Consensus as a Network Service

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Consensus is a Fundamental Problem

- Consensus protocols are the foundation for fault-tolerant systems
  - E.g., OpenReplica, Ceph, Chubby
- Many distributed problems can be reduced to consensus
  - E.g., Atomic broadcast, atomic commit

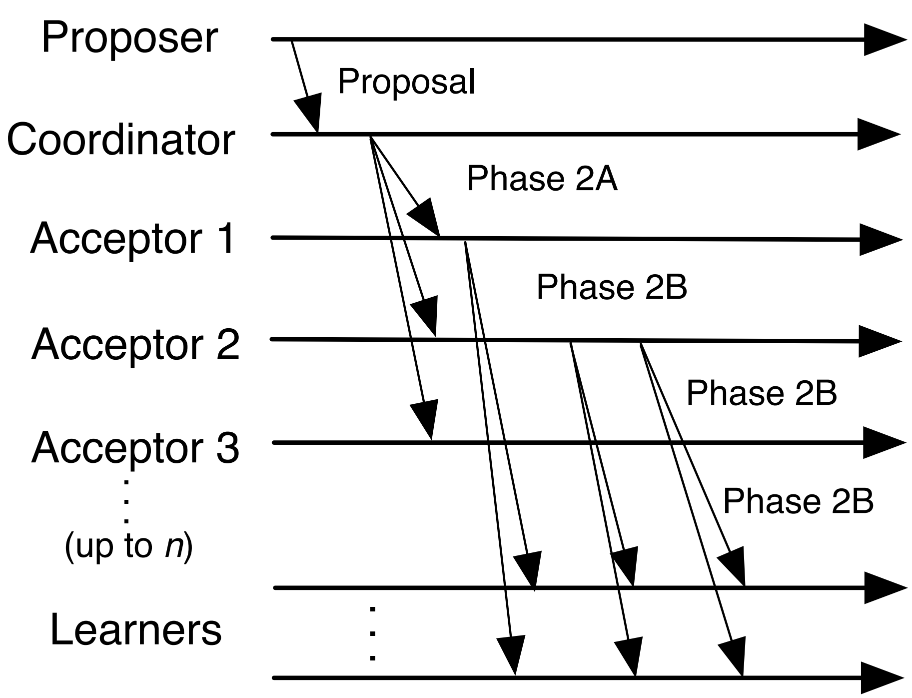
Key Idea: Move Consensus Into Network Hardware

- This work focuses on Paxos
    - One of the most widely used consensus protocol
    - “There are two kinds of consensus protocols: those that are Paxos, and those that are incorrect”,
      attributed to Butler Lampson
- Enabling technology trends:
    - Hardware is becoming more *flexible*: e.g. PISA, FlexPipe, NFP-6xxx
    - Hardware is becoming more *programmable*: e.g., POF, PX, and P4

Outline of This Talk

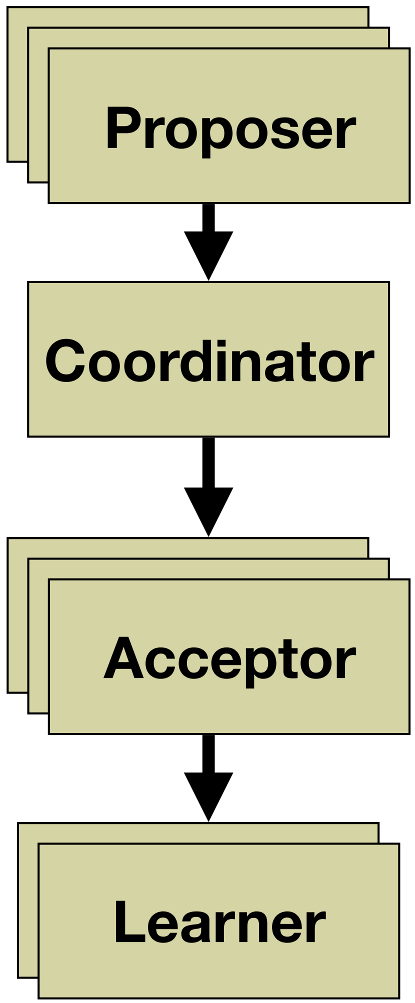
- Introduction
- **Background and Motivation**
- Design
- Implementation
- Evaluation
- Conclusions

Paxos Roles and Communication



- Proposers propose a value via the Coordinator (Phase 2).
- Acceptors accept value, promise not to accept any more proposals for instance (Phase 2).
- Learners require a quorum of messages from Acceptors, “deliver” a value (Phase 2).

Paxos Functionality and Requirements



Issue requests. Craft a message with value.

Advocate requests. Add a sequence number to the message.

Choose a value and provide memory. Execute logic, keep persistent state.

Provide replication. Return chosen value to the application via a callback.

