Demystifying Bitcoin

Prof R. Guerraoui EPFL

Have you heard about?

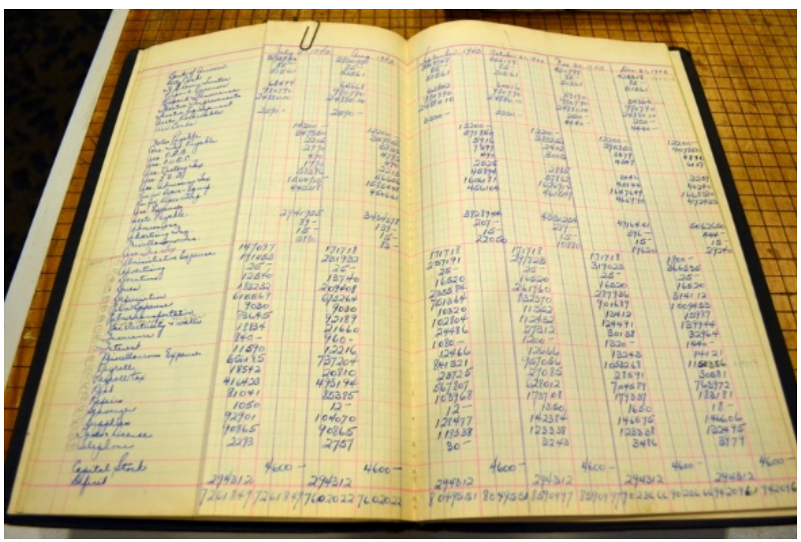
- Bitcoin
- Blockchain
- Ethereum
- Signatures
- Proof of work
- Smart contracts
- Turing Completeness
- NP vs P
- Consensus
- Snapshot

Perspectives

- (1) The journalist
  - (2) The user
    - (3) The participant
      - (4) The engineer
        - (5) The scientist

(1) The Journalist

- 2008: Financial crisis – Nakamoto (1/21m)
  - From 1c to 10000$ through 20000$
- From trading hardware to general trading
- 2014: Ethereum (CH) - Now 800 $
- 2020: Libra - FacebookCoin

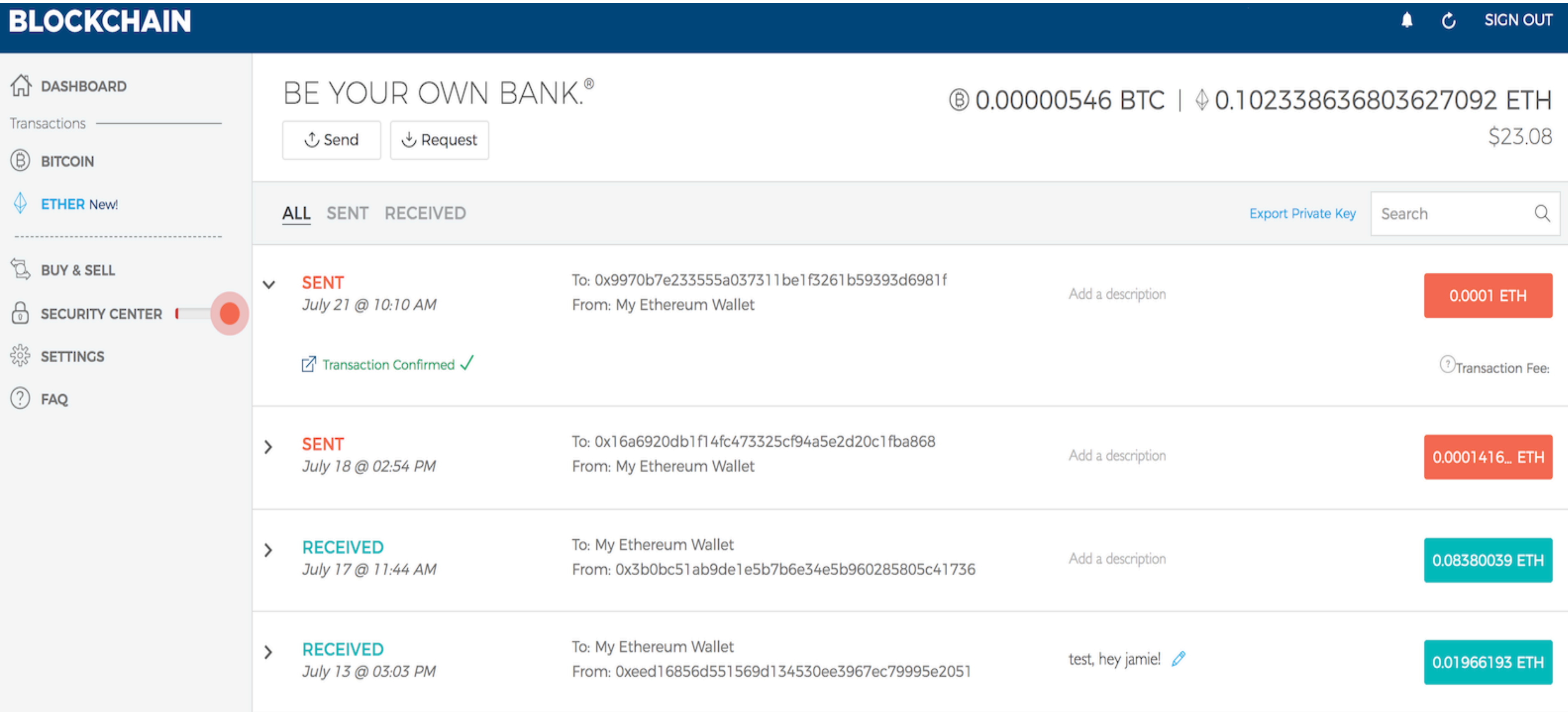


5	3			7				
6			1	9	5			
	9	8					6	
8				6				3
4			8		3			1
7				2				6
	6					2	8	
			4	1	9			5
				8			7	9

Perspectives

- (1) The journalist
    - (2) The user
        - (3) The participant
            - (4) The engineer
                - (5) The scientist

(2) The User


BLOCKCHAIN
SIGN OUT
DASHBOARD
Transactions
BITCOIN
ETHER New!
BUY & SELL
SECURITY CENTER
SETTINGS
FAQ
BE YOUR OWN BANK.®
Send
Request
0.00000546 BTC | 0.102338636803627092 ETH
$23.08
ALL SENT RECEIVED
Export Private Key
Search
SENT
July 21 @ 10:10 AM
To: 0x9970b7e233555a037311be1f3261b59393d6981f
From: My Ethereum Wallet
Add a description
0.0001 ETH
Transaction Confirmed
Transaction Fee:
SENT
July 18 @ 02:54 PM
To: 0x16a6920db1f14fc473325cf94a5e2d20c1fba868
From: My Ethereum Wallet
Add a description
0.0001416... ETH
RECEIVED
July 17 @ 11:44 AM
To: My Ethereum Wallet
From: 0x3b0bc51ab9de1e5b7b6e34e5b960285805c41736
Add a description
0.08380039 ETH
RECEIVED
July 13 @ 03:03 PM
To: My Ethereum Wallet
From: 0xeed16856d551569d134530ee3967ec79995e2051
test, hey jamie!
0.01966193 ETH

(2) The User

- The wallet: 1 private key + several public keys

- Transaction validation
  - Signing + gossiping + mining + chaining

- Transaction commitment
  - After time t: thousands of users have seen it

(3) The Participant

Honey, I'm home!

I found a block today!

5	3			7				
6			1	9	5			
	9	8					6	
8				6				3
4			8		3			1
7				2				6
	6					2	8	
			4	1	9			5
				8			7	9

Miner Jack

(3) The Participant

(3) The Participant

- To validate a transaction, a miner has to solve a puzzle including it
  - Fairness and cooperation
- Incentive: 12 bitcoins / puzzle
  - 50 bitcoins 3 years ago
- Total: 21 millions bitcoins
  - Now: 17 millions

(4) The Engineer

- Joinning (a P2P network)
  - Signing (a transaction)
    - Gossiping (the transaction)
      - Gathering (a block)
        - Mining (proof of work - nonce)
          - Chaining (hash)
            - Gossiping (the block)
              - Committing/Aborting

TECHNOLOGIES OF A BLOCKCHAIN

Asymmetric Encryption
Transaction signing

Hash Functions
Transaction/block hashing as well as obfuscating public keys

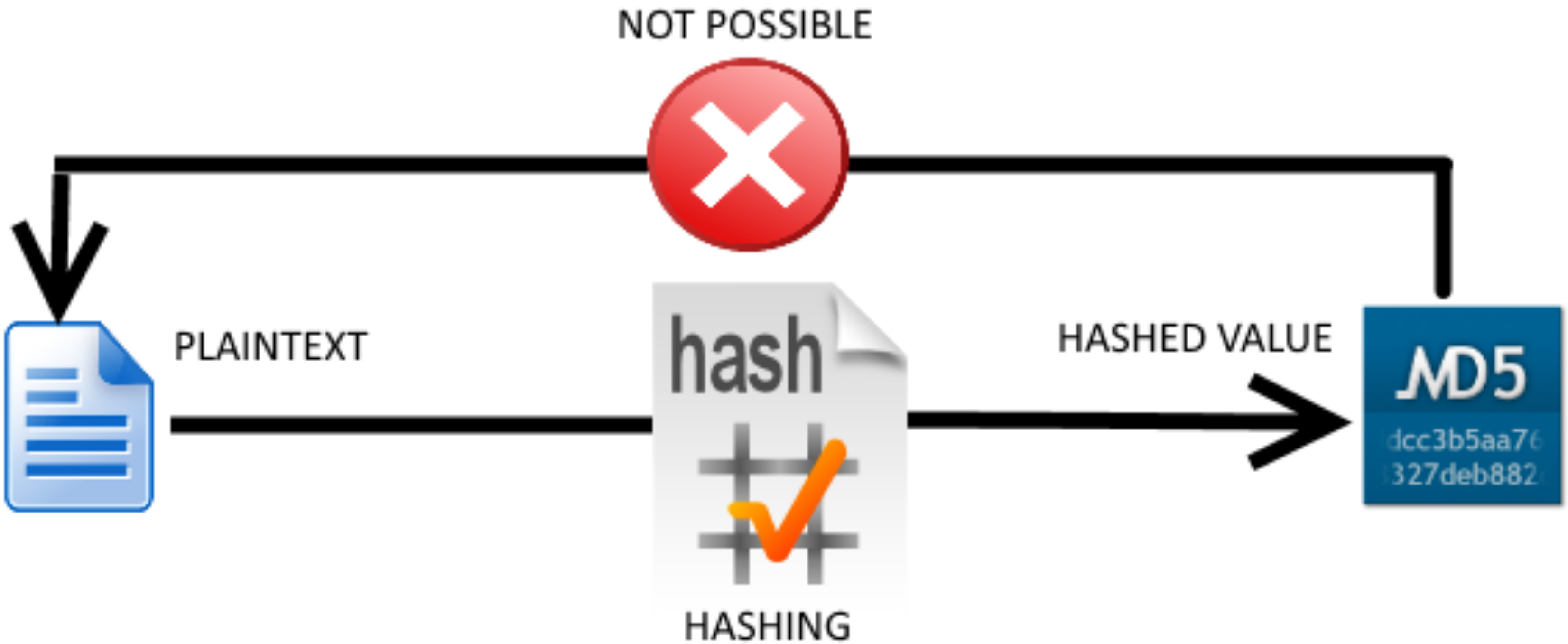
Merkle Trees
Efficient way to package transactions into blocks

