

Systems and Networking I

Applied Computer Science and Artificial Intelligence
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Synchronization as a solution to the critical section problem

Part III:

Process Synchronization

The Need for Synchronization

Consider the following scenario, involving 2 roommates: **Bob** and **Carla**

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5:20pm		Gets home
5:25pm	Gets at the grocery	Looks in the fridge → No milk!

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5:50pm		Buys milk

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

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5:25pm	Gets at the grocery	Looks in the fridge → No milk!
5:30pm	Buys milk	Leaves home for the grocery
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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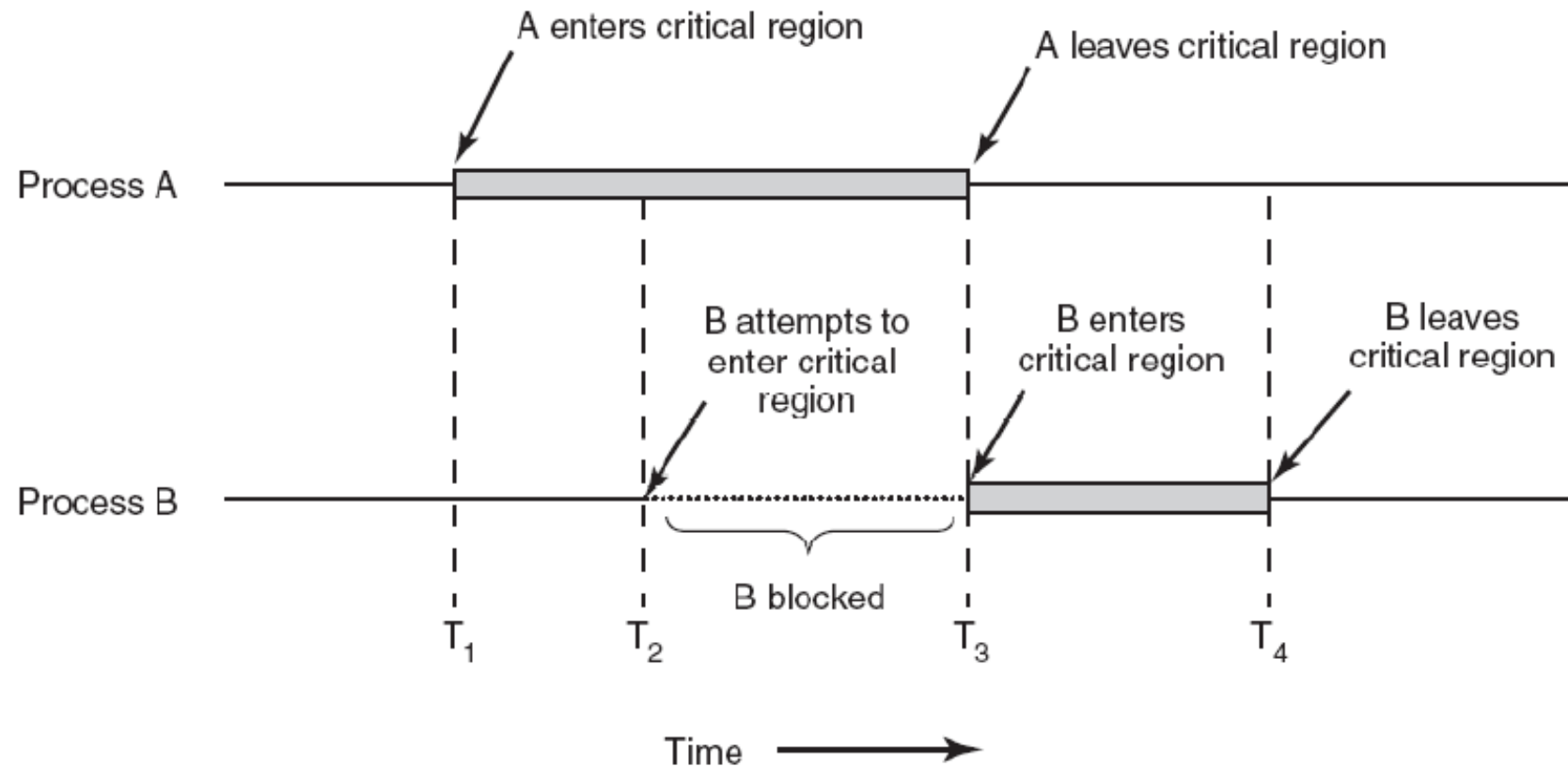
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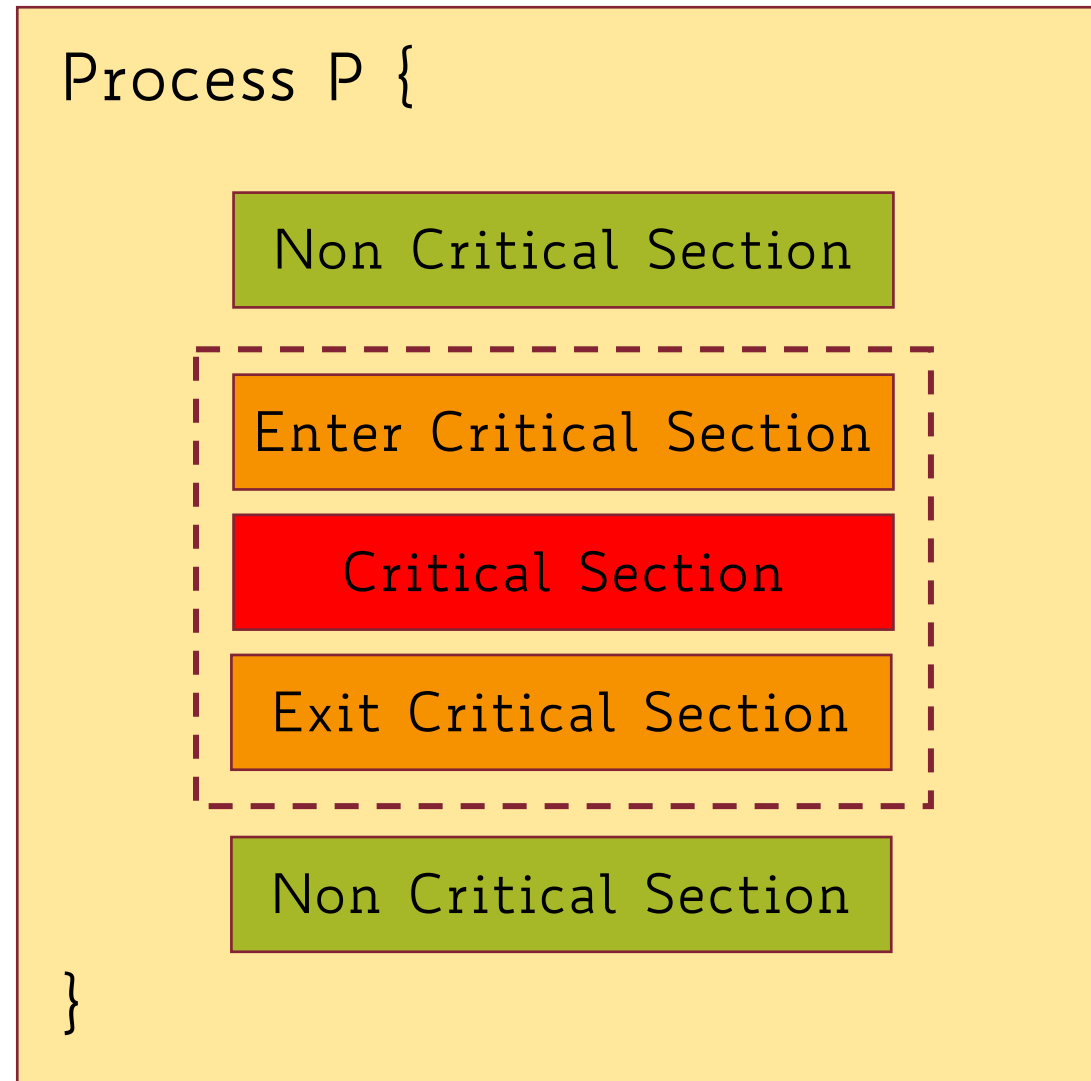
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What mechanism do we need to get independent yet cooperating processes to communicate with each other and have a consistent view of the "world" (i.e., computational state)?