Design

Design Goals 1: Be a Drop-In Replacement

- Istvav et al. [NSDI ’16] implement ZAB in an FPGA, but require that the application also be implemented in the FPGA
- High-level languages make hardware development easier
- Implementing LevelDB in P4 might still be tricky….

Standard Paxos API

```
void submit(struct paxos_ctx * ctx,
            char * value,
            int size);

void (*deliver)(struct paxos_ctx* ctx,
                int instance,
                char * value,
                int size);

void recover(struct paxos_ctx * ctx,
             int instance,
             char * value,
             int size);
```

Standard Paxos API

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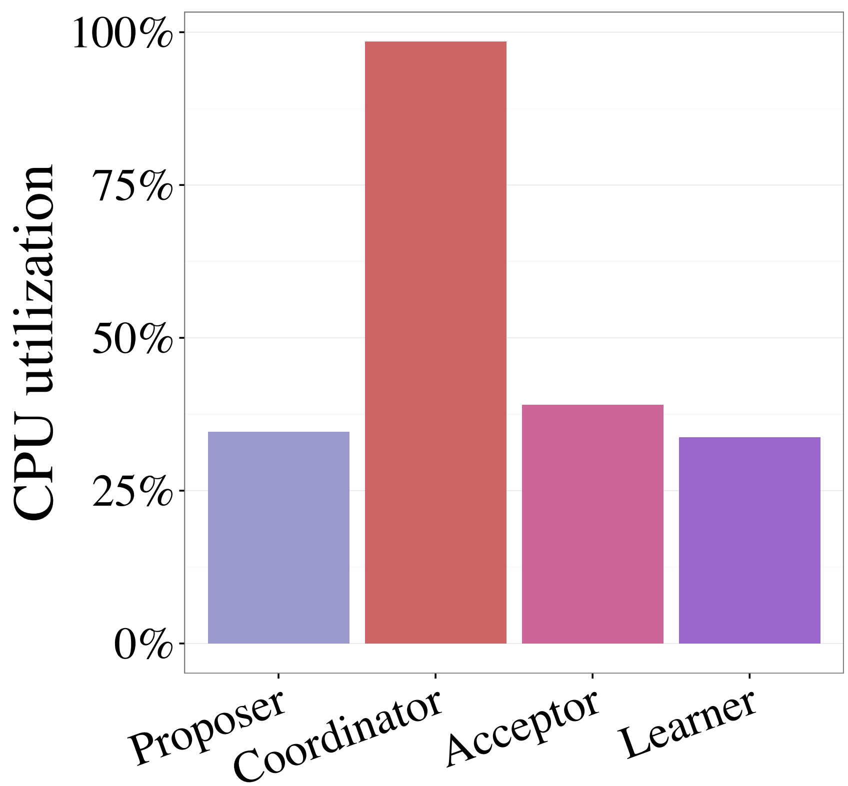