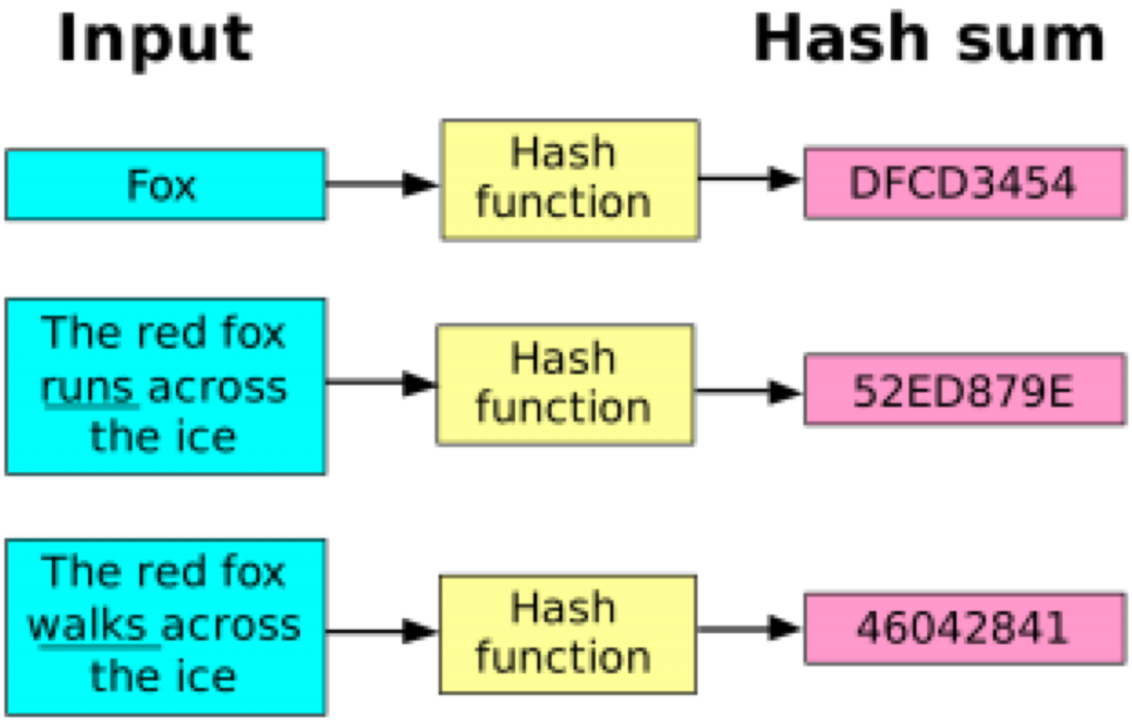
Key-Value Database
Lookups of previous transactions (prevent double-spends)

P2P Communication Protocol
Sharing transactions and blocks

Proof of Work
Method to achieve consensus

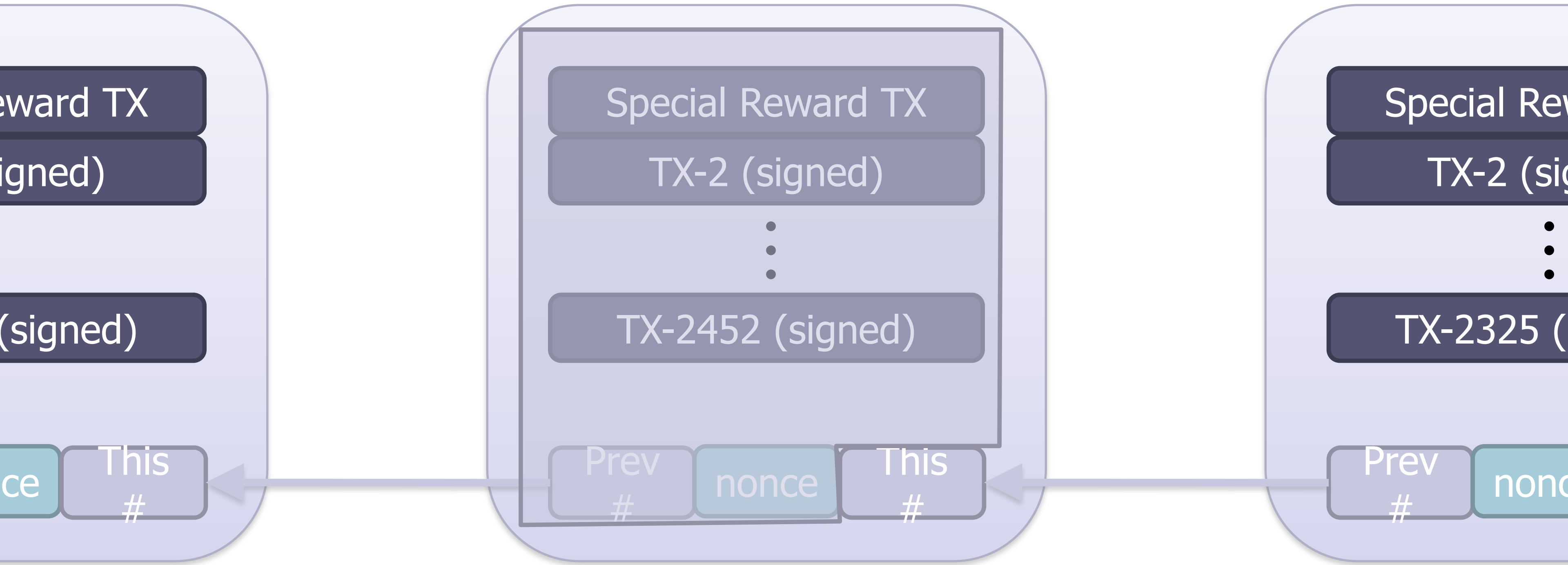
Hashing


NOT POSSIBLE
PLAINTEXT
hash
HASHED VALUE
MD5
dcc3b5aa76
327deb882
HASHING


Input
Hash sum
Fox
Hash function
DFCD3454
The red fox runs across the ice
Hash function
52ED879E
The red fox walks across the ice
Hash function
46042841

The Big Picture

Bitcoin block

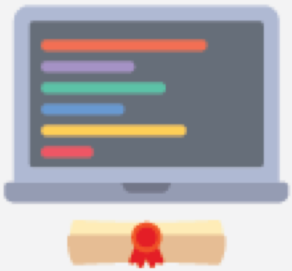


Mining: find nonce such that This # < *d*

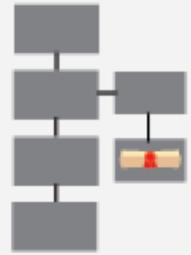
How? By trying different nonces (brute force)


Block:
1
Nonce:
2790
Data:
NCore
Hash:
0000c5f693ac77a18ae73ace5df932457fc62e8dfa23c2f3c6d8ebb125ba7843
Mine

Smart Contracts



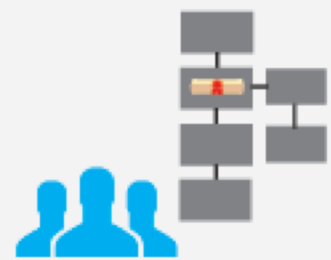
Option contract written as code into a blockchain.



Contract is part of the public blockchain.

Parties involved in the contract are anonymous.

Contract executes itself when the conditions are met.



Regulators use blockchain to keep an eye on contracts.

GitHub, Inc. [US] https://github.com

```
    partner_1 = contract.storage[I_PARTNER_1]
    partner_2 = contract.storage[I_PARTNER_2]

    if state == S_PROPOSED and tx.sender == partner_2 and tx.data[0] == partner_1:
        contract.storage[I_STATE] = S_MARRIED

    else if state == S_MARRIED and tx.sender == partner_1 or tx.sender == partner_2:
        if tx.data[0] == TX_WITHDRAW:
            creator = contract.storage[I_WITHDRAW_CREATOR]
            if creator != 0 and contract.storage[I_WITHDRAW_TO] == tx.data[1] and contract.storage[I_WITHDRAW_AMOUNT] == tx.d
                mktx(tx.data[1], tx.data[2], 0, 0)
                contract.storage[I_WITHDRAW_TO] = 0
                contract.storage[I_WITHDRAW_AMOUNT] = 0
                contract.storage[I_WITHDRAW_CREATOR] = 0
            else:
                contract.storage[I_WITHDRAW_TO] = tx.data[1]
                contract.storage[I_WITHDRAW_AMOUNT] = tx.data[2]
                contract.storage[I_WITHDRAW_CREATOR] = tx.sender

        else if tx.data[0] == TX_DIVORCE:
            creator = contract.storage[I_DIVORCE_CREATOR]
            if creator != 0 and creator != tx.sender:
                balance = block.account_balance(contract.address)
                mktx(partner_1, balance / 2, 0, 0)
                mktx(partner_2, balance / 2, 0, 0)
                contract.storage[I_STATE] = S_DIVORCED
```

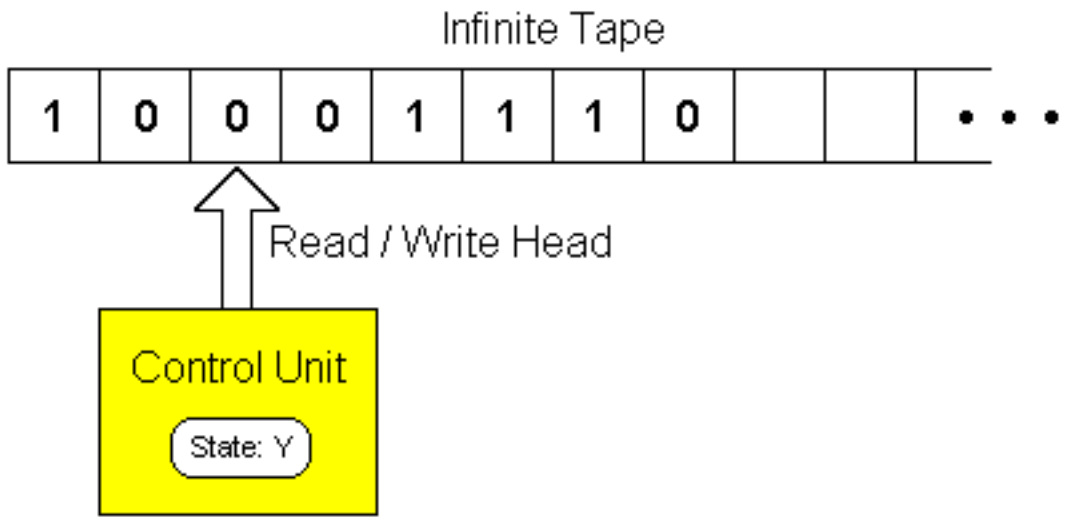
Perspectives

- (1) The journalist
- (2) The user
- (3) The participant
- (4) The engineer
- (5) The scientist

