Distributed Systems

CS425/ECE428

May 1st 2023

Instructor: Radhika Mittal

Logistics

- No class on Wednesday May 3rd.
- I'll hold an extra office hour on May 3rd, 11am-noon, CSL257.
- I won't hold my office hour on May 8th.
  - Manoj will hold an office hour on May 8th instead.

Logistics

- Final exam on: May 4-11
  - Reservation via PrairieTest.
  - Same format as your midterm, but longer.
  - Unless you have approved accommodations, you have 1 hour 50mins to complete the exam from the start time.
  - **Comprehensive:** includes everything covered in the course.
    - Higher weightage assigned to materials that were not covered in midterm syllabus (i.e. Raft and beyond).

PrairieLearn

- Exam format:
  - Multiple choice questions and True/False
    - For questions with multiple choices correct, there is negative marking for selecting incorrect choices to discourage guesswork (the minimum score per question is capped at zero).
  - Numerical questions
    - No step marking!
- If a subpart is not attempted or has invalid format, entire question will be left ungraded.

Exam Syllabus

- All topics covered so far
  - Midterm content
  - Post-midterm content (higher weightage, > 65%)
    - Starting from Raft, up until distributed datastores.

Exam Syllabus

- **Midterm content (included in finals)**
  - System model and Failures
  - Failure Detection
  - Clock Synchronization
  - Event ordering and Logical Timestamps
  - Global Snapshot
  - Multicast
  - Mutual Exclusion
  - Leader Election
  - Synchronous Consensus and Paxos

Exam Syllabus

- Remaining topics (included in finals)
  - Raft
  - Blockchains
  - Transaction Processing and Concurrency Control
  - Distributed Transactions
  - ~~External consistency and Spanner~~
  - Distributed Hash Tables (Chord)
  - MapReduce
  - Distributed Datastores

Disclaimer

- Quick reminder of the relevant concepts we covered in class.
- Not meant to be an exhaustive review!
- Go over the slides for each class.
  - Refer to lecture videos and textbook to fill in gaps in understanding.

and reference materials

System model and Failures

- What is a distributed system?
- Relationship between processes
- Synchronous and Asynchronous Systems
- Types of failures

Failure Detection

- Ping-ack and Heartbeats
  - what are appropriate timeout values?
- Correctness of failure detection algorithms
  - accuracy and completeness
  - synchronous vs asynchronous systems
- Performance of failure detection algorithms
  - bandwidth usage and worst-case failure detection times
- Extending to a system of N processes.

Clock Synchronization

- Clock skew and drift rates
- External vs Internal Synchronization
- Clock synchronization in synchronous systems
- Clock synchronization in asynchronous systems
  - Cristian Algorithm
  - Berkeley Algorithm
  - NTP symmetric mode synchronization

