Regular register algorithms

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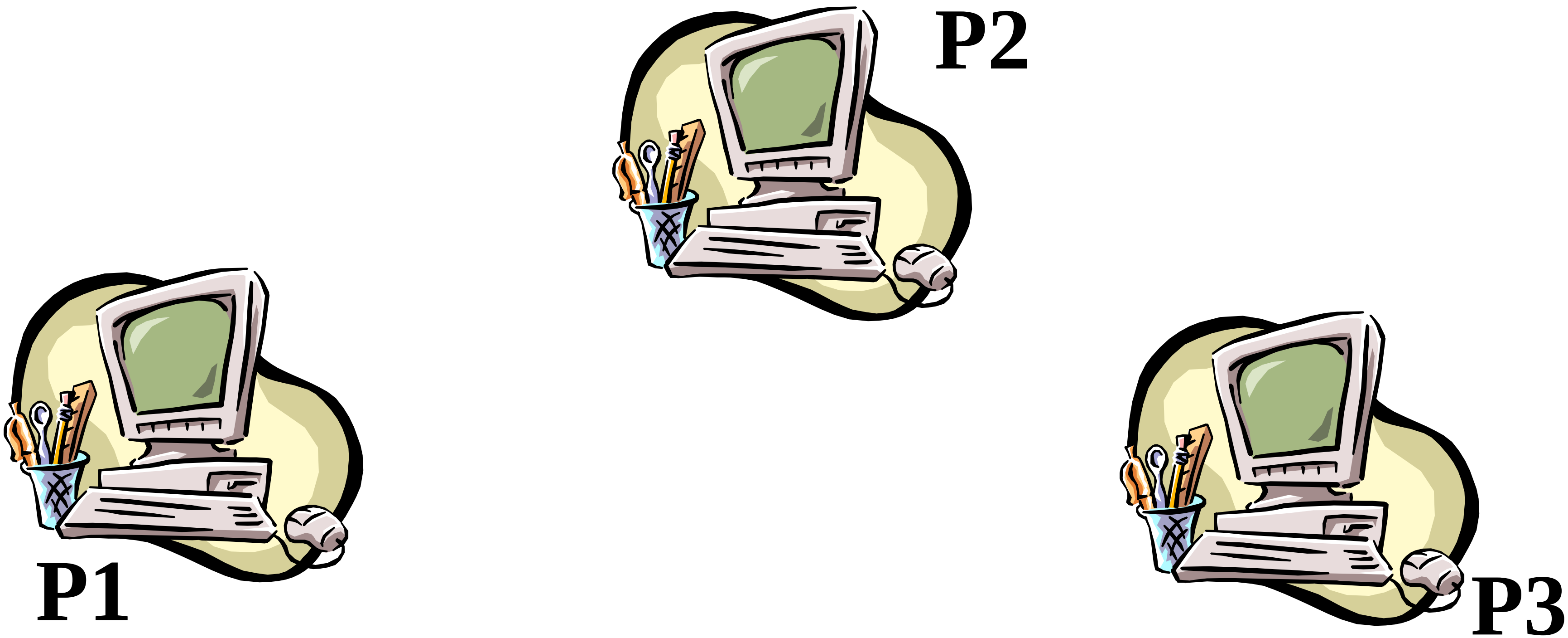
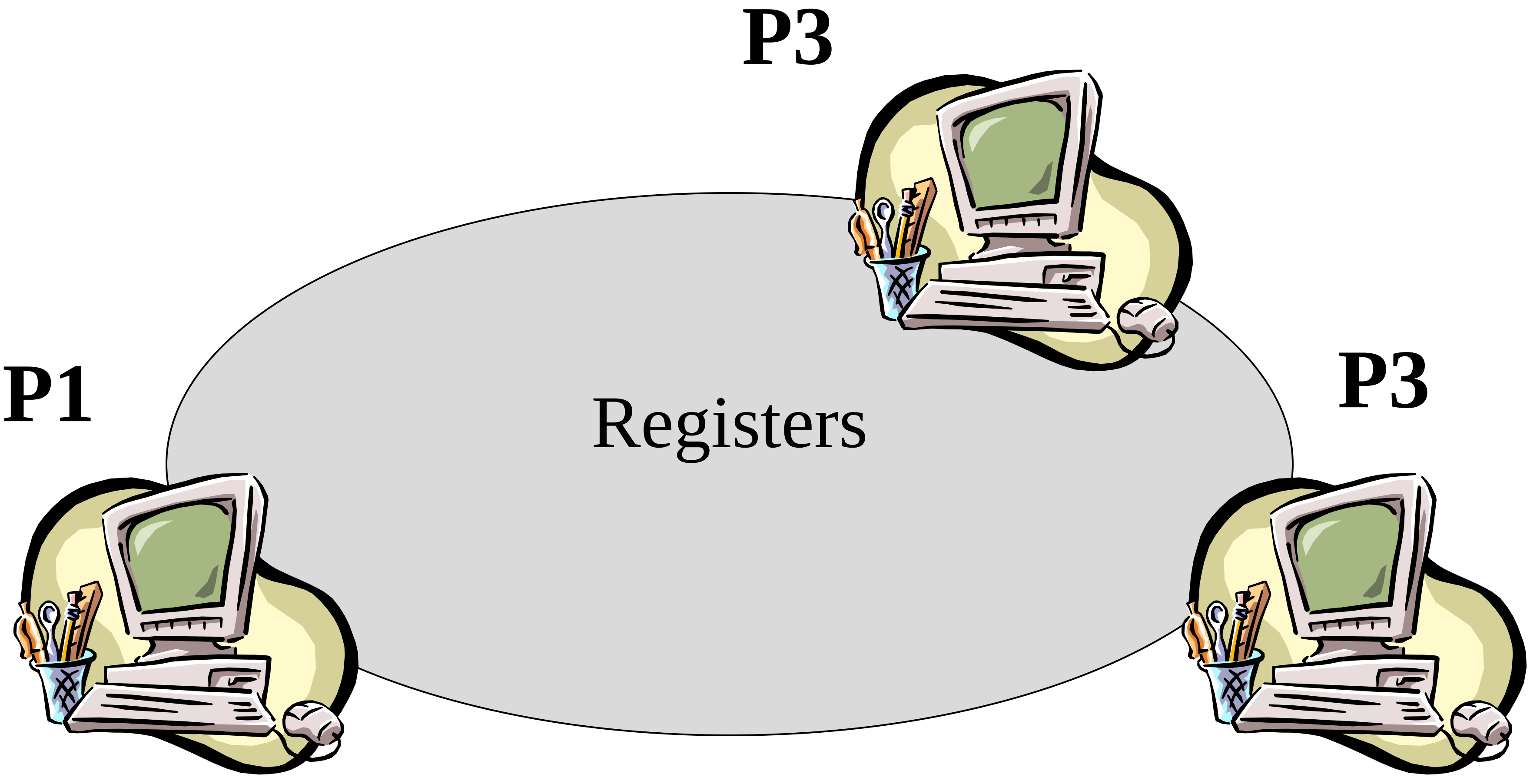
Overview of this lecture

