Special Topics in Distributed Computing:

Shared Memory Algorithms

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Distributed Programming Laboratory

This course introduces a theory of ***robust*** *and* ***concurrent*** *computing...*

Major chip manufacturers have recently announced a major paradigm shift:

New York Times, 8 May 2004:

Intel … [has] decided to focus its development efforts on «dual core» processors … with two engines instead of one, allowing for greater efficiency because the processor workload is essentially shared.

Multi-processors *and* ***Multicores***

vs

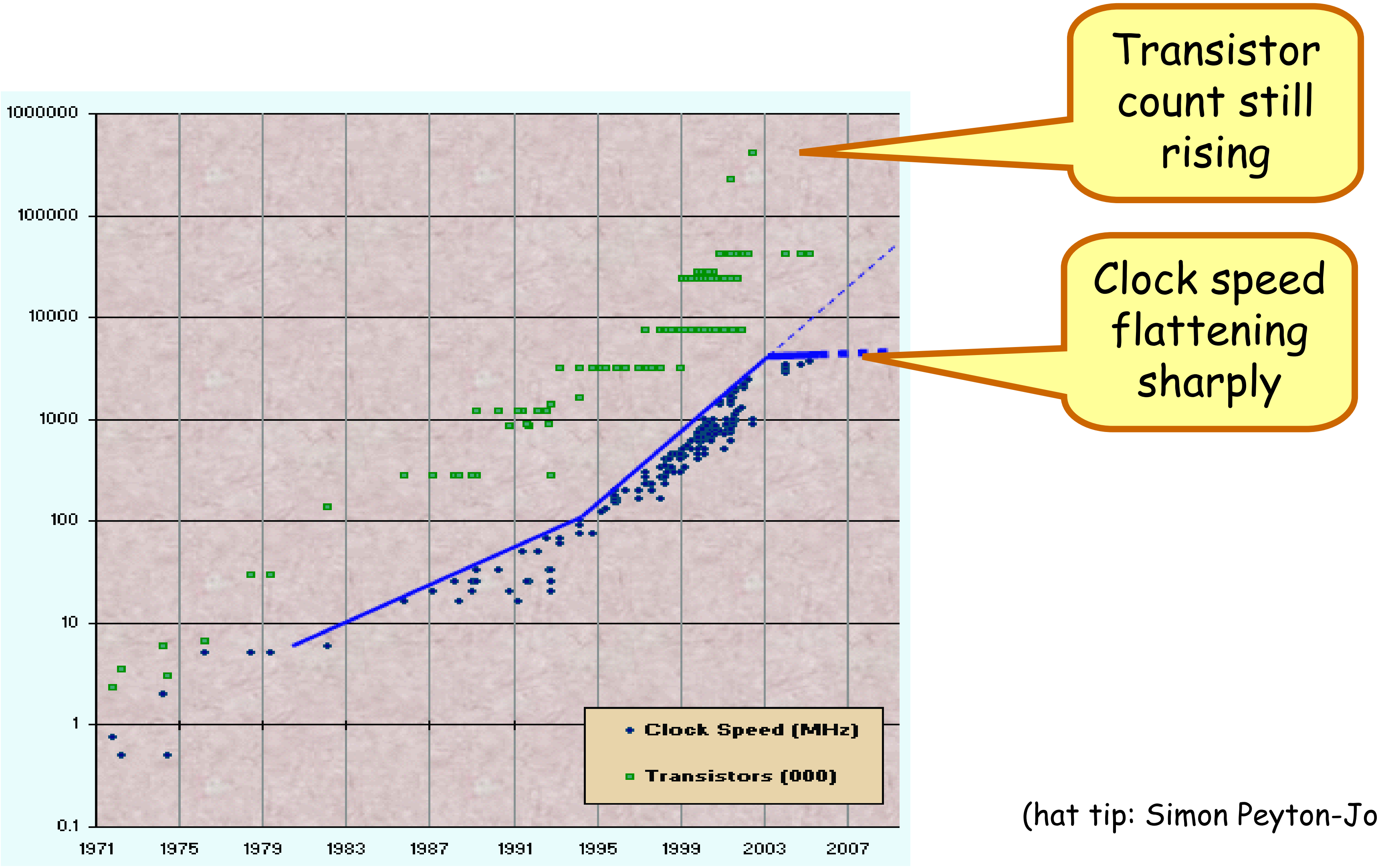
faster processors

(Thanks for the quote, Maurice Herlihy.)

The clock speed of a processor cannot be increased without overheating.

But

More and more processors can fit in the same space.



(hat tip: Simon Peyton-Jones)

Slide borrowed from Maurice Herlihy's talk at PODC 2008:
"The Future of Distributed Computing: Renaissance or Reformation?"

Speed will be achieved by having several processors work on independent parts of a task.

But

The processors would occasionally need to pause and synchronize.

But

If the task is shared, then pure parallelism is usually impossible and, at best, inefficient.

Concurrent computing for the masses

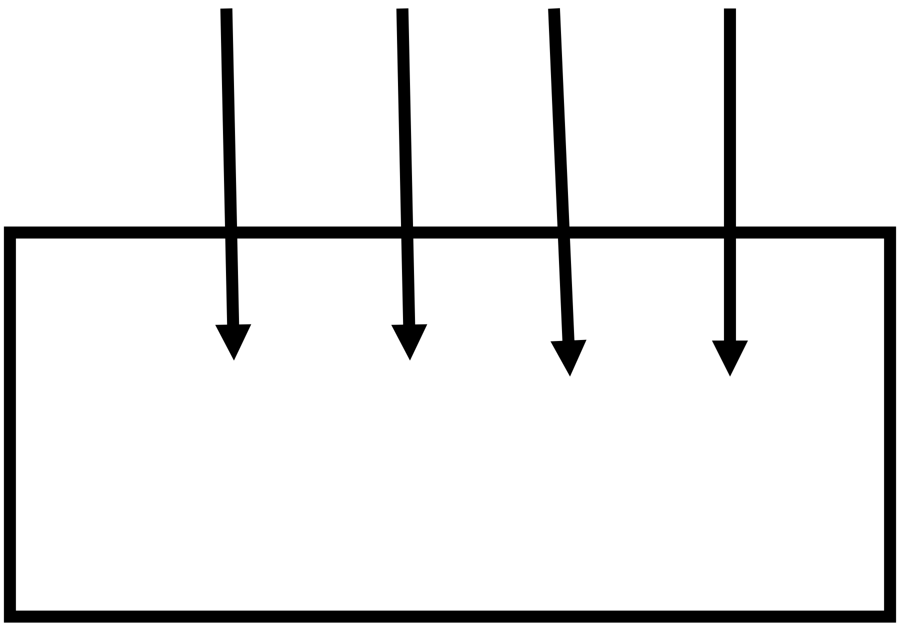
- *Forking processes might be more frequent*

But...

- *Concurrent accesses to shared objects might become more problematic and harder.*

How do devices synchronize?

Concurrent processes

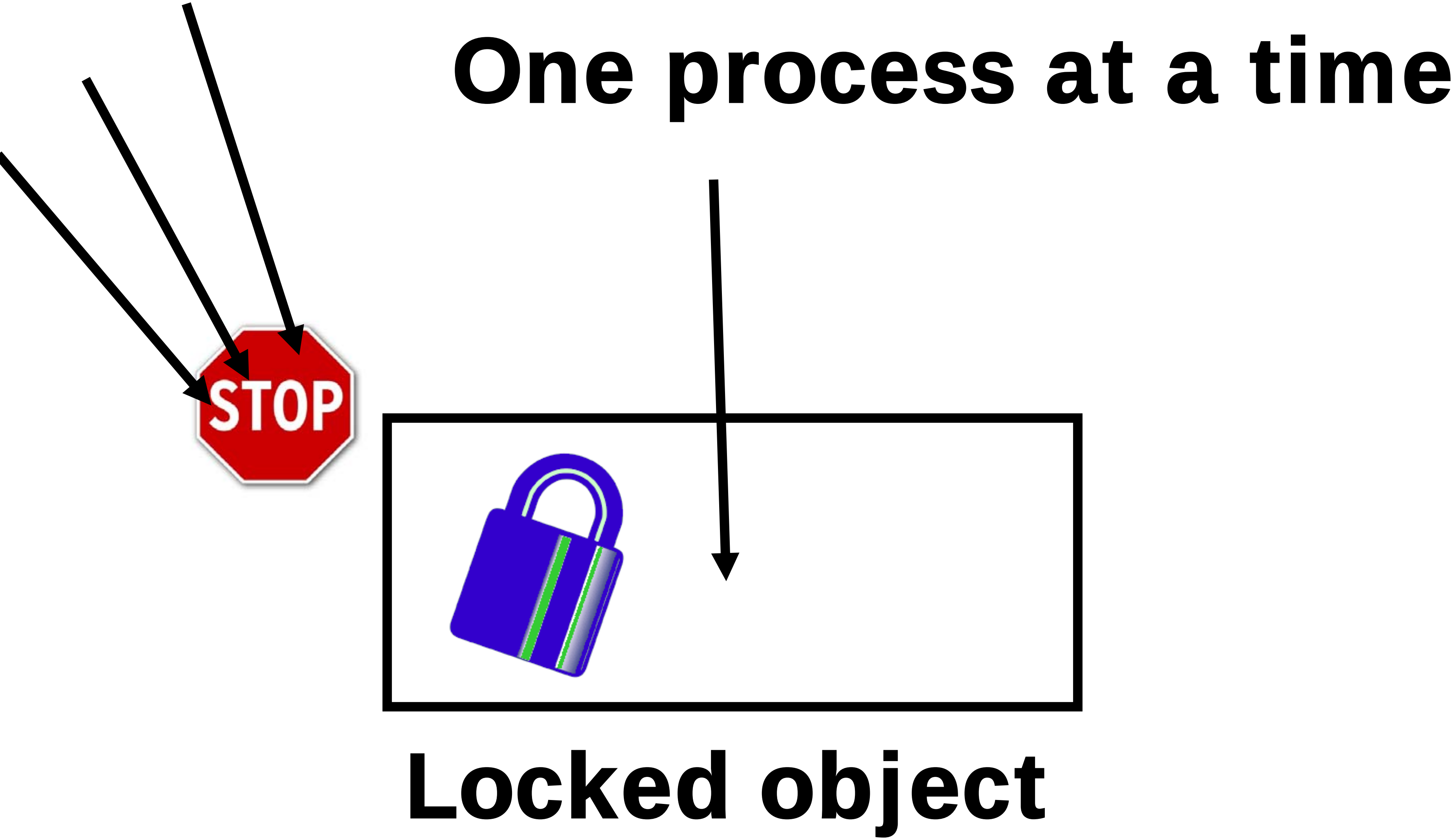


Shared object

How do devices synchronize?

Locking (mutual exclusion)

How do devices synchronize?



Locking (mutual exclusion)

- ***Difficult:*** 50% of the bugs reported in Java come from the use of « synchronized »
- ***Fragile:*** a process holding a lock prevents all others from progressing
- ***Other:*** deadlock, livelock, priority inversion, etc.

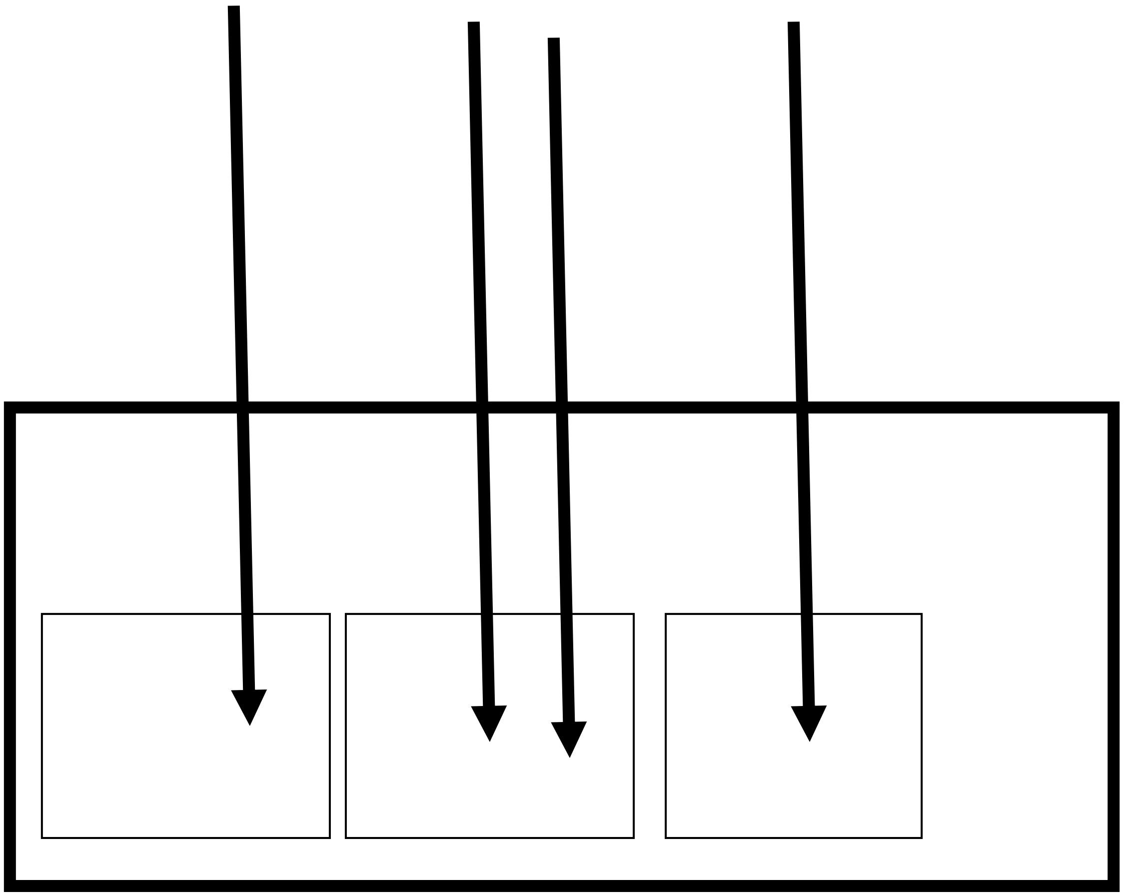
Why is locking hard?