(5) The Scientist

- Conjecture 1: Turing Universality
- Conjecture 2: P is not NP
- Theorem 1: Lamport (Consensus) Universality
- Theorem 2: Consensus Impossibility

Turing Universality (36)



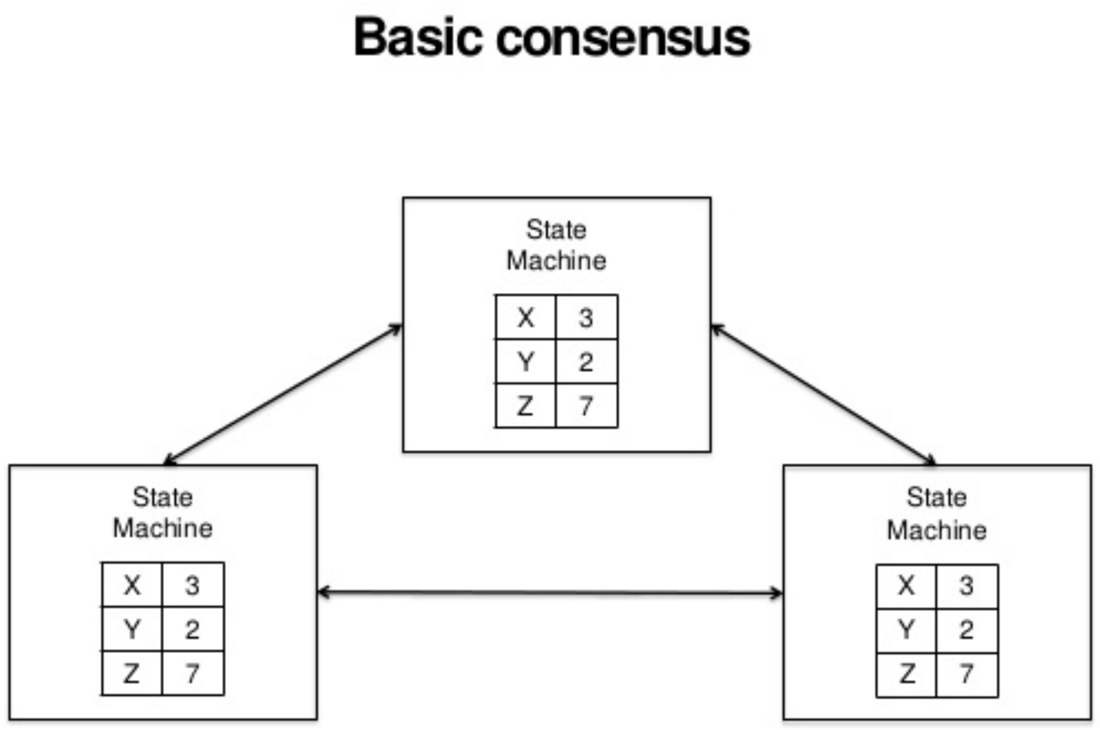
P vs NP (Nash/GV 50 – Ford 70)

$$? \; * \; ? \; = 91$$

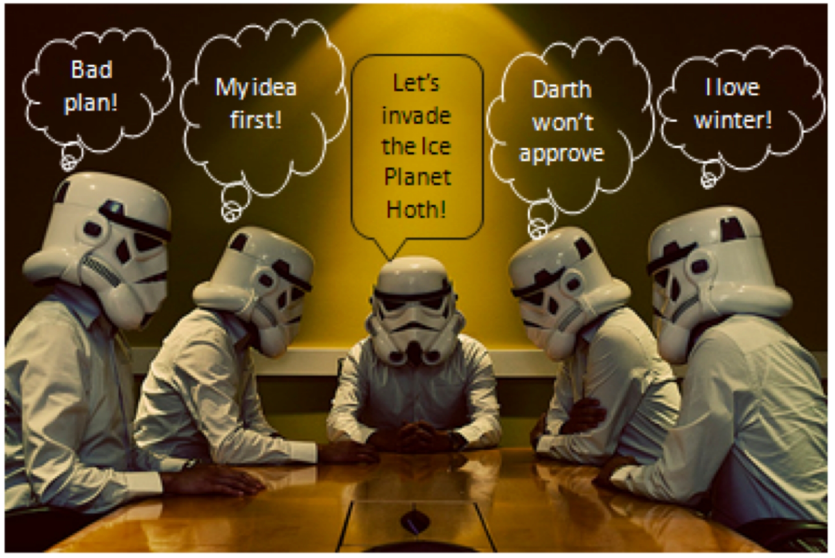
$$7 * 13 = ?$$

5	3			7				
6			1	9	5			
	9	8					6	
8				6				3
4			8		3			1
7				2				6
	6					2	8	
			4	1	9			5
				8			7	9

Lamport Universality (78)



Consensus Universality (78)



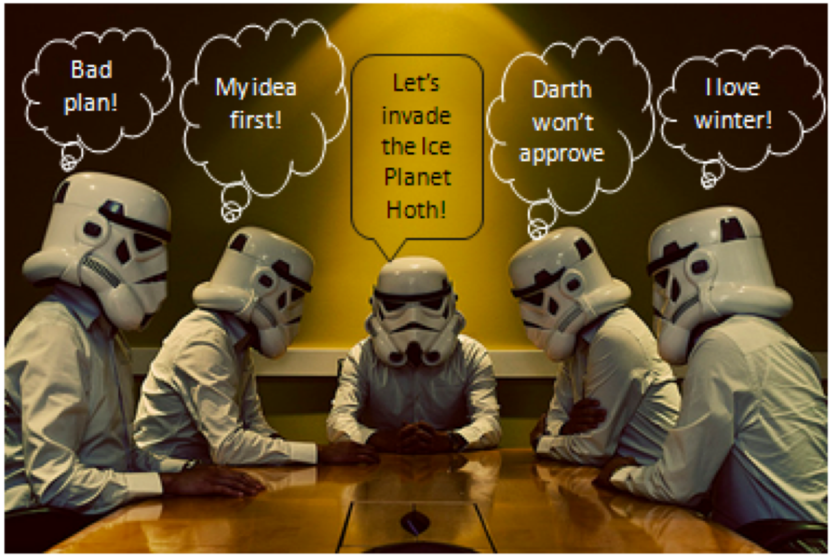
Safety: No two nodes must choose different values.

The chosen value must have been proposed by a node.

Liveness: Each node must eventually choose a value.

Every service can be implemented in a highly available manner using Consensus

Consensus Impossibility (84)

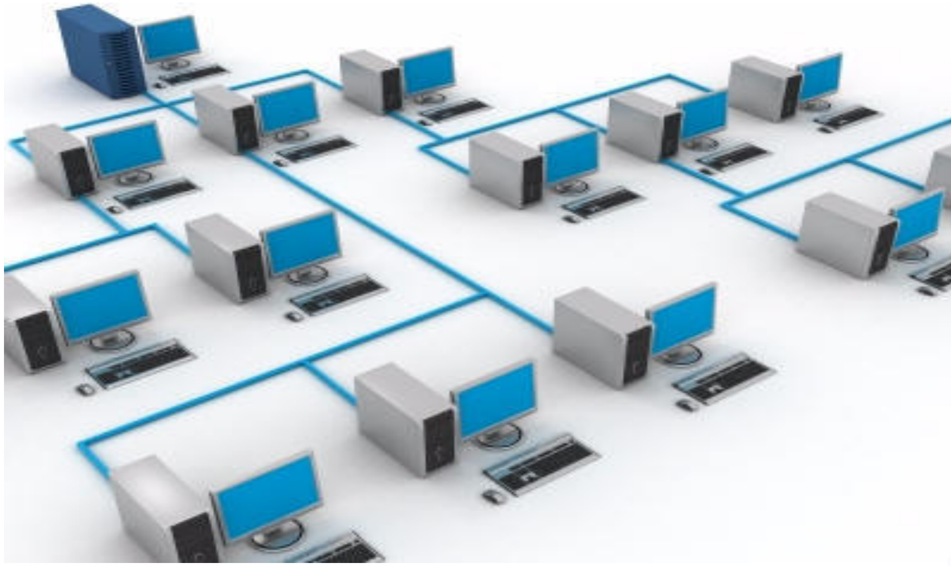


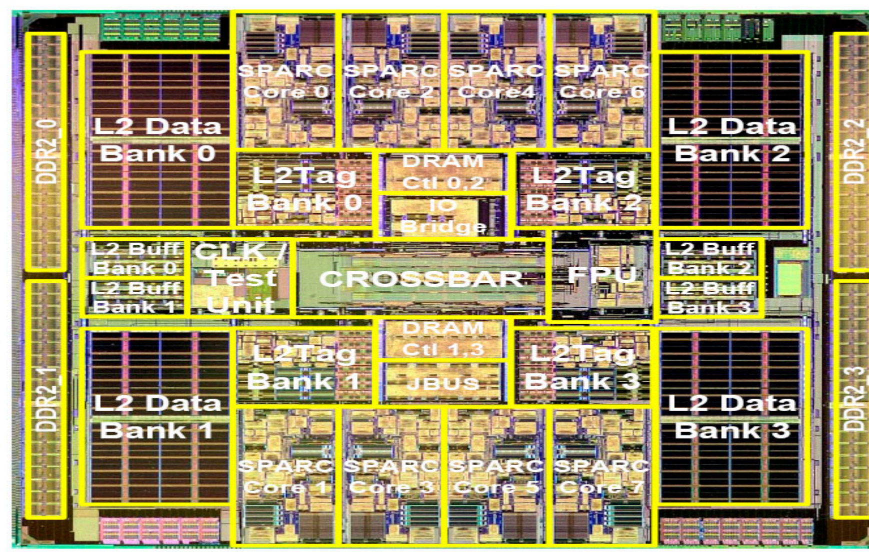
Consensus is impossible in an asynchronous system

Payment System

Can we implement a payment system asynchronously?