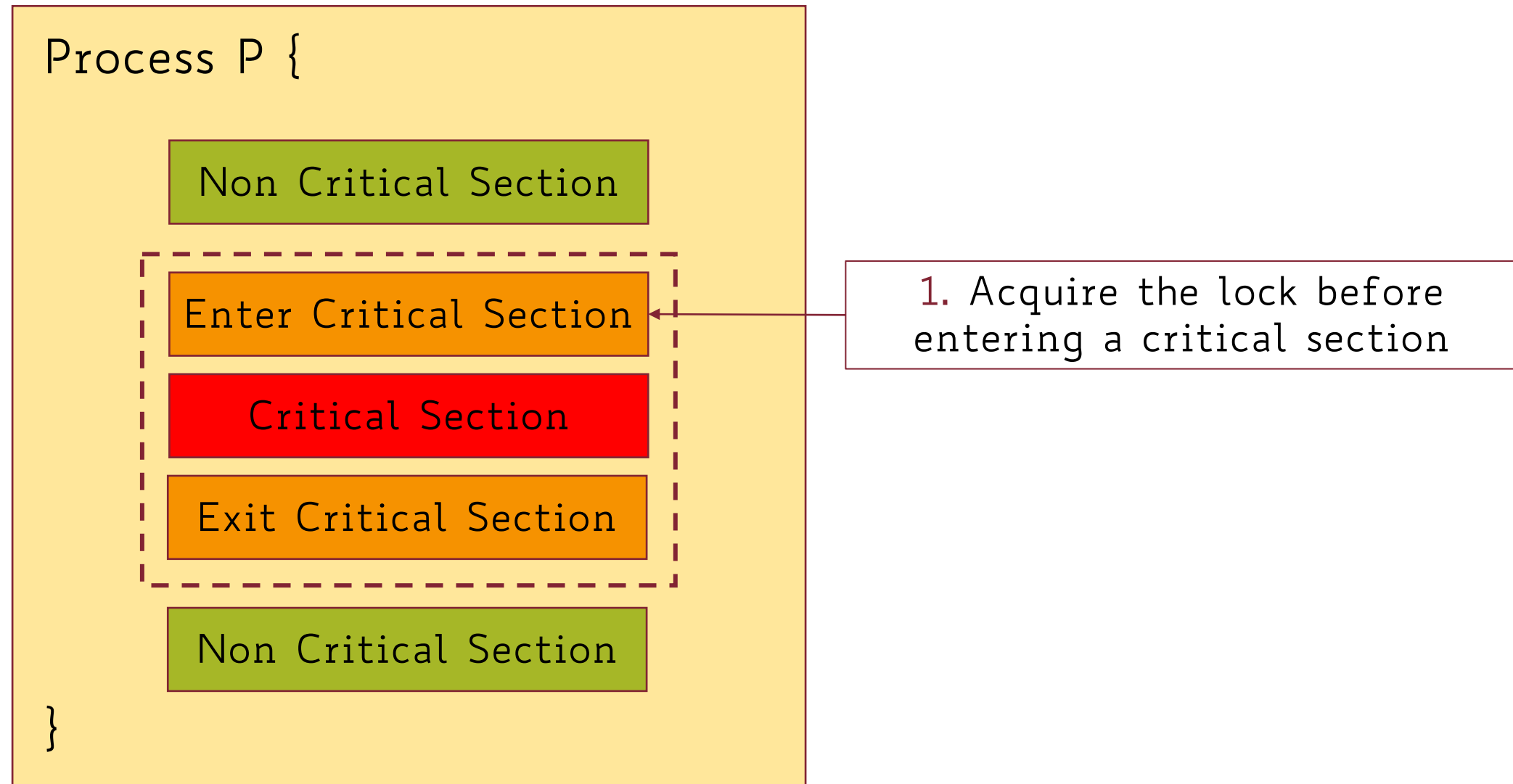
The Critical Section Problem



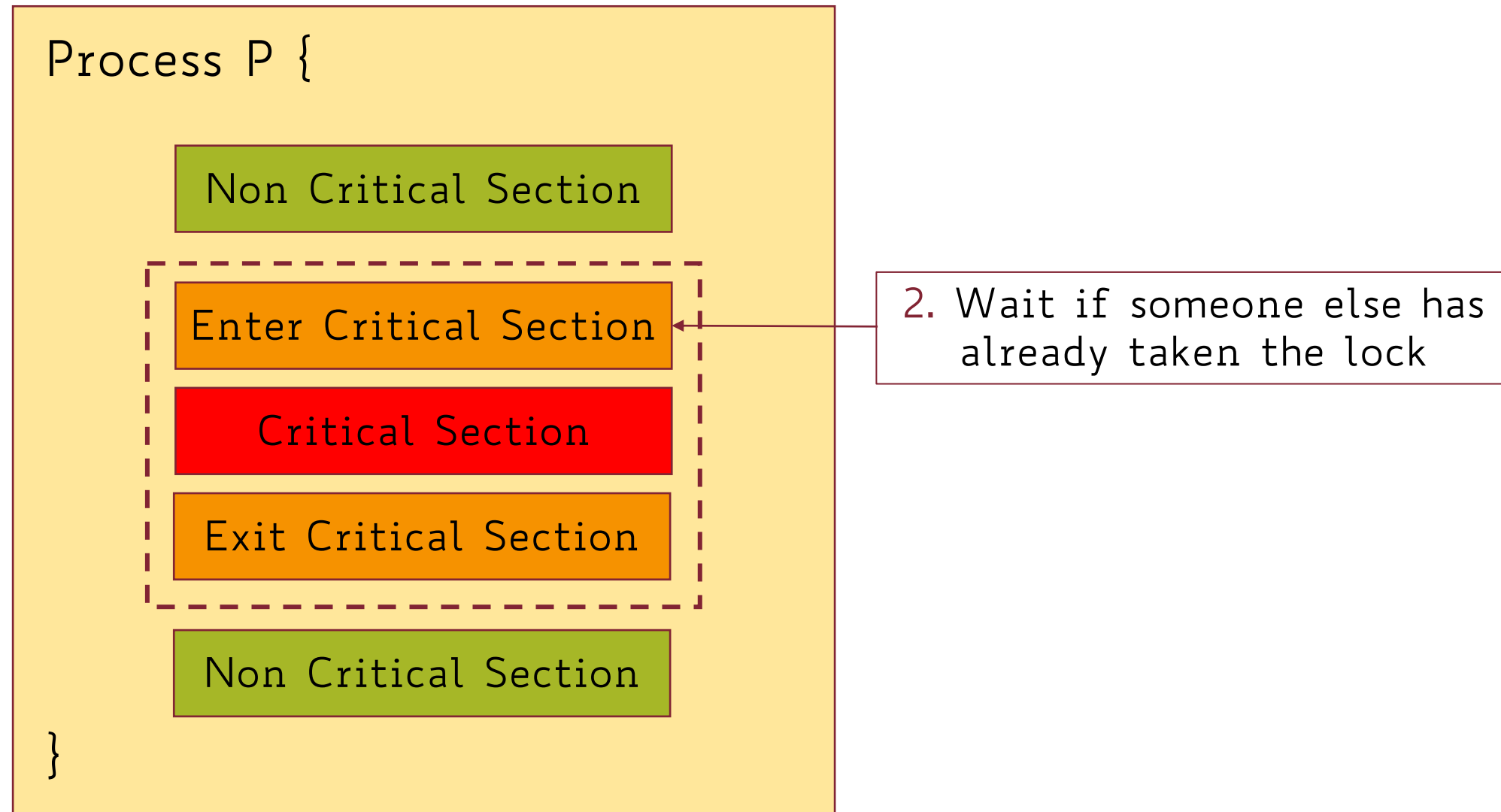
The Anatomy of a Critical Section



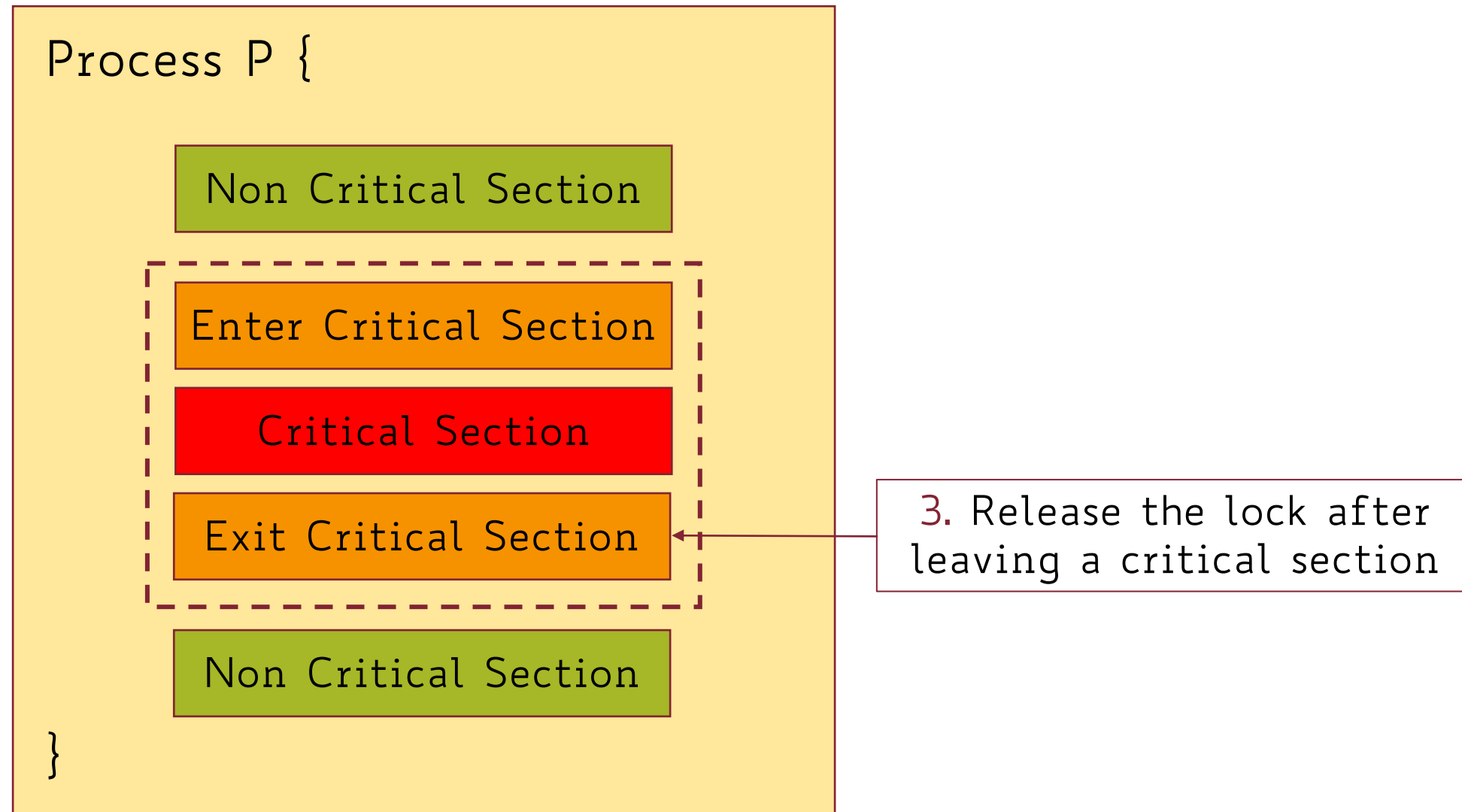
Locking Critical Section



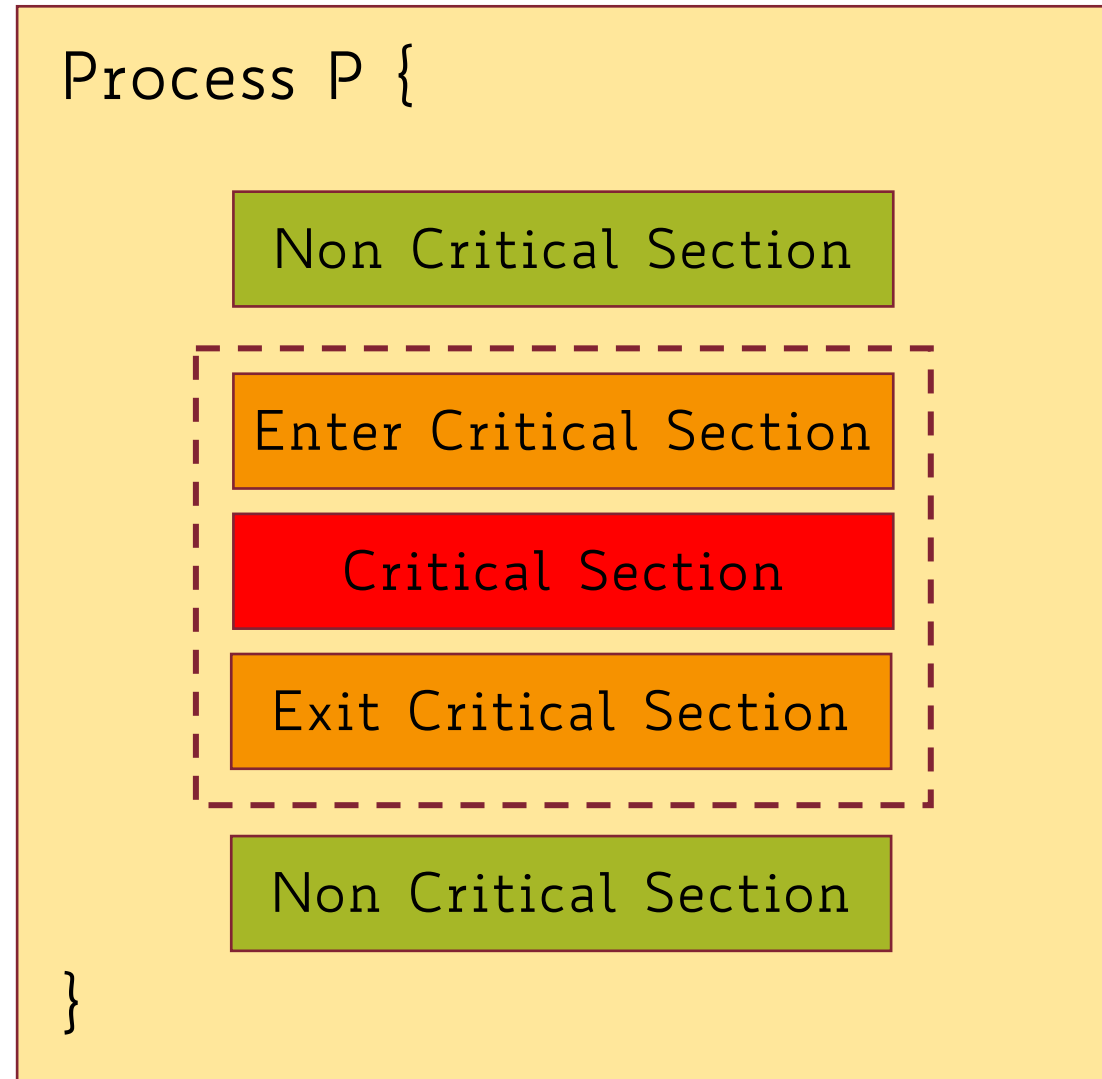
Locking Critical Section



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Locking Critical Section



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

Synchronization: Goals

- In the milk example:
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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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```
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    leave_note()  