- (1) ***Overview of a register algorithm***
- (2) ***A bogus algorithm***
- (3) ***A simplistic algorithm***
- (4) ***A simple fail-stop algorithm***
- (5) ***A tight asynchronous lower bound***
- (6) ***A fail-silent algorithm***

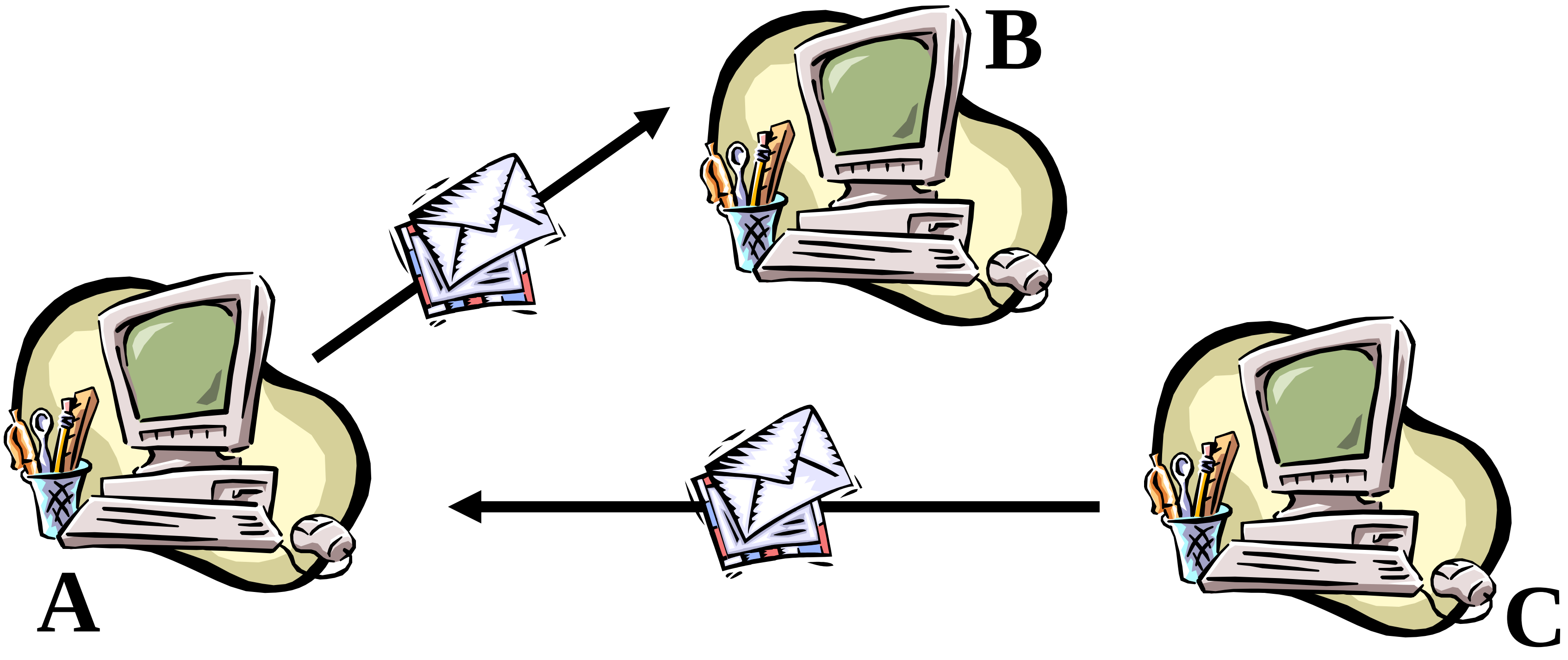
A distributed system



Shared memory model



Message passing model



Implementing a register

- From message passing to shared memory
- Implementing the register comes down to implementing ***Read()*** and ***Write()*** operations at every process

Implementing a register

- Before returning a ***Read()*** value, the process must communicate with other processes

- Before performing a ***Write(),*** i.e., returning the corresponding ok, the process must communicate with other processes

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A bogus algorithm

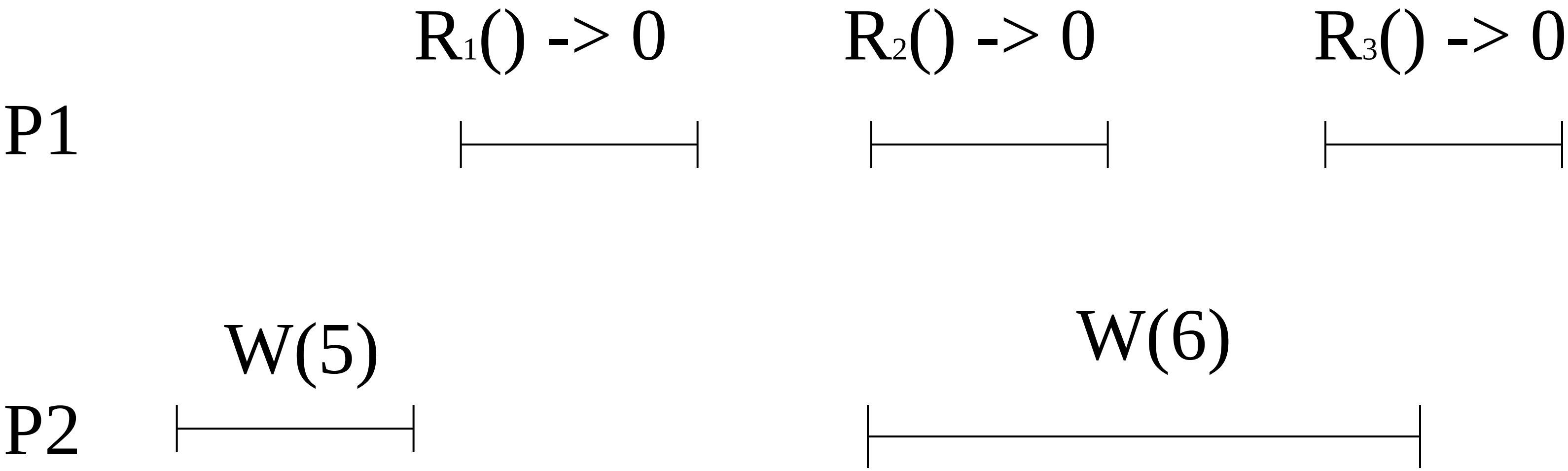
- We assume that channels are reliable (perfect point to point links)
- Every process pi holds a copy of the register value vi

