ScalableBulk:
Scalable Cache Coherence for Atomic Blocks in a Lazy Envionment

Xuehai Qian, Wonsun Ahn, Josep Torrellas
University of Illinois

University of Illinois

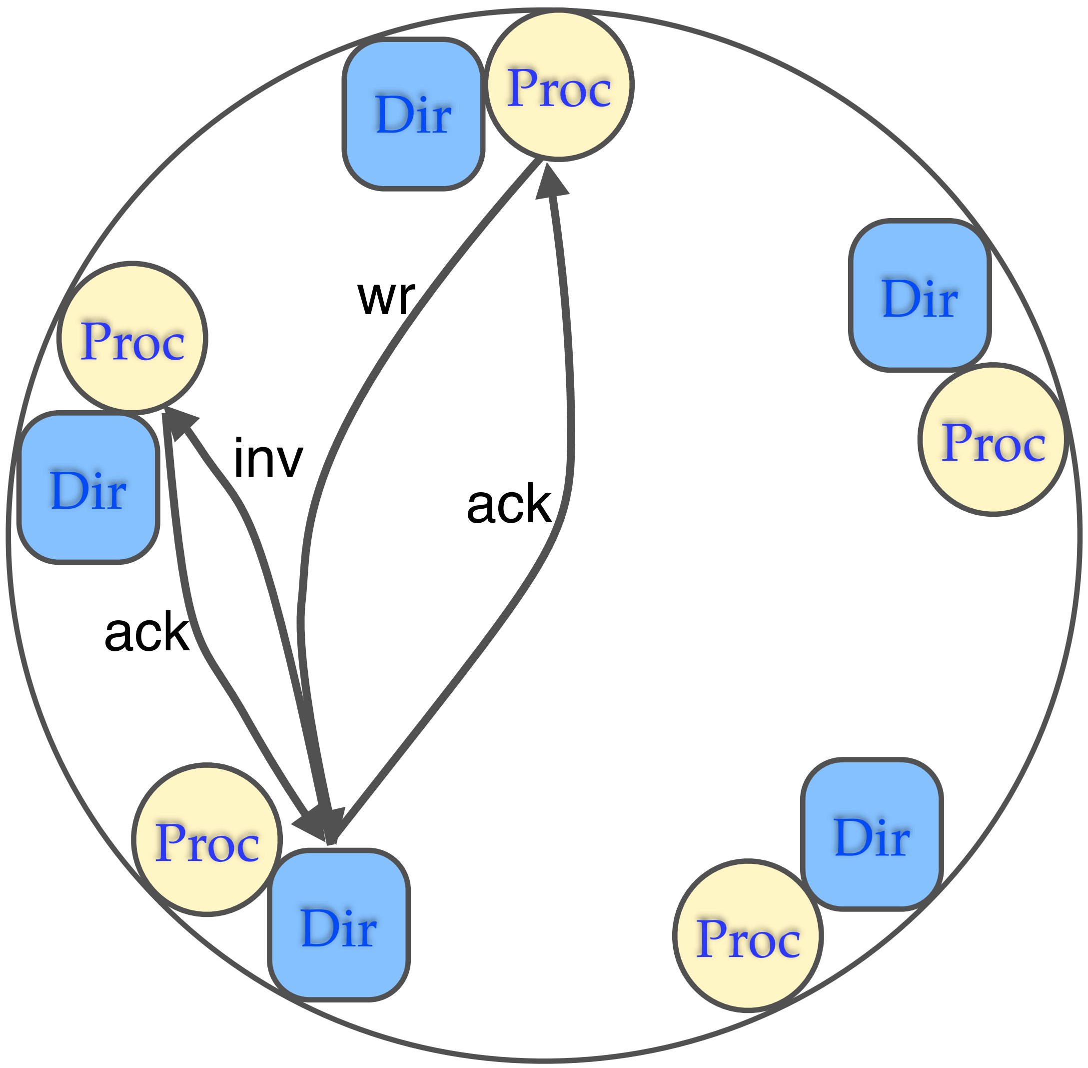
http://iacoma.cs.uiuc.edu/

i-acoma group

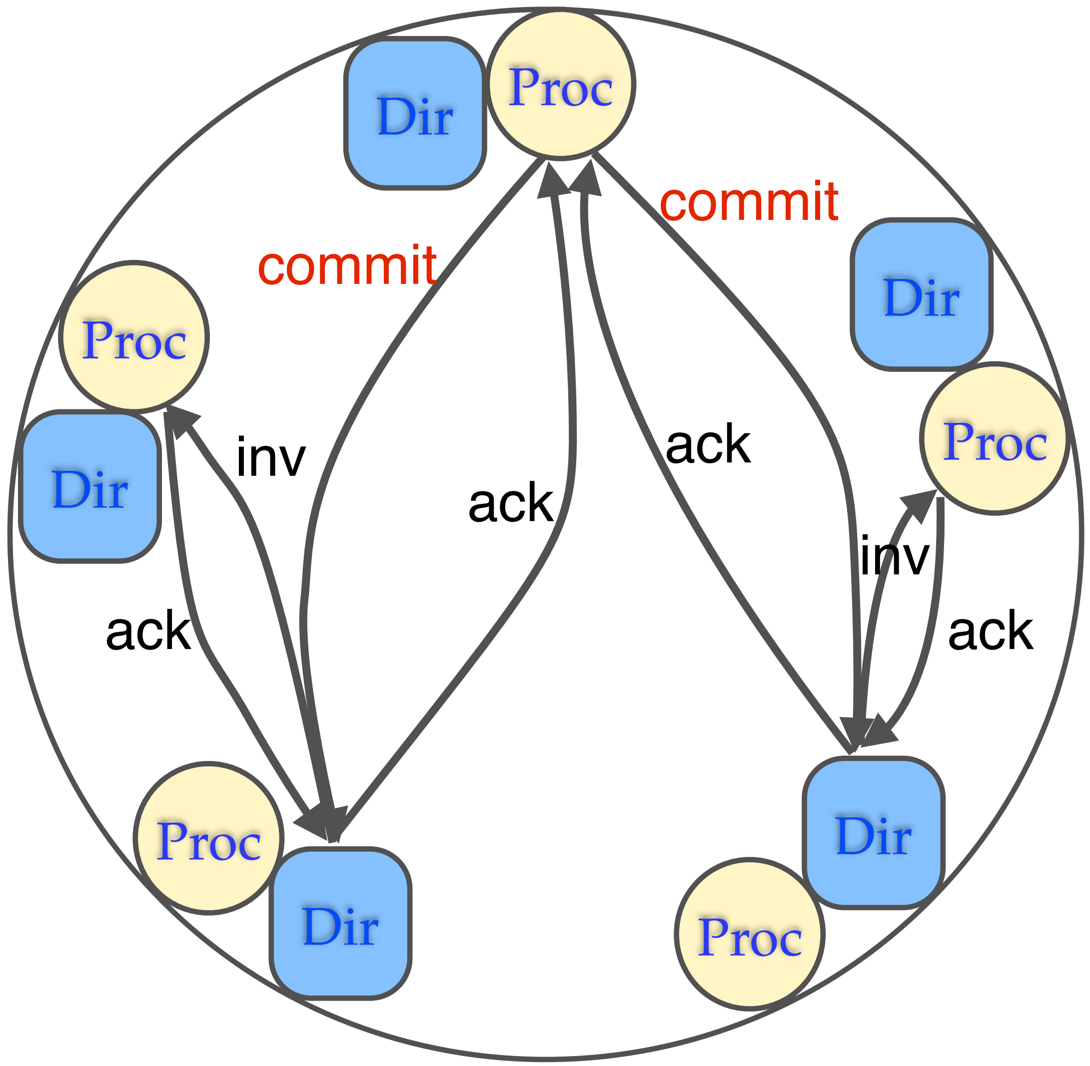
Motivation

- Architectures that continuously execute Atomic Blocks or Chunks (e.g.,TCC, BulkSC)
    - Chunk: group of dynamically contiguous instructions executed atomically
    - Provide performance and programmability advantages [Hammond 04], [Ahn 10]
    - An important operation is commit: makes the state of chunk visible atomically
- Designs with lazy detection of chunk conflicts
    - Commit involves updating cache states and checking for conflicts
- In lazy directory-based cache coherent systems, commit is very challenging
    - Requires updating the states of the distributed caches in a way that appears that chunks execute in a total order
    - In large systems, it results in an execution bottleneck