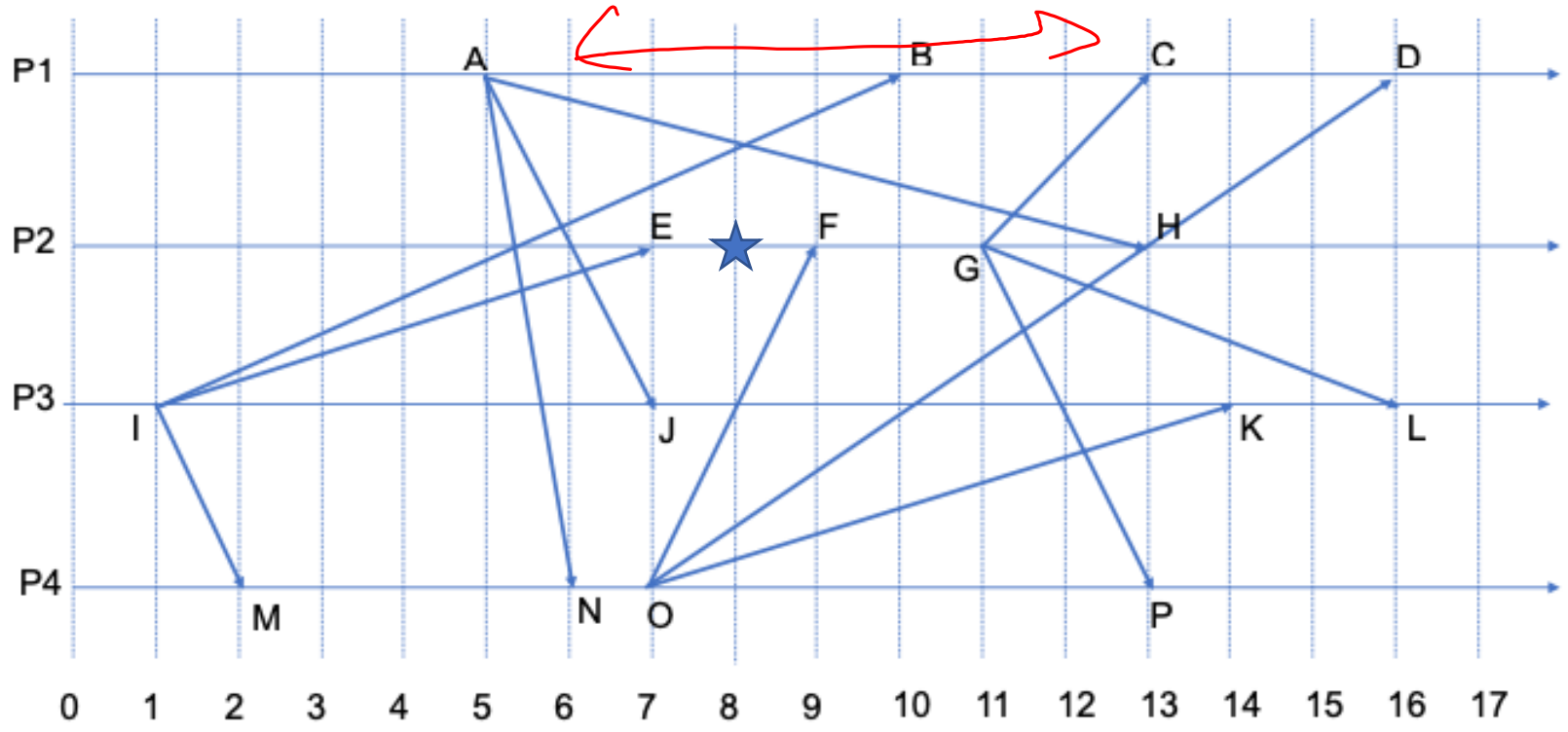
Event ordering and Logical Timestamps

- Happened before relationship
- Lamport Clocks
- Vector Clocks

Global Snapshots

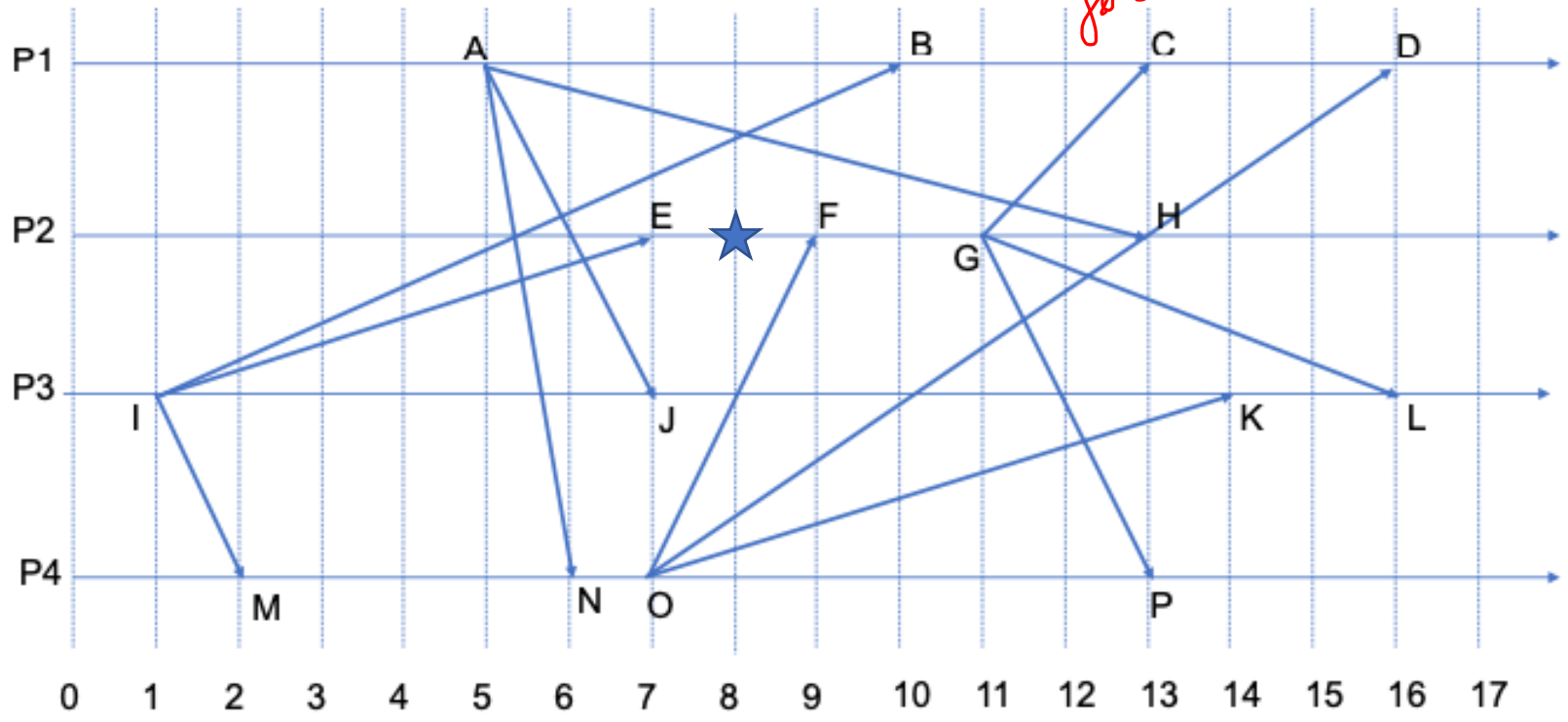
- Process and channel states
- Consistent cuts
- Chandy-Lamport algorithm
- Runs and Linearizations
- Safety and liveness properties, stable global predicates