Processes are asynchronous

- *Page faults*
- *Pre-emptions*
- *Failures*
- *Cache misses, …*

- A process can be delayed by millions of instructions ...

Alternative to locking?



Wait-free atomic objects

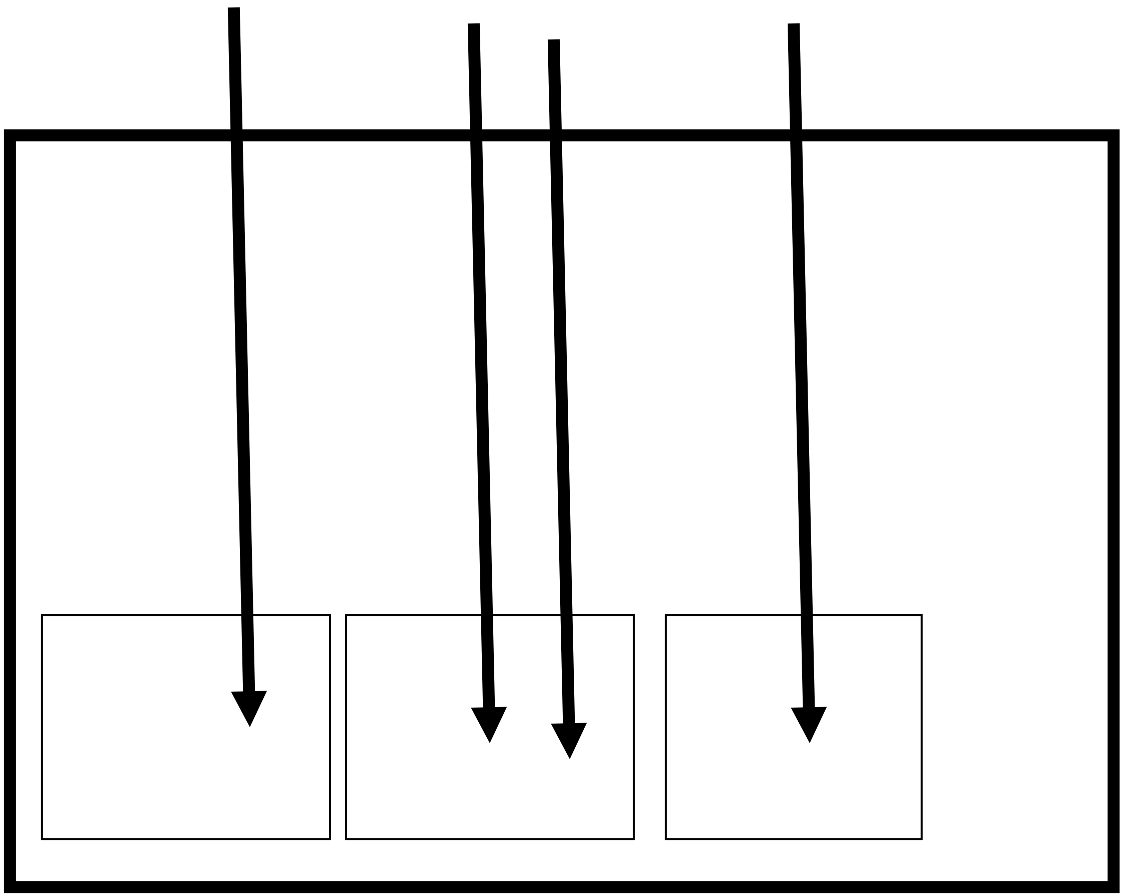
- ***Wait-freedom:*** every process that invokes an operation eventually returns from the invocation
  - *Robust* ... unlike locking.

- ***Atomicity:*** every operation appears to execute instantaneously.
  - As if the object were locked.

In short

This course shows how to ***wait-free*** implement high-level ***atomic*** objects out of more primitive base objects.

Concurrent processes



Shared object

Administrative Issues

Timing:

- Class: *Monday* 9:15-11:00
- Exercise sessions: *Monday* 11:15-12:00
  - Room: BC03
  - First session: Week 3

Text book:

- None. Handouts on the webpage.

Final Exam:

- Written, closed-book, date/time/room TBA.

Administrative Issues

What about the other class?

« Distributed Computing »

Monday, 15:15-17:00, ELA01

- The courses are complementary.
  - This course: ***shared memory***.
  - Other course: ***message passing.***

- Consider taking both! (Recommended...)

Today's Lecture:

1. Introduction:
   - What is the goal of this course?
2. Model:
   - Processes and objects
   - Atomicity
   - Wait-freedom
3. Examples

Processes

We assume a finite set of processes:

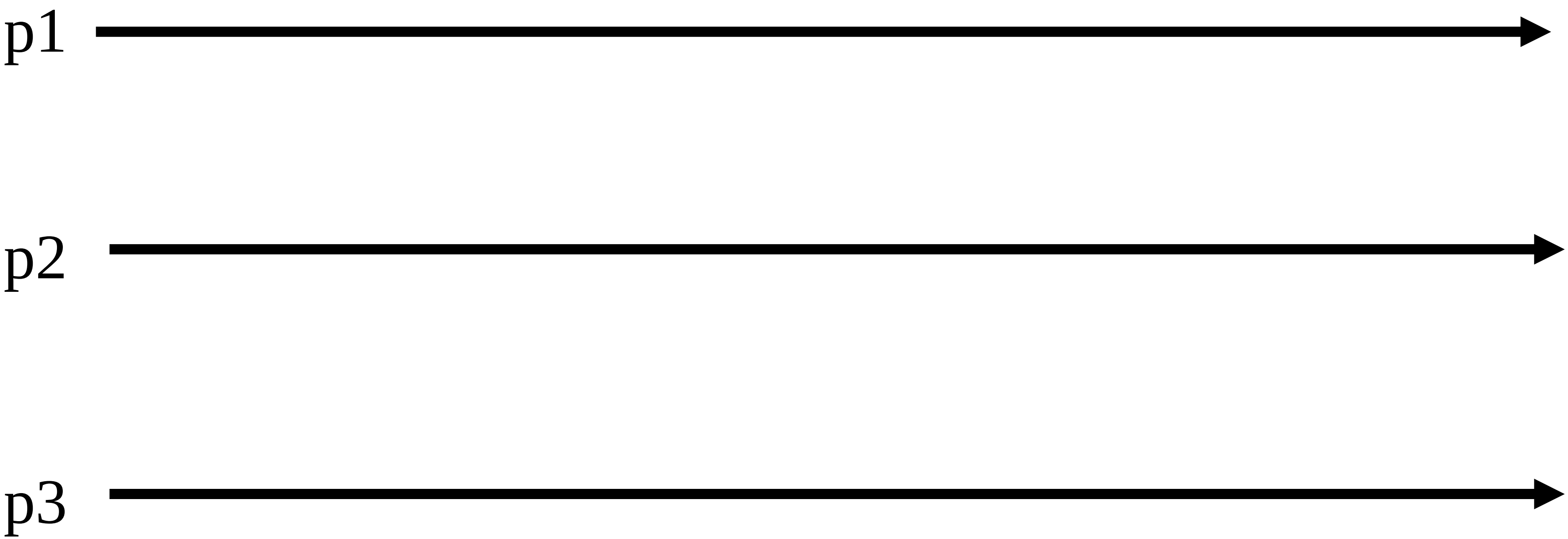
- Processes have unique identifiers.
- Processes are denoted as « $p_1, \ldots, p_N$ »
  or « p, q, r »
- Processes know each other.
- Processes can coordinate via *shared objects*.

Processes

We assume a finite set of processes:

- Each process models a sequential program.
- Each *clock tick* each process takes a step.
- In each step, a process:
  a) Performs some computation. (LOCAL)
  b) Initiates an operation on a shared object. (GLOBAL)
  c) Receives a response from an operation. (GLOBAL)
- We make no assumptions on process (relative) speeds. (Asynchronous)

Processes

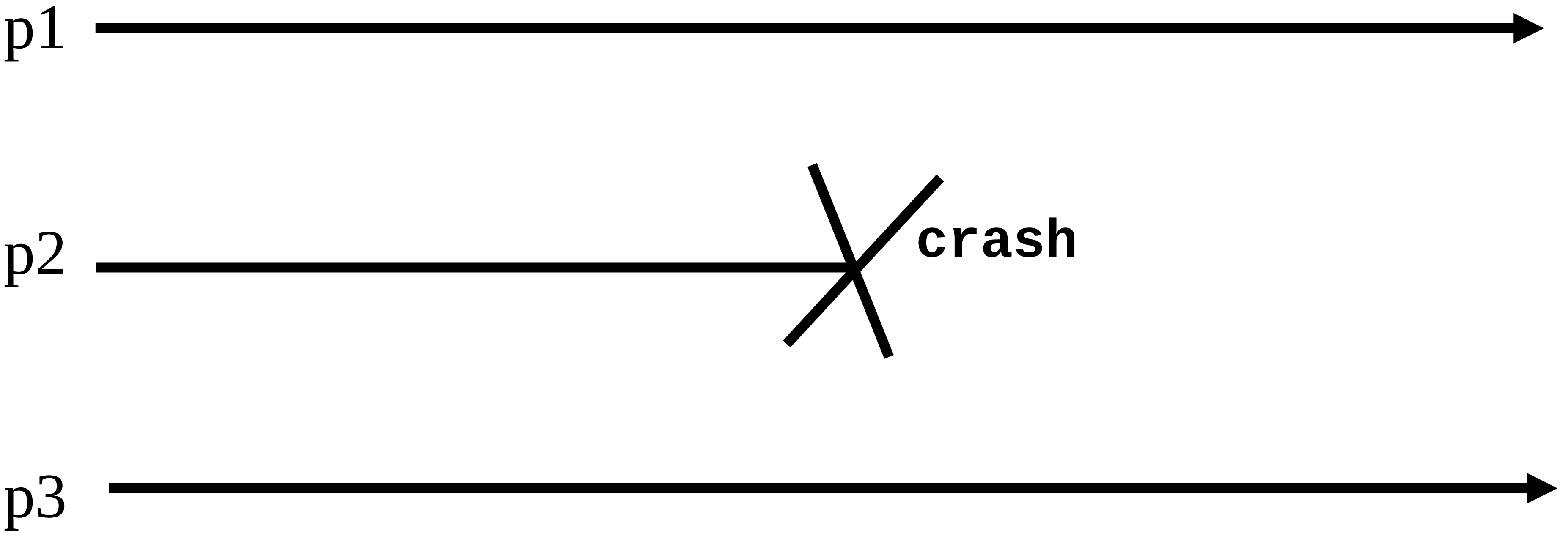


Processes

Crash Failures:

- A process either executes the algorithm assigned to it or crashes.
- A process that crashes does not recover.
- A process that does not crash in a given execution (computation or run) is called correct (in that execution).

Processes

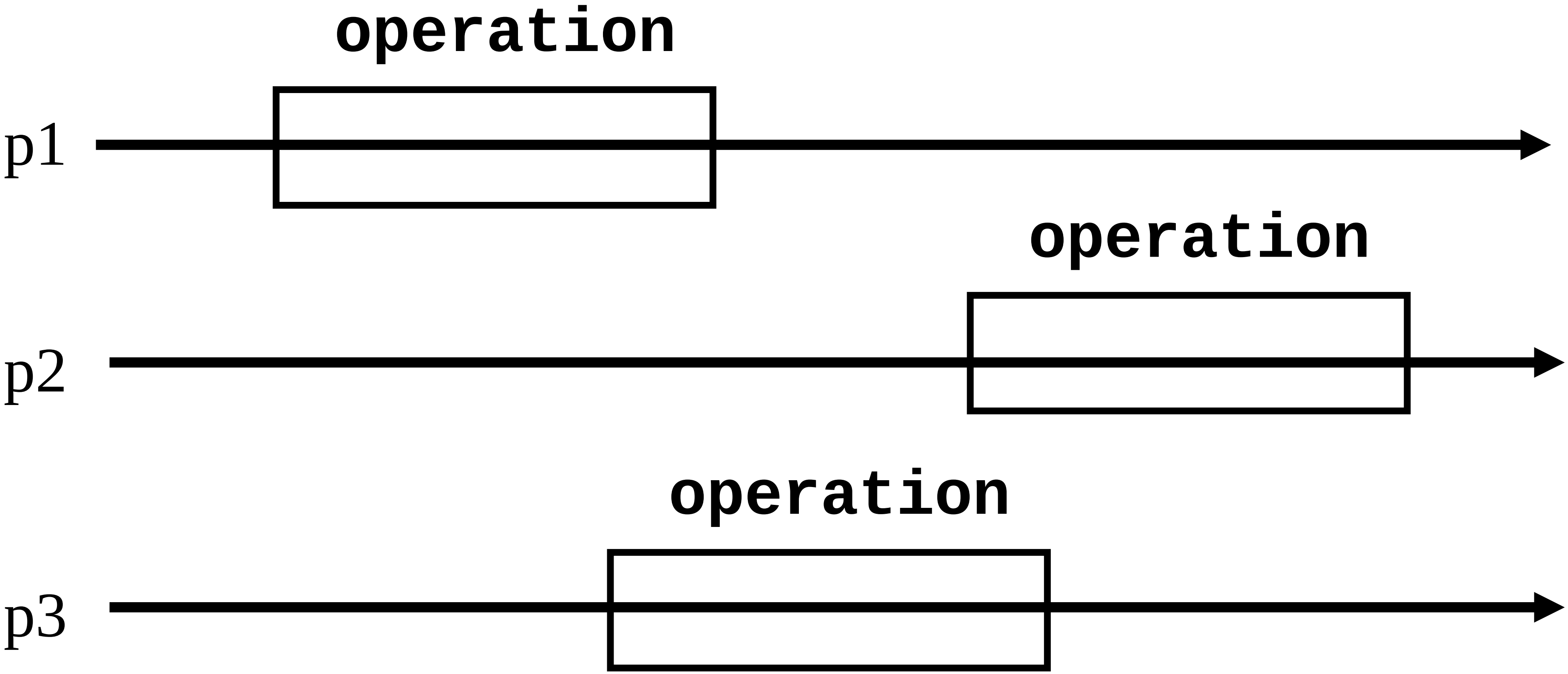


On objects and processes

Processes interact via shared objects:

- A process can initiate an ***operation*** on a particular object.
- Every operation is expected to return a reply.
- Each process can initiate only one operation at a time.