```

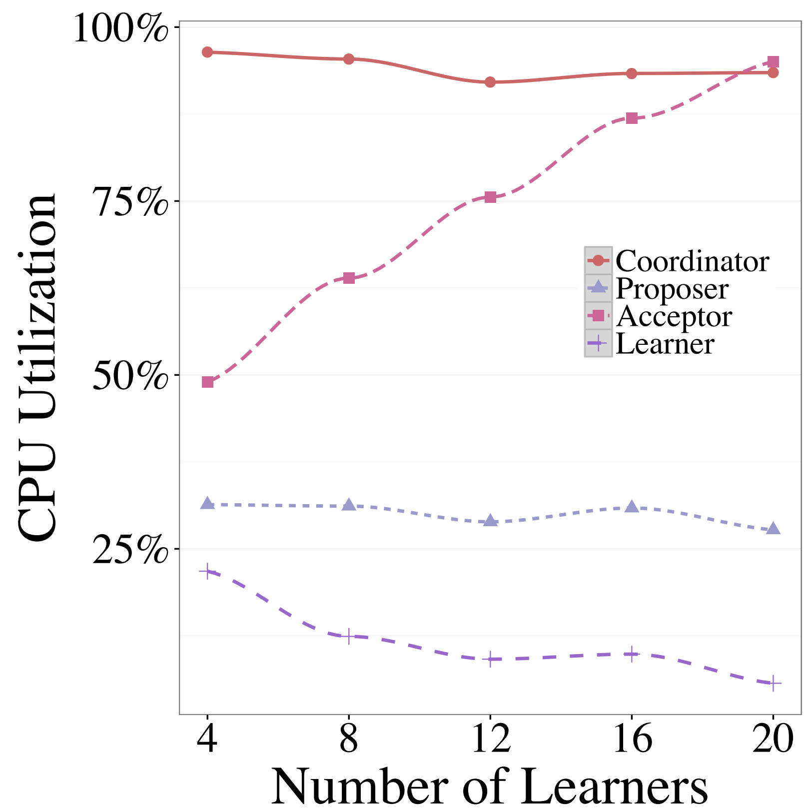
Send a value

Deliver a value

Discover prior value

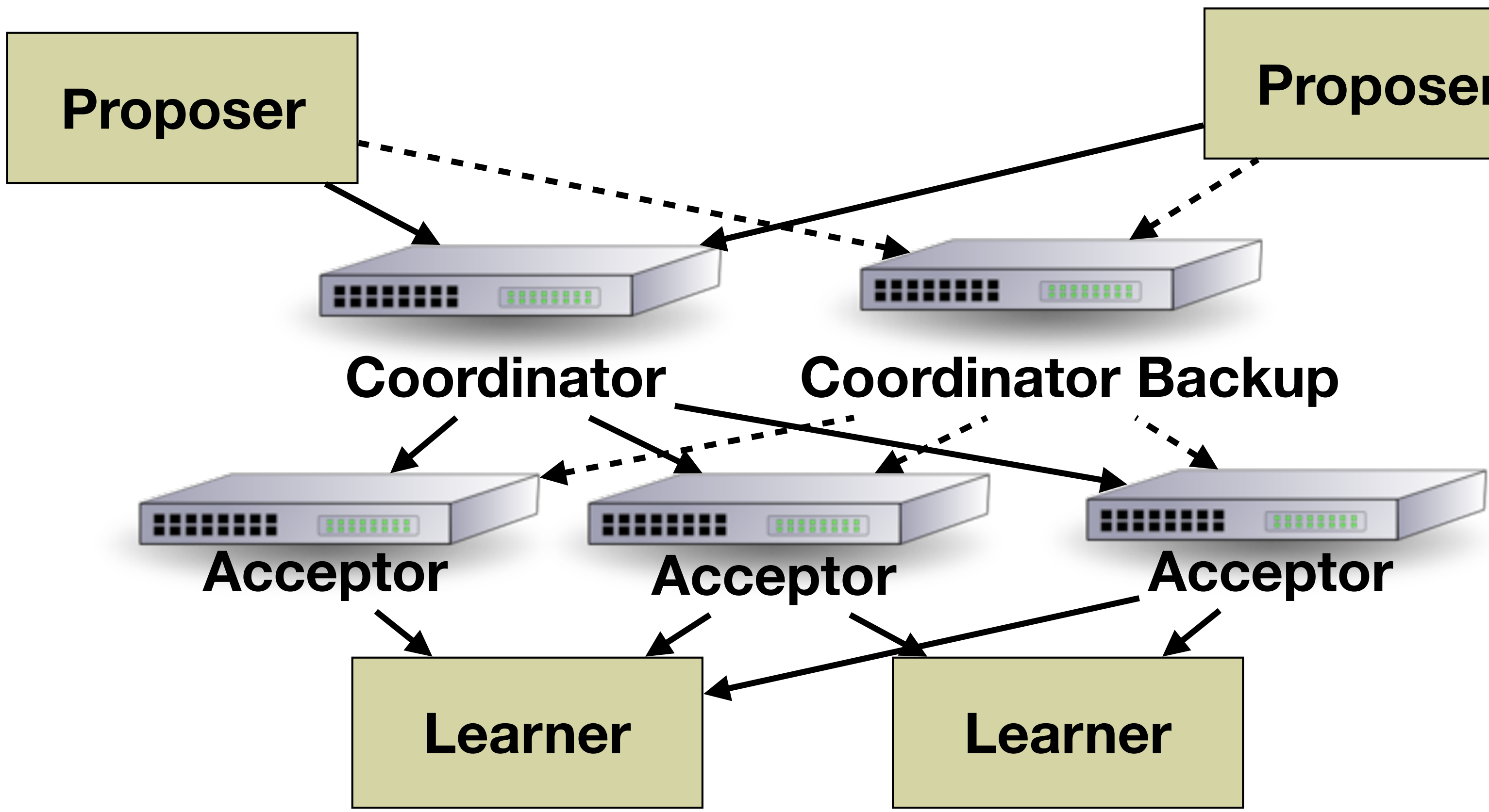
Design Goals 2: Alleviate Bottlenecks



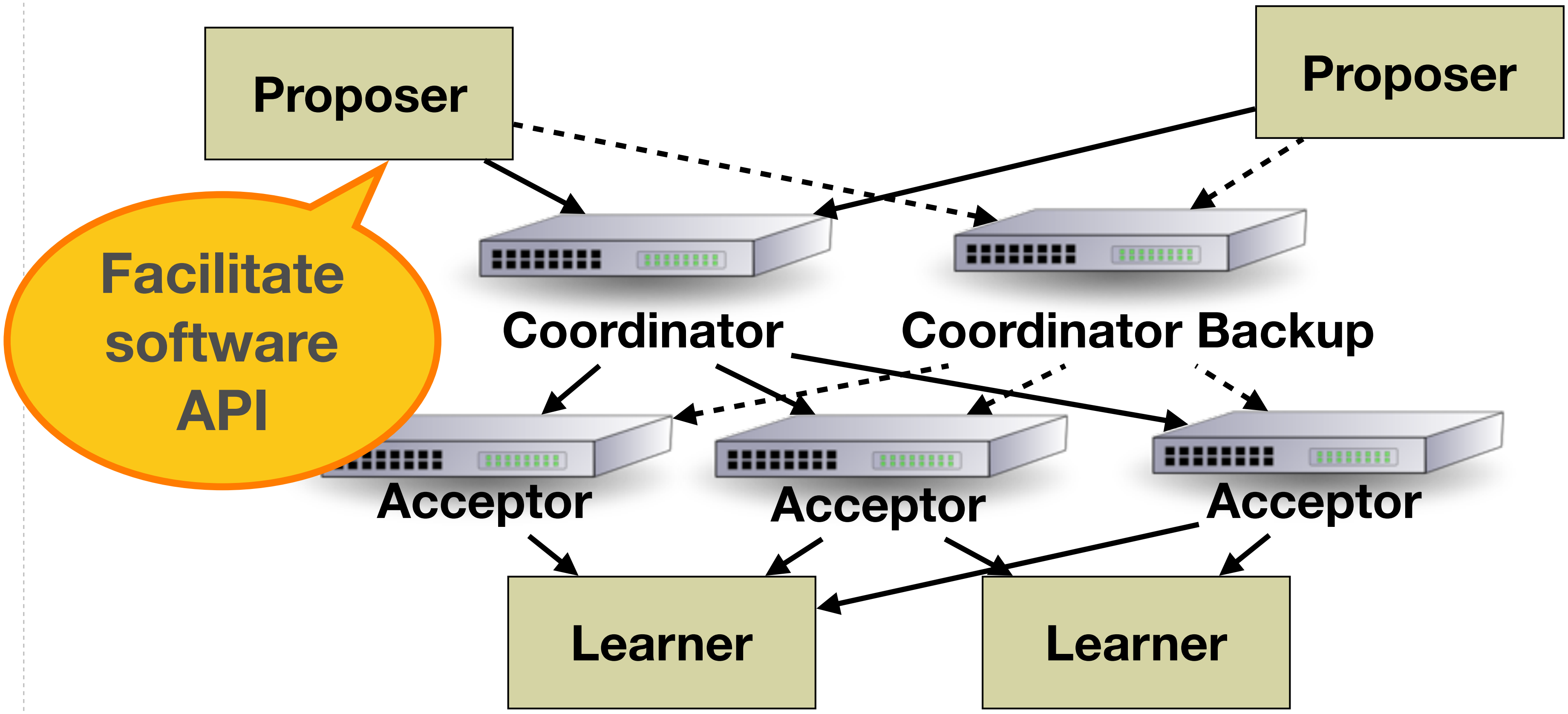


Coordinator and acceptors are to blame!

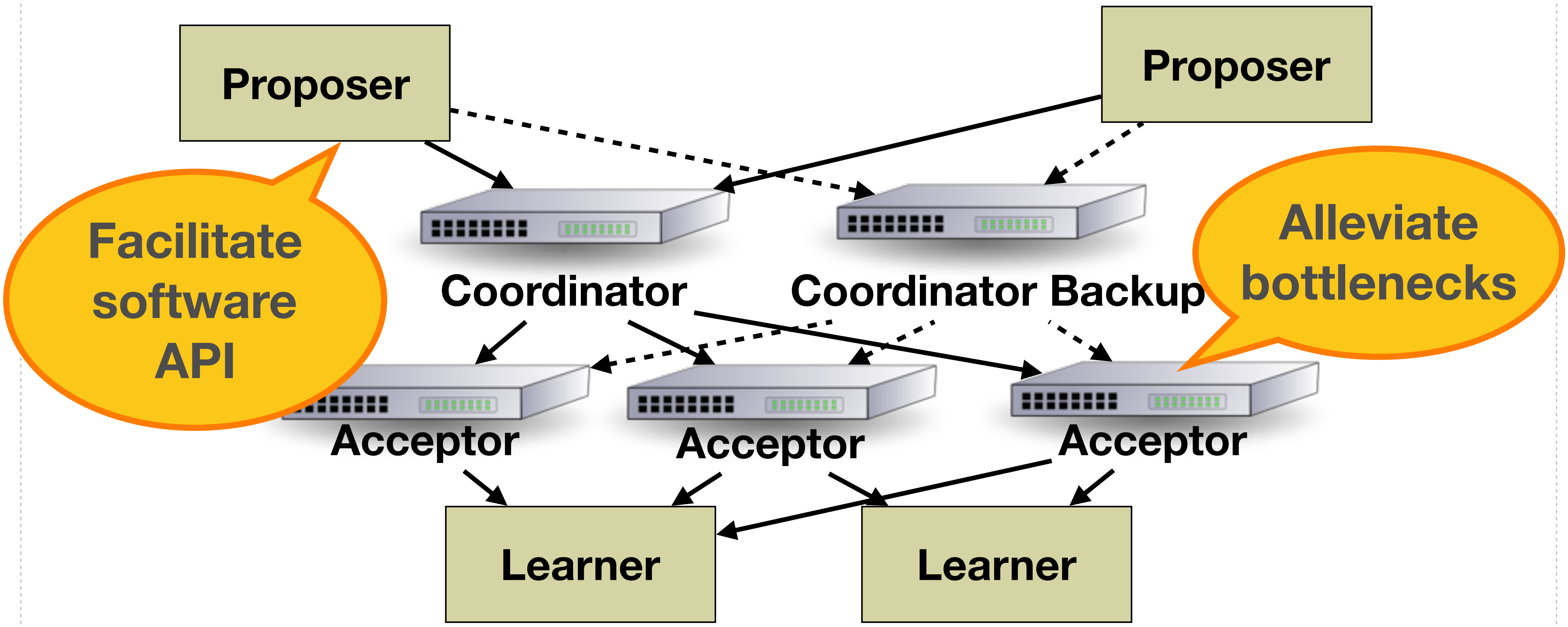
Hardware/Software



