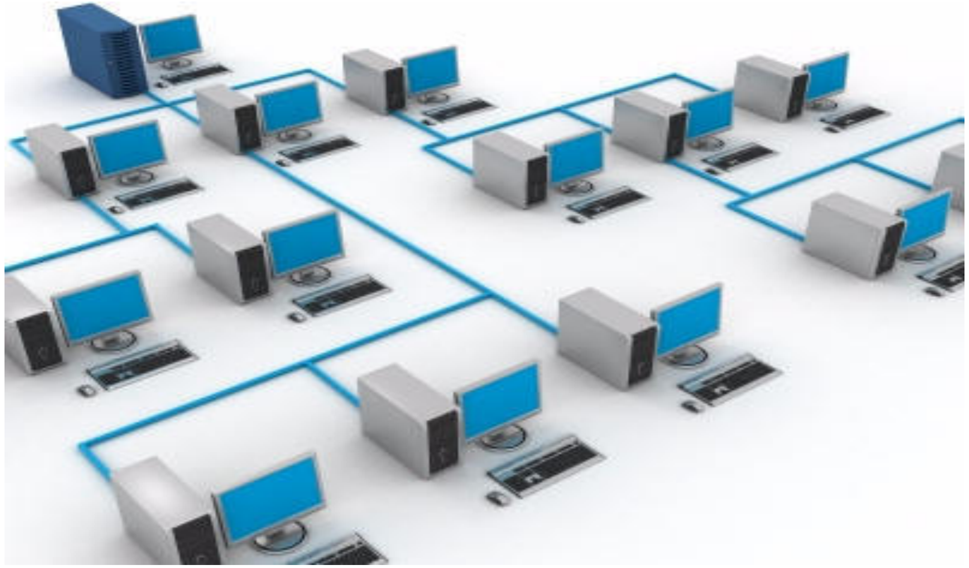
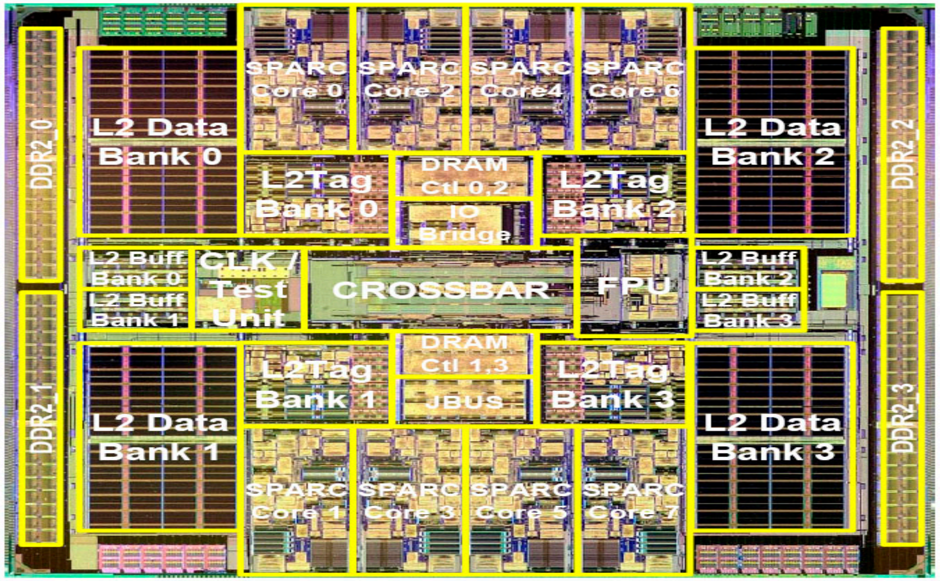
# Journeys to the Center of Distributed Computing