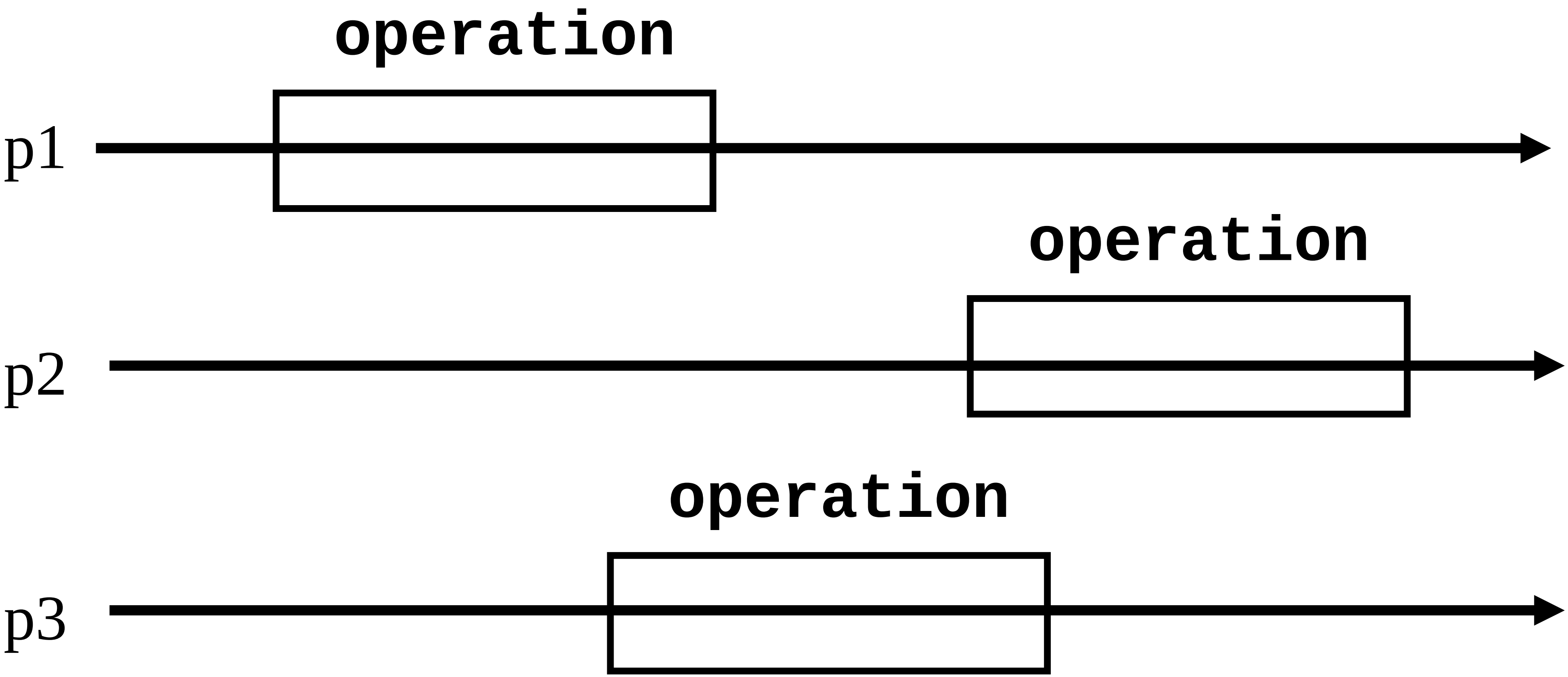
Processes



On objects and processes

- ***Sequentiality:***
  - After invoking an operation op1 on some object O1...
  - A process does not invoke a new operation on the same or on some other object...
  - Until it receives the reply for op1.
- ***Remark***. Sometimes we talk about operations when we should be talking about operation invocations

Processes

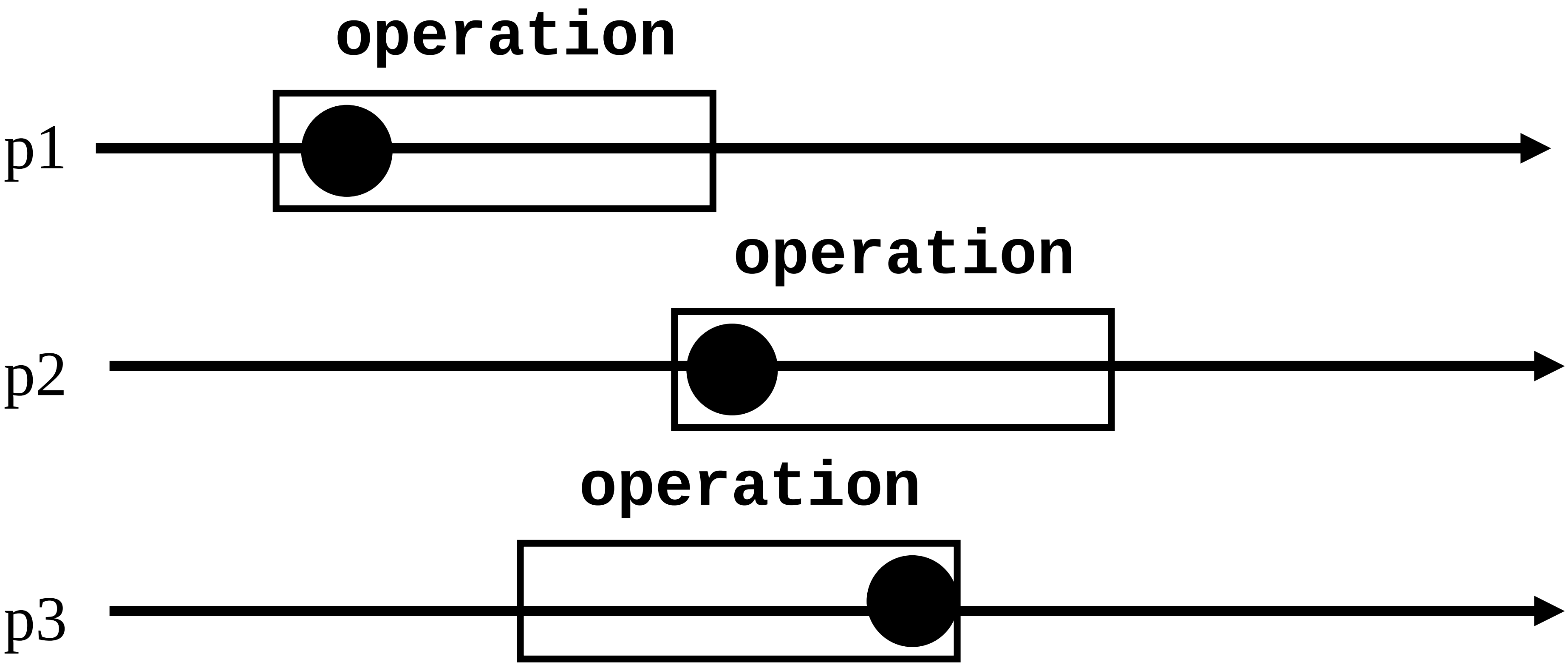


Atomicity

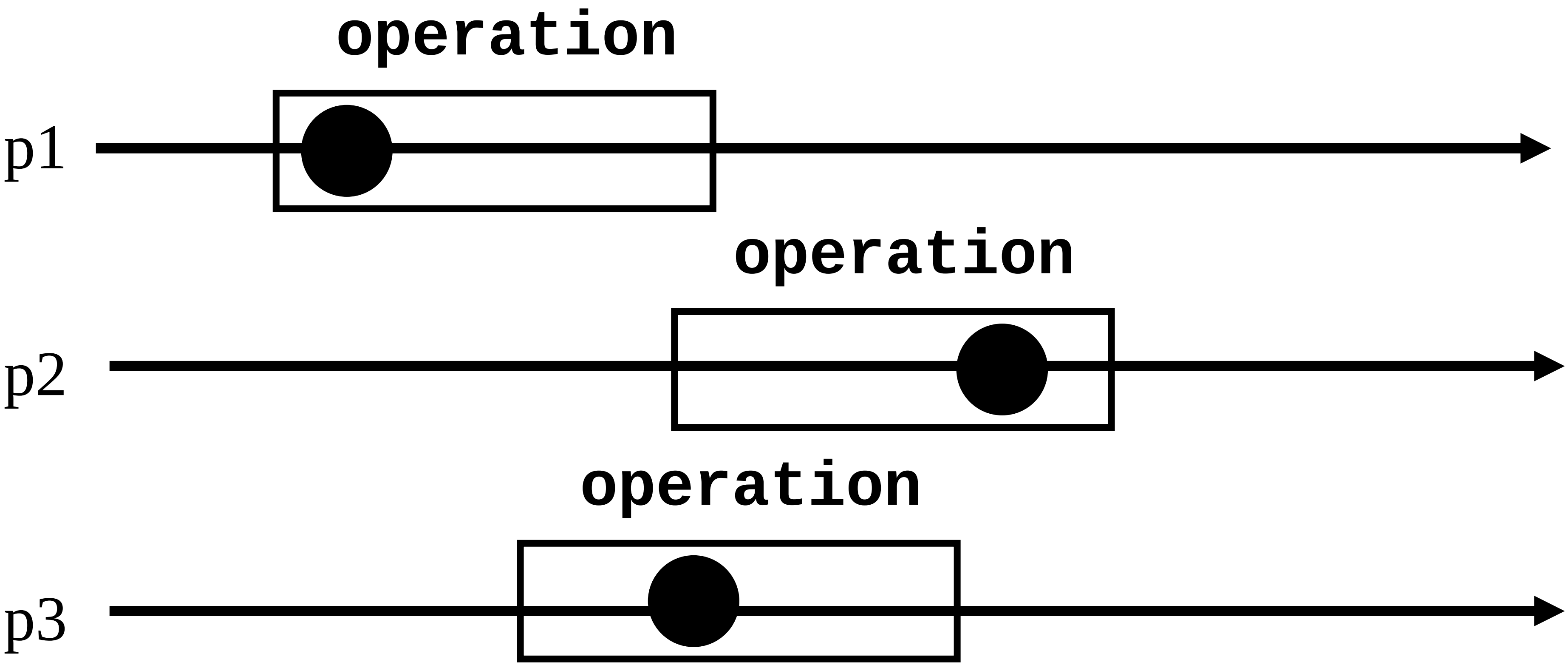
- We mainly focus in this course on how to implement ***atomic*** objects.

- ***Atomicity*** (or linearizability):
  - Every operation *appears* to execute at some indivisible point in time.
  - This is called the linearization point.
  - This point is between the invocation and the reply.