A bogus algorithm

- Read() at pi
  - ✓ Return vi
- Write(v) at pi
  - ✓ vi := v
  - ✓ Return ok

- The resulting register is live but not safe:
  - ✓ Even in a sequential and failure-free execution, a ***Read()*** by pj might not return the last written value, say by pi

No safety



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A simplistic algorithm

- We still assume that channels are reliable but now we also assume that no process fails
- Basic idea: one process, say p1, holds the value of the register

A simplistic algorithm

- Read() at pi
  - ✓ send [R] to p1
  - ✓ when receive [v]
  - ✓ Return v
- Write(v) at pi
  - ✓ send [W,v] to p1
  - ✓ when receive [ok]
  - ✓ Return ok

- At p1:

T1:

when receive [R] from pi

send [v1] to pi

T2:

when receive [W,v] from pi

v1 := v

send [ok] to pi

Correctness (liveness)

- By the assumption that
  - ✓ (a) no process fails,
  - ✓ (b) channels are reliable

no wait statement blocks forever, and hence every invocation eventually terminates

Correctness (safety)

- (a) If there is no concurrent or failed operation, a ***Read()*** returns the last value written
- (b) A ***Read()*** must return some value concurrently written or the last value written
- NB. If a ***Read()*** returns a value written by a given ***Write(),*** and another ***Read()*** that starts later returns a value written by a different ***Write(),*** then the second ***Write()*** cannot start after the first ***Write()*** terminates

Correctness (safety – 1)

- (a) If there is no concurrent or failed operation, a ***Read()*** returns the last value written
  - Assume a Write(x) terminates and no other Write() is invoked. The value of the register is hence x at p1. Any subsequent Read() invocation by some process pj returns the value of p1, i.e., x, which is the last written value

Correctness (safety – 2)

- (b) A ***Read()*** returns the previous value written or the value concurrently written
  - Let x be the value returned by a Read(): by the properties of the channels, x is the value of the register at p1. This value does necessarily come from a concurrent or from the last Write().

What if?

- Processes might crash?
- If p1 crashes, then the register is not live (wait-free)
- If p1 is always up, then the register is regular and wait-free

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A fail-stop algorithm

- We assume a ***fail-stop*** model; more precisely:
  - any number of processes can fail by crashing (no recovery)
  - channels are reliable
  - failure detection is perfect (we have a perfect failure detector)

A fail-stop algorithm

- We implement a ***regular*** register
  - every process pi has a local copy of the register value vi
  - every process reads ***locally***
  - the writer writes ***globally,*** i.e., at all (non-crashed) processes

A fail-stop algorithm

- Write(v) at pi
  - send [W,v] to all
  - for every pj, wait until either:
    - receive [ack] or
    - suspect [pj]
  - Return ok

- At pi:

  when receive [W,v] from pj

  vi := v

  send [ack] to pj

- Read() at pi
  - Return vi

Correctness (liveness)

- ✓ A Read() is local and eventually returns

- ✓ A Write() eventually returns, by the
  - (a) the strong completeness property of the failure detector, and
  - (b) the reliability of the channels

Correctness (safety – 1)

- (a) In the absence of concurrent or failed operation, a Read() returns the last value written
  - Assume a Write(x) terminates and no other Write() is invoked. By the accuracy property of the failure detector, the value of the register at all processes that did not crash is x. Any subsequent Read() invocation by some process pj returns the value of pj, i.e., x, which is the last written value

Correctness (safety – 2)

- (b) A Read() returns the value concurrently written or the last value written
  - Let x be the value returned by a Read(): by the properties of the channels, x is the value of the register at some process. This value does necessarily come from the last or a concurrent Write().

What if?

- Failure detection is not perfect
- Can we devise an algorithm that implements a regular register and tolerates an arbitrary number of crash failures?