Commit in Directory-Based Machine



Conventional Cache Coherence

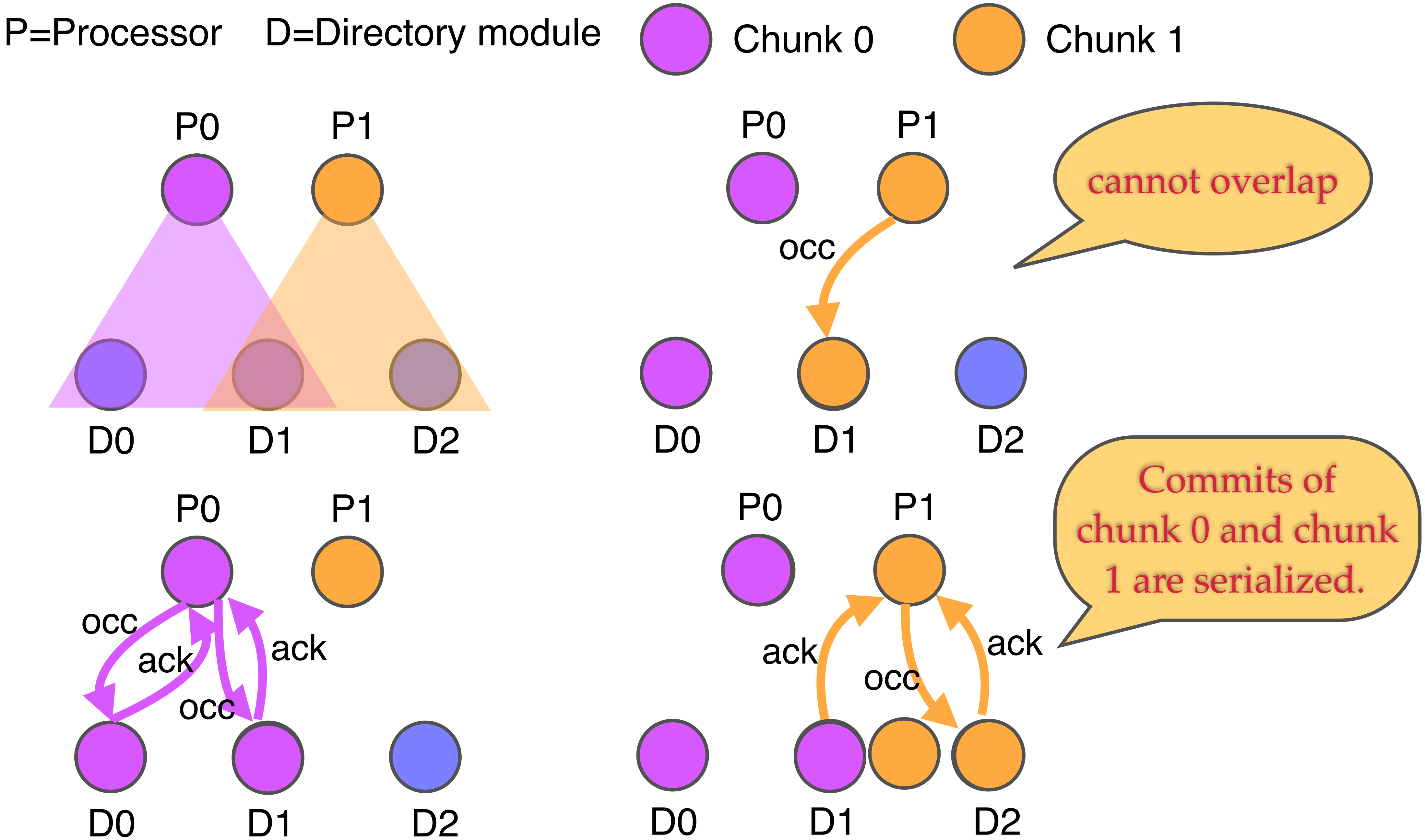


Chunk-based Cache Coherence

Recent Commit Protocols

- BulkSC [Ceze 07]:
  - Centralized commit arbiter
- Scalable TCC [Chafi 07]:
  - First distributed scheme
  - Enforce total order by grabbing a commit token
    - Serialization and global communication
- SEQ Protocol [Pugsley 08]:
  - Extends Scalable TCC by eliminating global communication
  - Still requires serialization of commits that use the same directory module

SEQ Protocol



Commits that use the same directory module are serialized even when they touch non-overlapped lines

Outline

- Motivation
- ScalableBulk
- Evaluation

Goals for Scalable Commit

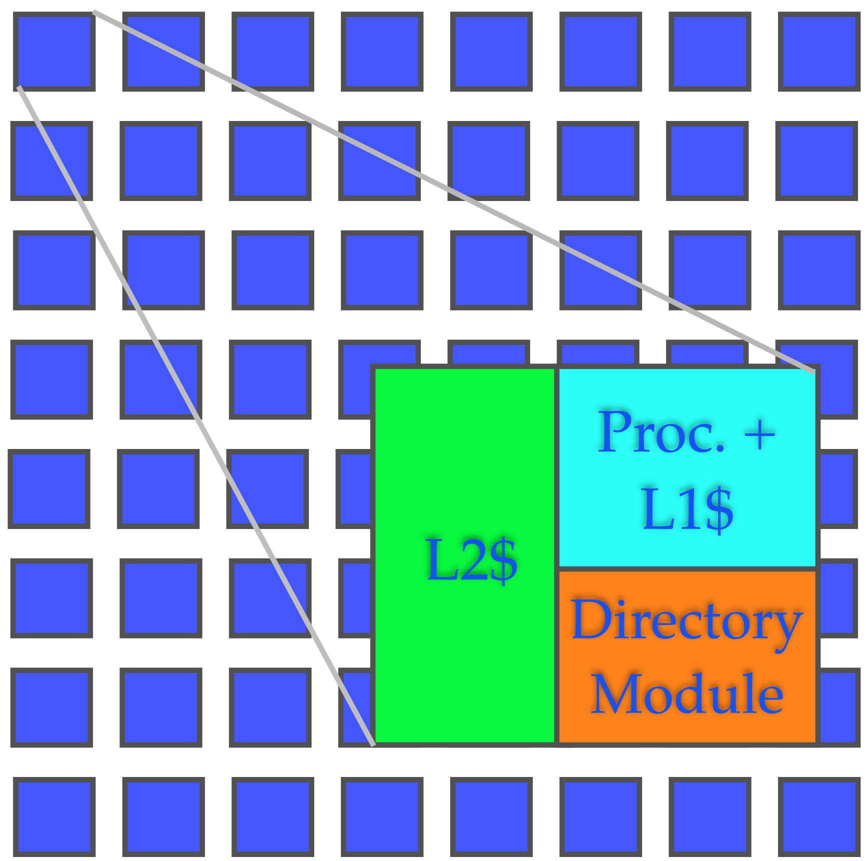
- No centralized structure
- Committing processor communicates only with the relevant directory modules
- Allow concurrent commits of chunks that use the same directory module, as long as the accessed addresses do not overlap

Contribution: ScalableBulk

- ScalableBulk: protocol for bottleneck-free commit of chunks in directory-based system
- Key properties:
  - Enable multiple concurrent chunk commits that use the same directory module
    - Made possible by integrating signatures into directory design
    - Better tolerance to commits that use many directories
  - Eliminates all centralized structures and global communications
    - Committing processor only communicates with the relevant directories (the homes of the addresses accessed by the chunk)
  - More scalable than previous schemes
- Results: practically eliminates all commit stall overhead for 64 processors

ScalableBulk Protocol Primitives

- Allowing multiple non-overlapping commits to use the same directory module
- Grouping directory modules
- Initiating the commit optimistically