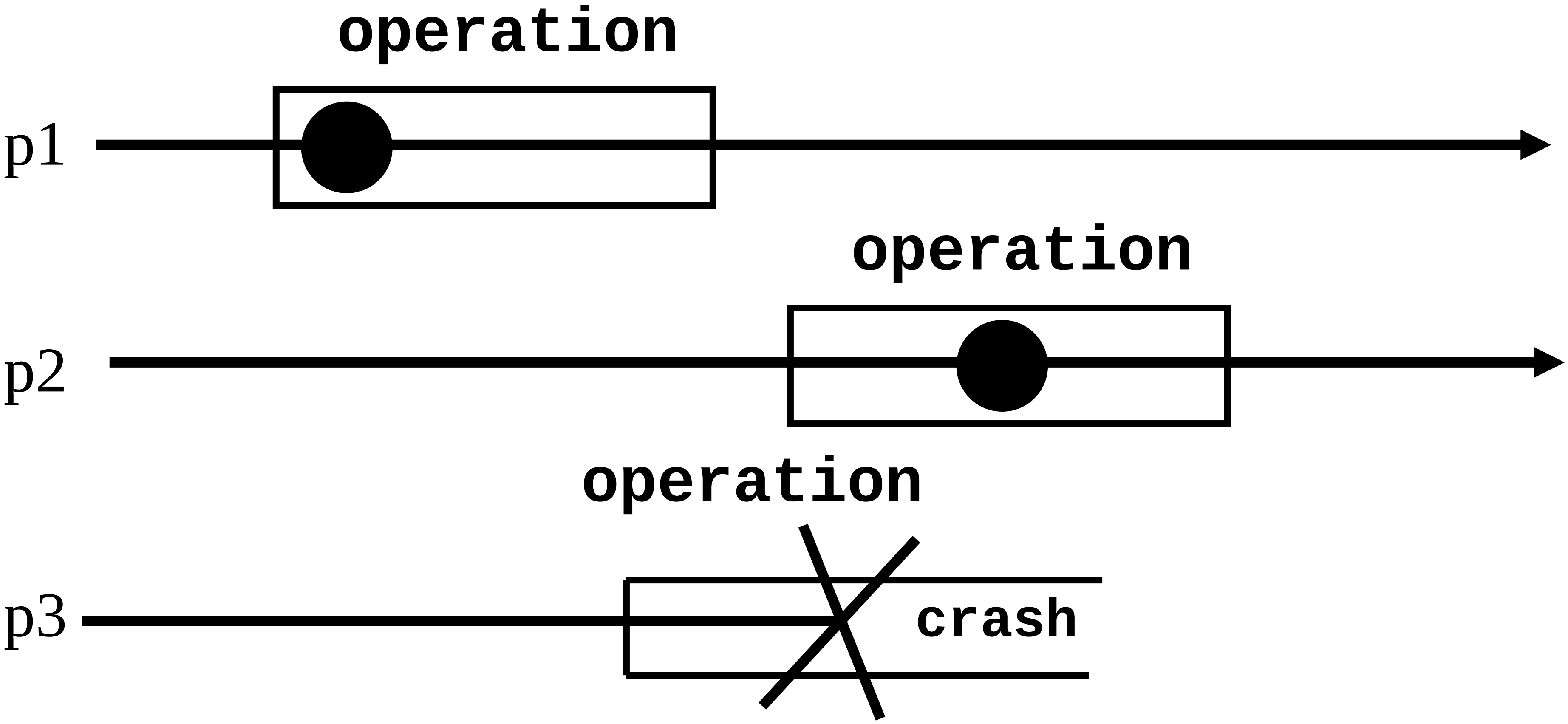
Atomicity



Atomicity



Atomicity (the crash case)



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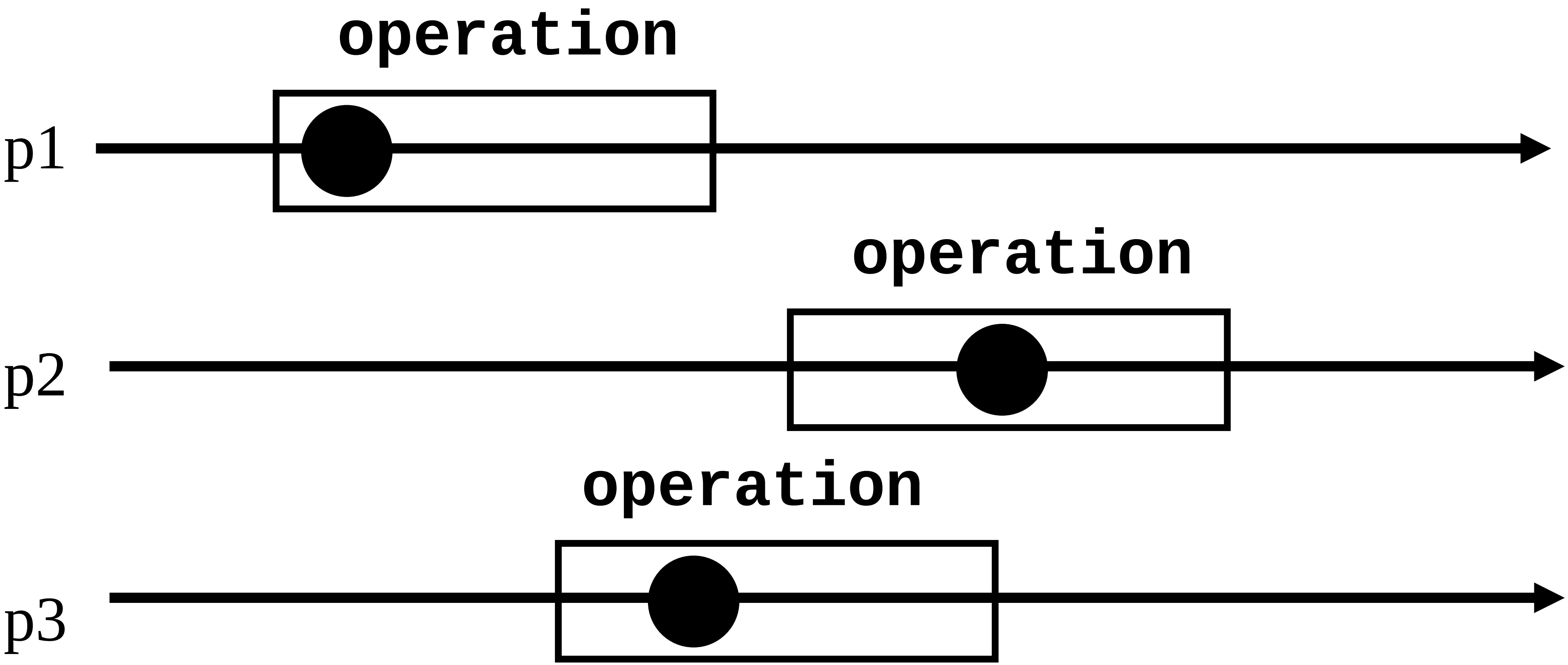

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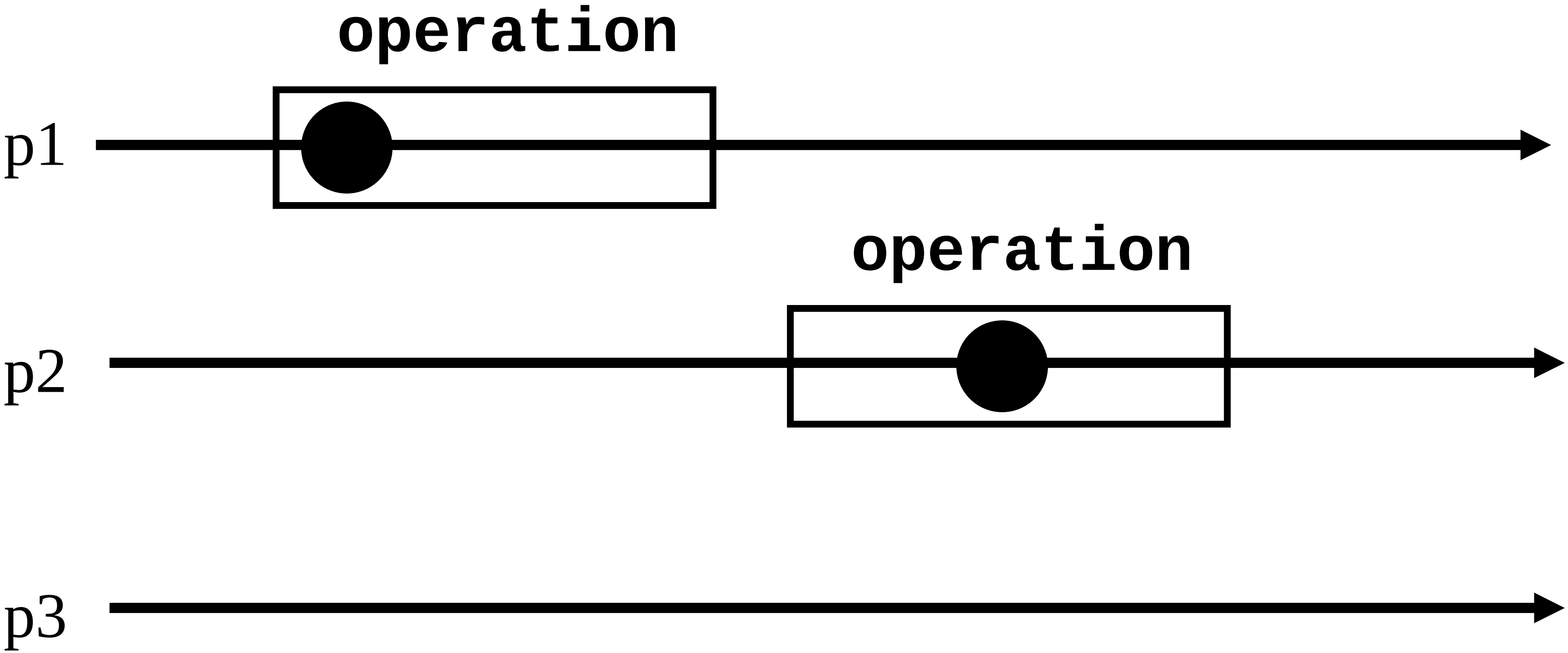


Atomicity

- Theorem:

  Consider executions of algorithm **A** in which every operation completes.

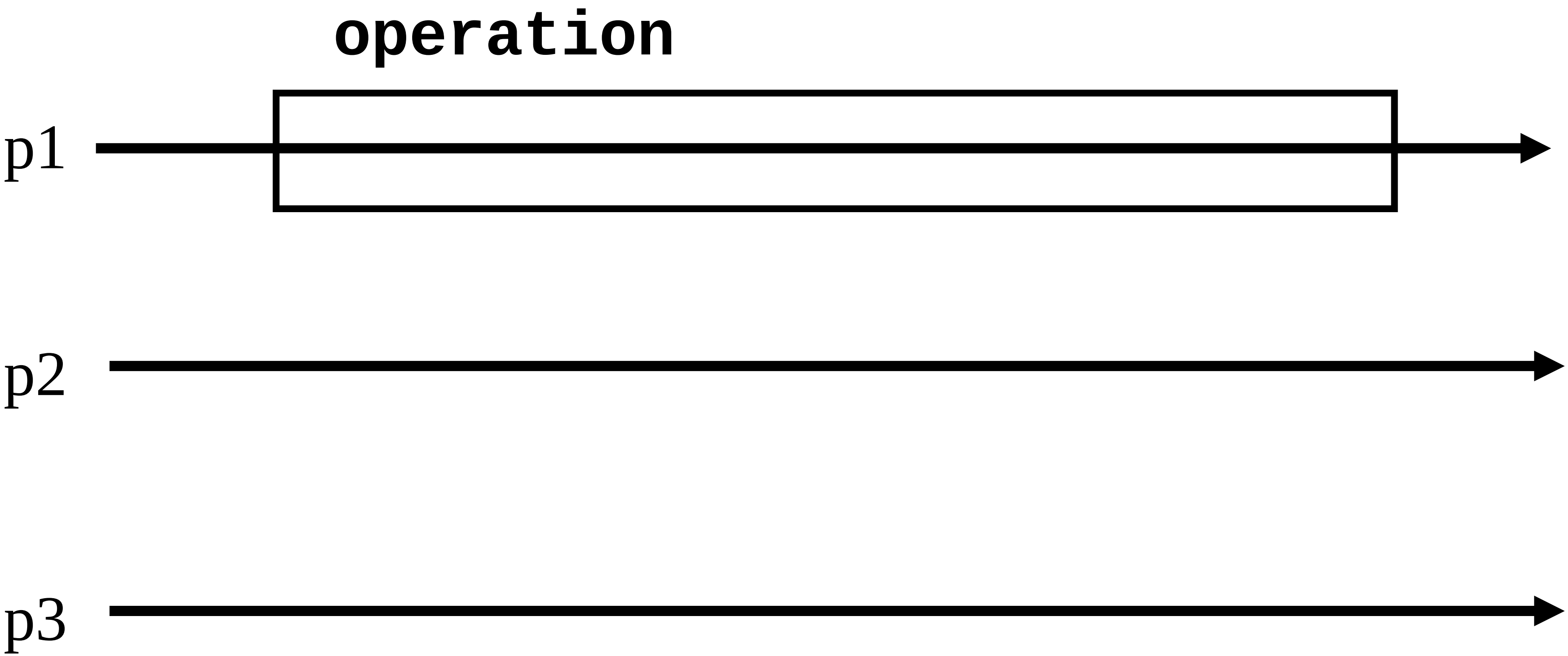
  If every such execution is atomic, then **A** guarantees atomicity in all executions (even those with operations that do not complete).

Wait-freedom

- We mainly focus in this course on ***wait-free*** implementations

- An implementation is wait-free if:
  - Any correct process that invokes an operation eventually gets a reply.
  - This does not depend on any other process.
  - Other processes may crash or be very slow.