    buy_milk()  
    remove_note()
```

Does this solution work?

Too Much Milk: Solution 1

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Does this solution work regardless of the scheduling?

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```
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if (!milk and !note):  
    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()
```

Too Much Milk: Solution 2

Use 2 (labeled) notes

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# Thread Bob

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if (!note(Carla)):
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remove_note()
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Does this solution work regardless of the scheduling?

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# Thread Bob  
  
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if (!note(Carla)):  
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remove_note()
```

```
# Thread Carla  
  
leave_note(Carla)  
  
if (!note(Bob)):  
    if (!milk):  
        buy_milk()  
  
remove_note()
```

Does this solution work regardless of the scheduling?

No! Liveness property 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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Does this solution work regardless of the scheduling?

Yes!

Too Much Milk: Solution 3

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# Thread Bob  
  
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Y: →

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Case 1: no note from Bob

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Thread Bob must be
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Carla will buy milk
only if needed

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Y: →

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# Thread Carla  
leave_note(Carla)  
  
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remove_note()
```

Case 2: Bob has left a note

Too Much Milk: Solution 3

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So has Carla,
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Case 2: Bob has left a note



So has Carla,
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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)):
    do_nothing()
if (!milk):
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remove_note()
```

Case 1: no note from Carla

```
# Thread Carla
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Too Much Milk: Solution 3

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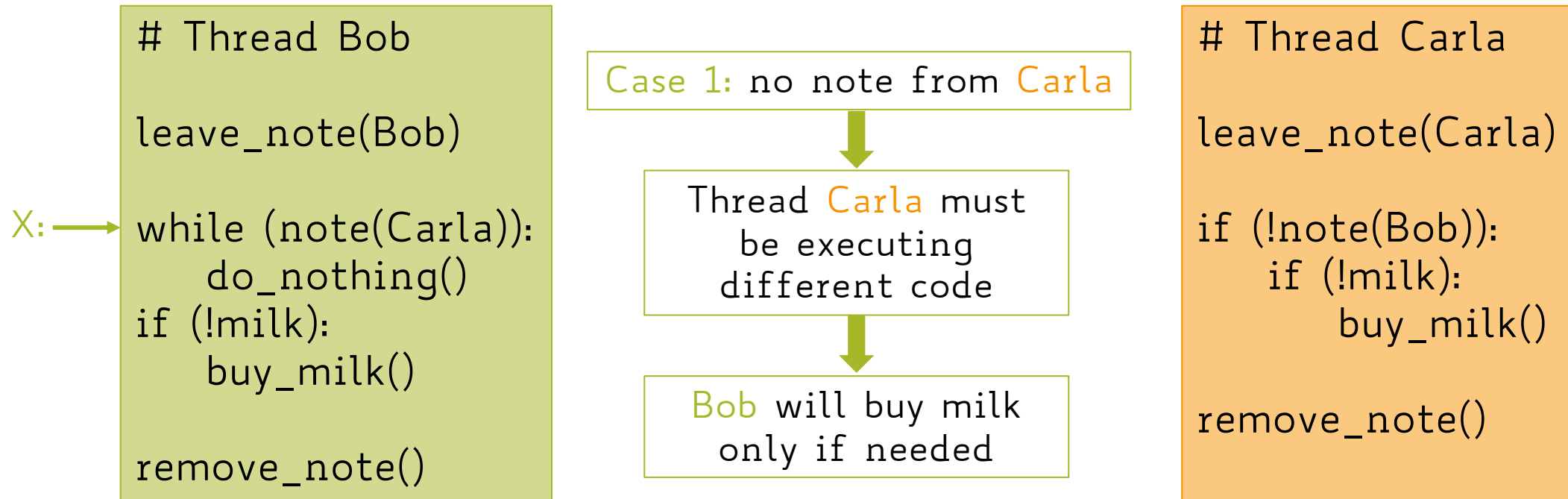
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Too Much Milk: Solution 3