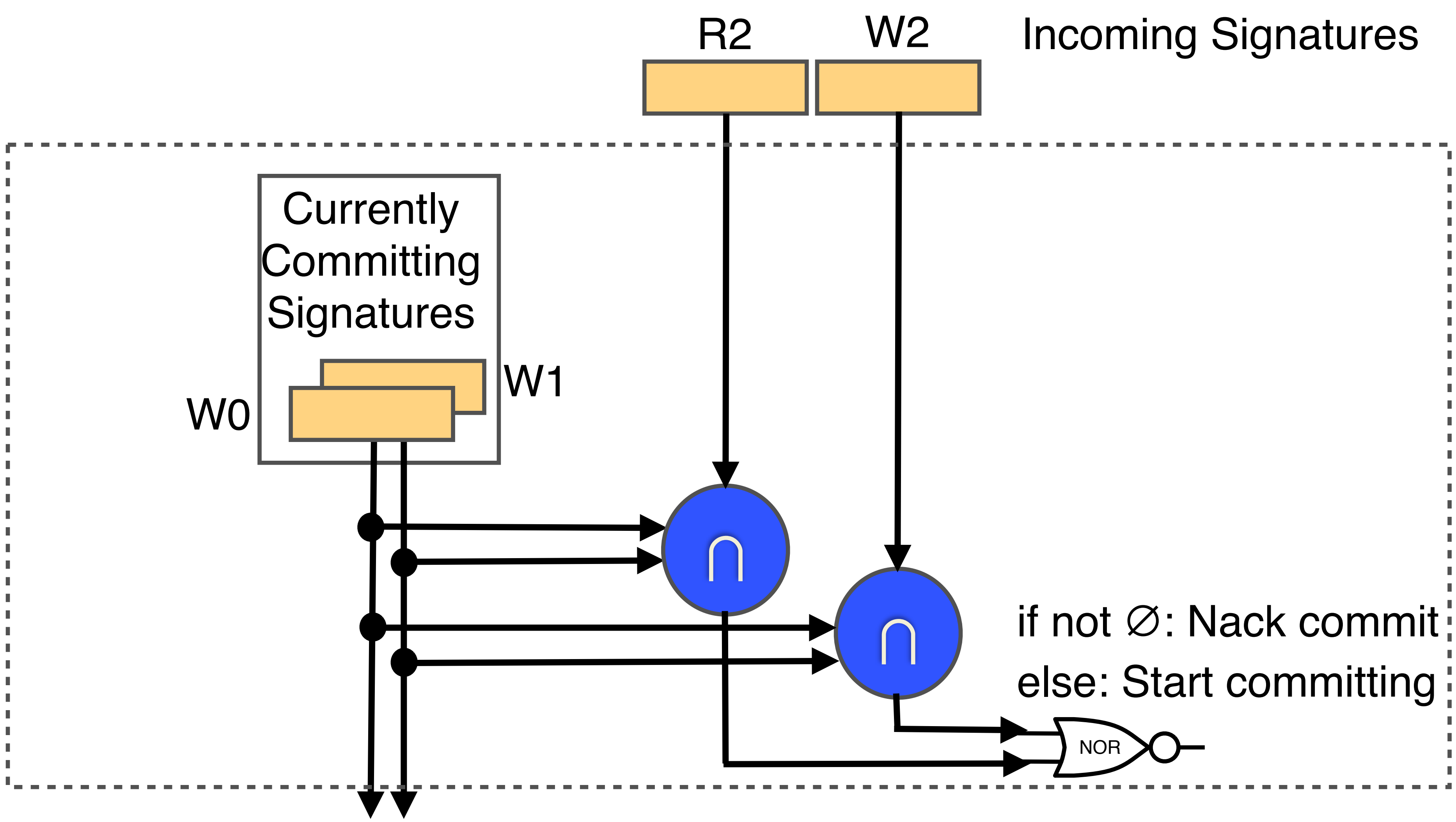


Many-Core Architecture Considered

Primitive 1: Allowing Concurrent Non-overlapping Commits

- Read and write footprint of a chunk is summarized in read and write signatures using Bloom filters
- On commit: signatures are sent to the relevant directory modules
- Only the addresses in the signature are locked in the directory during the commit
- Other chunks can commit using the same directory if their signatures do not conflict with the committing signatures