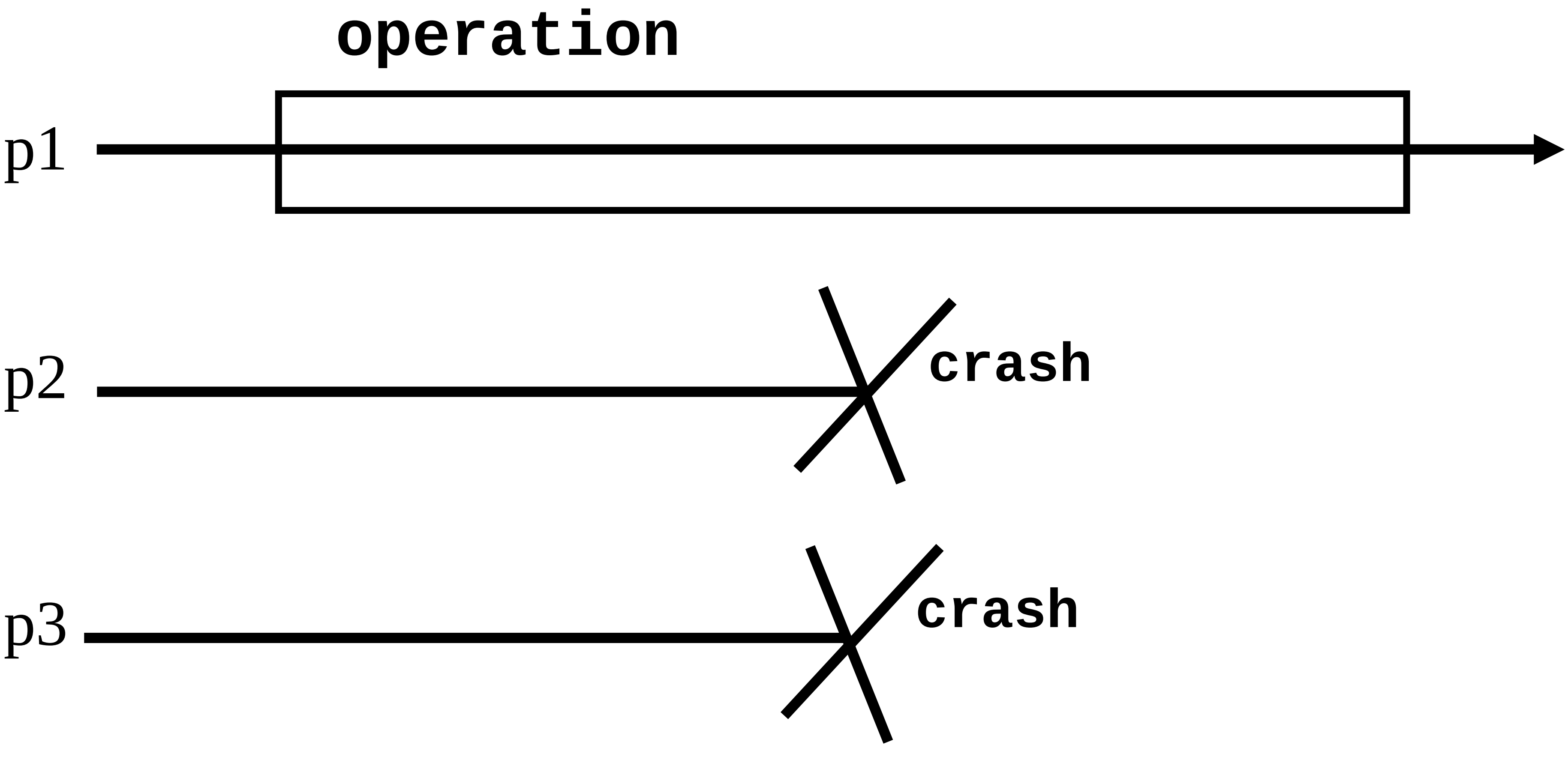
Wait-freedom



Wait-freedom

- Wait-freedom conveys the robustness of the implementation
- With a wait-free implementation, a process gets replies *despite* the crash of the *n*-1 other processes
- Note that this precludes implementations based on locks (i.e., mutual exclusion).

Wait-freedom



Today's Lecture:

1. Introduction:

- What is the goal of this course?

2. Model:

- Processes and objects
- Atomicity
- Wait-freedom

3. Examples

Motivation

- Most synchronization primitives (problems) can be precisely expressed as atomic objects (implementations)

- Studying how to ensure robust synchronization boils down to studying wait-free atomic object implementations

Example 1

- The reader/writer synchronization problem corresponds to the ***register*** object
- Basically, the processes need to read or write a shared data structure such that the value read by a process at a time t, is the last value written before t

Register

- A ***register*** has two operations:
  - ***read()***
  - ***write()***

- Assume (for simplicity) that:
  - a ***register*** contains an integer
  - the register is denoted by *x*
  - the register is initially 0

Read/Write Register

Sequential specification:

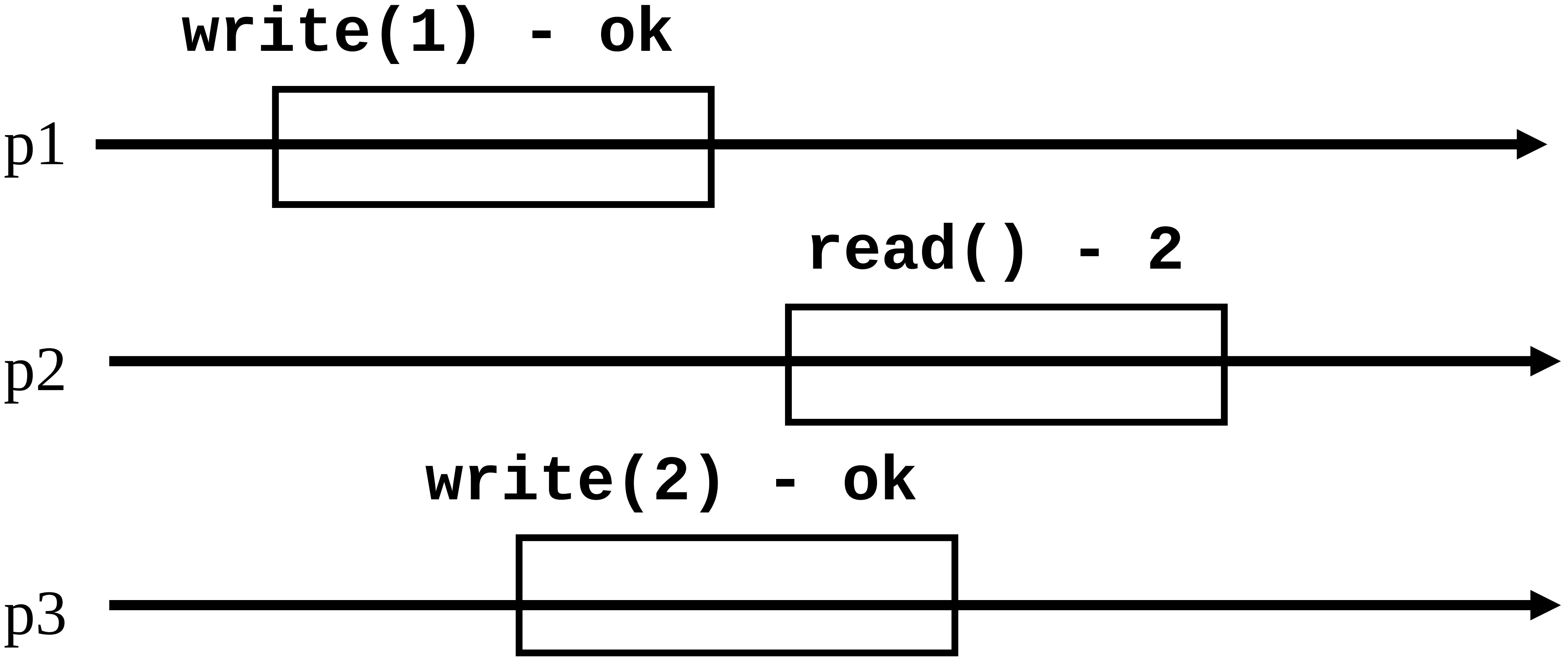
read()

```
return(x)
```

write(v)

```
x ← v;
return(ok)
```

Atomicity?



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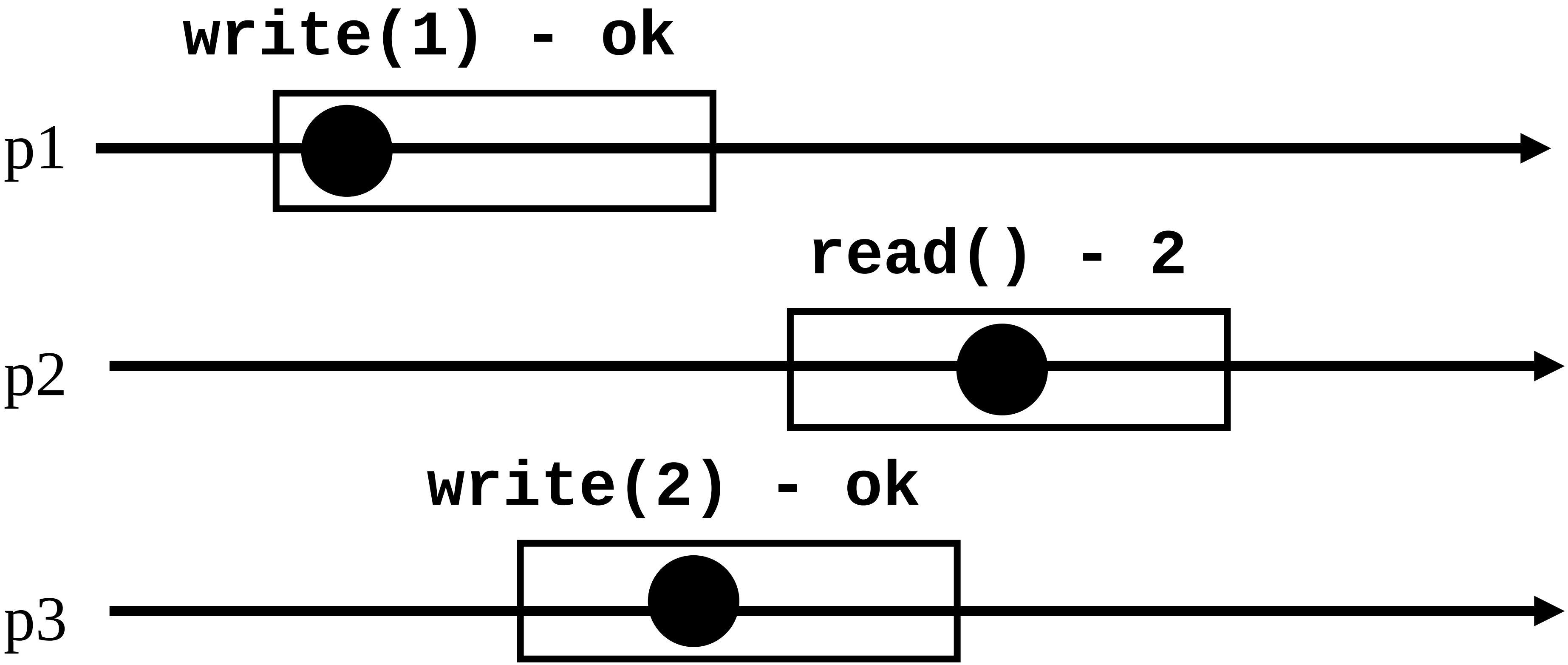

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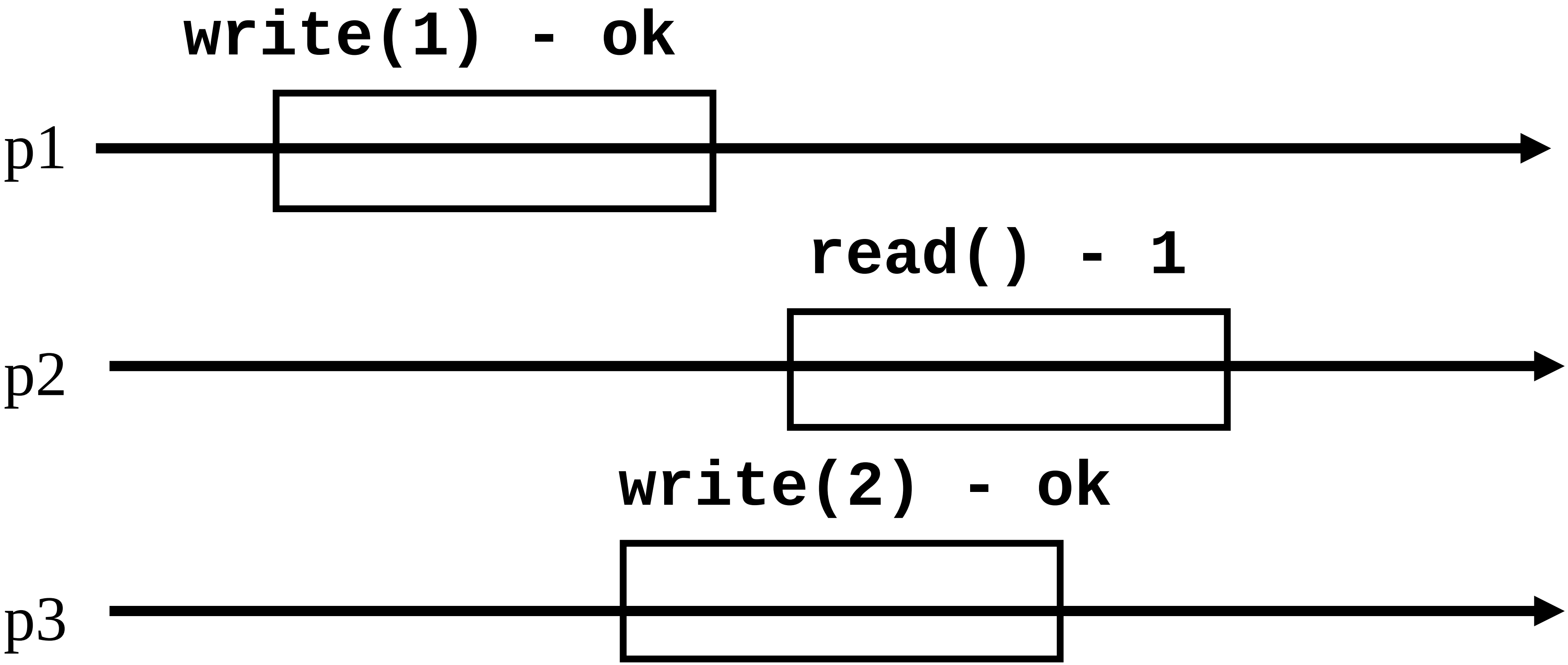