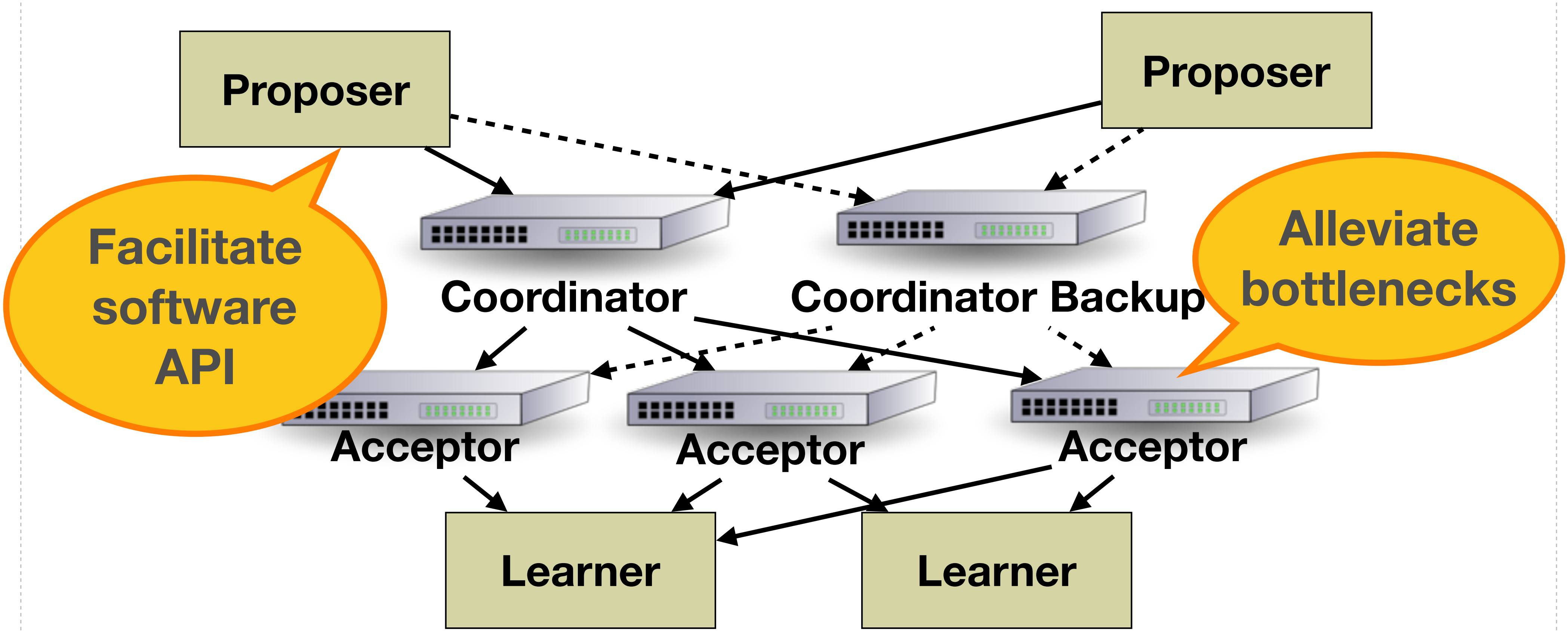
Hardware/Software



Hardware/Software



Hardware/Software



Challenge: map Paxos logic into stateful forwarding decisions

Paxos Header Format

- Network devices don't create messages, only forward them
- Header is union of all Paxos message fields
- Tradeoff: larger instance number allows for pre-initialization; requires more space