Primitive 1: Allowing Concurrent Non-overlapping Commits



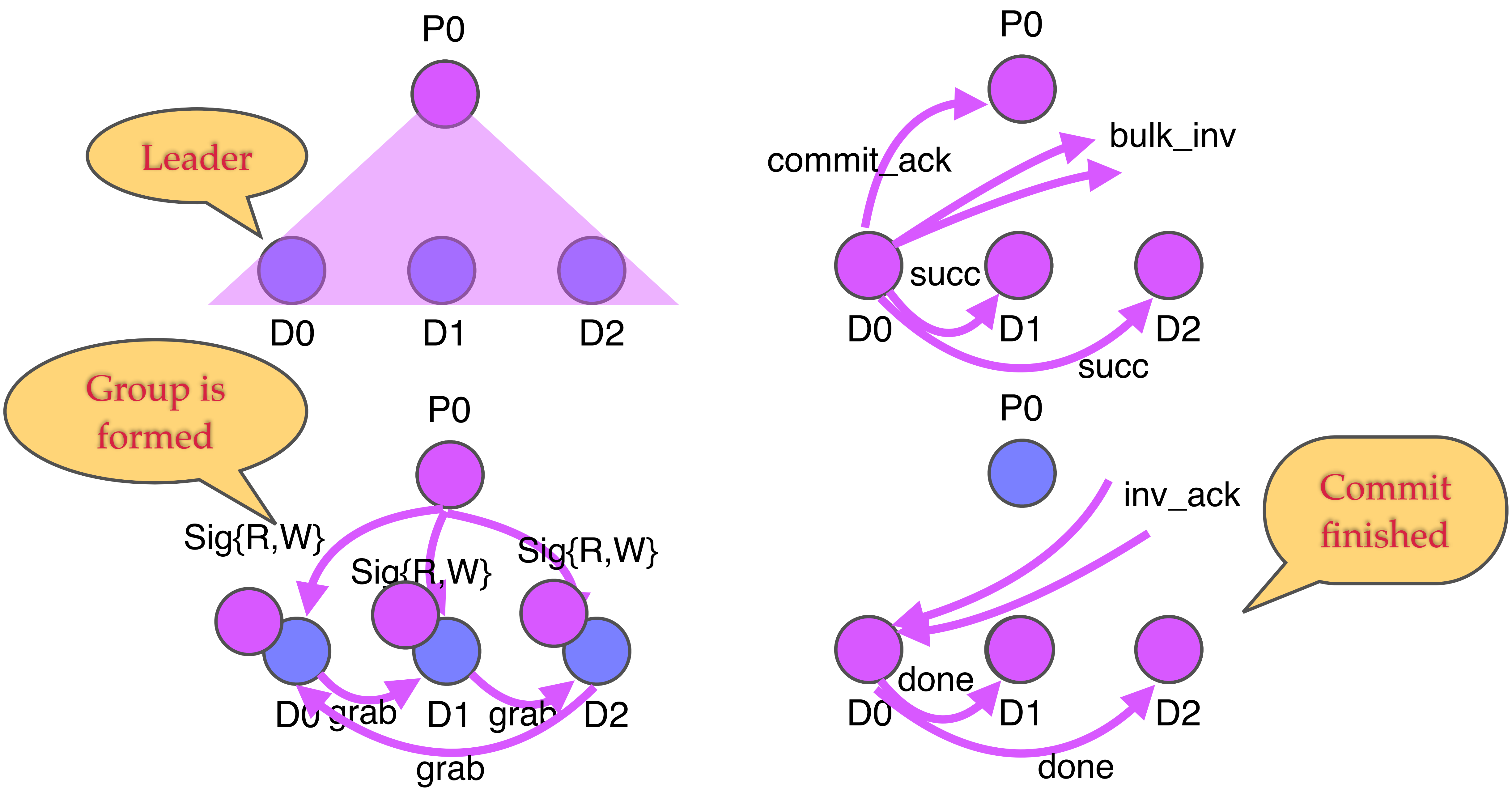
- Enables more concurrent commits

Primitive 2: Grouping Directory Modules

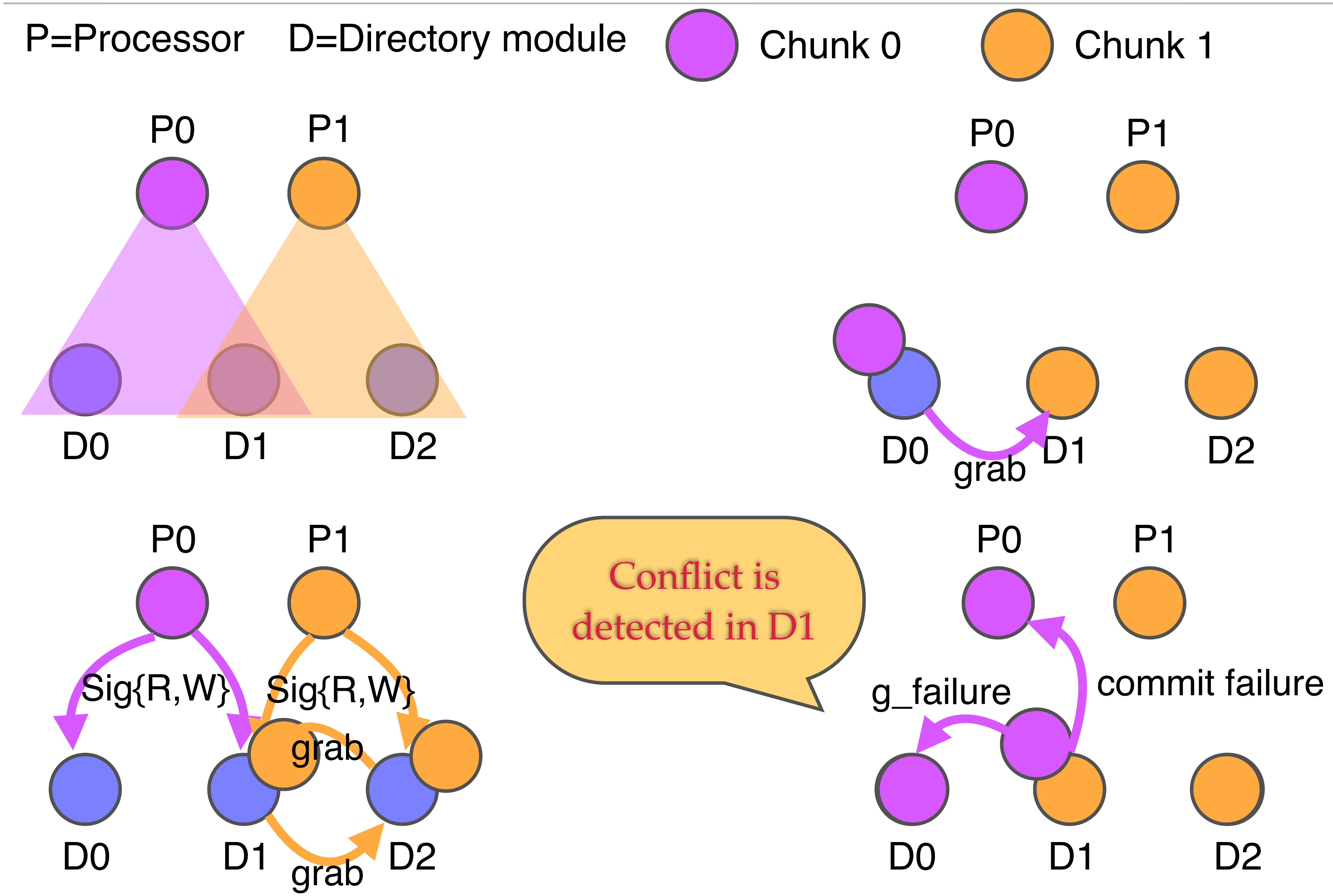
- On a chunk commit: the relevant directory modules
  - Coordinate their transitions by exchanging messages
  - Form a Directory Group
  - Identify a leader module that sends messages to the caches and the committing processor on behalf of the group
- Grouping Protocol:
  - Complete distributed operation
  - Few messages are required
  - Leader: lowest-numbered directory module in the group