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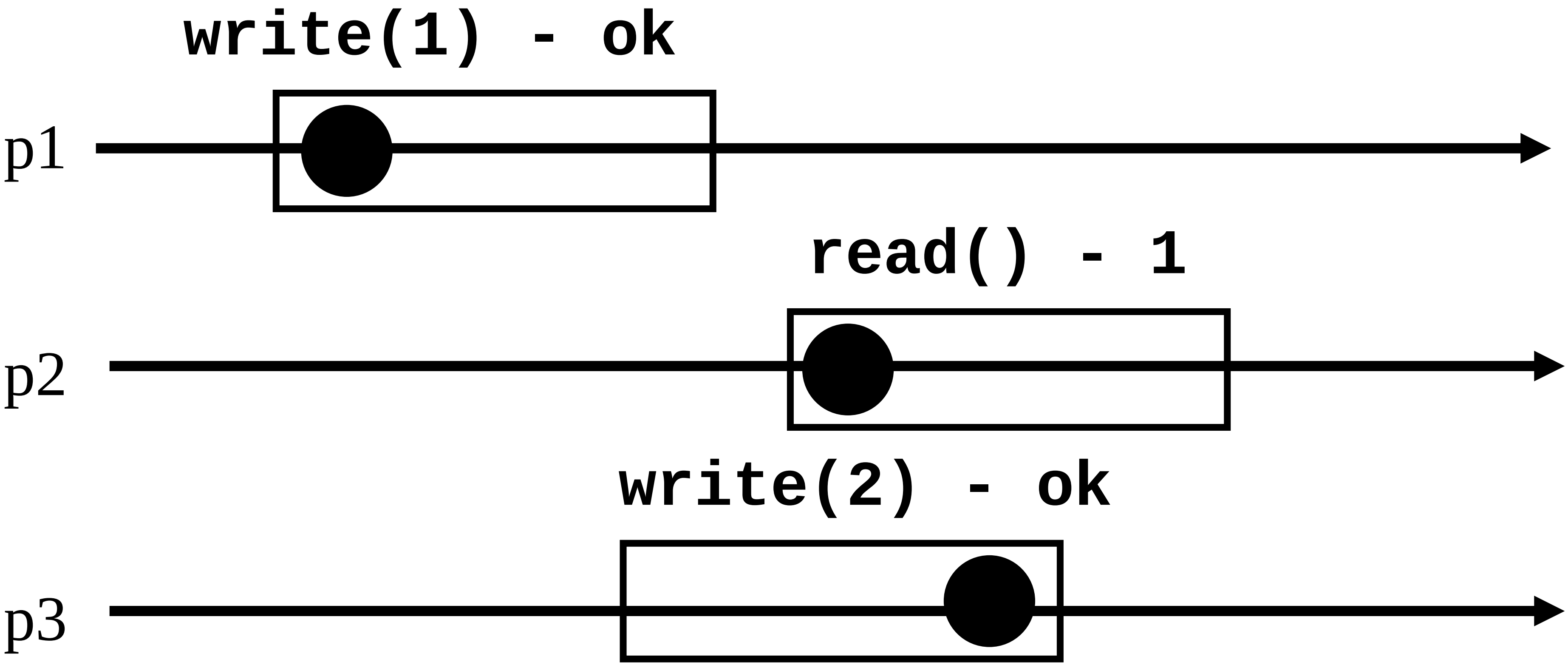

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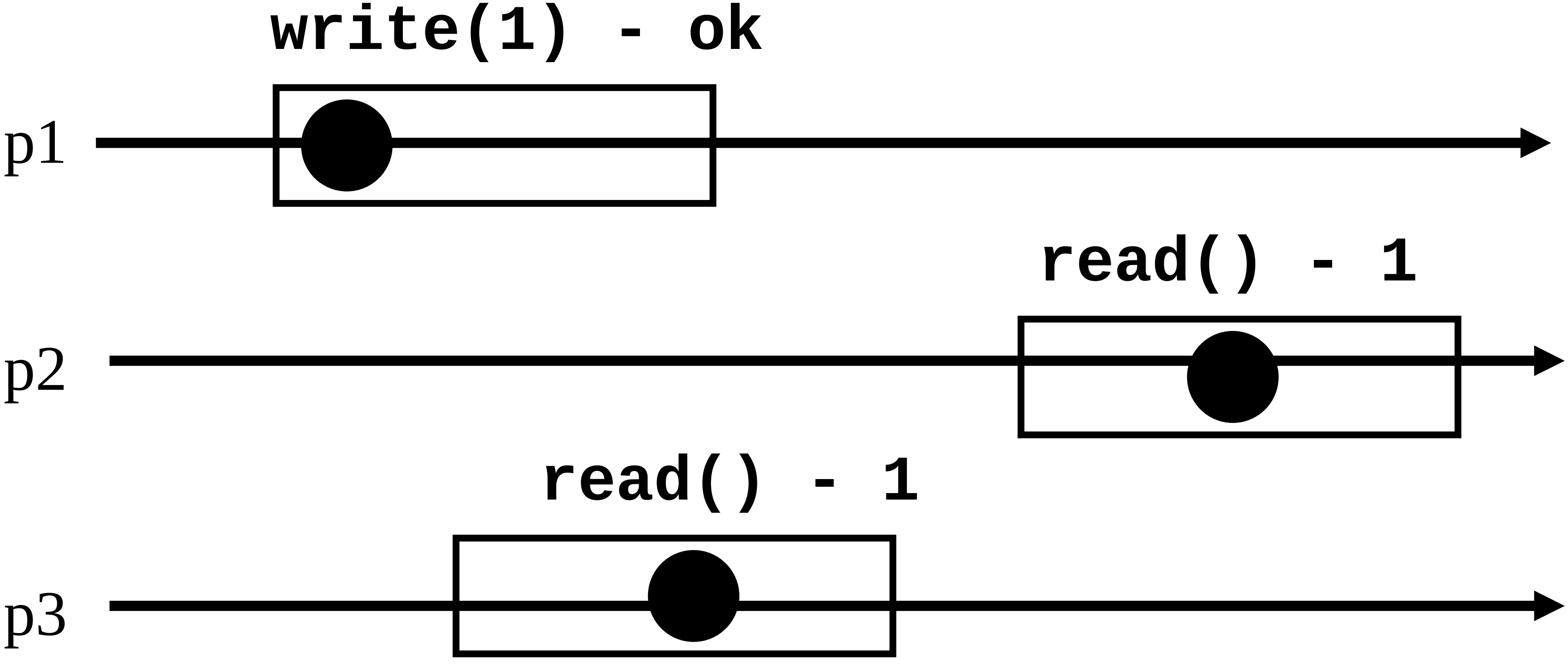

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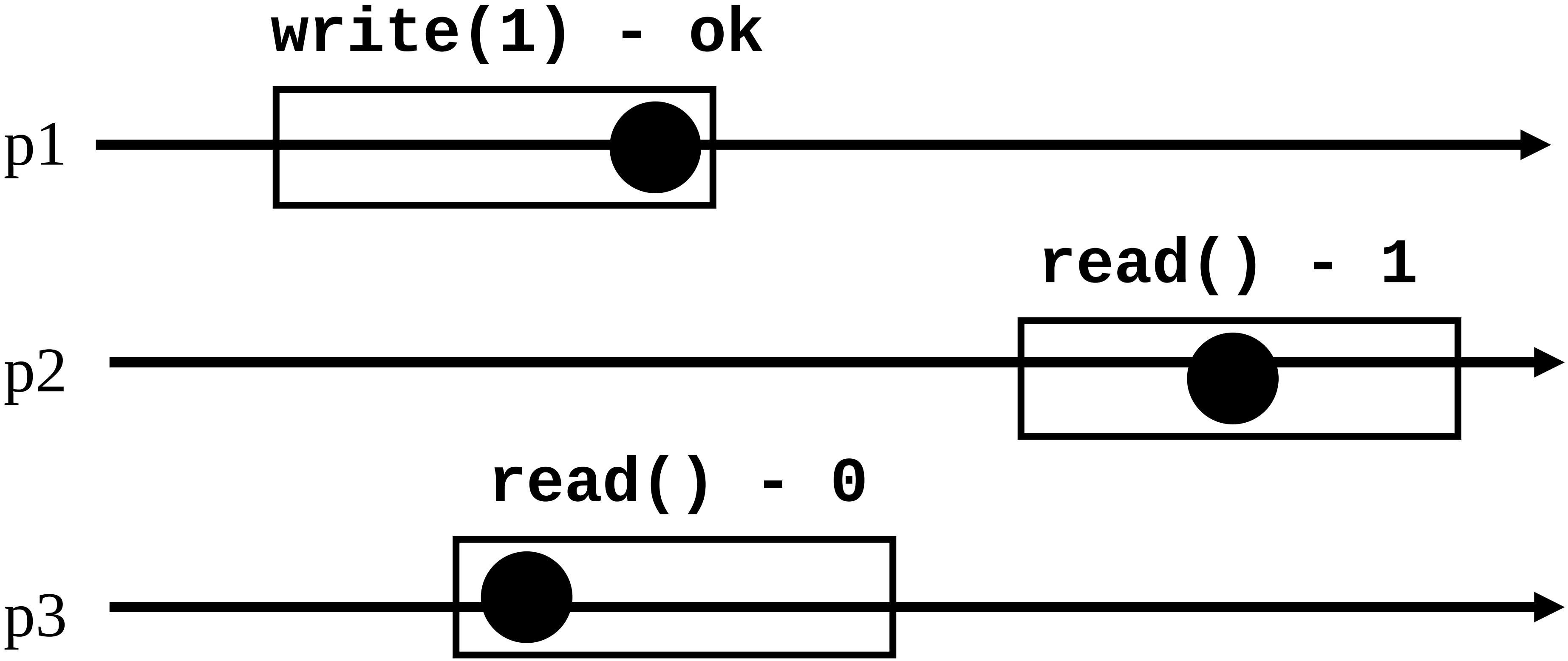

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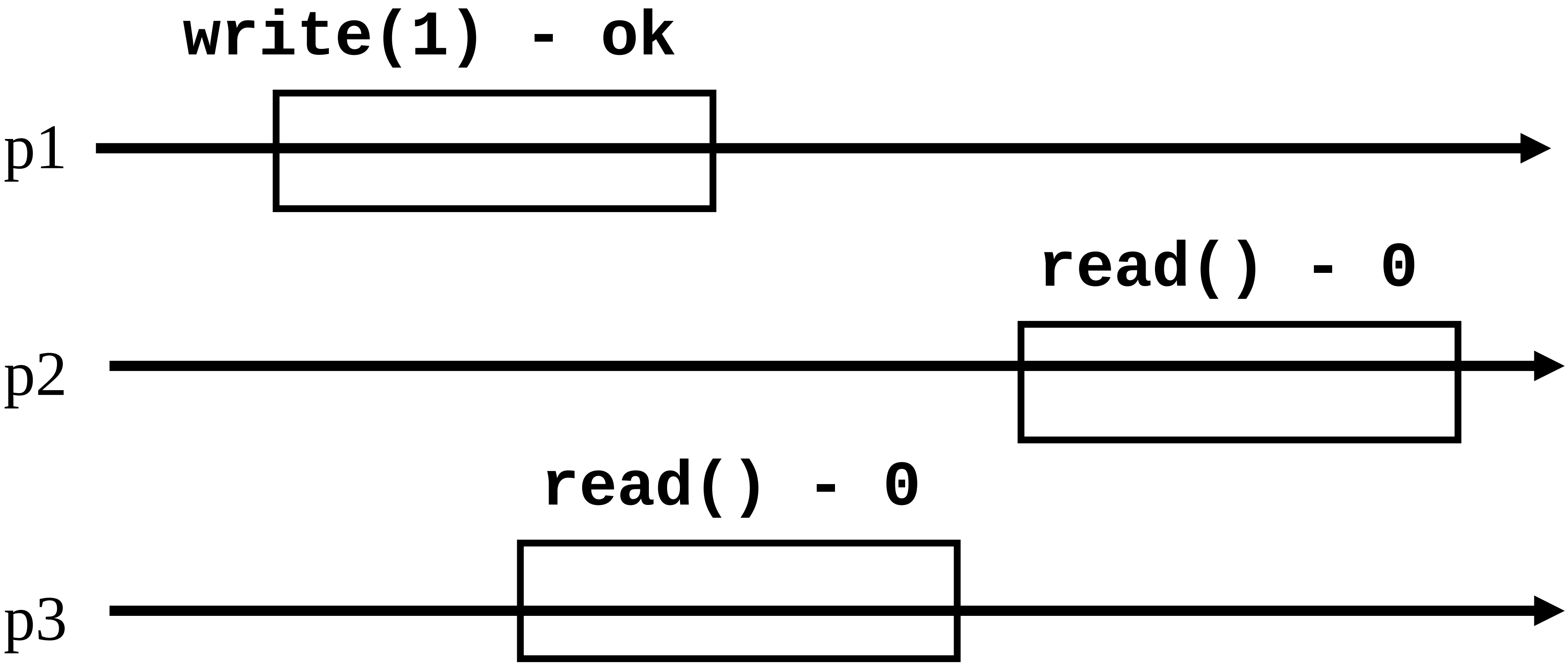