```
header_type paxos_t {
    fields {
        msgtype : 8;
        inst : INST_SIZE;
        rnd : 8;
        vrnd : 8;
        swid : 64;
        value : VALUE_SIZE;
    }
}
```

Implementation

Implementation

- Source code
  - Proposer and learner written in C
  - Coordinator and acceptor written in P4
- 3 Compilers
  - P4FPGA
  - Netronome Open-NFP
  - Xilinx SDNet

- 4 Hardware target platforms
  - NetFPGA SUME (4x10G)
  - Netronome AgilIO-CX (1x40G)
  - Alpha Data ADM-PCIE-KU3 (2x40G)
  - Xilinx VCU109 (4x100G)

P4 Tools

- **P4FPGA**: *P4 to Bluespec to FPGA. We implemented some code by hand in Bluespec, and optimized by hand (e.g., naive translation produced 6 tables, only needed 3).*
- **Xilinx SDNet:** *P4 to PX to FPGA. We wrote a Verilog wrapper around SDNet IP block, matching SDNet interface to SUME interface*
- **Netronome OpenNFP**: *Does not support register operations, uses a custom P4 syntax to call actions written in MicroC.*

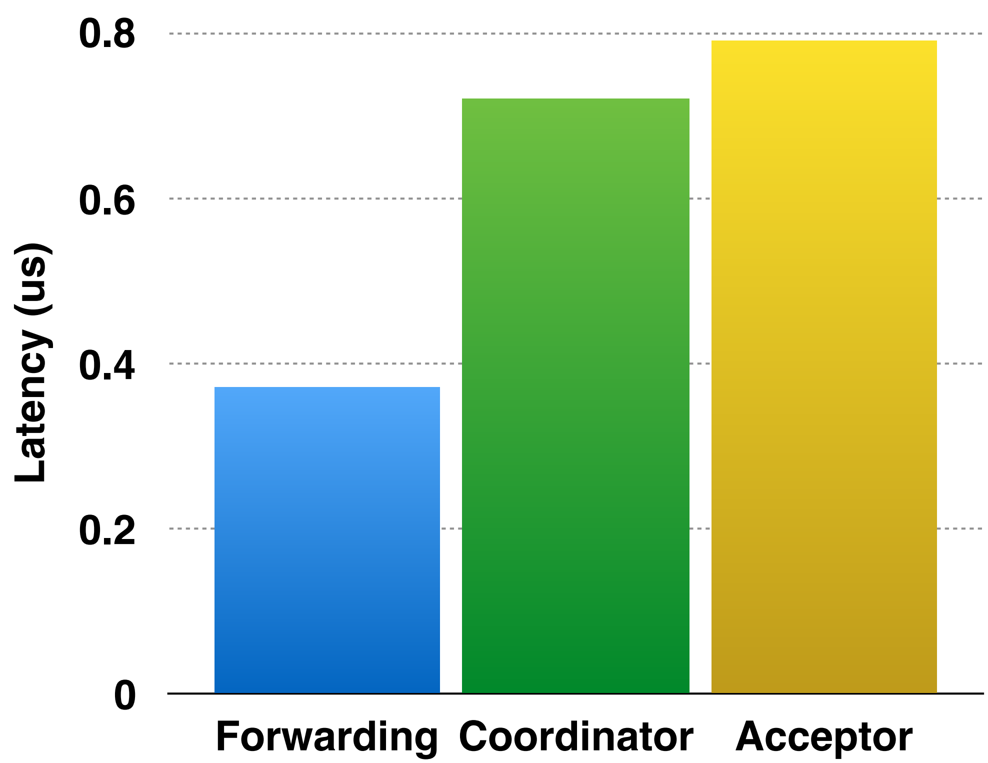
Evaluation

Experiments

- Focus on three questions:
  - What is the absolute performance?
  - What is the end-to-end performance?
  - What is the performance after failure?
- Testbed:
  - Four NetFPGA SUME boards in SuperMicro Servers
  - One Pica8 Pronto 3922 switch, 10Gbps links

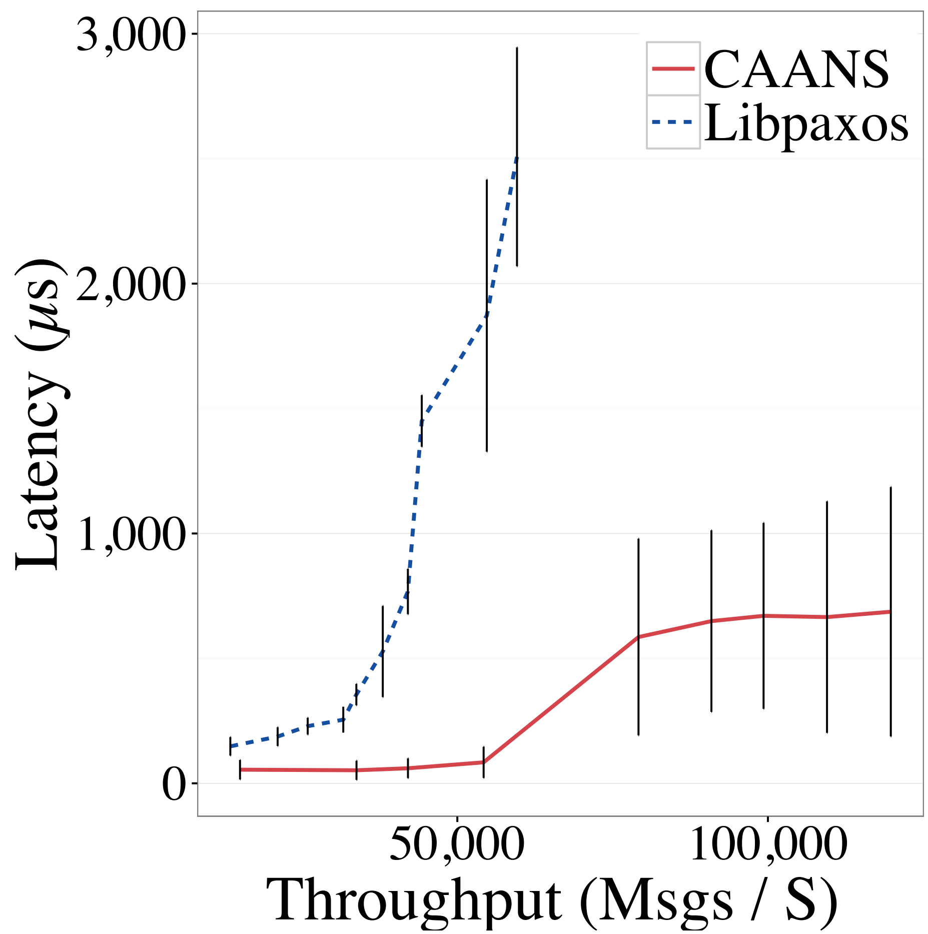
Absolute Performance

- Measured on NetFPGA SUME using P4FPGA
- Throughput is over **9 million consensus messages / second** (close to line rate)
- Little overhead latency compared to simply forwarding packets

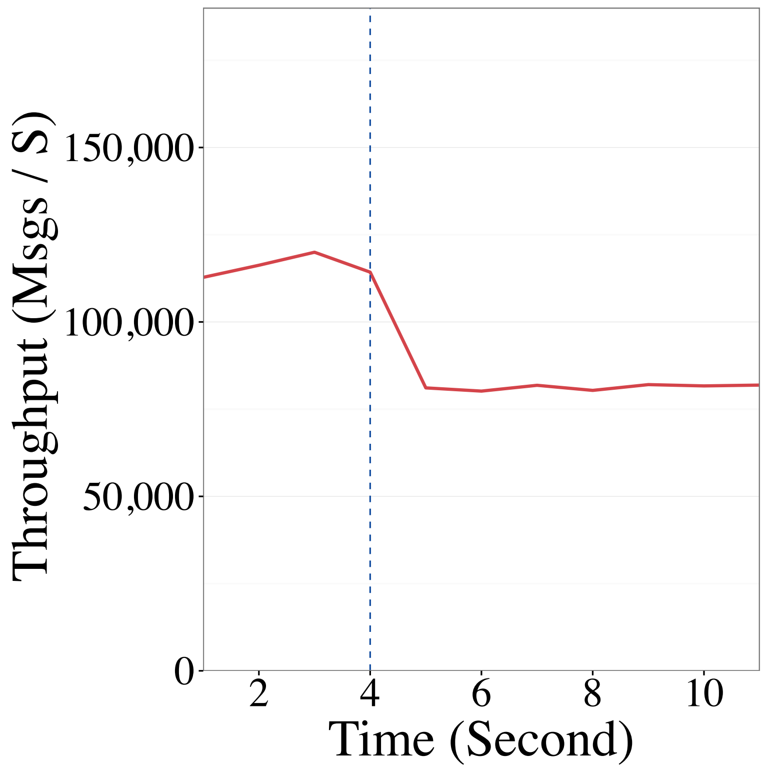


End-to-End Performance

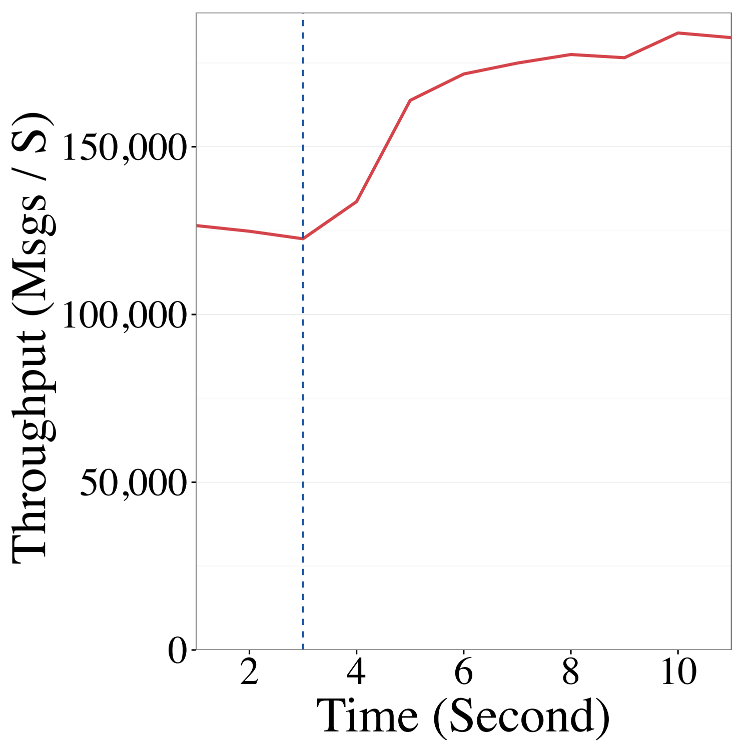
- Application discards result from “deliver” callback