Global Snapshots



Set of consistent cuts?

Global Snapshots

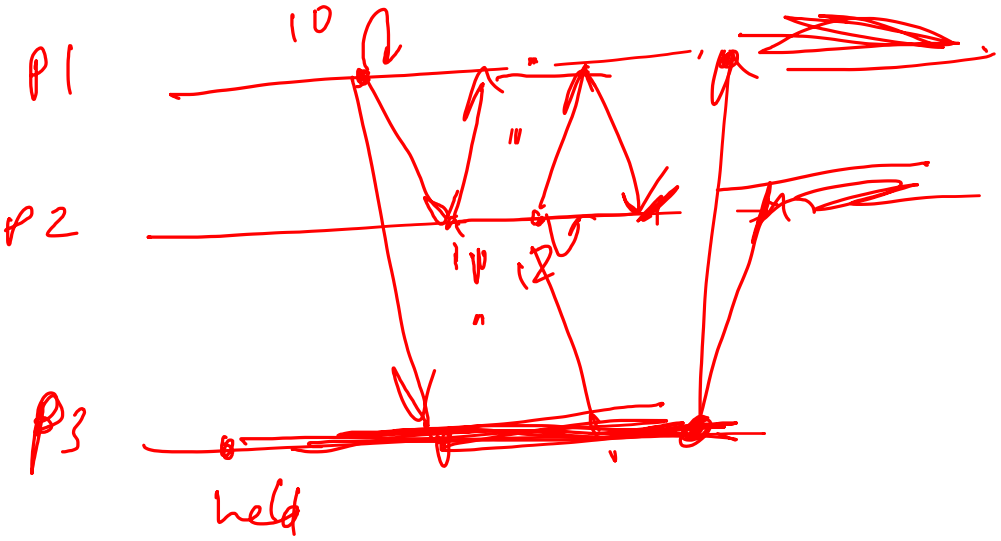


Incoming channels at P1?

Multicast

- Basic multicast
- Reliable multicast
- Ordered multicast: FIFO, Causal, Total
  - Implementing FIFO ordered multicast
  - Implementing causal ordered multicast
  - Implementing total ordered multicast
    - centralized (sequencer) algorithm
    - ISIS algorithm

Mutual Exclusion

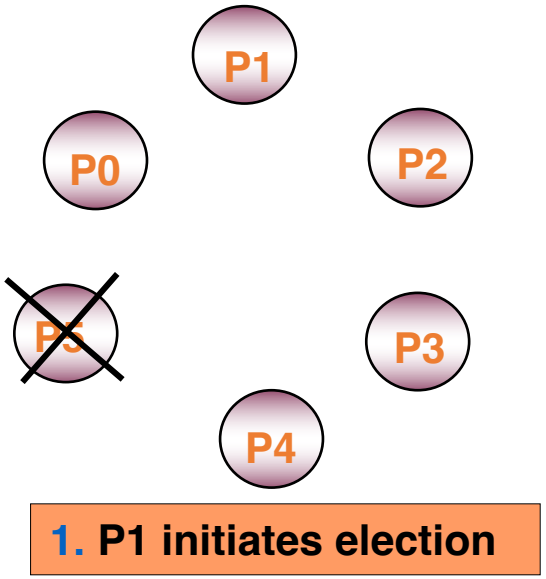


- Central server algorithm
- Ring-based algorithm
- Ricart Agrawala algorithm
- Maekawa algorithm (breaking deadlock not in your syllabus)
- Analyzing these algorithms:
  - Safety, liveness, and ordering
  - Client delay, Synchronization delay, and Bandwidth.

