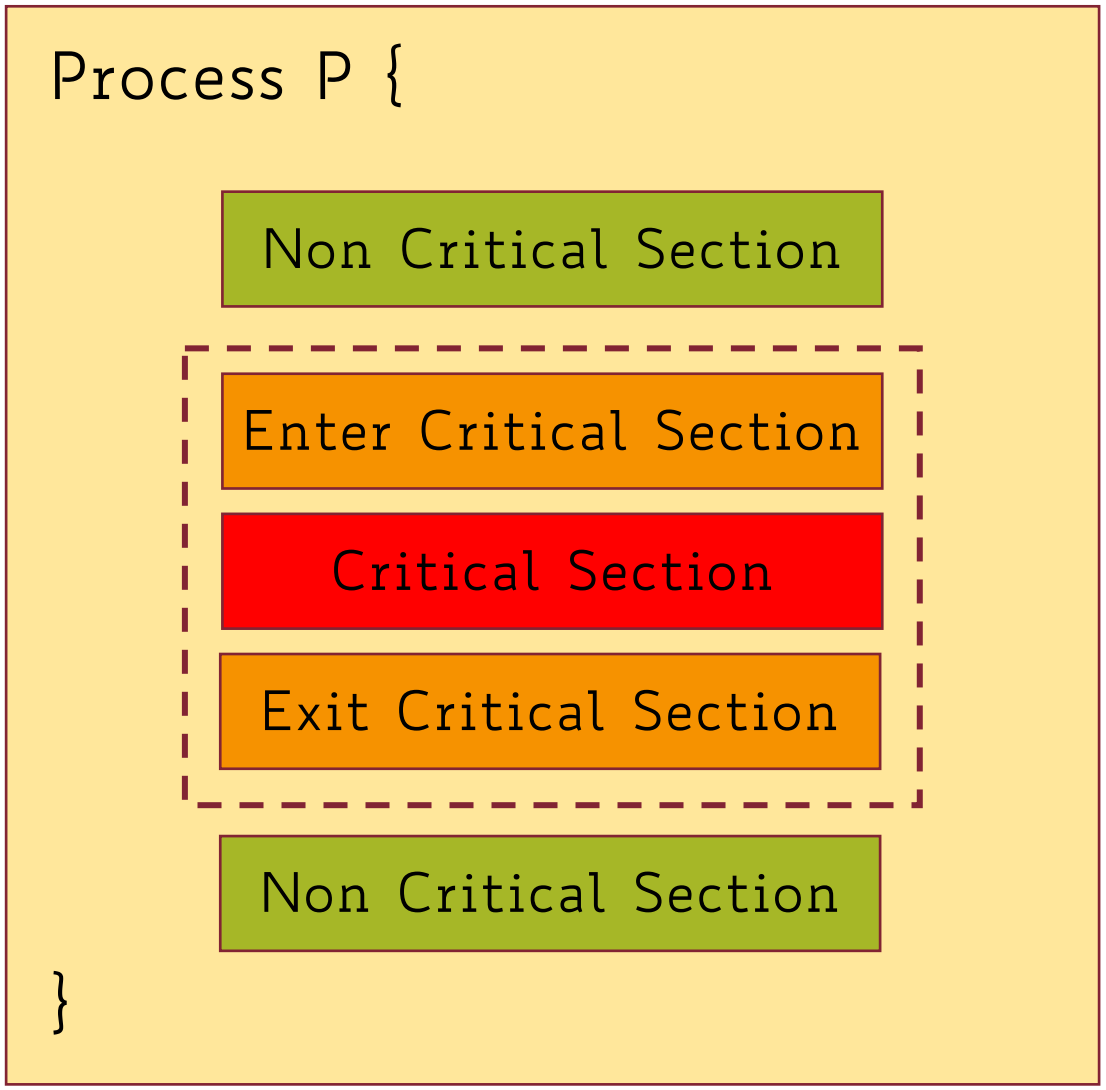

All synchronization involves waiting!

Synchronization: Goals

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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!
  - **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

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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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    leave_note()
    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 Bob

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remove_note()
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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)):
    if (!milk):
        buy_milk()

remove_note()
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Too Much Milk: Solution 3

Use 2 (labeled) notes… more cleverly

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

remove_note()
```

Does this solution work regardless of the scheduling?

Yes!

Too Much Milk: Solution 3

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# Thread Bob

leave_note(Bob)

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    do_nothing()
if (!milk):
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remove_note()
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Y: → if (!note(Bob)):
        if (!milk):
            buy_milk()

remove_note()
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Too Much Milk: Solution 3

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# Thread Bob

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Case 1: no note from Bob

Too Much Milk: Solution 3

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# Thread Bob

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Case 1: no note from Bob

Thread Bob must be executing different code

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        buy_milk()

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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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remove_note()
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Case 2: Bob has left a note

Too Much Milk: Solution 3

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Y:

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leave_note(Carla)

if (!note(Bob)):
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Case 2: Bob has left a note

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

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Case 2: Bob has left a note

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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

```
# Thread Bob

leave_note(Bob)

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

remove_note()
```

Case 1: no note from Carla

```
# Thread Carla

leave_note(Carla)

if (!note(Bob)):
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Too Much Milk: Solution 3

X:

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leave_note(Bob)

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remove_note()
```

Case 2: Carla has left a note

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# Thread Carla

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

remove_note()
```

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# Thread Bob

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

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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  - busy waiting → thread Bob is consuming CPU cycles doing nothing

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- 3 main reasons why this solution is not viable:
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  - **asymmetrical** → thread Bob and Carla are different (adding more threads will mess up things even more!)
  - **busy waiting** → thread Bob is consuming CPU cycles doing nothing

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)
provided by programming languages
used as atomic building blocks for synchronization

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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()
```

Too Much Milk: Solution Using Locks

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# Thread Bob

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This solution is clean and symmetric

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

HW Support for Synchronization

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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)

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- A critical section is a piece of code that cannot be executed in parallel or concurrently by multiple threads

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- Communication among threads is usually done via **shared variables**
- Access or modification to those shared variable often identifies **critical sections**
- A critical section is a piece of code that cannot be executed in parallel or concurrently by multiple threads
- **Synchronization primitives** ensure only one thread at a time executes a critical section (**mutual exculsion**), e.g., **locks**