# The Rise and Fall of Distributed Computing

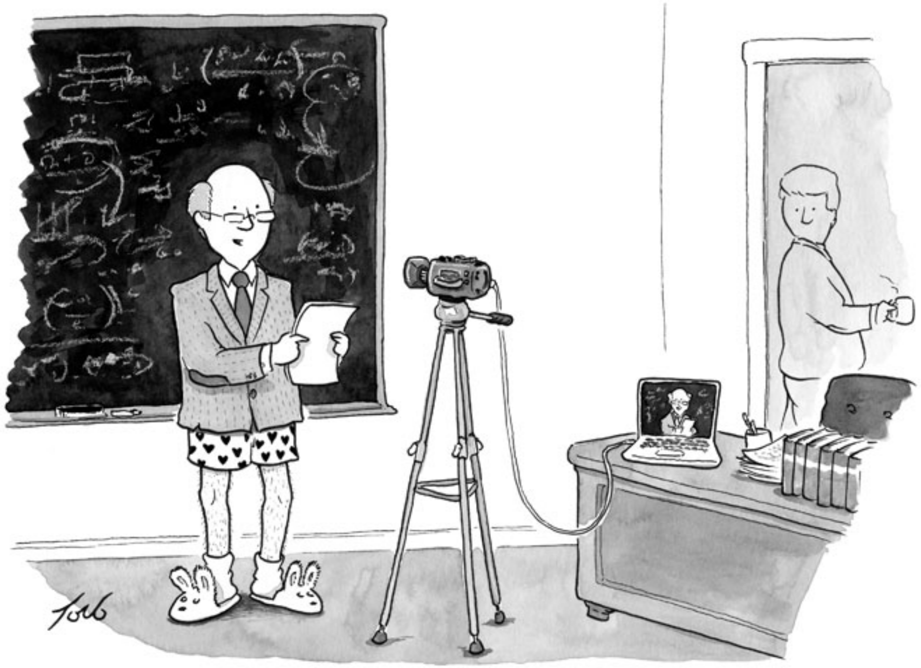
- **The infinitely big**
- **The infinitely small**






# The Rise and Fall of Distributed Computing

# Academics vs. Engineers



"I'm honored to share my research at your virtual academic conference."

# Relevance vs. Innovation

# Distributed Computing Research

# Road to Salvation

**"Puisque ces mystères nous dépassent, feignons d'en être les organisateurs" J. Cocteau**

# Journeys to the Center of DC

Applications (SIFT 1978)

Middleware (FLP 1985)

Hadware (Mutex 1965)


« Computing's central challenge is how not to make a mess of it ...» E. Dijkstra


# Distributed Payment

## X000 implementations

### Bitcoin: A Peer-to-Peer Electronic Cash System

Satoshi Nakamoto
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www.bitcoin.org

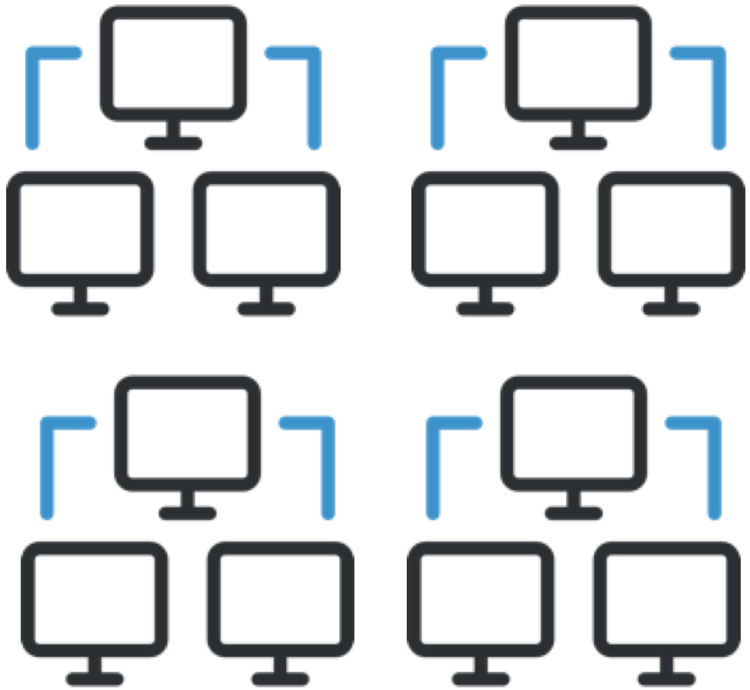
**Abstract.** A purely peer-to-peer version of electronic cash would allow online payments to be sent directly from one party to another without going through a financial institution. Digital signatures provide part of the solution, but the main benefits are lost if a trusted third party is still required to prevent double-spending. We propose a solution to the double-spending problem using a peer-to-peer network. The network timestamps transactions by hashing them into an ongoing chain of hash-based proof-of-work, forming a record that cannot be changed without redoing the proof-of-work. The longest chain not only serves as proof of the sequence of events witnessed, but proof that it came from the largest pool of CPU power. As