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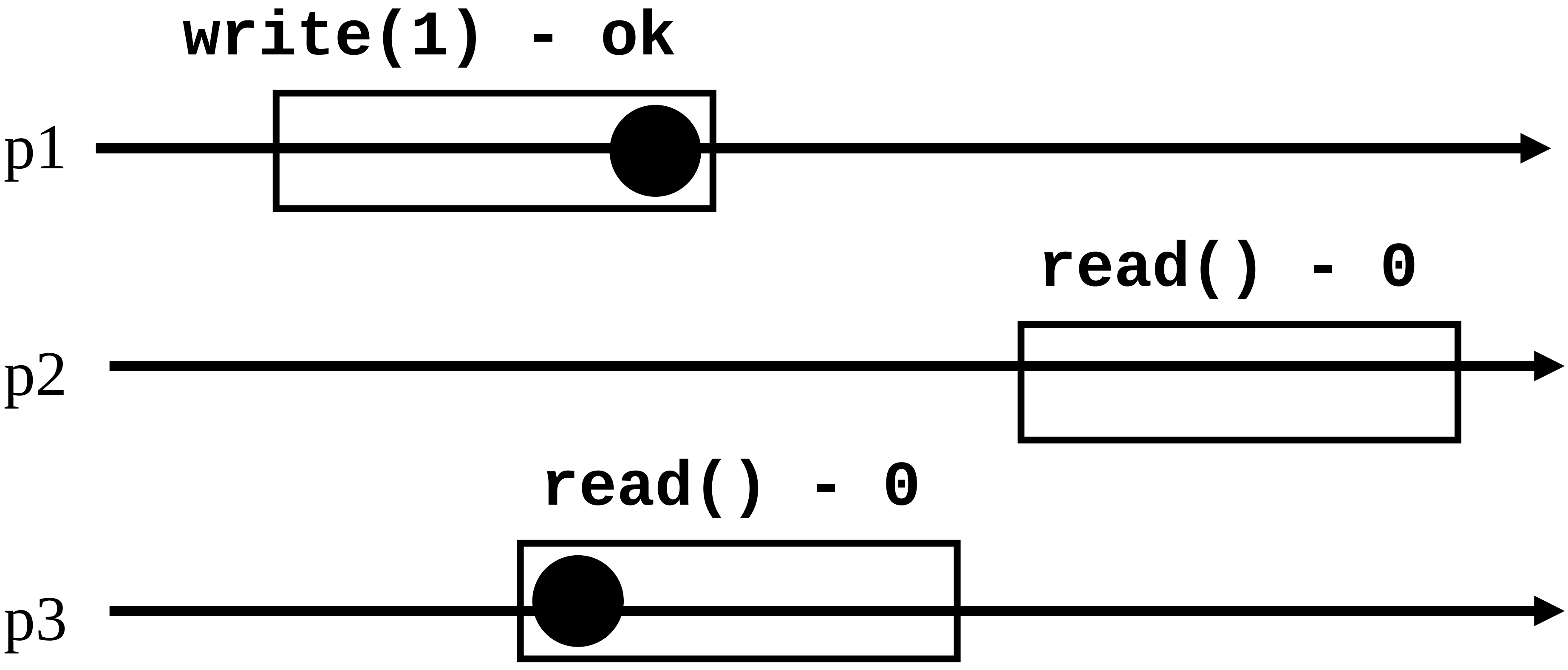

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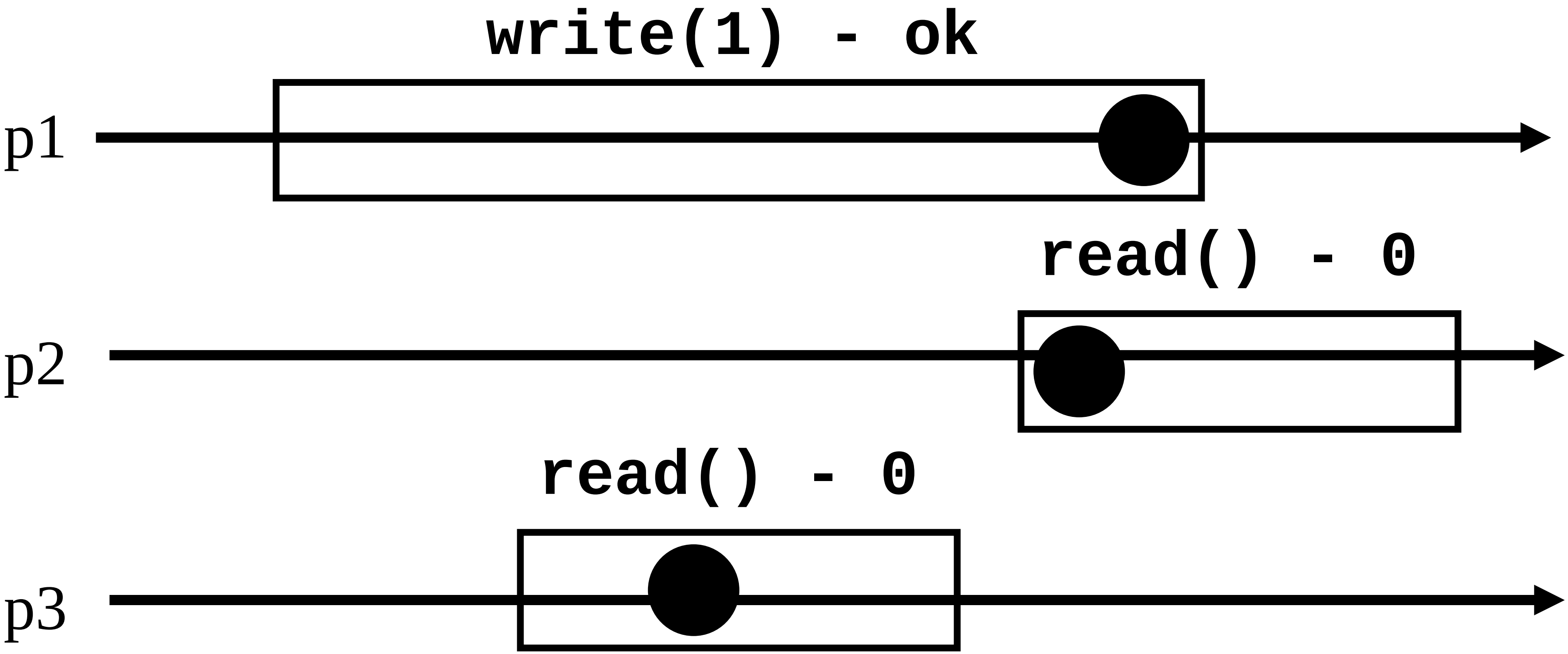
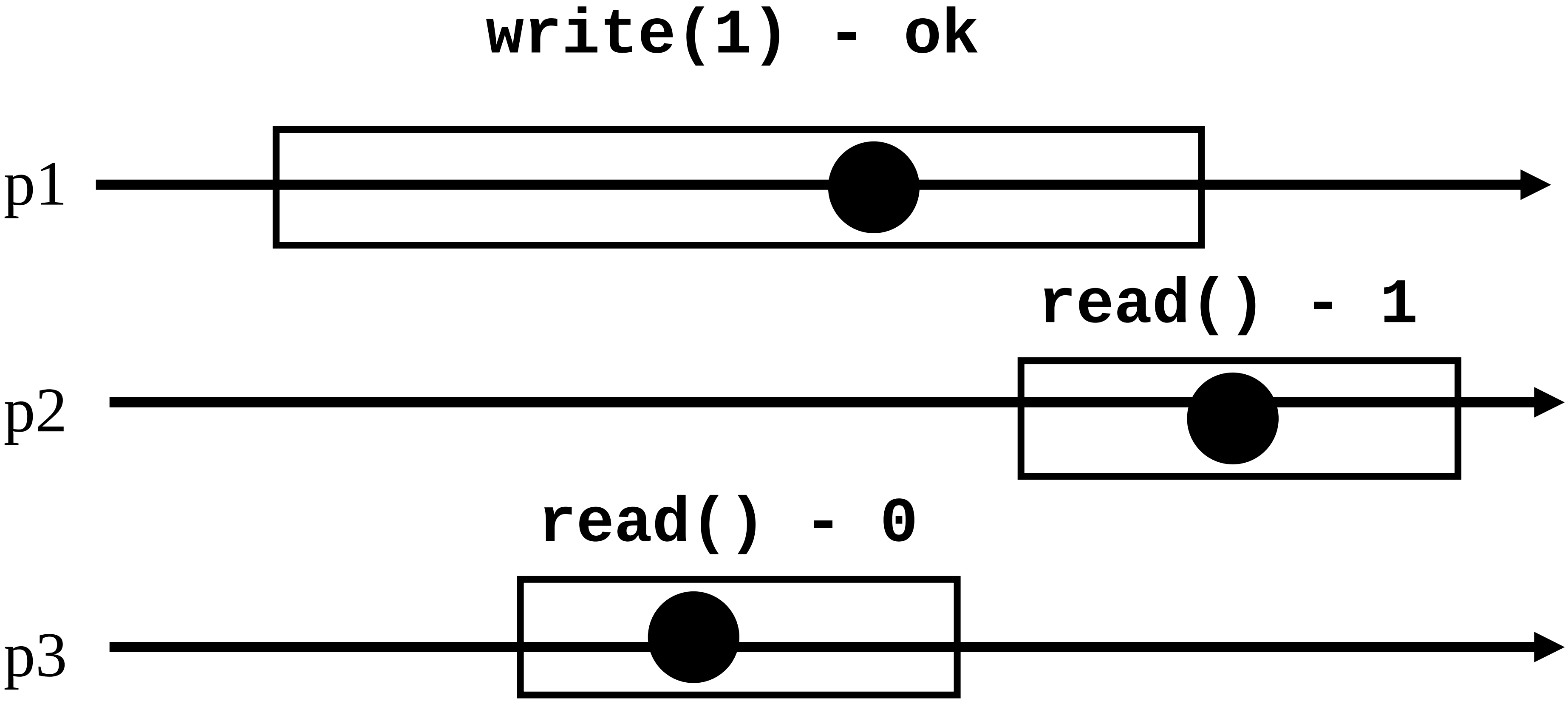
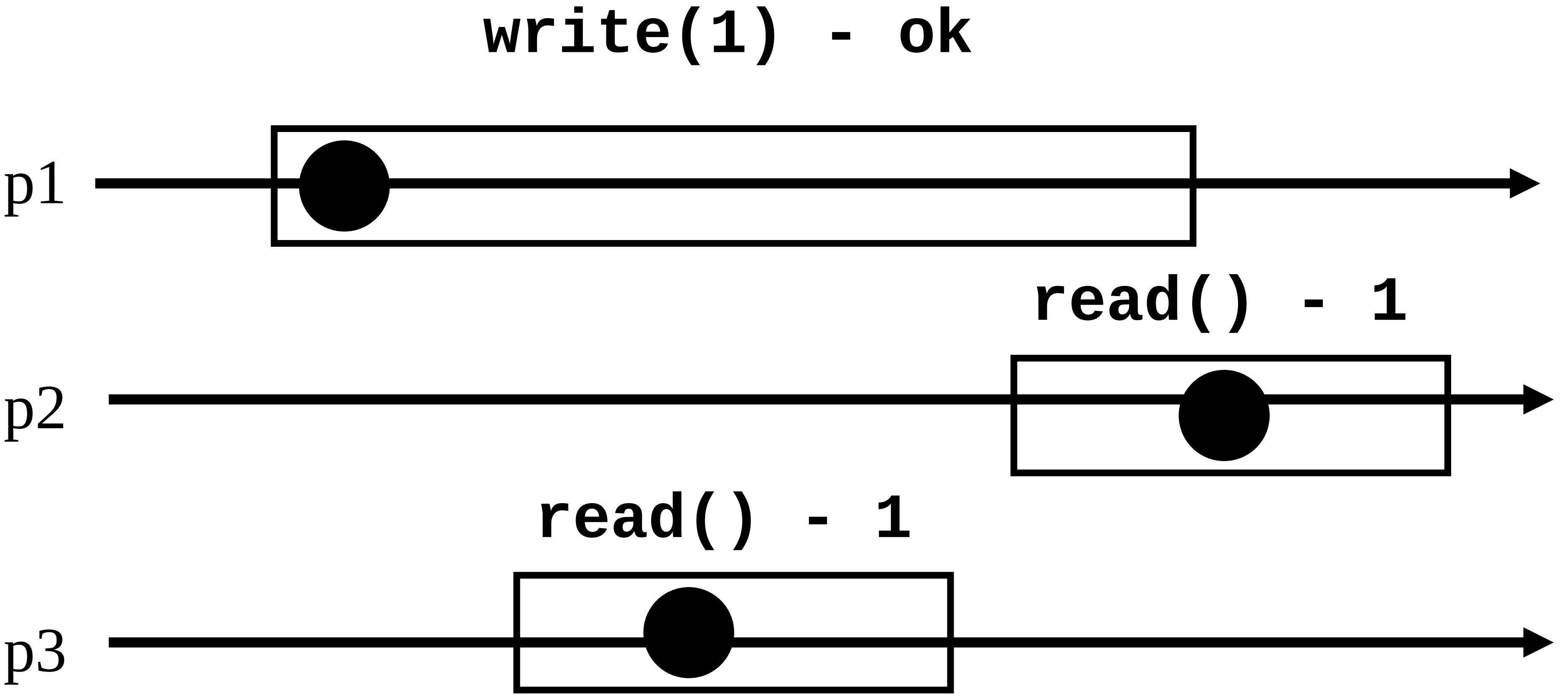


Atomicity?



Atomicity?



Example 2

- Producer/consumer synchronization: corresponds to the ***queue*** object.
- Producer processes create items; consumer processes use items.
- Requirements:
  - An item cannot be consumed by 2 processes.
  - The first item produced is the first consumed (FIFO).

Queue

- A ***queue*** has two operations: ***enqueue()*** and ***dequeue()***

- We assume that a ***queue internally*** maintains a list x which supports:
  - *append():* put an item at the end of the list;
  - *remove():* remove an element from the head of the list.

