Alternative system models

Tudor David

Outline

- **The multi-core as a distributed system**
- Case study: agreement
- The distributed system as a multi-core

The system model

- Concurrency: several <u>communicating</u> processes executing at the same time;
- Implicit communication: shared memory;
  - Resources – shared between processes;
  - Communication – implicit through shared resources;
  - Synchronization – locks, condition variables, non-blocking algorithms, etc.
- Explicit communication: message passing;
  - Resources – partitioned between processes;
  - Communication – explicit message channels;
  - Synchronization – message channels;

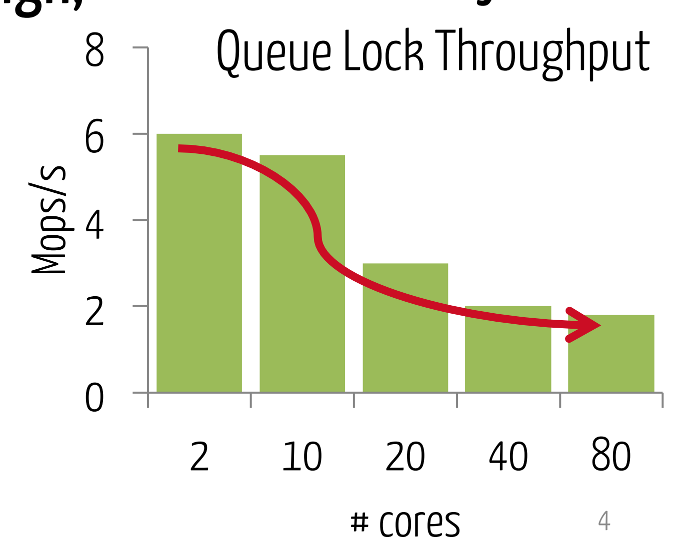
Whatever can be expressed using shared memory

can be expressed using message passing

So far – shared memory view

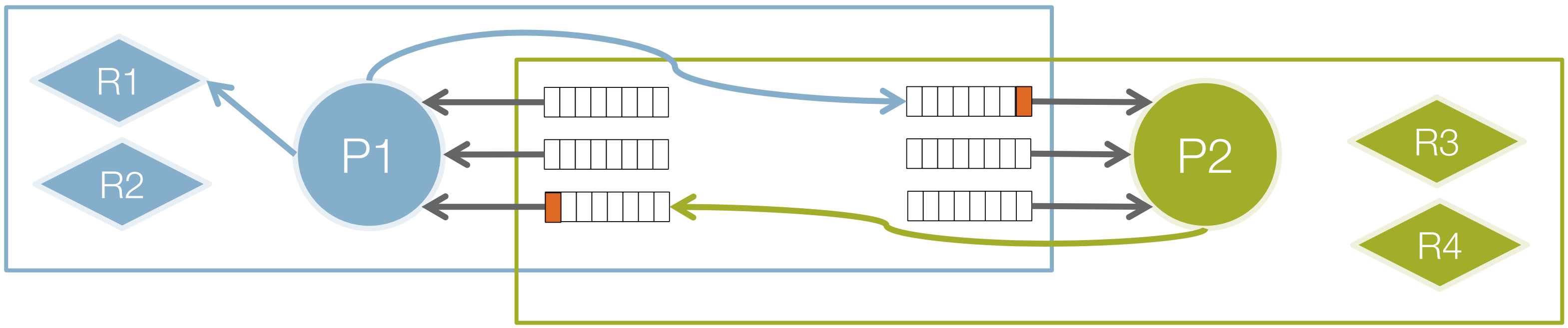
- set of registers that any process can read or write to;
- communication – implicit through these registers;
- problems:
  – concurrency bugs – very common;
  – scalability - not great when contention high;

Scalability



Alternative model: message passing

- more verbose
  - but – can better control how information is sent in the multi-core.



- how do we get message passing on multicores?
  - dedicated hardware message passing channels (e.g. Tilera)
  - more common – use dedicated cache lines for message queues

Programming using message passing

- System design – more similar to distributed systems;
- Map concepts from shared memory to message passing;

- A few examples:
  - Synchronization, data structures: flat combining;
  - Programming languages: e.g. Go, Erlang;
  - Operating systems: the multikernel (e.g. Barrelfish)

Barrelfish: All Communication - Explicit

- Communication – exclusively message passing
- Easier reasoning: know what is accessed when and by whom
- Asynchronous operations – eliminate wait time
- Pipelining, batching
- More scalable

Barrelfish: OS Structure – Hardware Neutral

Separate OS structure from hardware

Machine dependent components

- Messaging
- HW interface

Better layering, modularity

Easier porting

Barrelfish: Replicated State

- No shared memory => replicate shared OS state
- Reduce interconnect load
- Decrease latencies
- Asynchronous client updates
- Possibly NUMA aware replication

Consistency of replicas: agreement protocol

Implicit communication (shared memory) → Explicit communication (message passing)

Locally cached data → Replicated state

State machine replication → Total ordering of updates → Agreement

High availability, High scalability

How should we do message-passing agreement in a multi-core?