# P vs NP

# Asynchronous vs Synchronous

## Is payment an asynchronous problem?

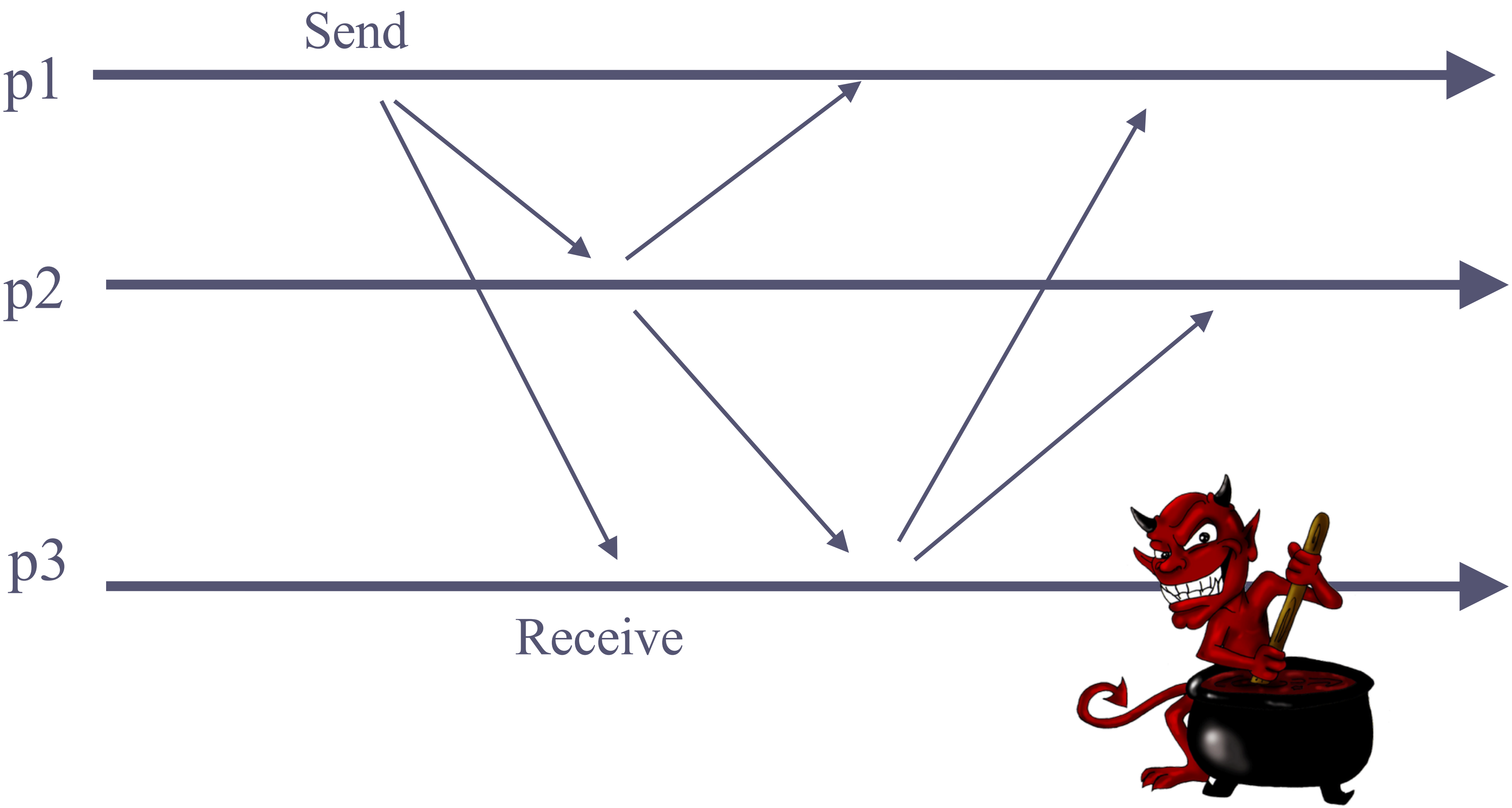
- «  To understand a distributed computing problem: bring it to shared memory » T. Lannister