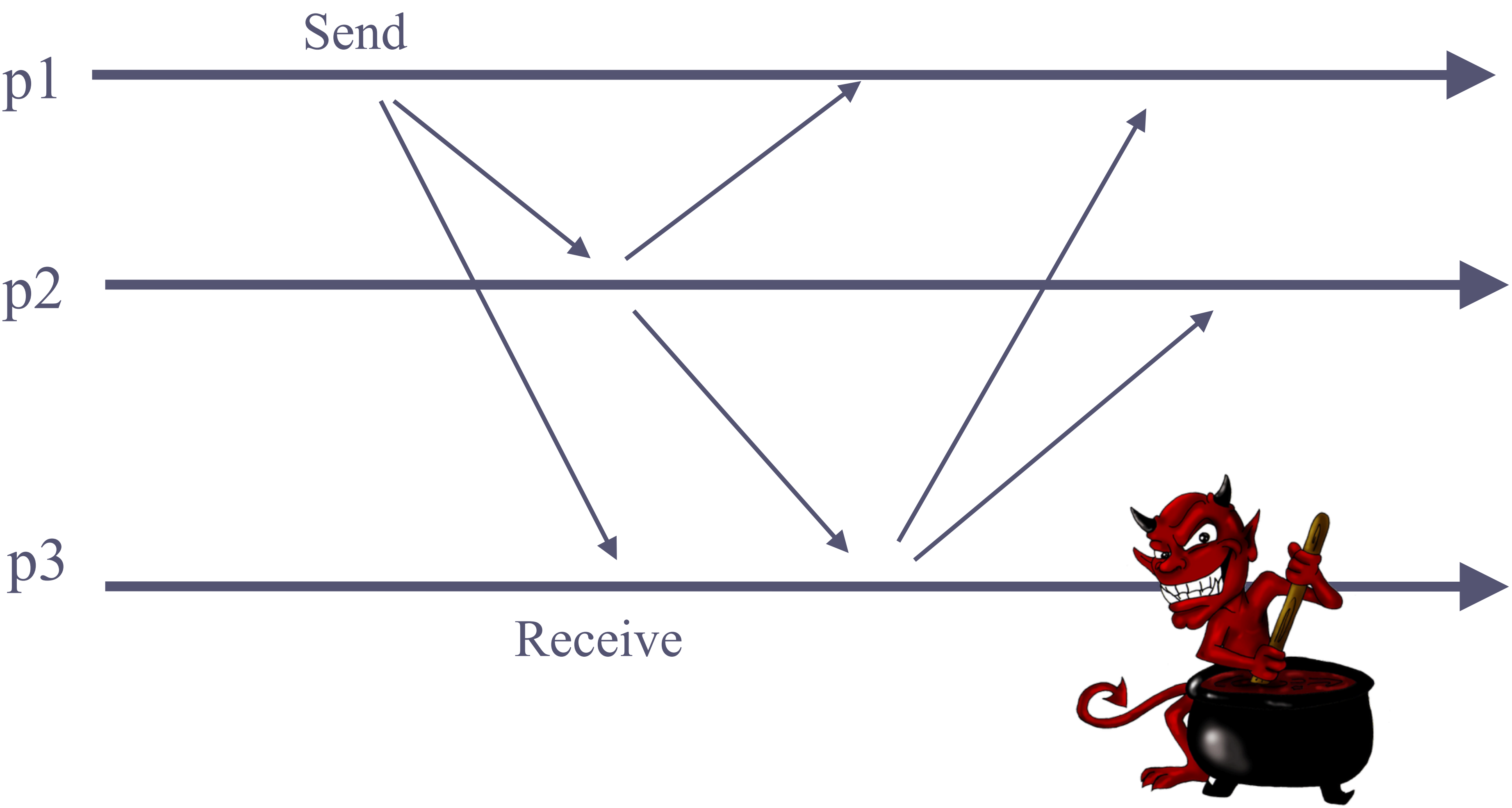
The infinitely big



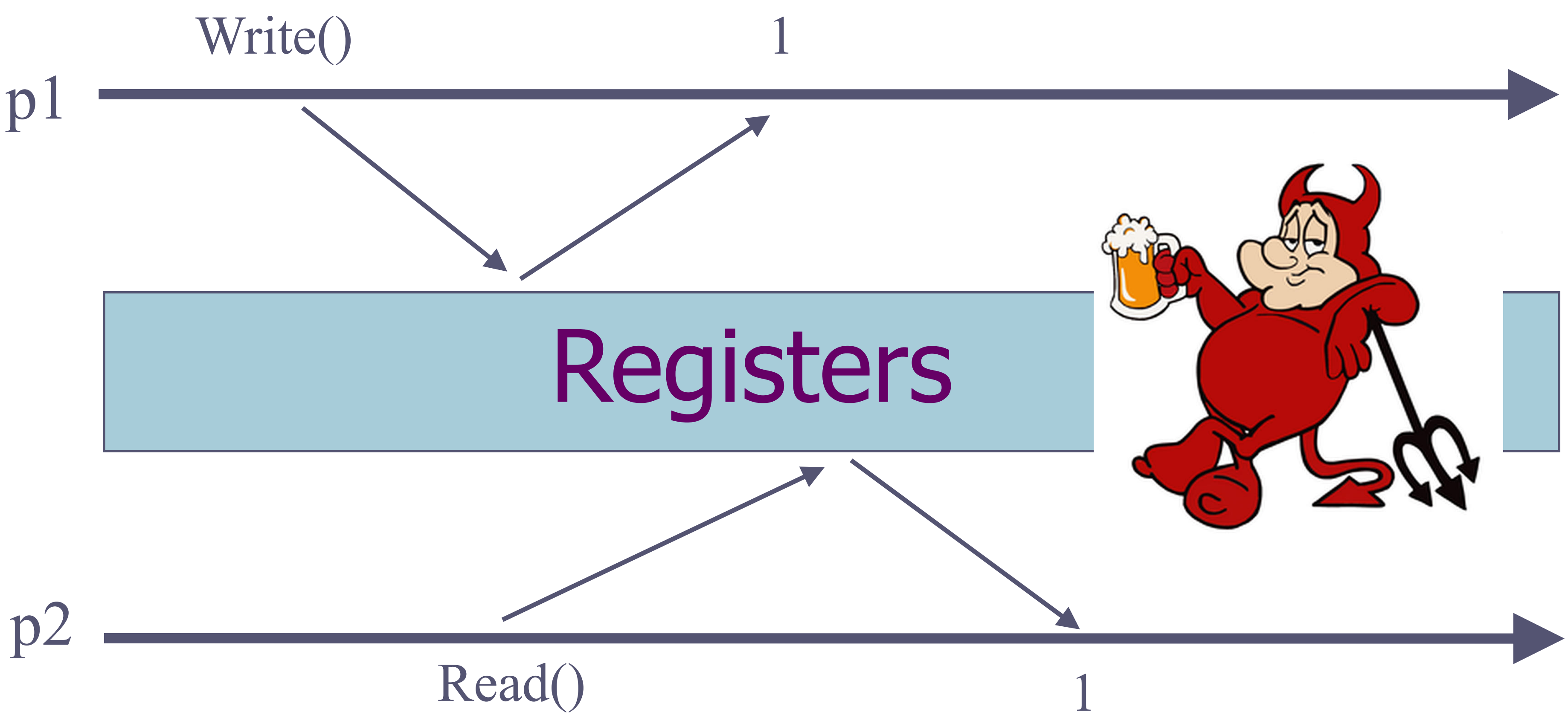


The infinitely small

Message Passing

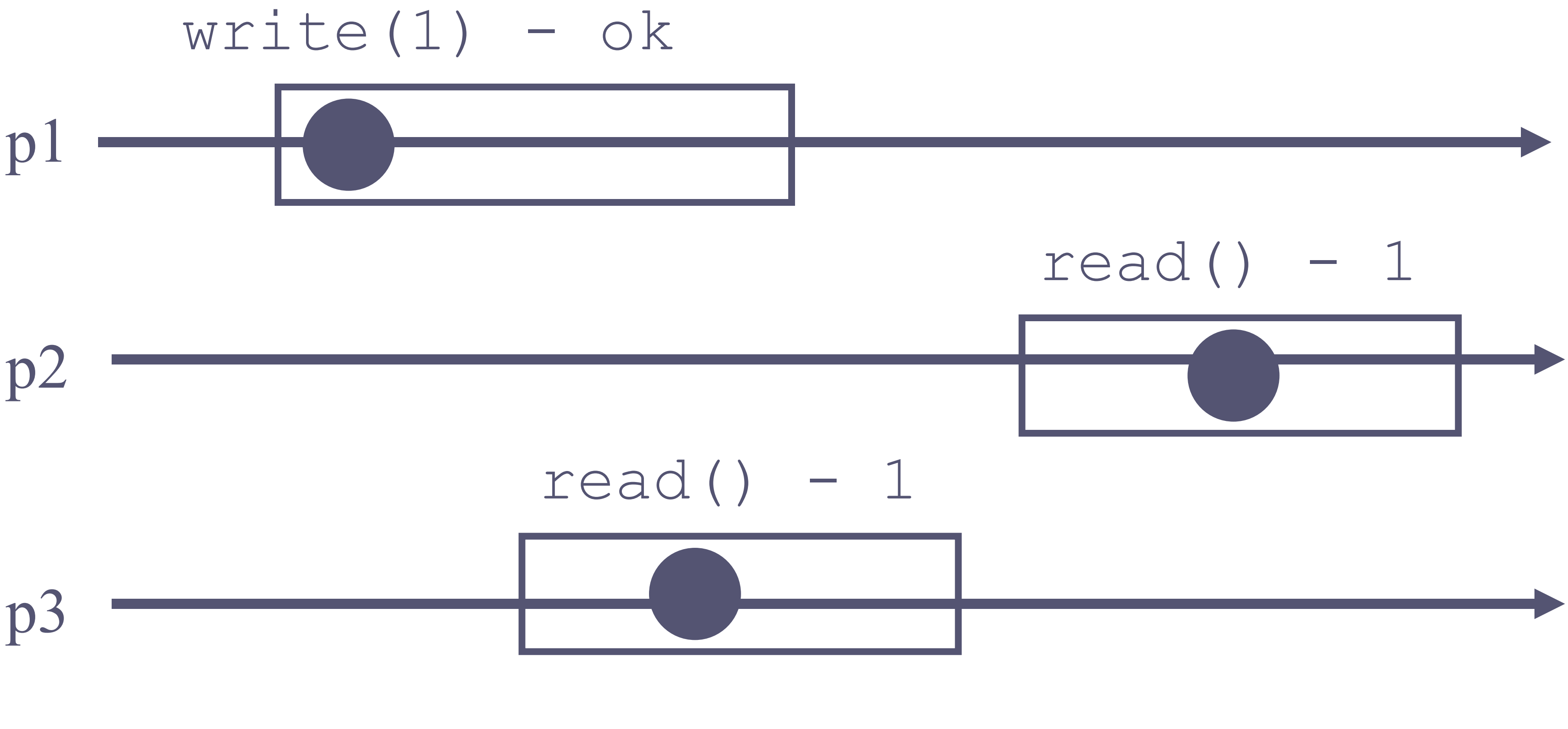


Shared Memory

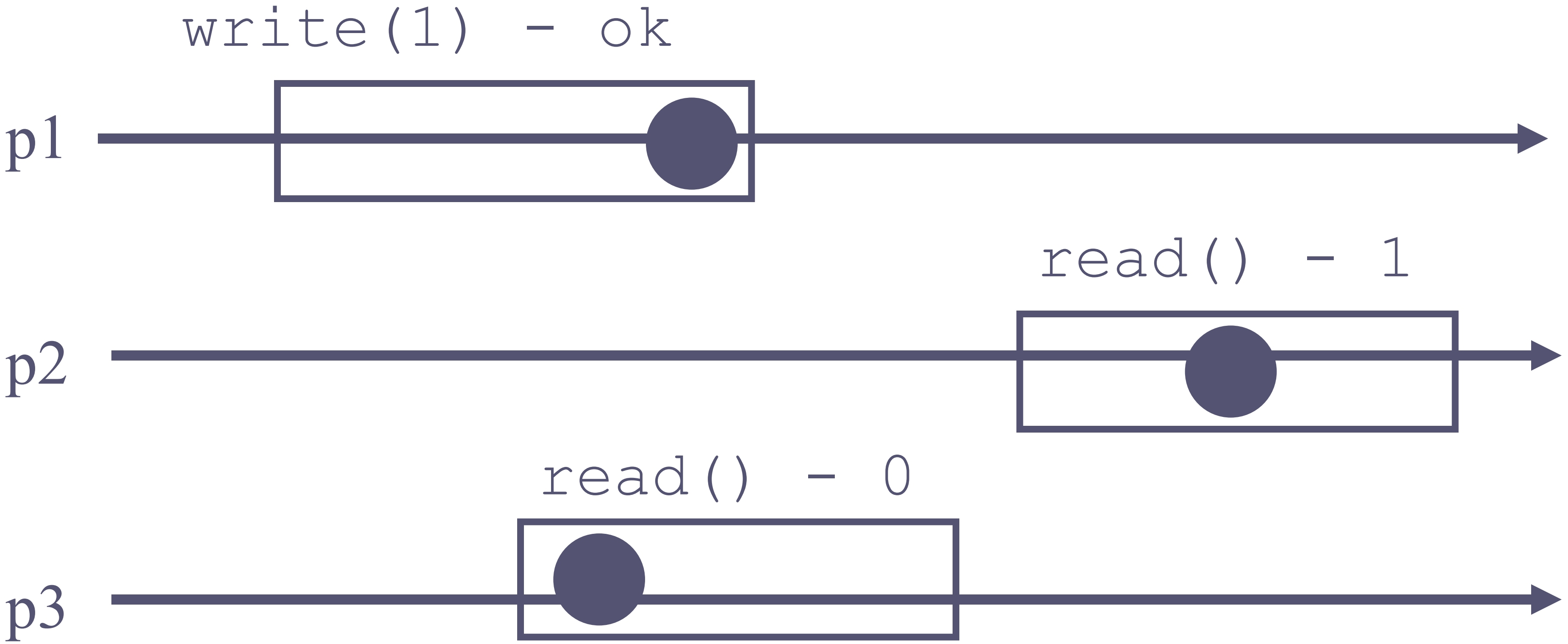


⇔ Message Passing

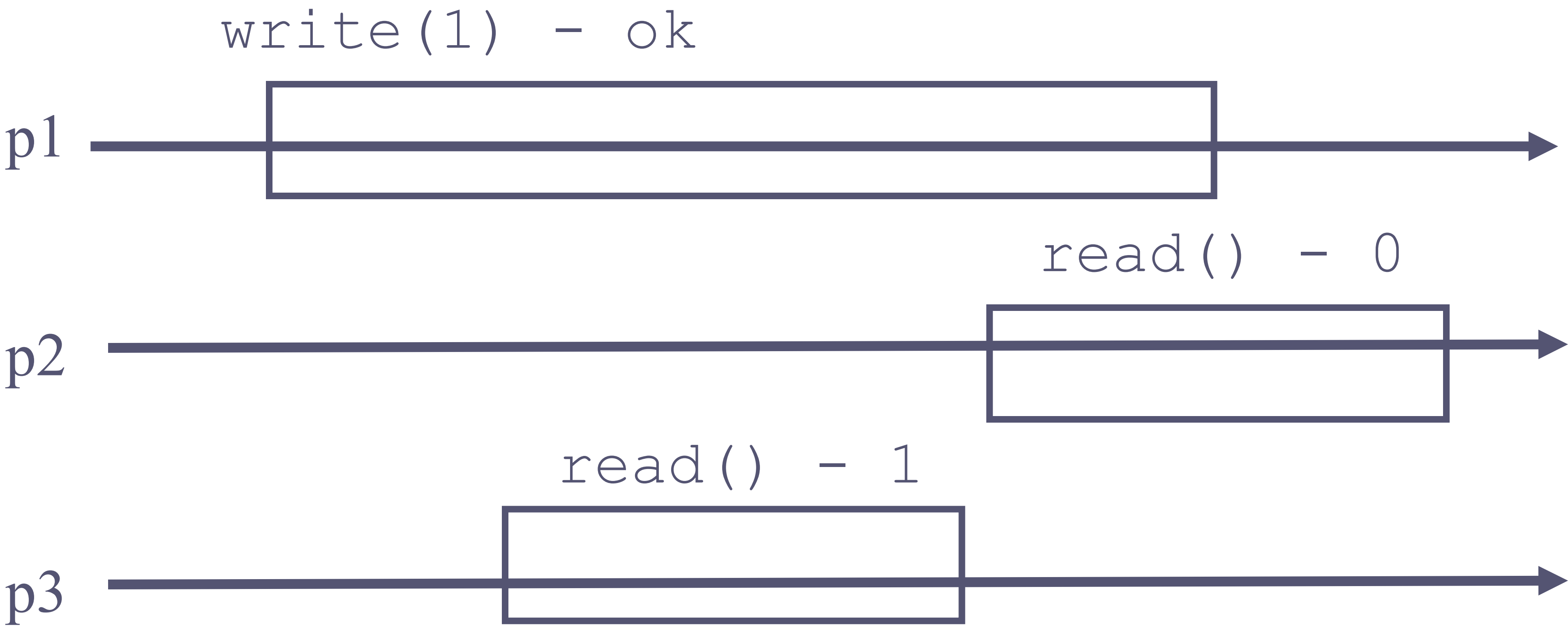
Atomic Shared Memory



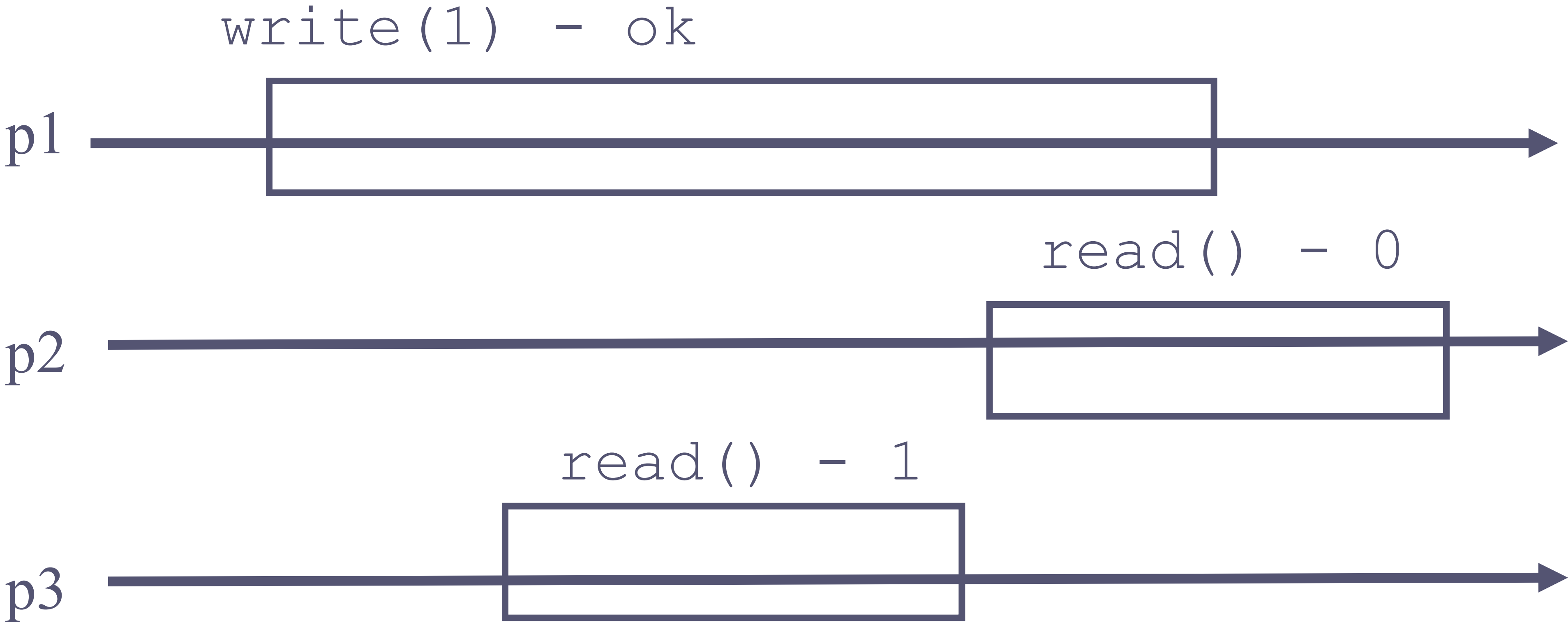