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Lower bound

- ***Proposition:*** any wait-free asynchronous implementation of a regular register requires a majority of correct processes
- Proof (sketch): assume a Write(v) is performed and n/2 processes crash, then a Read() is performed and the other n/2 processes are up: the Read() cannot see the value v
- The impossibility holds even with a 1-1 register (one writer and one reader)

The majority algorithm [ABD95]

- We assume that p1 is the writer and any process can be reader
- We assume that a majority of the processes is correct (the rest can fail by crashing – no recovery)
- We assume that channels are reliable
- Every process pi maintains a local copy of the register vi, as well as a sequence number sni and a read timestamp rsi
- Process p1 maintains in addition a timestamp ts1

Algorithm - Write()

- Write(v) at p1
  - ✓ ts1++
  - ✓ send [W,ts1,v] to all
  - ✓ when receive [W,ts1,ack] from majority
  - ✓ Return ok
- At pi
  - ✓ when receive [W,ts1, v] from p1
  - ✓ If ts1 > sni then
    - vi := v
    - sni := ts1
    - send [W,ts1,ack] to p1

Algorithm - Read()

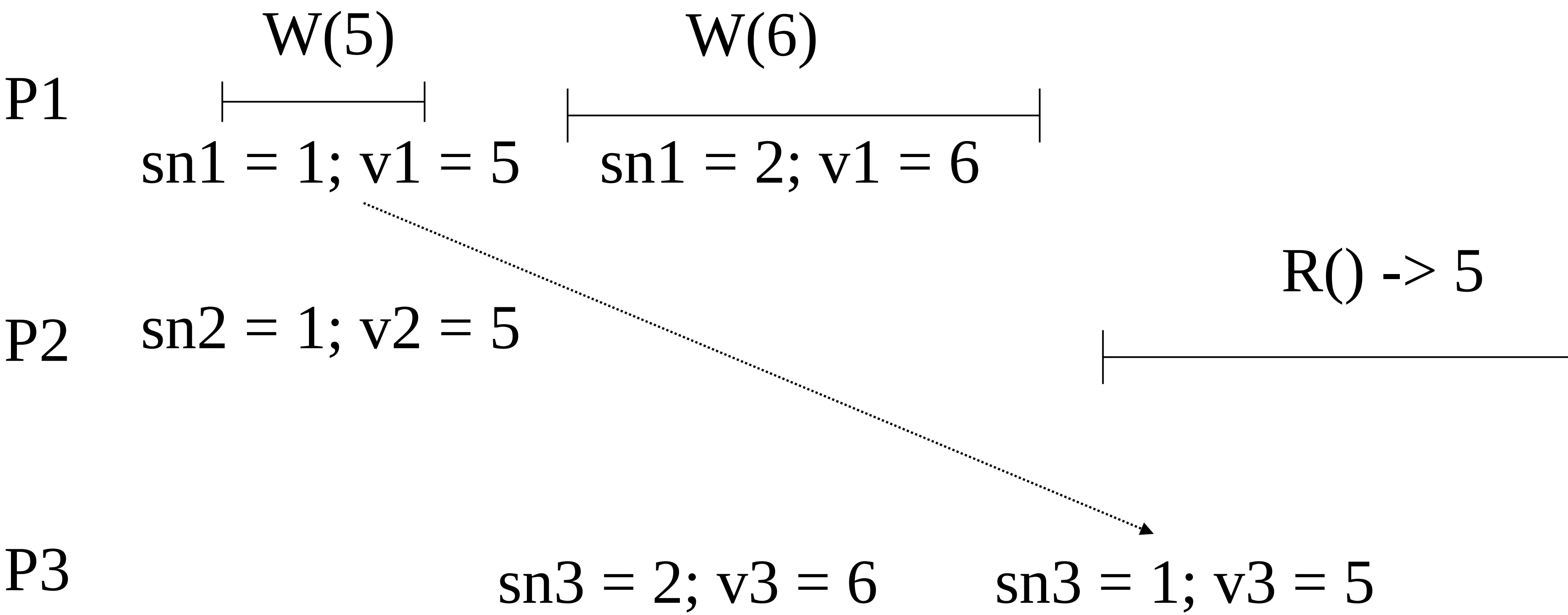
- Read() at pi
  - ✓ rsi++
  - ✓ send [R,rsi] to all
  - ✓ when receive [R, rsi,snj,vj] from majority
  - ✓ v := vj with the largest snj
  - ✓ Return v

- At pi
  - ✓ when receive [R,rsj] from pj
  - ✓ send [R,rsj,sni,vi] to pj

What if?