Too Much Milk: Solution 3

X: →

```
# Thread Bob
leave_note(Bob)

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

remove_note()
```

Case 2: Carla has left a note

```
# Thread Carla
leave_note(Carla)

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

remove_note()
```

Too Much Milk: Solution 3

X: →

```
# Thread Bob
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while (note(Carla)):
    do_nothing()
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Case 2: Carla has left a note



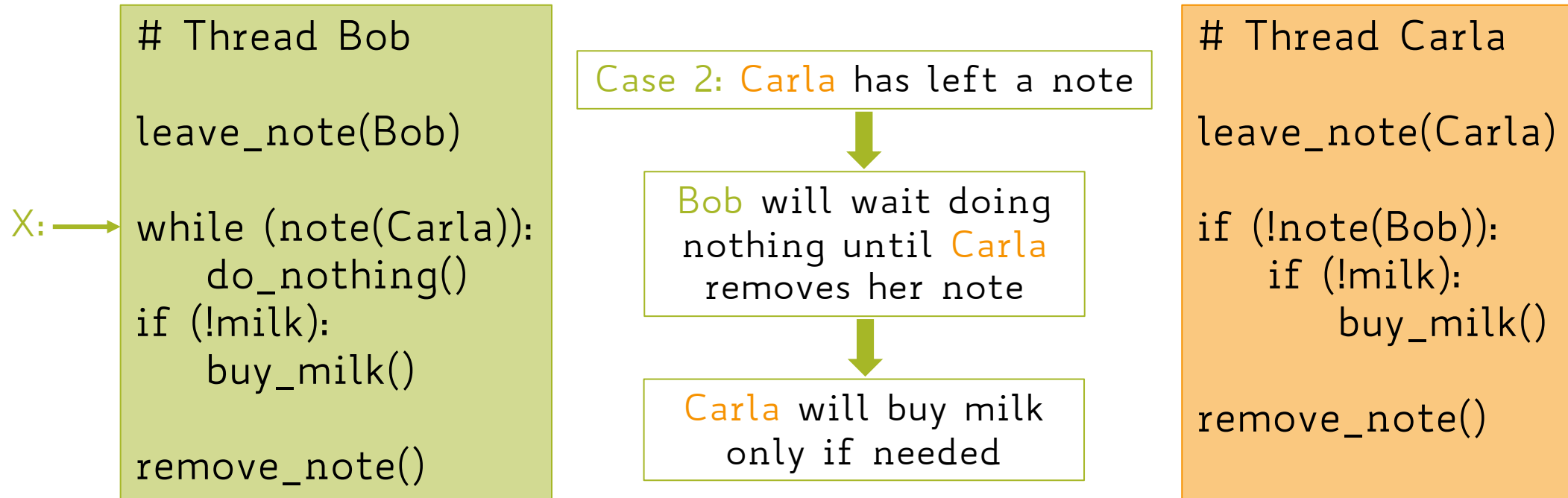
Bob will wait doing nothing until Carla removes her note

```
# Thread Carla
leave_note(Carla)

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

remove_note()
```


Too Much Milk: Solution 3



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 - **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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- **Monitors** → To connect shared data to synchronization primitives

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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

- Provide **mutual exclusion** to shared data using **2** atomic primitives:

Locks

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 - 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

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)

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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**