Atomic Shared Memory



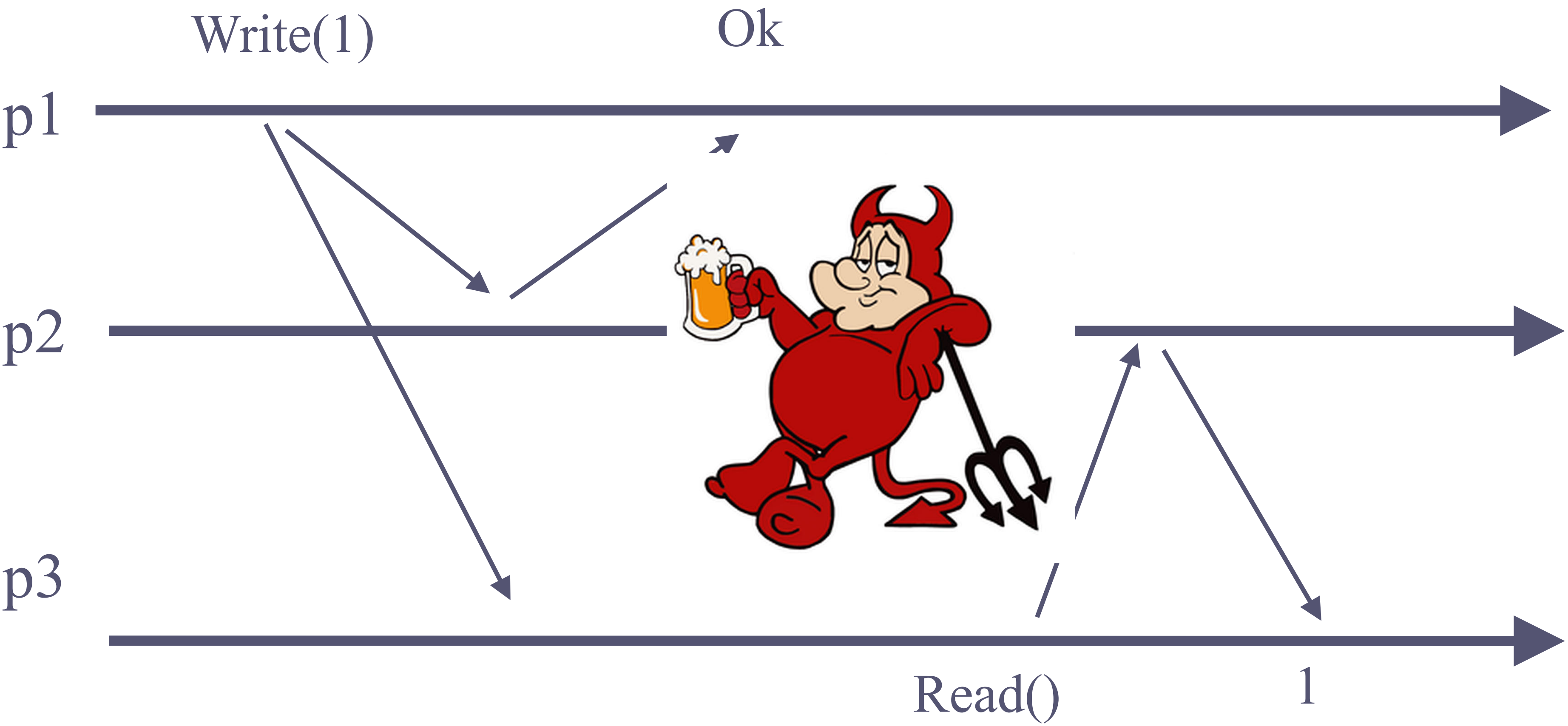
Non-Atomic Shared Memory



Non-Atomic Shared Memory

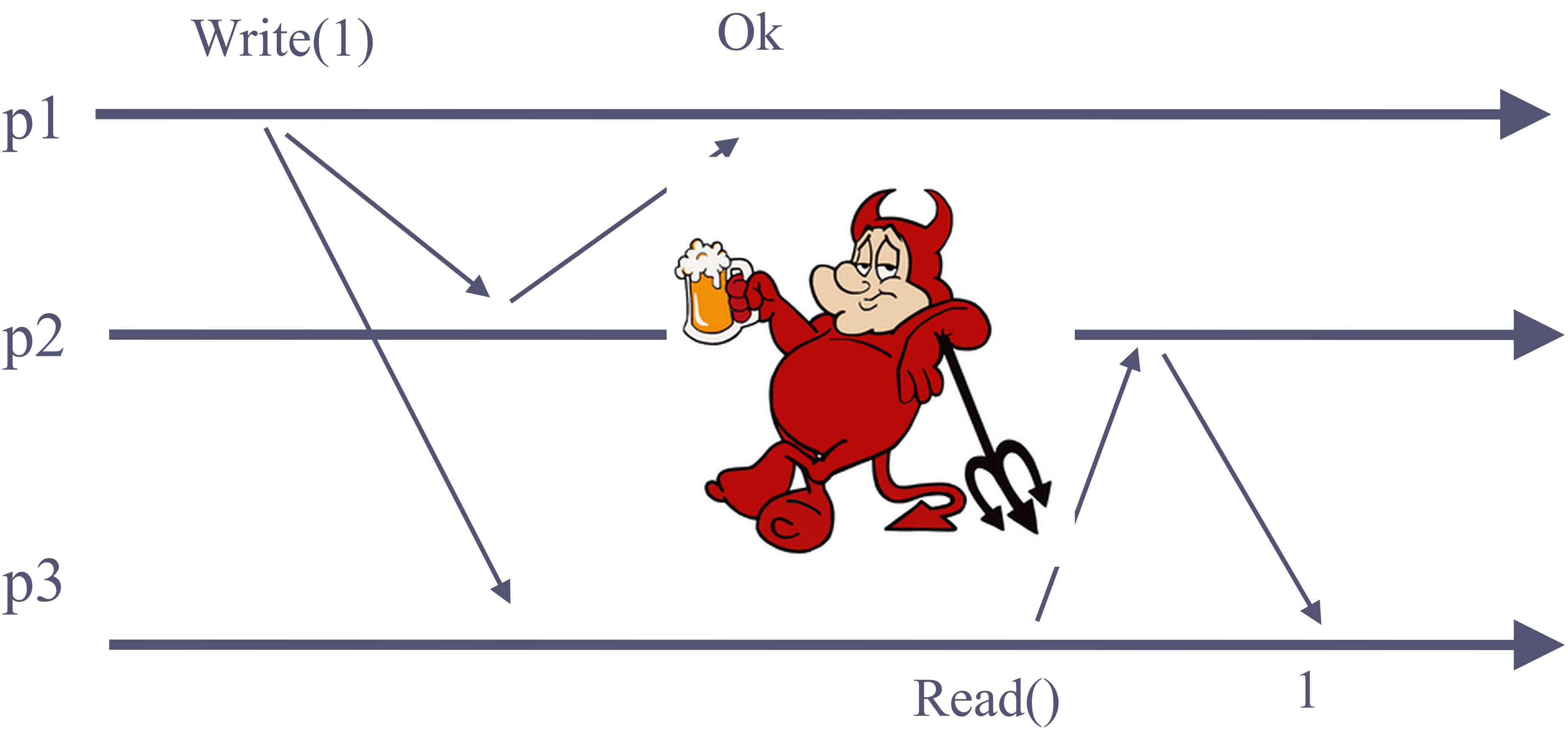


Message Passing ⇔ Shared Memory



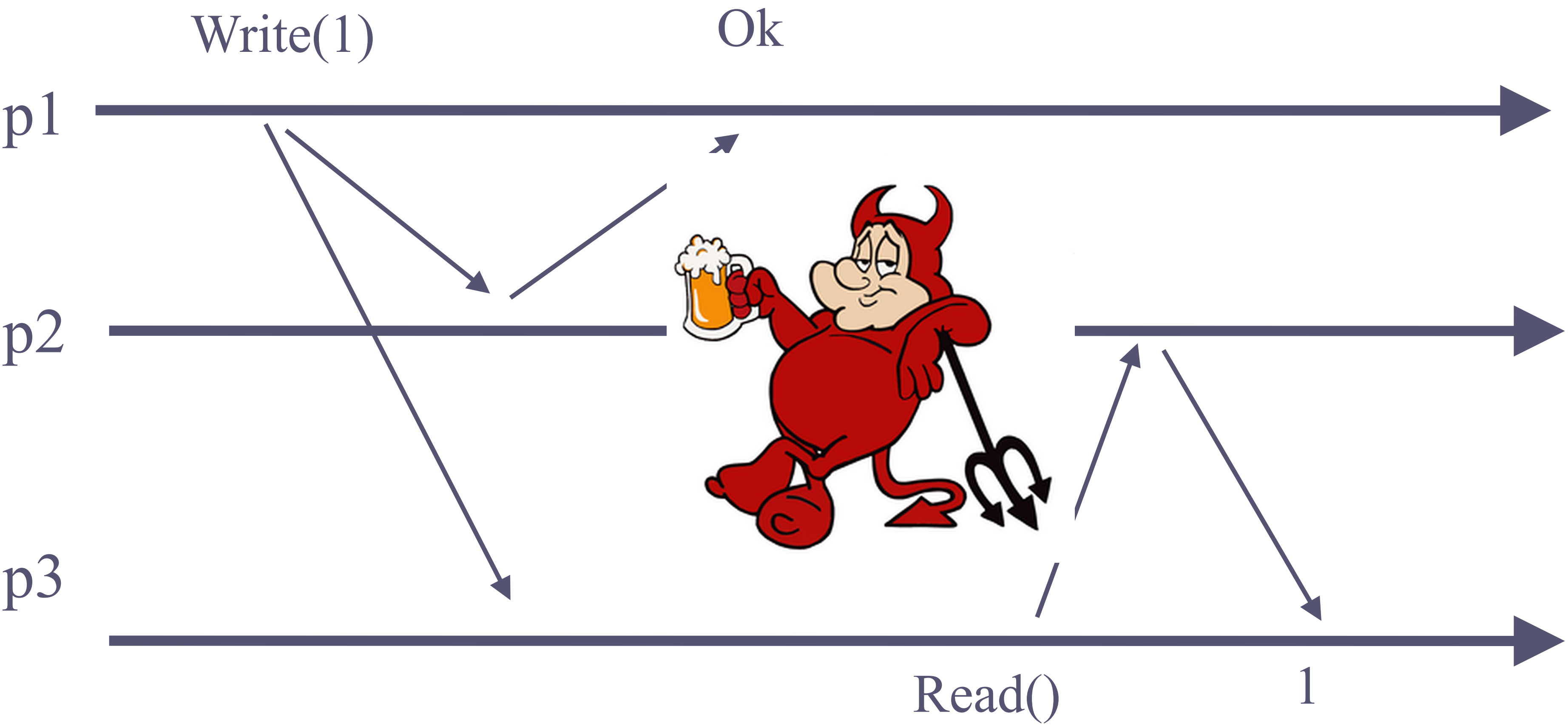
Quorums (asynchrony)

Message Passing ⇔ Shared Memory



Quorums (asynchrony)

Message Passing ⇔ Shared Memory



Quorums (asynchrony)