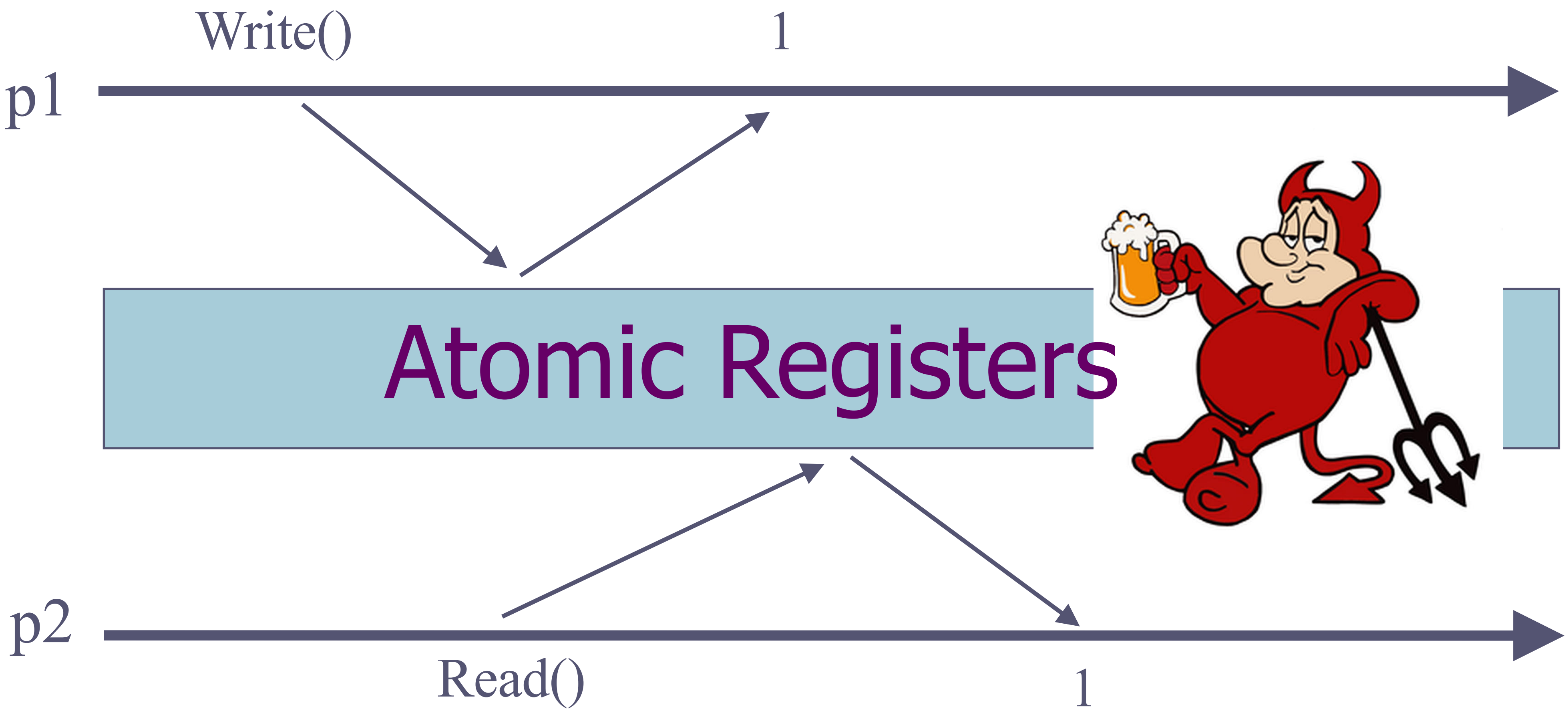
## Message Passing

## Shared Memory

# Message Passing



# Shared Memory



# Message Passing ⇔ Shared Memory Modulo Quorums

⇔

# Is payment an asynchronous problem?

- **Payment Object**


- Atomicity
- Wait-freedom

# 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

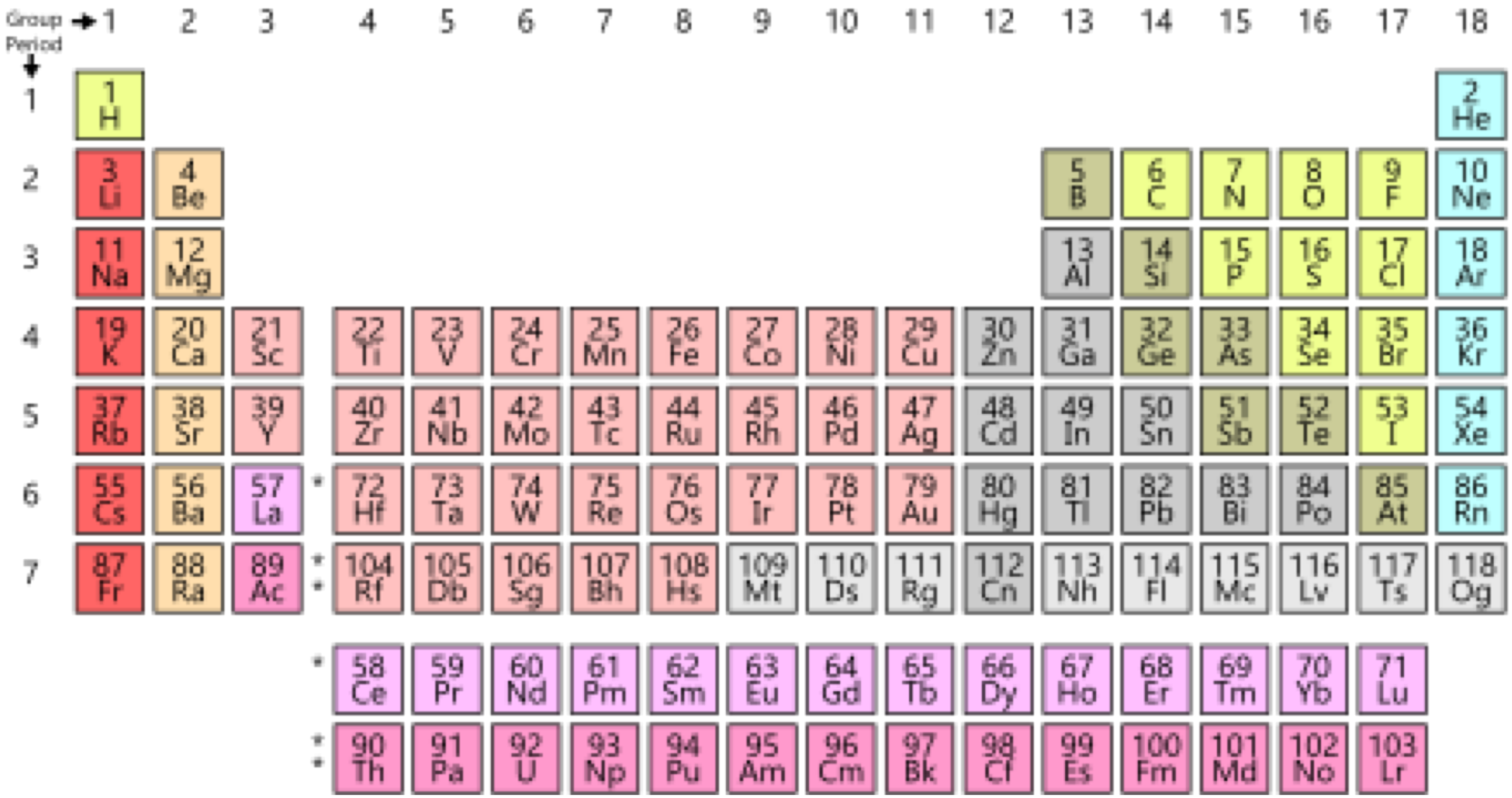
- Process pI:
- propose(vI)
- RI.write(vI)
- res := C.dec()
- if(res = ok) then
  - ✓ return(vI)
  - ✓ else return(R{1-I}.read())

# 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*

- 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)
- **Important**. Only the owner of a invokes Pay(a,*,*)

- 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)

# 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

# Faster and Simpler Payment Systems (AT2)

- AT2_S (PODC 2019)
- AT2_D (DNS 2020)
- AT2_R (DISC 2019)