Primitive 2: Grouping Directory Modules

P=Processor D=Directory module Chunk 0



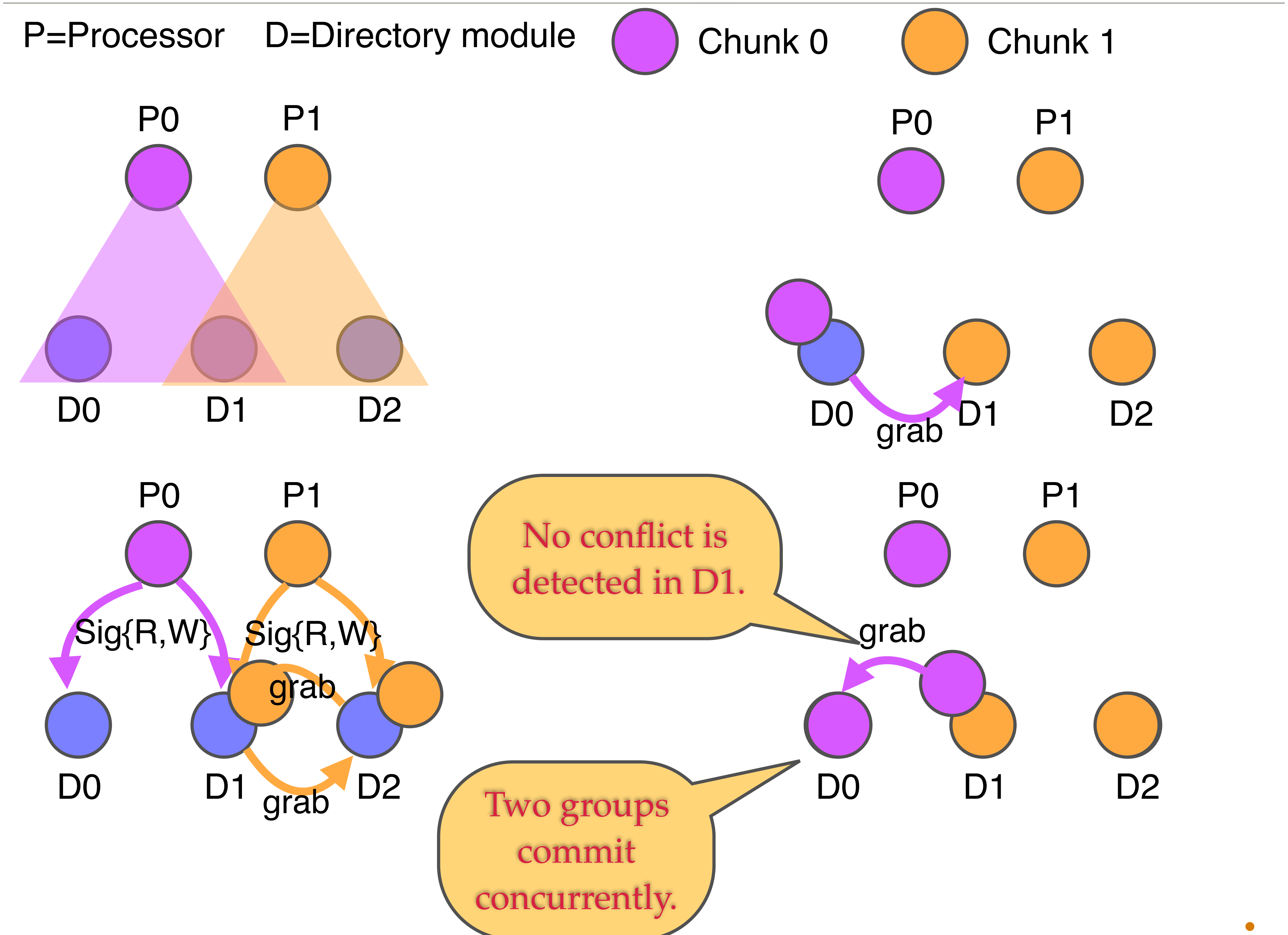
Distributed Conflict Detection



Primitive 2: Grouping Directory Modules

- Deadlock is avoided by following a fixed directory-module traversal order
- Multiple groups can commit concurrently

Concurrent Commit



Primitive 3: Optimistic Commit Initiation

- Idea:
  - Committing processor (CP) assumes its commit transaction will succeed
  - CP consumes incoming messages before receiving OK to commit
- Advantages: it enables more overlapping of commits
- Details in the paper

Summary: Scalable Commit

- Commit has no centralization point
- Committing processor communicates only with relevant directory modules (no message broadcasting)
- Multiple committing chunks can use the same directory modules, if the addresses that they access do not overlap
  - Similar to how conventional protocols support concurrent writes
- Optimistic Commit Initiation removes operations from critical path of the commit