- « To understand a distributed computing problem: bring it to shared memory » T. Lannister

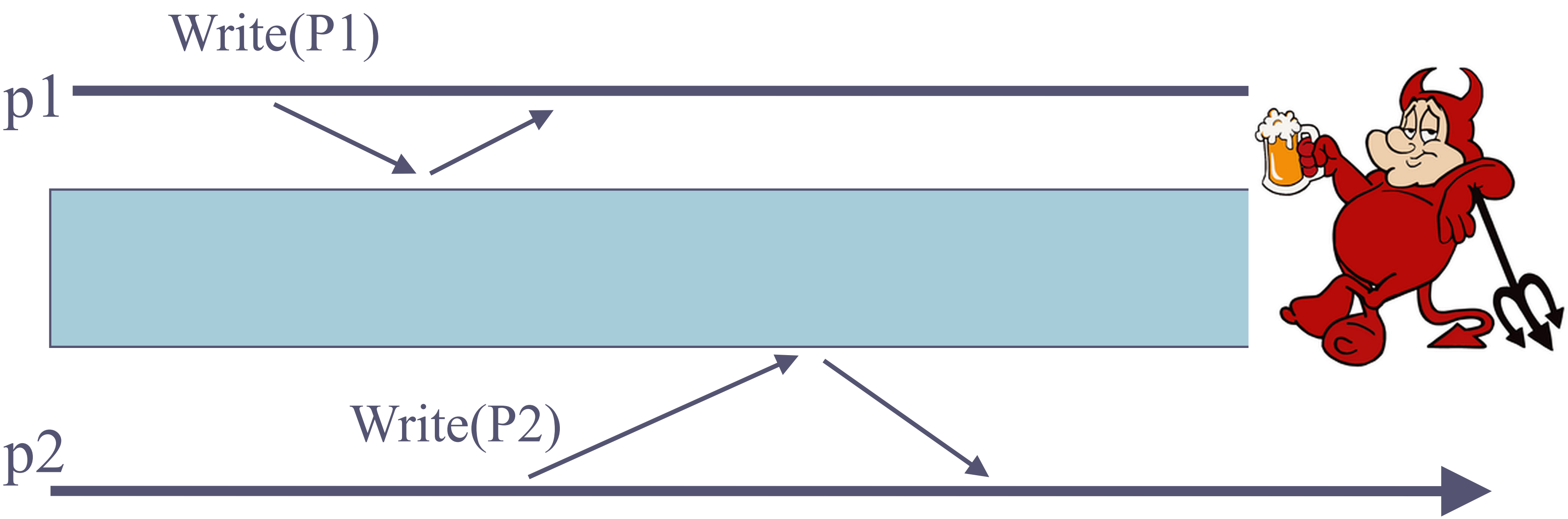
$\Leftrightarrow$

- « Optimization is the source of all evil » D. Knuth

P vs NP

$7 * 13 = ?$ $? * ? = 91$

Asynchronous vs Synchronous



Payment System

- Atomicity
- Wait-freedom

Can we implement a payment system asynchronously?