# Journey to the Center of DC

- Bitcoin
- Blockchain
- Proof of work
- Smart contracts
- Ethereum

- Atomicity
- Wait-freedom
- Snapshot
- Consensus
- Quorums
- Secure Broadcast

# Distributed Tracing

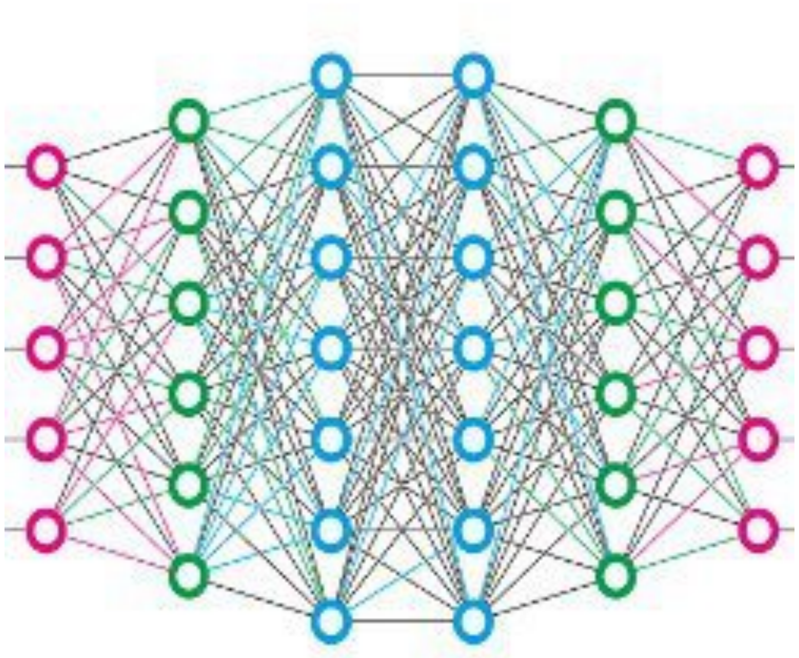
## Gossip Algorithms (DISC 2020)
## Populations Protocols

# Journeys to the Center of DC

**Applications**

**Middleware**

# Distributed ML



**PODC 2020 / ArXiv 2020 / SRDS 2020**

# Folklore & Misunderstandings

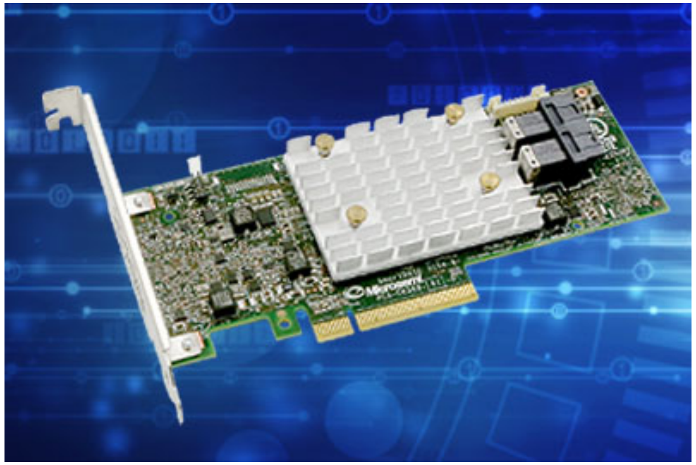
- Distributed systems are synchronous (DC 2018)
- Causal transactions are fast & robust (IPDPS 2020)
- SMR ⇔ Consensus (DISC 2018)

# Journeys to the Center of DC

**Applications**

**Middleware**

**Hardware**



# RDMA

- Remote shared / protected memory
- Consensus with 2f+1 and f+1 (vs 3f+1 and 2f+1) and 2 steps (vs 4 steps) – PODC 2018/2019
- µ: SMR in 1µs / 1ms

# NVRAM

- Persistent objects with durable linearizability / detectable recovery
- Tight bound: 1 pfence per operation (SPAA 2019)
- MCAS with 2 pfences and k+1 CASes per k-Cas (DISC 2020)

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## Journeys to the Center of DC

- Applications (SIFT 1978)
- Middleware (FLP 1985)
- Hardware (Mutex 1965)

S. Baehni
R. Boichat
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P. Kouznetsov
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