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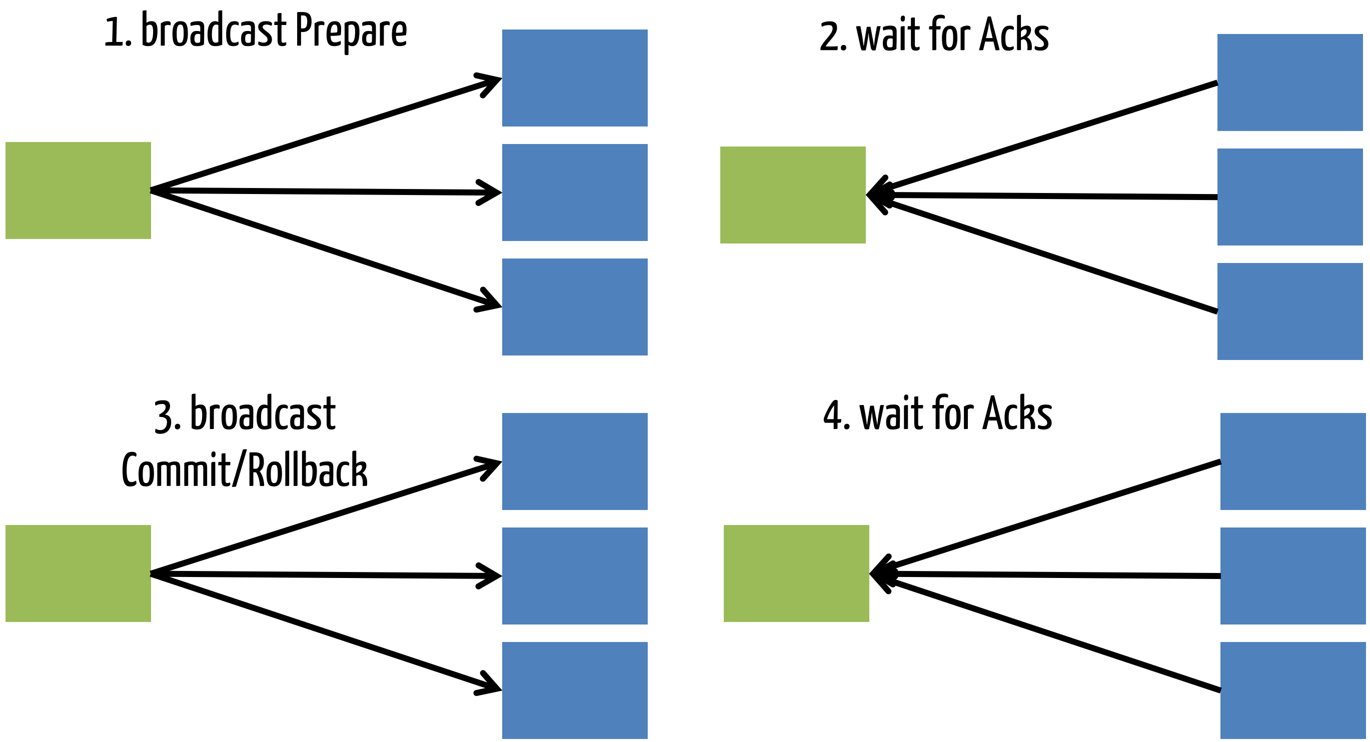
First go – a blocking protocol

Two-Phase Commit (2PC)



Blocking, all messages go through coordinator

Is a blocking protocol appropriate?

Blocking agreement –
only as fast as the slowest participant

- Scheduling?
- I/O?

Use a non-blocking protocol

"Latency numbers every programmer should know"	
L1 cache reference	0.5 ns
Branch mispredict	5 ns
L2 cache reference	7 ns
Mutex lock/unlock	25 ns
Main memory reference	100 ns
Compress 1K bytes	3 000 ns
Send 1K bytes over 1 Gbps network	10 000 ns
Read 4K randomly from SSD	150 000 ns
Read 1MB sequentially from memory	250 000 ns
Round trip within datacenter	500 000 ns
Read 1 MB sequentially from SSD	1 000 000 ns
Disk seek	10 000 000 ns
Read 1 MB sequentially from disk	20 000 000 ns
Send packet CA->Netherlands->CA	150 000 000 ns
	Source: Jeff Dean

Non-blocking agreement protocols

Consensus ~ non-blocking agreement between distributed processes on one out of possibly multiple proposed values

Paxos

- Tolerates non-malicious faults or unresponsive nodes: in multi-cores, slow cores
- Needs a majority of responses to progress (tolerates partitions)

Lots of variations and optimizations: CheapPaxos, MultiPaxos, FastPaxos etc.