Commit is truly scalable

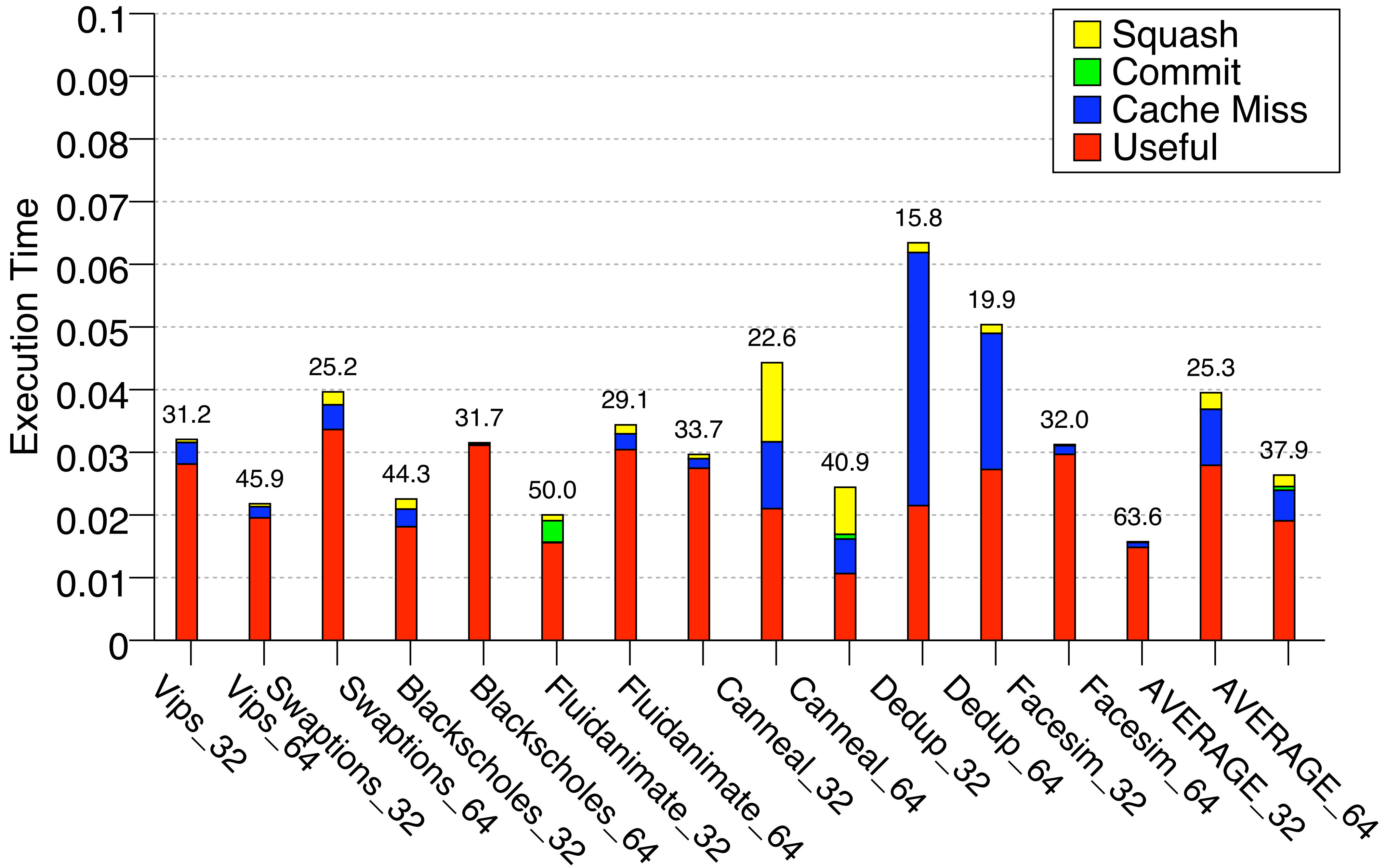
Outline

- Motivation
- ScalableBulk
- Evaluation

Evaluation

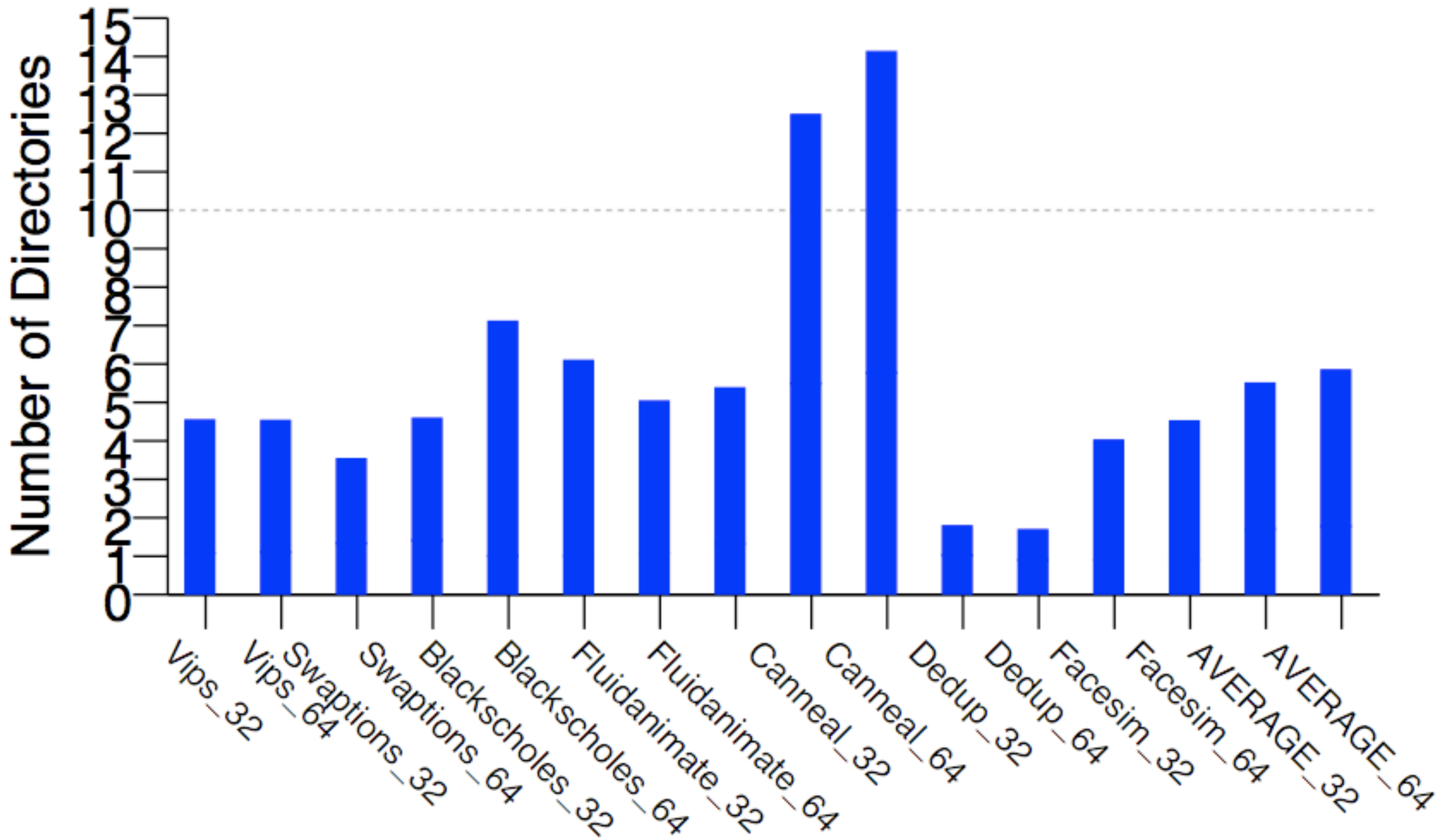
- Cycle-accurate execution-driven simulator based on SESC and Pin
- Number of cores: 32 and 64
- 11 SPLASH-2 and 7 PARSEC applications
- Implemented all existing protocols:
  - ScalableBulk
  - Scalable TCC
  - SEQ
  - BulkSC