Counter: Specification

- A *counter* has two operations *inc()* and *read()*; it maintains an integer *x init to 0*
- *read():*
  - return(x)
- *inc():*
  - x := x + 1;
  - return(ok)

Counter: Algorithm

- The processes share an array of registers Reg[1,..,N]
- *inc():*
  - Reg[i].write(Reg[i].read() +1);
  - return(ok)
- *read():*
  - sum := 0;
  - for j = 1 to N do
    - sum := sum + Reg[j].read();
  - return(sum)

Counter*: Specification

- *Counter** has, in addition, operation *dec()*
- *dec():*
  - if x > 0 then x := x - 1; return(ok)
  - else return(no)

Can we implement Counter* asynchronously?

2-Consensus with Counter*

- Registers R0 and R1 and Counter* C - initialized to 1
- Process pI:
- propose(vI)
- RI.write(vI)
- res := C.dec()
- if(res = ok) then
  - ✓ return(vI)
  - ✓ else return(R{1-I}.read())

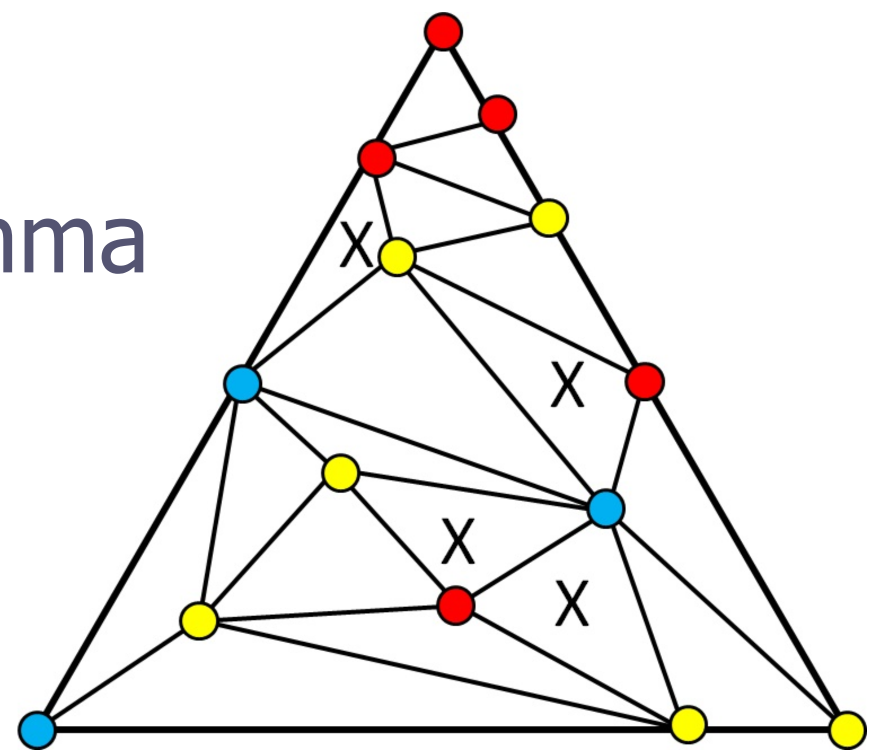
Impossibility [FLP85,LA87]

- ***Theorem**:* no *asynchronous* algorithm implements *consensus* among two processes using *registers*

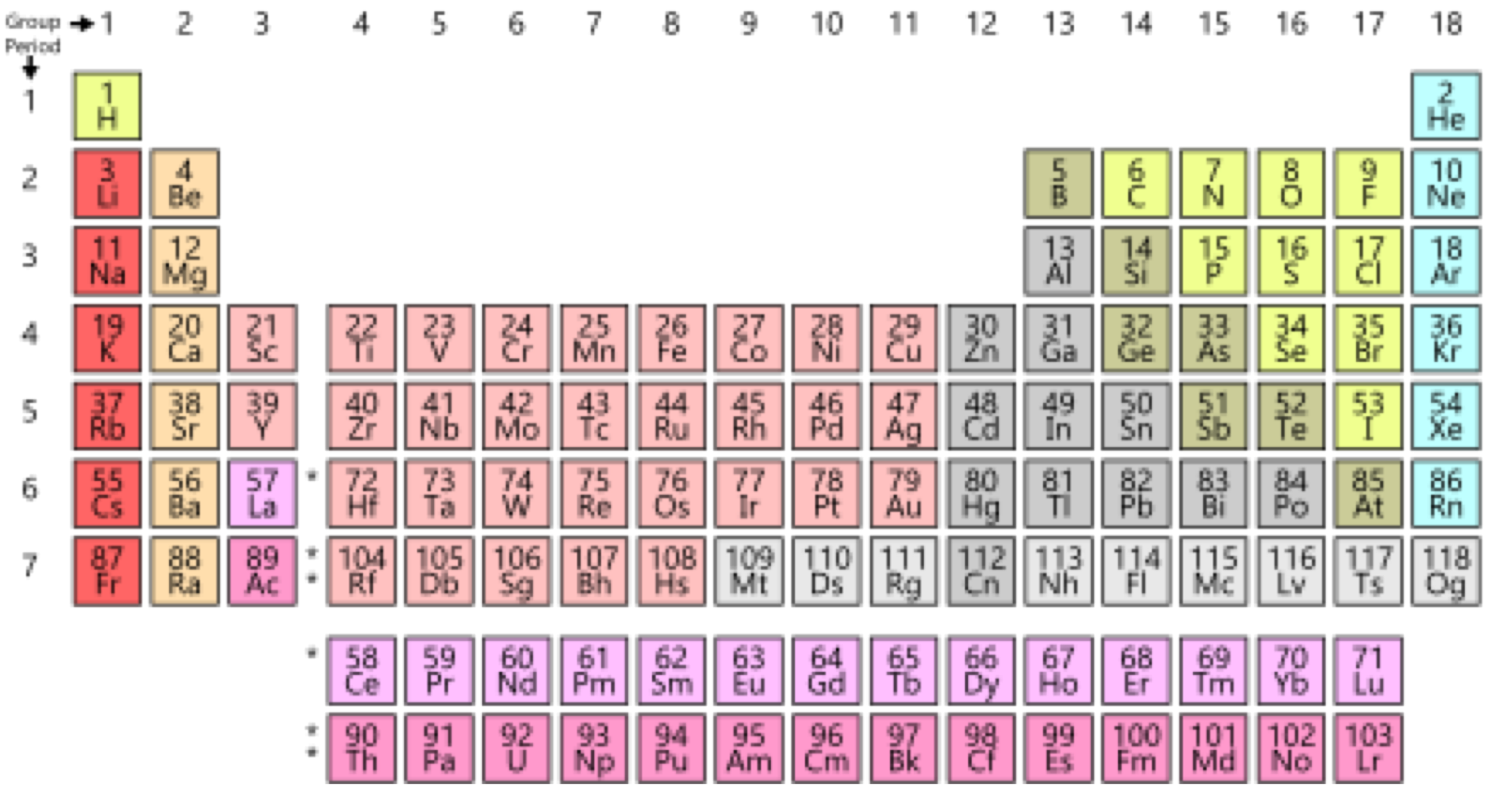
- ***Corollary**:* no asynchronous algorithm implements Counter* among two processes using *registers*

- ***Theorem:*** no *asynchronous* algorithm implements *set-agreement* using *registers*

Sperner's Lemma



- The **consensus number** of an object is the maximum number of processes than can solve consensus with it



Payment Object (PO): Specification

- Pay(a,b,x): transfer amount x from a to b if a > x (return ok; else return no)
- NB. Only the owner of a invokes Pay(a,*,*)

- ***Questions****:* can PO be implemented asynchronously? what is the consensus number of PO?

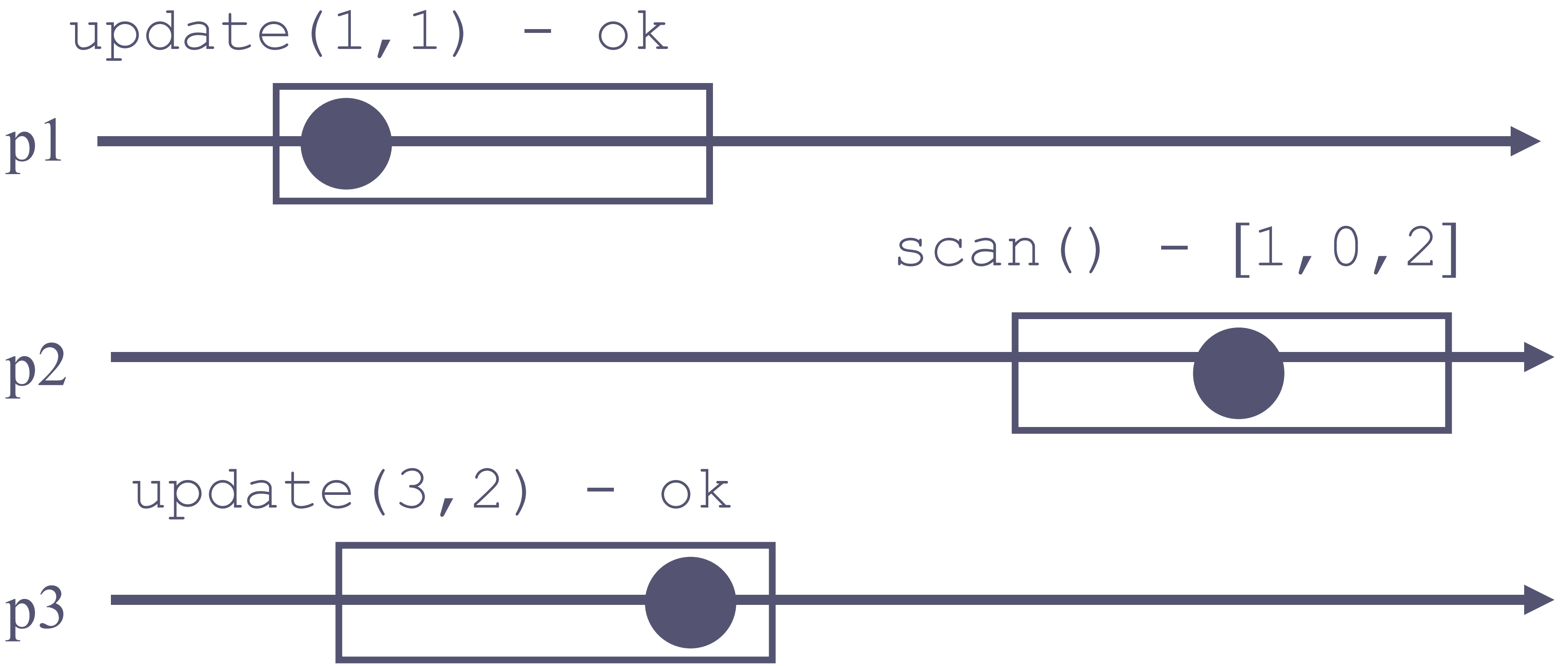
Snapshot: Specification

- A *snapshot* has operations *update()* and *scan()*; it maintains an array *x* of size *N*
- *scan():*
  - return(x)
- *update(i,v):*
  - x[i] := v;
  - return(ok)