Phase 1: prepare
Phase 2: accept

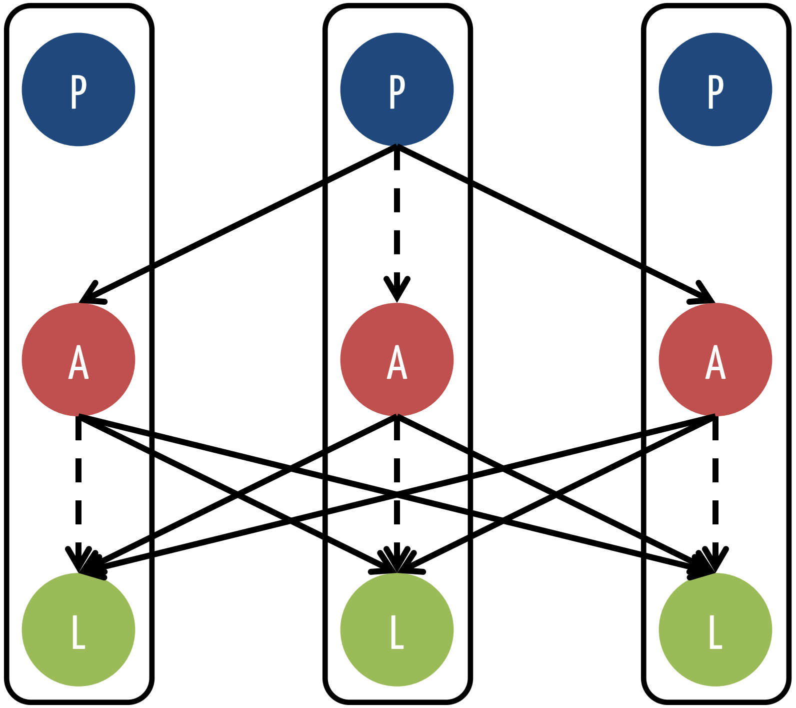
Roles:

- Proposer
- Acceptor
- Learner

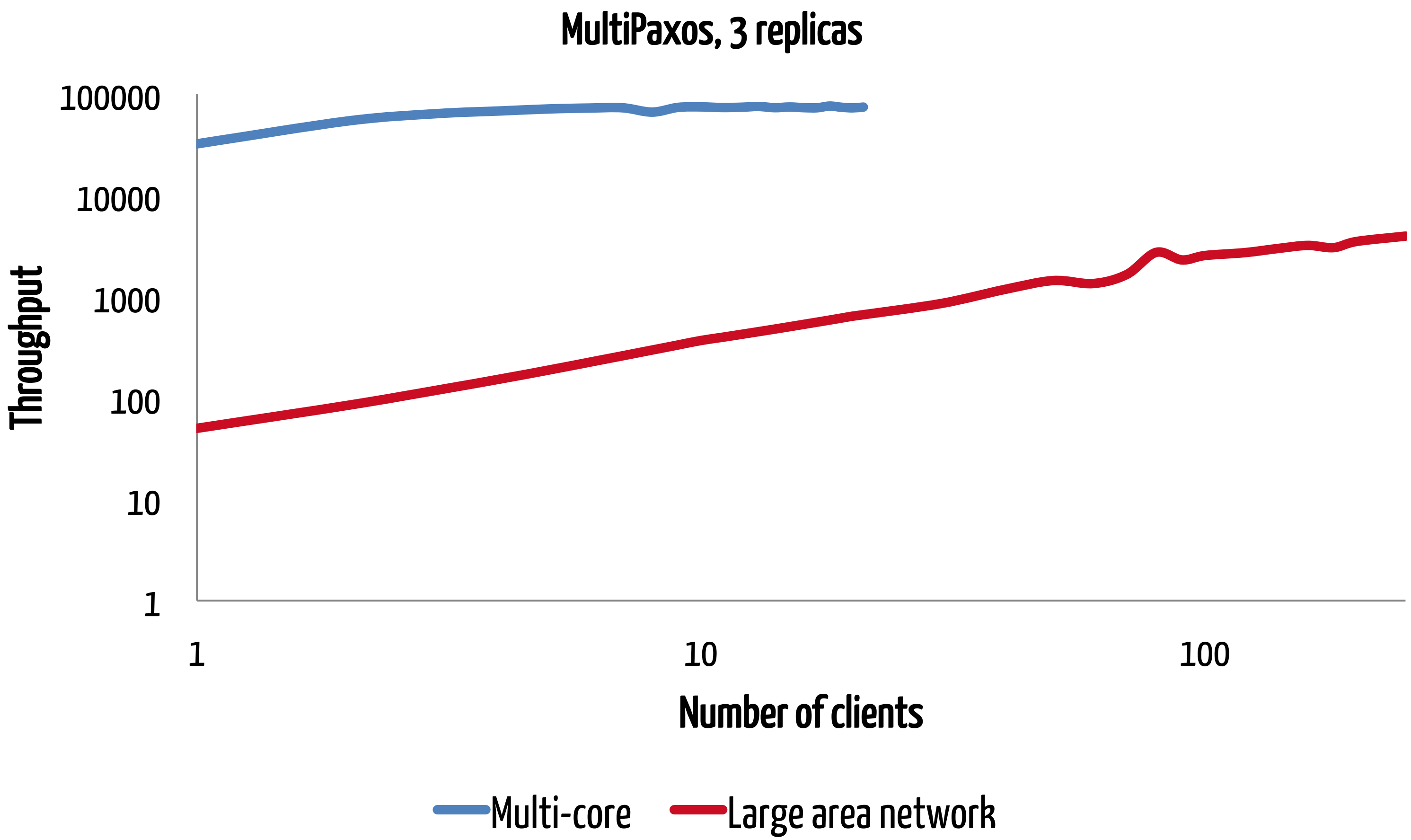
Usually – all roles on a physical node (Collapsed Paxos)