- 2.24x throughput improvement over software implementation
- 75% reduction in latency
- Similar results when replicating LevelDB as application



Performance After Failure



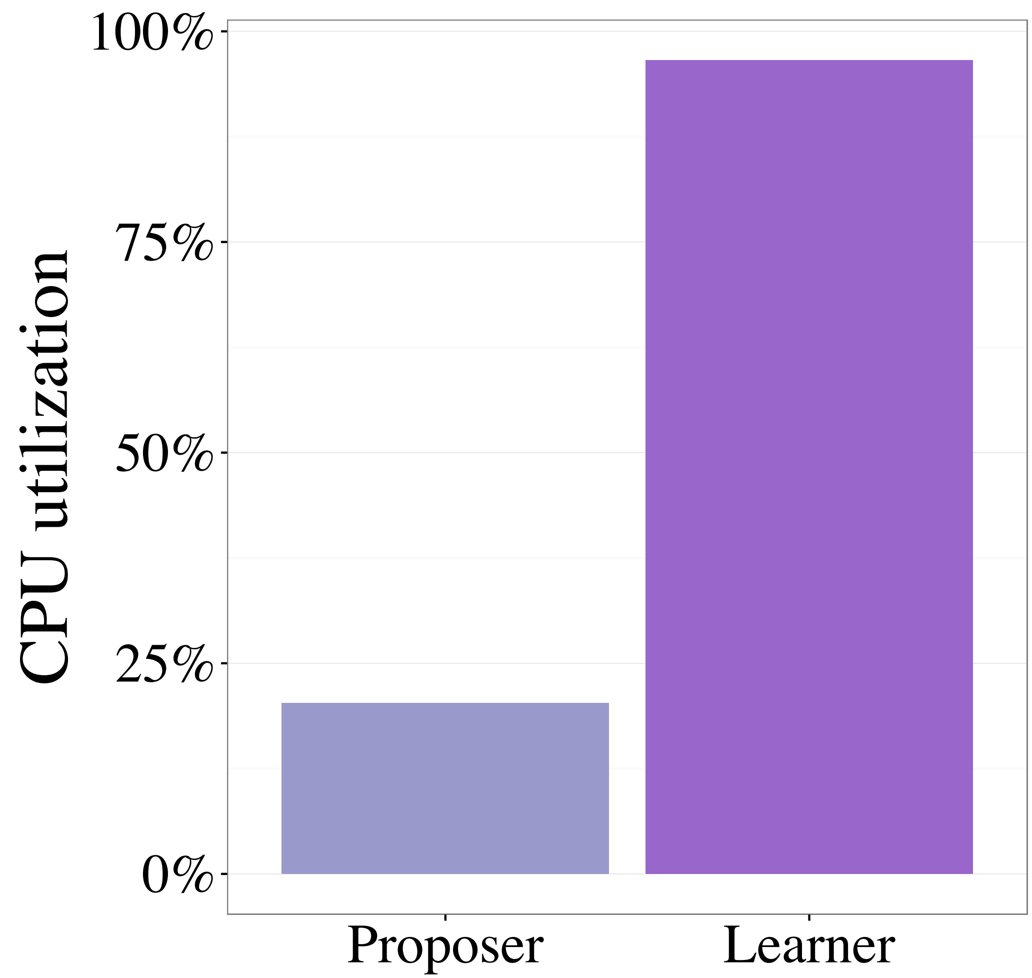
Coordinator failure with software backup



Acceptor failure

Conclusion

- We make consensus great again!
- The ball is now in the application developer's court
- Suggests direction for future work



Outlook

- The performance of consensus protocols has a dramatic impact on the performance of data center applications
- Moving consensus logic into network hardware results in significant performance improvements
- Suggests new line of research: don’t optimize the protocol, investigate how to handle lots of consensus messages

Acknowledgements

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http://www.inf.usi.ch/faculty/soule/netpaxos.html