- Any process that receives a write message (with a timestamp and a value) updates its value and sequence number, i.e., without checking if it actually has an older sequence number

Old writes



Correctness 1

- ✓ Liveness: Any Read() or Write() eventually returns by the assumption of a majority of correct processes (if a process has a newer timestamp and does not send [W,ts1,ack], then the older Write() has already returned)

- ✓ Safety 2: By the properties of the channels, any value read is the last value written or the value concurrently written

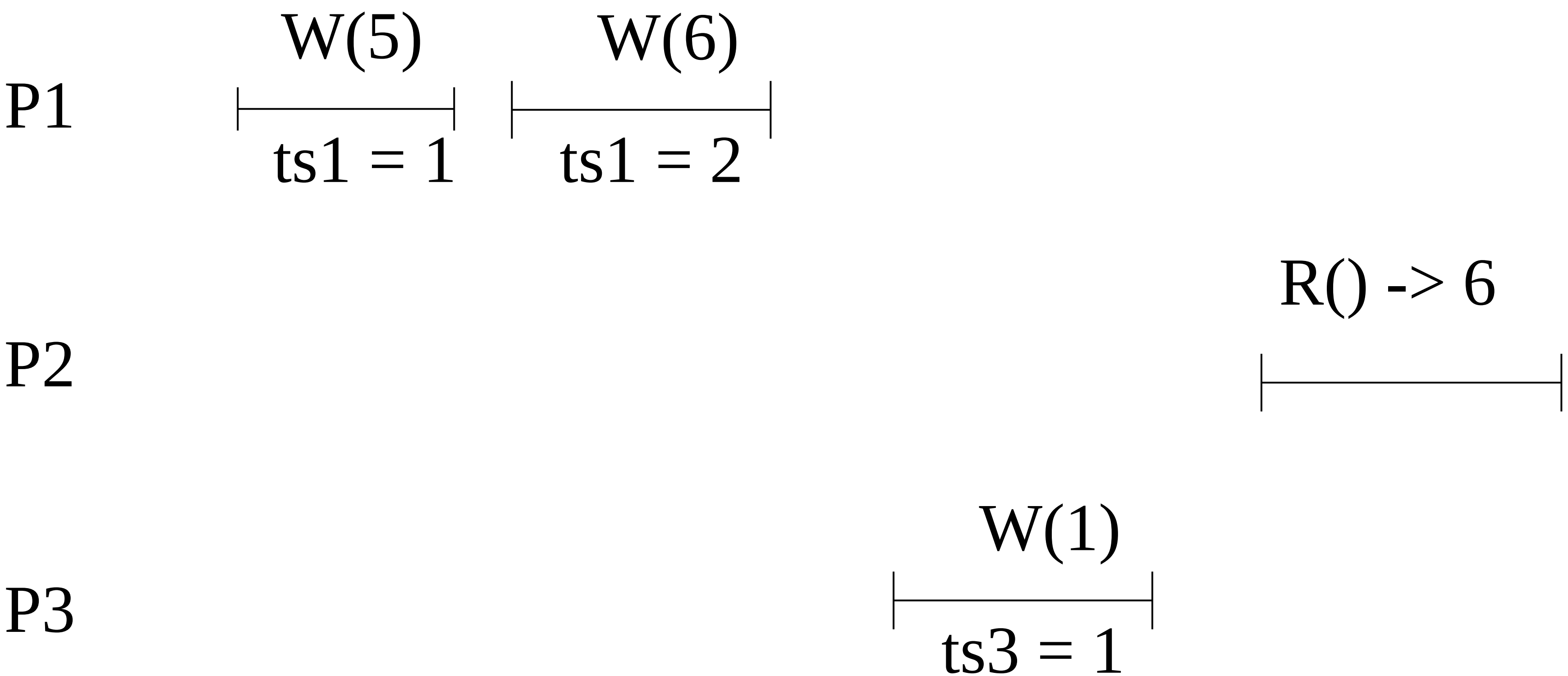
Correctness 2 (safety – 1)

- (a) In the absence of concurrent or failed operation, a Read() returns the last value written
  - Assume a Write(x) terminates and no other Write() is invoked. A majority of the processes have x in their local value, and this is associated with the highest timestamp in the system. Any subsequent Read() invocation by some process pj returns x, which is the last written value

What if?

- Multiple processes can write concurrently?

Concurrent writes



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