MultiPaxos

- Unless failed, keep same leader in subsequent rounds



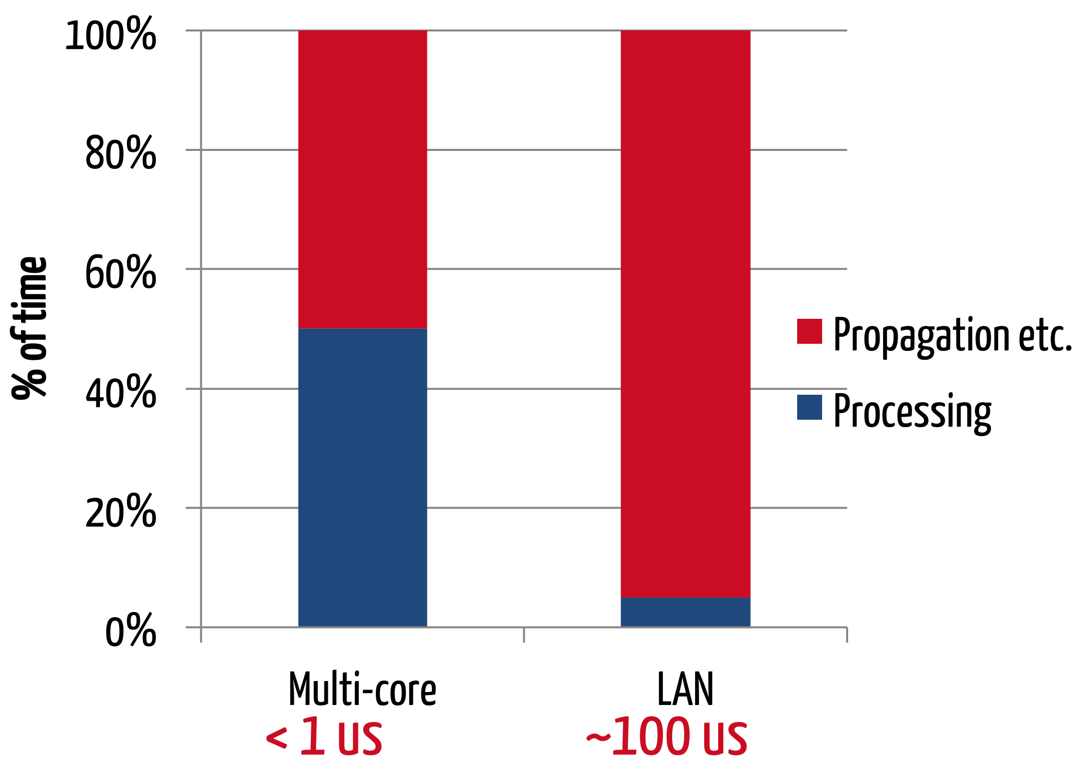
Does MultiPaxos scale in a multi-core?



Limited scalability in the multi-core environment

A closer look at the multi-core environment

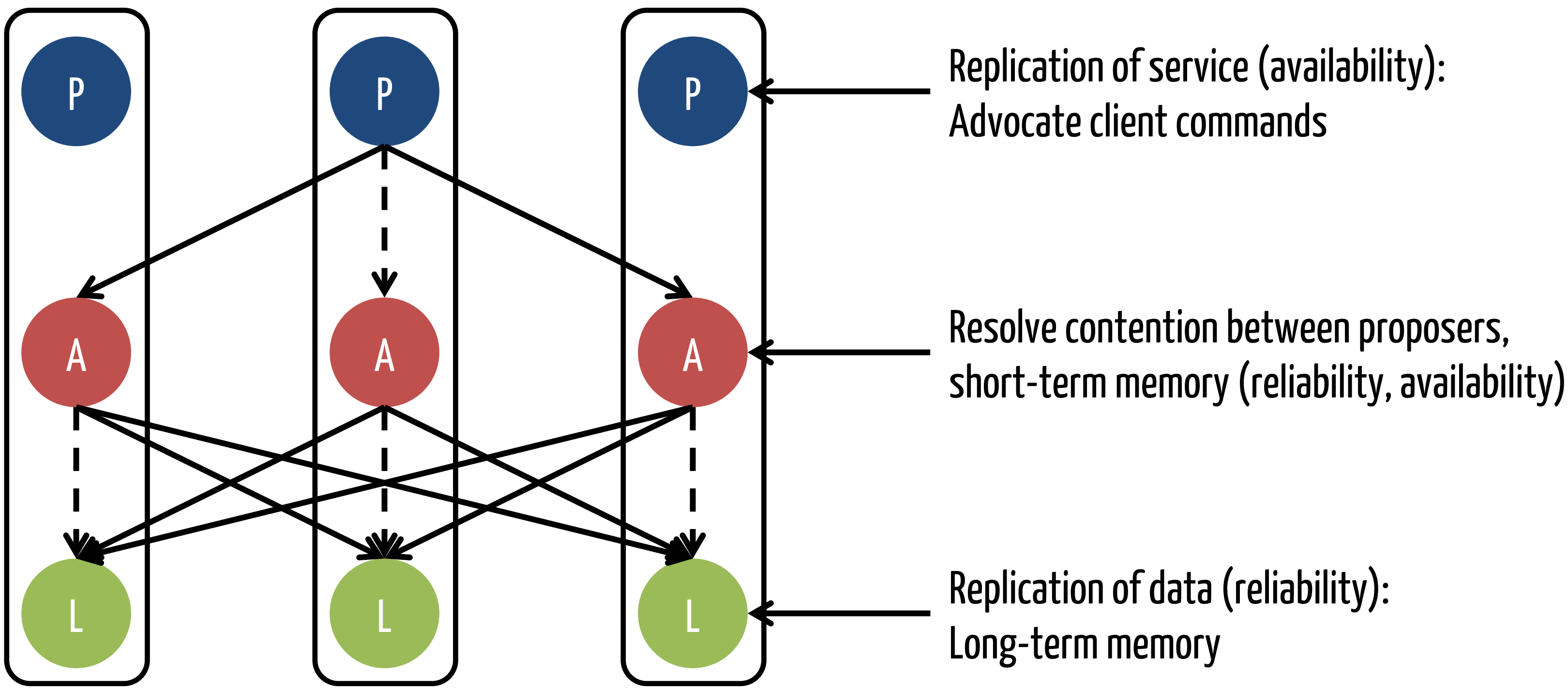
Where does time go when sending a message?