Execution Time



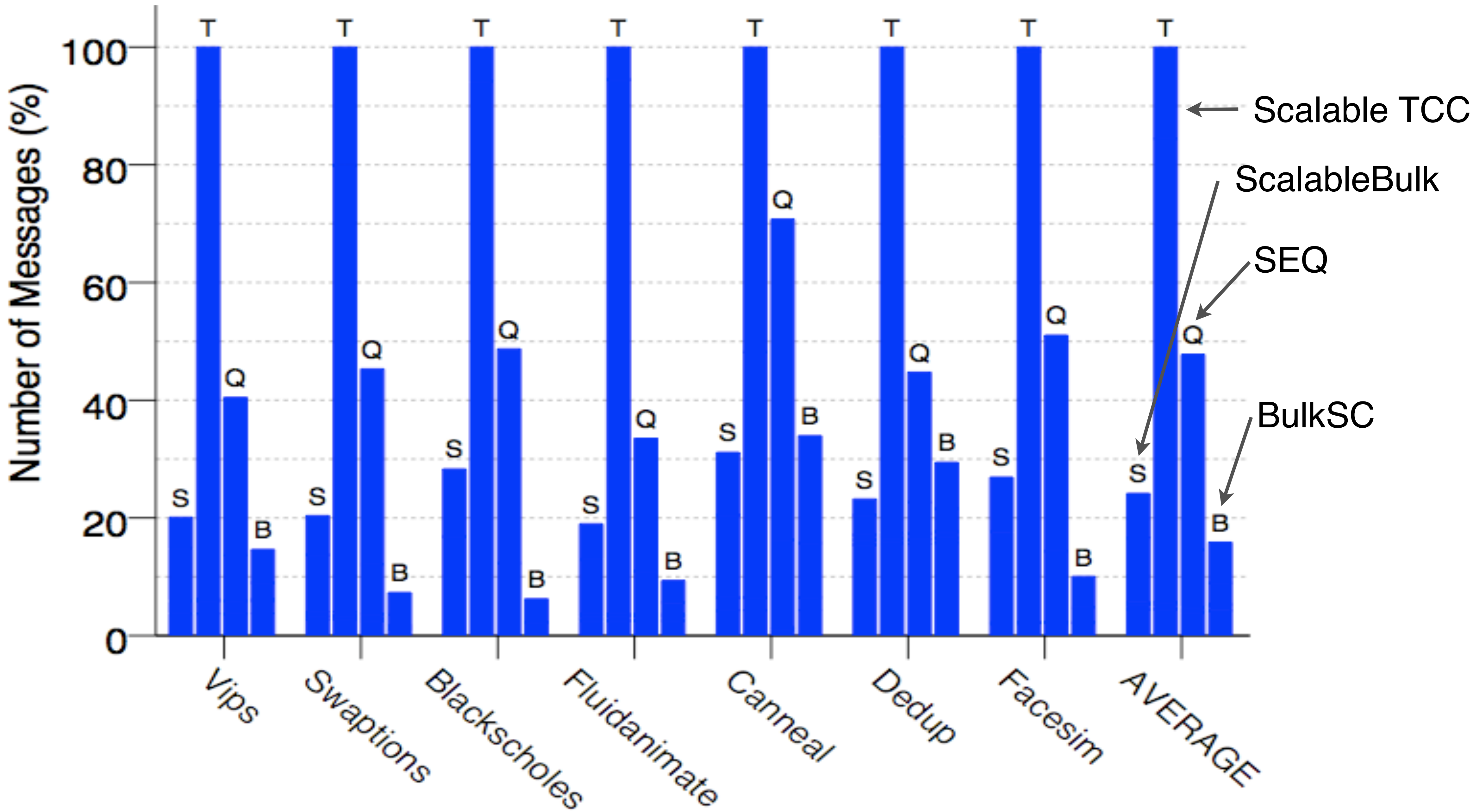
- ScalableBulk practically eliminates all commit stall time
- Other existing protocols suffer commit stall (see paper)

Directories Used Per Commit



- Chunk commits use about 6 directories on average
- ScalableBulk is able to overlap the commits that use the same directories if the signatures do not conflict

Network Message Characterization



- ScalableBulk sends fewer messages than other distributed protocols

Also in the paper

- Mechanism to handle fairness and avoid starvation
- Many details on the implementation of the ScalableBulk protocol
- Detailed results characterizing various aspects of the protocol

Conclusion

- Proposed ScalableBulk: protocol for bottleneck-free commit of chunks in lazy directory-based system
- Key properties:
  - Enables multiple concurrent chunk commits that use the same directory module
    - Thanks to use of signatures
  - Eliminates all centralized structures and global communications
- Results: practically eliminates all commit stall overhead for 64 processors
- Effectively enables a large-scale chunk-based machine

ScalableBulk:

Scalable Cache Coherence for Atomic Blocks in a Lazy Envionment

Xuehai Qian, Wonsun Ahn, Josep Torrellas
University of Illinois