Sequential specification

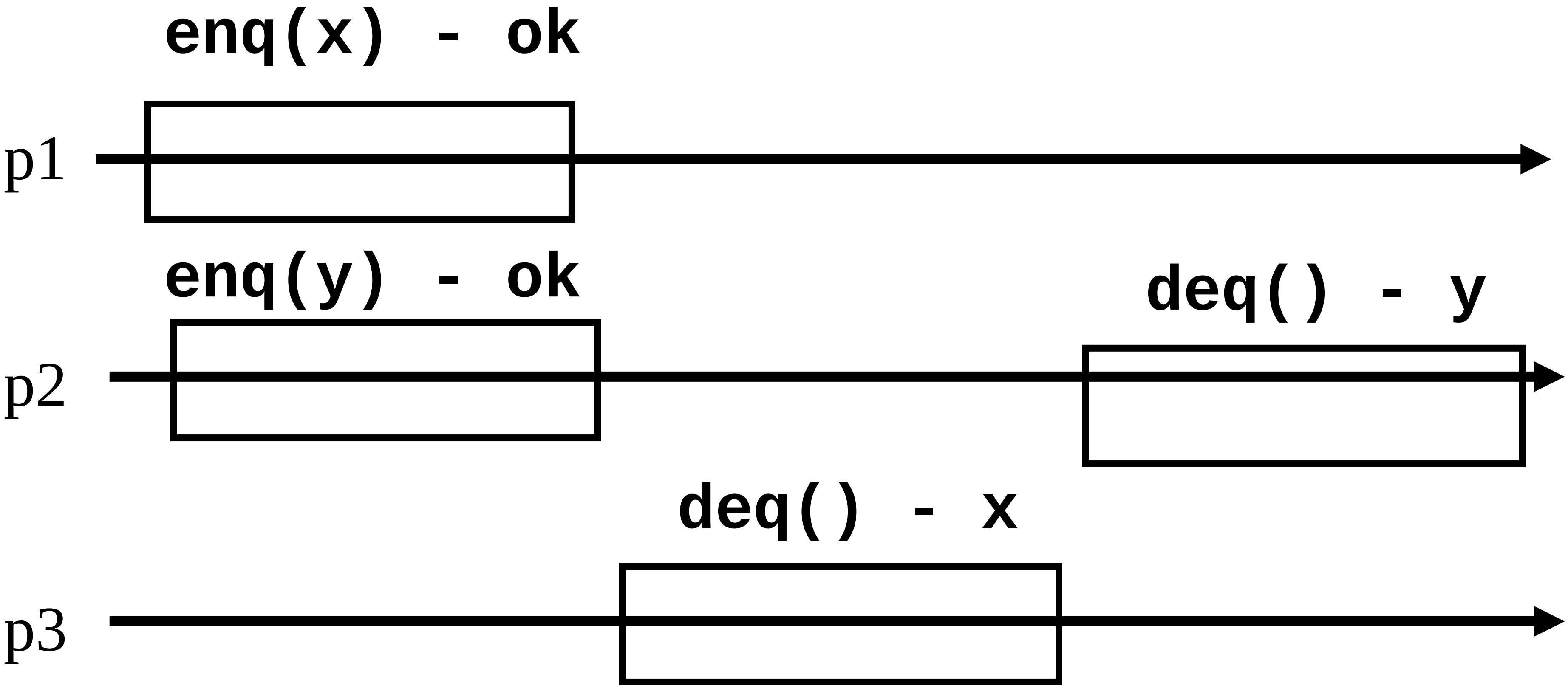
dequeue()

```
if (x = 0) then return(nil);
else return(x.remove())
```

enqueue(v)

```
    x.append(v);
    return(ok)
```

Atomicity?



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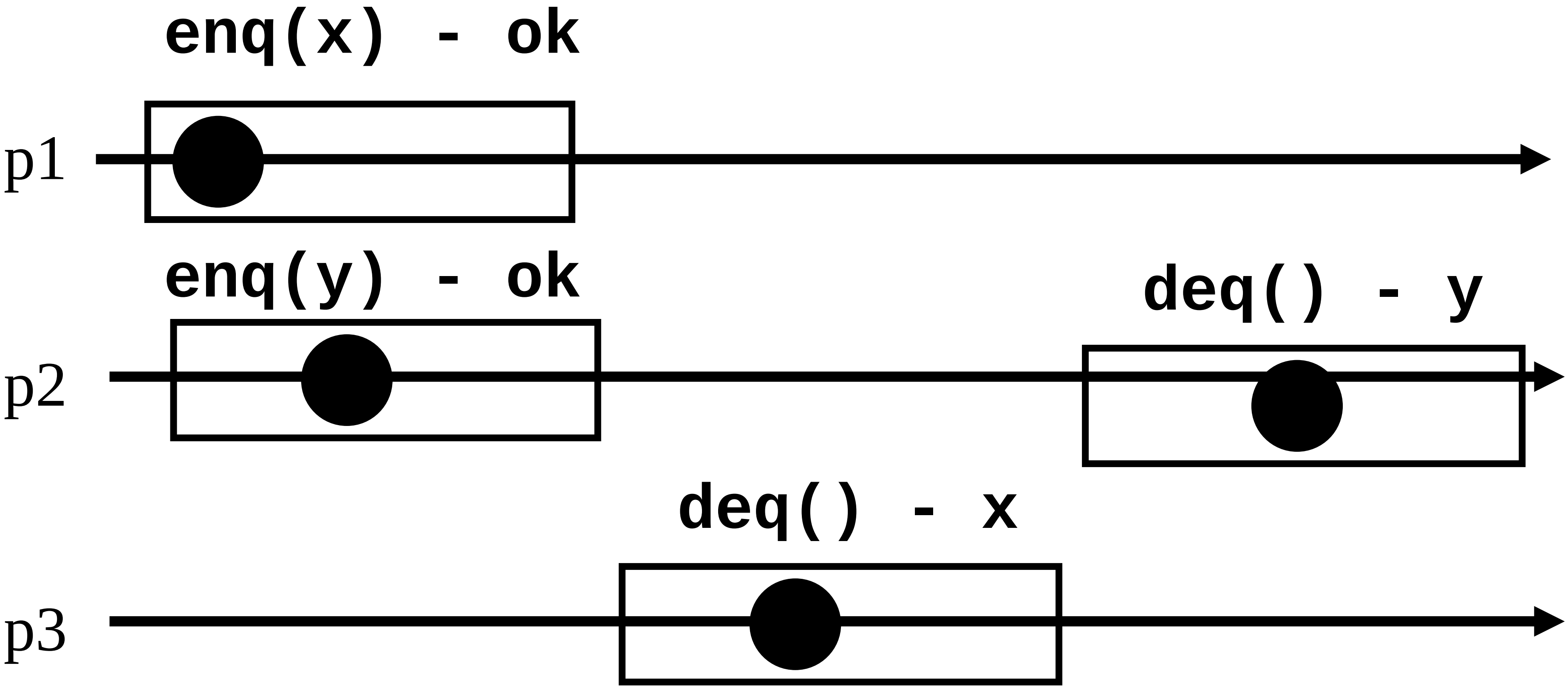

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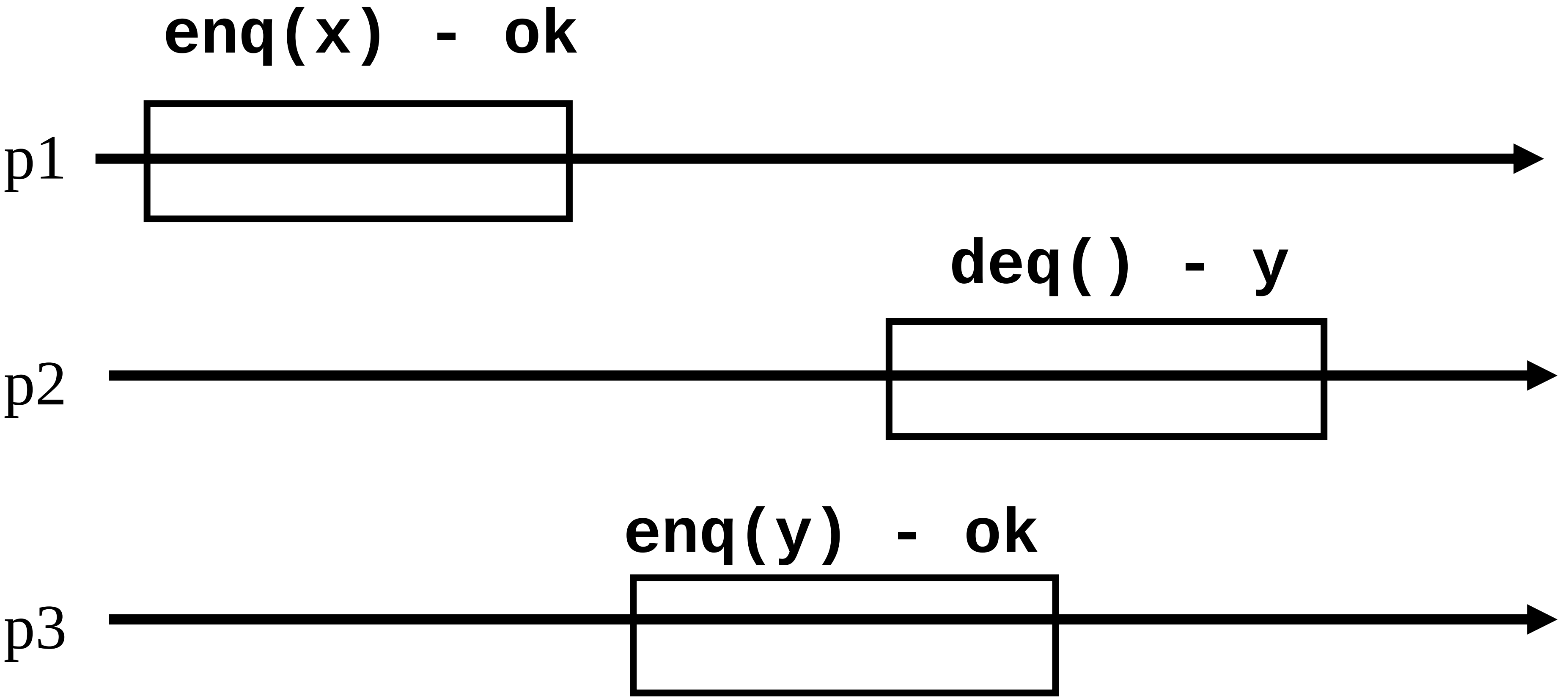

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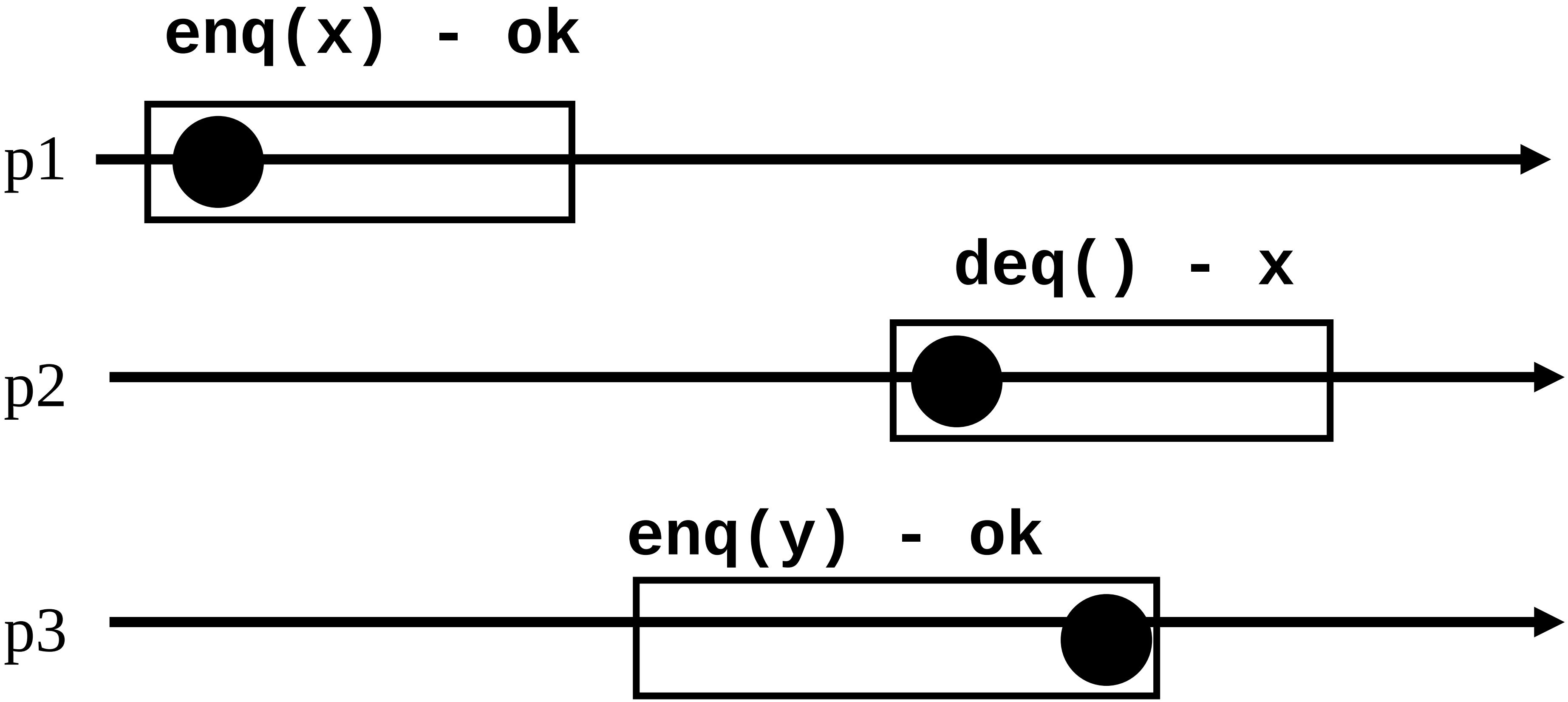

Content

- (1) Implementing ***registers***
- (2) The power & limitation of ***registers***
- (3) ***Universal*** objects & synchronization number
- (4) The power of ***time*** & failure detection
- (5) Tolerating ***failure*** prone objects
- (6) ***Anonymous*** implementations
- (7) ***Transaction*** memory

In short

This course shows how to wait-free implement high-level atomic objects out of basic objects

Remark: unless explicitely stated otherwise: *objects* mean *atomic objects* and *implementations* are *wait-free.*