Large networks:
Minimize number of rounds/instance

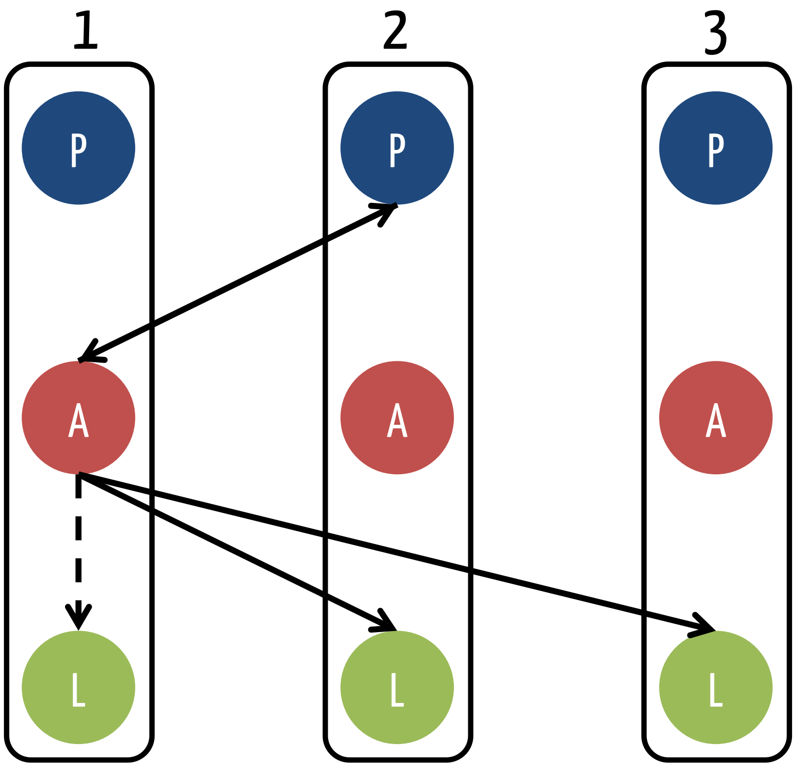
Multi-core:
Minimize the number of messages

Can we adapt Paxos to this scenario?



Using one acceptor significantly reduces the number of messages

1Paxos: The failure-free case



1. P2: obtains active acceptor A1 and sends prepare_request(pn)

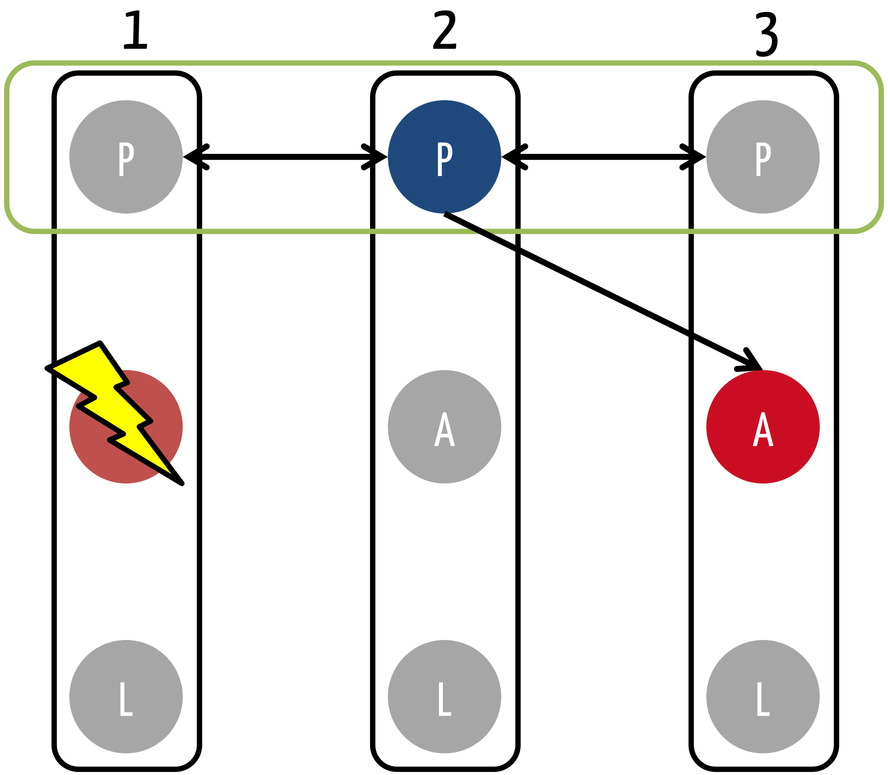
2. A1: if pn -> max. proposal received, replies to P2 with ack