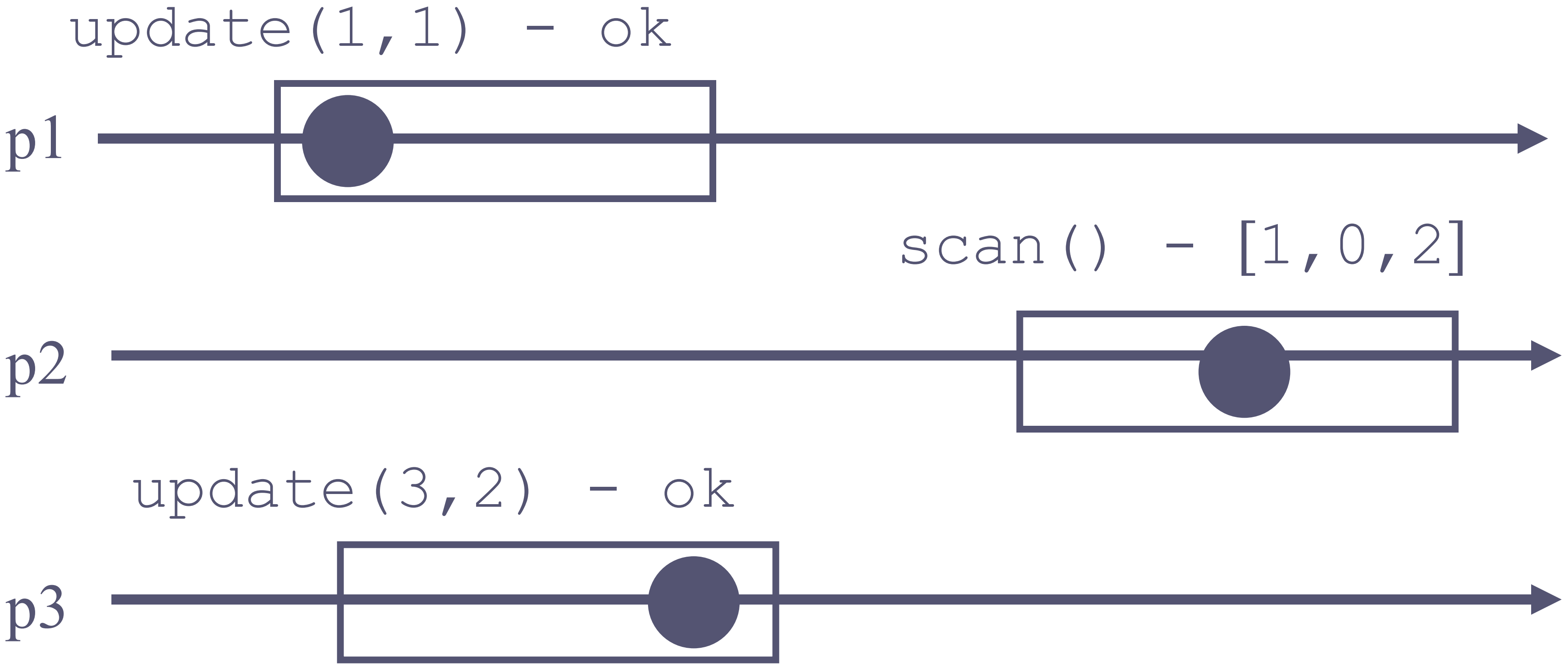
Algorithm?

- The processes share one array of N registers Reg[1,..,N]
- *scan():*
  - for j = 1 to N do
    - x[j] := Reg[j].read();
  - return(x)
- *update(i,v):*
  - Reg[i].write(v); return(ok)

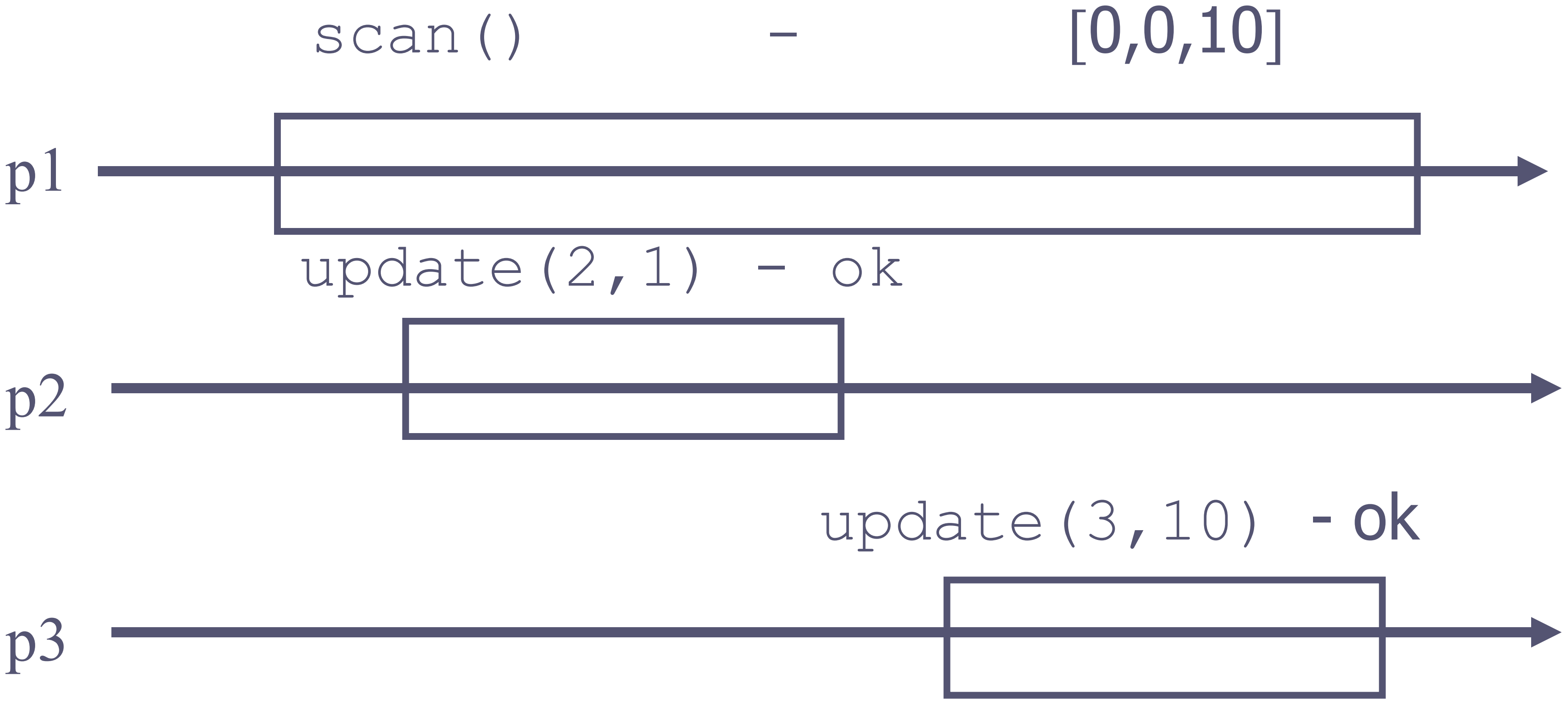
Atomicity?



Atomicity?



Atomicity?



Key idea for atomicity

- To *scan*, a process keeps reading the entire snapshot (i.e., *collecting*), until two arrays are the same

Key idea for wait-freedom

- To update, scan then write the value and the scan
- To *scan*, a process keeps collecting and returns a collect if it did not change, or some collect returned by a concurrent *scan*

The Payment Object: Algorithm

- Every process stores the sequence of its outgoing payments in its snapshot location

- To ***pay***, the process scans, computes its current balance: if bigger than the transfer, updates and returns ok, otherwise returns no
- To ***read***, scan and return the current balance

PO can be implemented Asynchronously

Consensus number of PO is 1

Consensus number of PO(k) is k

(5) The Scientist

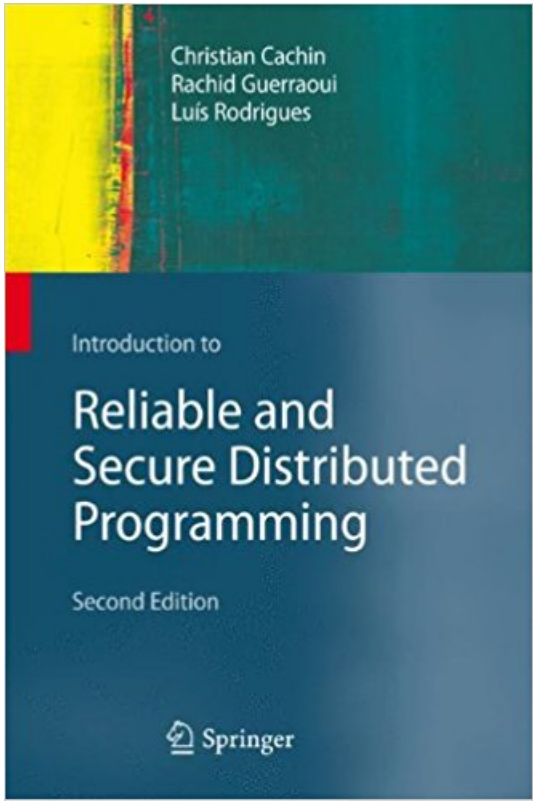
- Conjecture 1: Turing Universality
- Conjecture 2: P is not NP
- Theorem 1: Lamport (Consensus) Universality
- Theorem 2: Consensus Impossibility
- Theorem 3: PO < Consensus

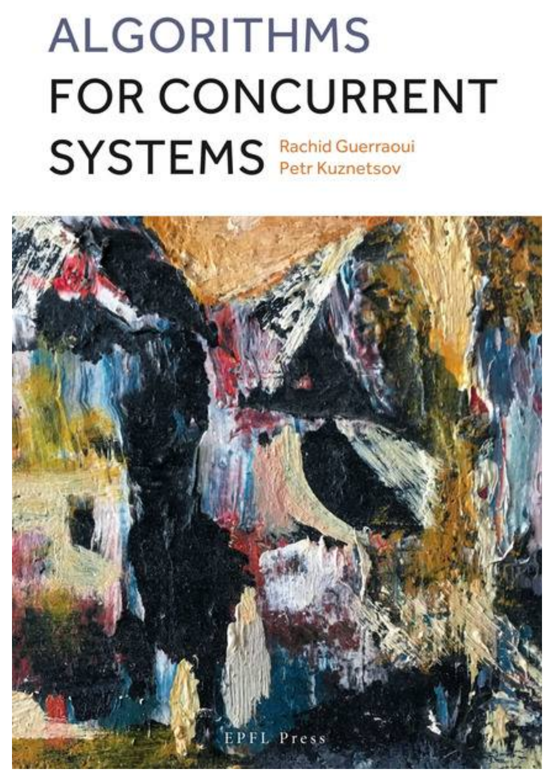
Payment System (AT2)

- **AT2_S**
  - **AT2_D**
    - **AT2_R**

- Number of lines of code: one order of magnitude less
- Latency: seconds (at most)

References


Christian Cachin
Rachid Guerraoui
Luís Rodrigues
Introduction to
Reliable and Secure Distributed Programming
Second Edition
Springer


ALGORITHMS
FOR CONCURRENT
SYSTEMS
Rachid Guerraoui
Petr Kuznetsov
EPFL Press