3. P2 -> A1
   accept_request(pn, value)

4. A1 broadcasts value to learners

Common case: only steps 3 and 4

1Paxos: Switching the acceptor

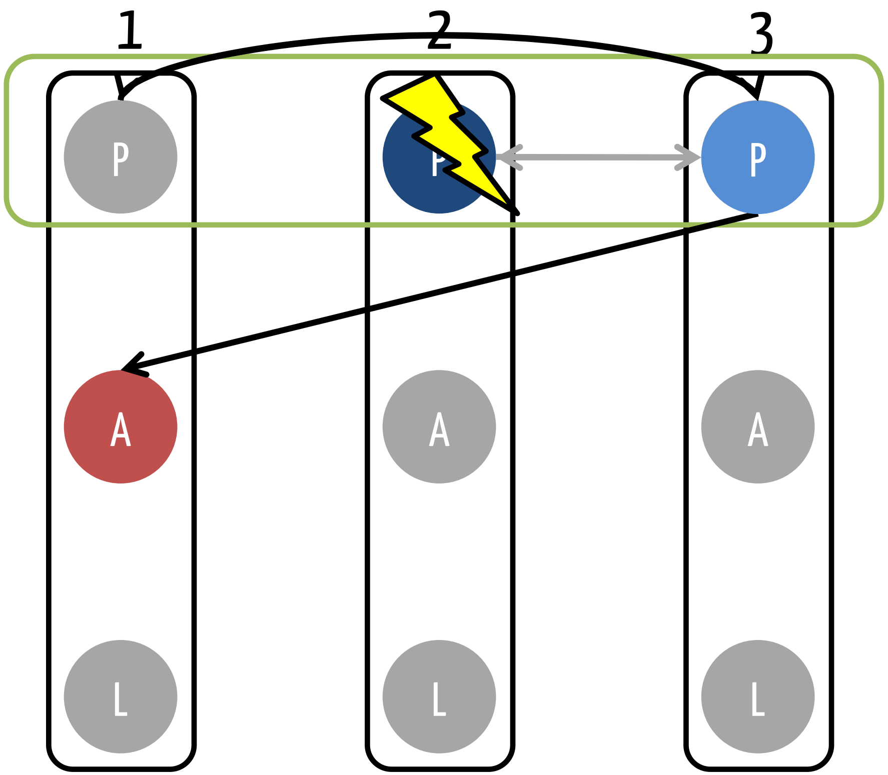


1. P2 leader?

2. PaxosUtility: P2 proposes
- A3 active acceptor
- Uncommitted proposed values

3. P2 -> A3: prepare_request

1Paxos: Switching the leader

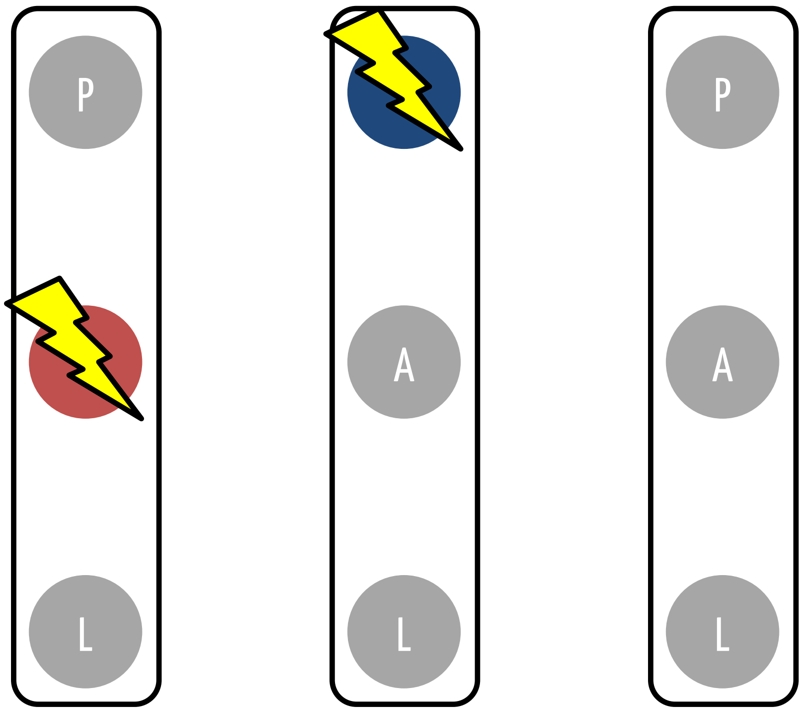


1. A1 – active acceptor?

2. PaxosUtility: P3 new leader and A1 active acceptor

3. P3 -> A1: prepare_request

Switching leader and acceptor



The trade-off:

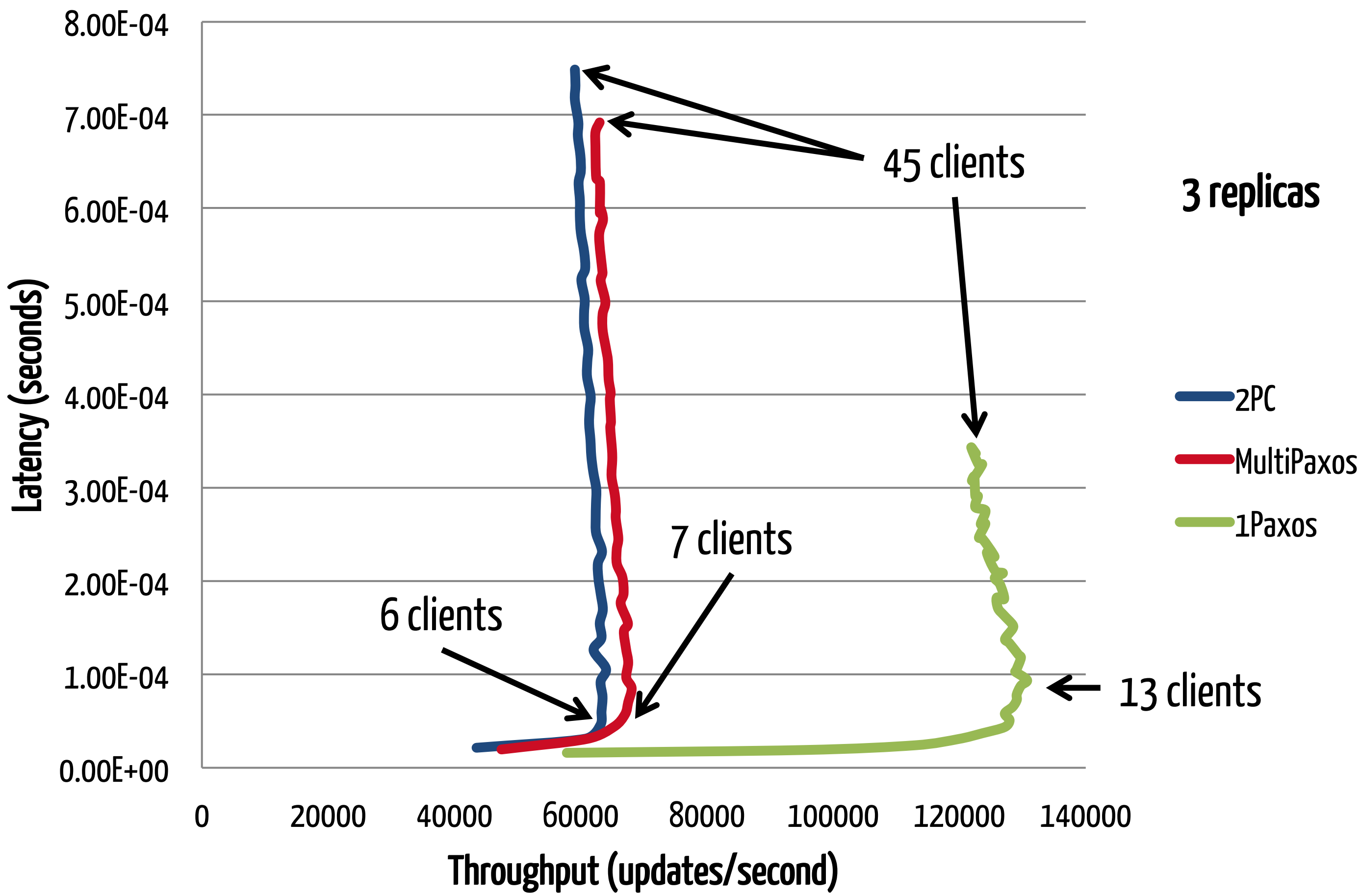
while leader **and** active acceptor non-responsive at the same time

✖ liveness ✔ safety

Why is it reasonable?

- small probability event
- no network partitions
- if nodes not crashed, but slow -> system becomes responsive after a while

Latency and throughput



Smaller # of messages - smaller latency and increased throughput

Agreement - summary

Multi-core – message passing distributed system,
but distributed algorithm implementations different

Agreement in multi-cores

- non blocking
- reduced # of messages

Use one acceptor: 1Paxos

- reduced latency
- increased throughput

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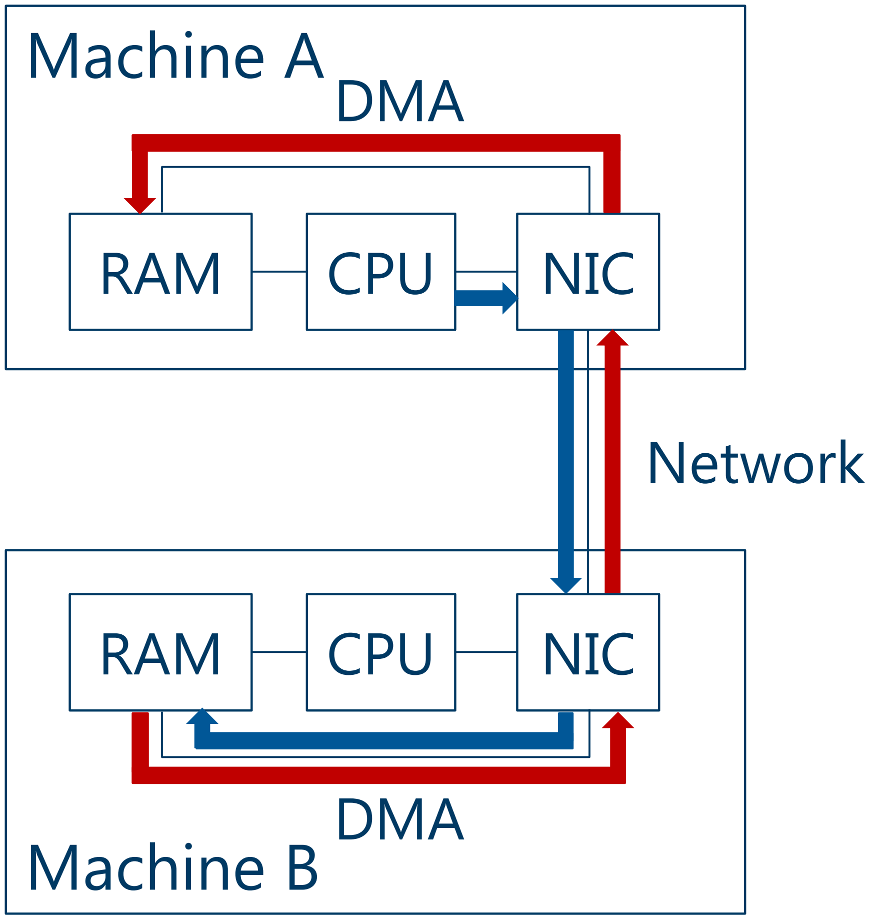
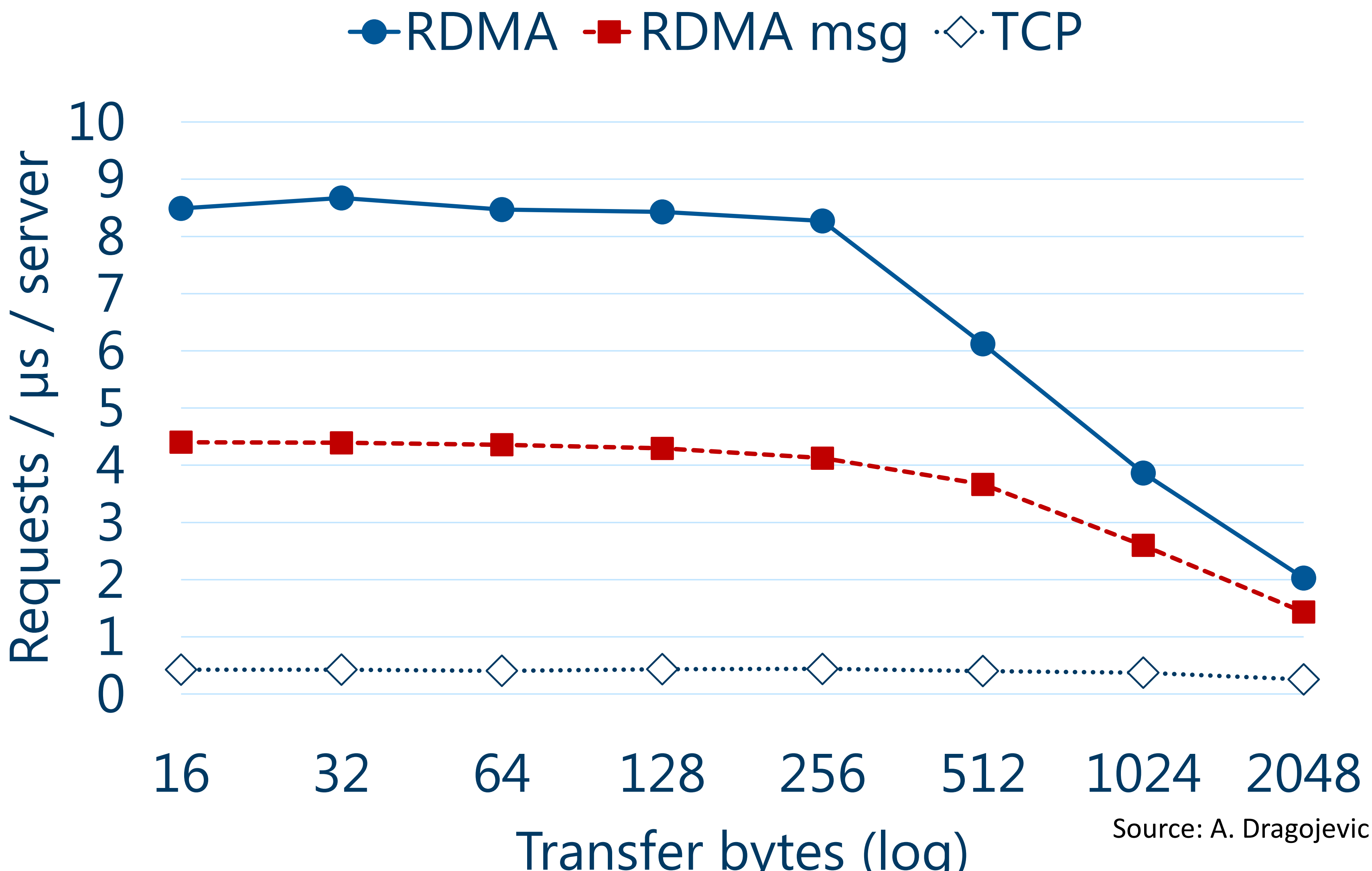
Remote Direct Memory Access (RDMA)

Read/Write remote memory
NIC performs DMA requests

Great performance
Bypasses the kernel
Bypasses the remote CPU



Source: A. Dragojevic



FaRM: Fast Remote Memory (NSDI'14) – Dragojevic et al.