Leader Election

- Ring election algorithm (Chang and Roberts algorithm)
- Bully algorithm
- Analyzing these algorithms:
  - Safety and liveness for synchronous and asynchronous systems
  - Turnaround time and bandwidth

Bully Algorithm



To begin with,
only P1 knows of P5's failure.
No other failures.

Number of messages sent by P2? 4

Number of messages received by P2? 4

Turnaround time? 4T

Synchronous vs Asynchronous Consensus

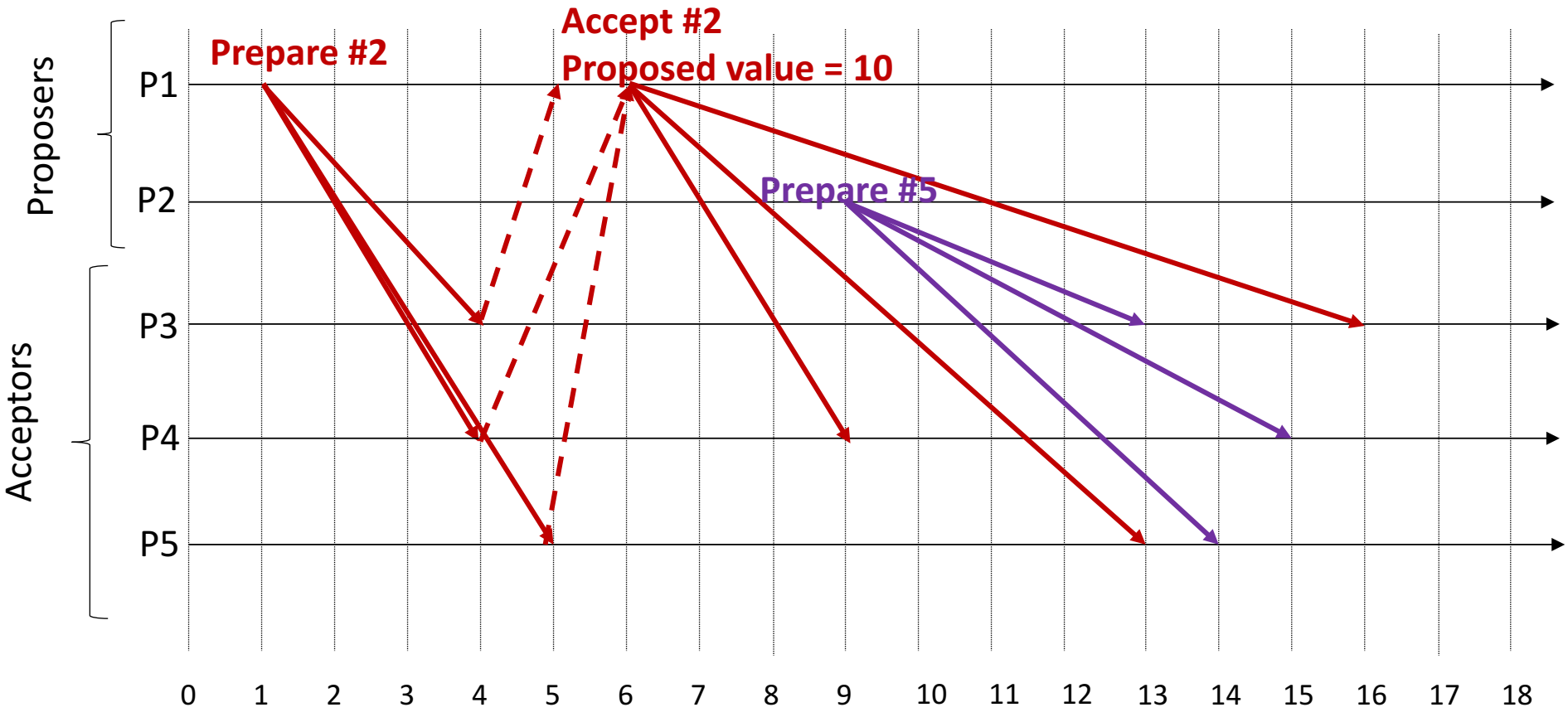
- Round-based algorithm for synchronous consensus
  - how many rounds are needed to tolerate up to f failures?

- Impossibility of consensus in asynchronous systems
  - cannot achieve both safety and liveness for consensus in an asynchronous system.
  - proof not in your syllabus.

Paxos

- Three roles: proposer, acceptor, learner.
- Phase 1: *prepare* request and response.
  - When will an acceptor respond with a promise?
  - What are the contents of the promise?
- Phase 2: *accept* request (if applicable)
  - When will an accept request be sent?
  - What will be the proposed value?
- When is a value implicitly decided? How is the value shared with the learners? What is required to guarantee safety?

Paxos

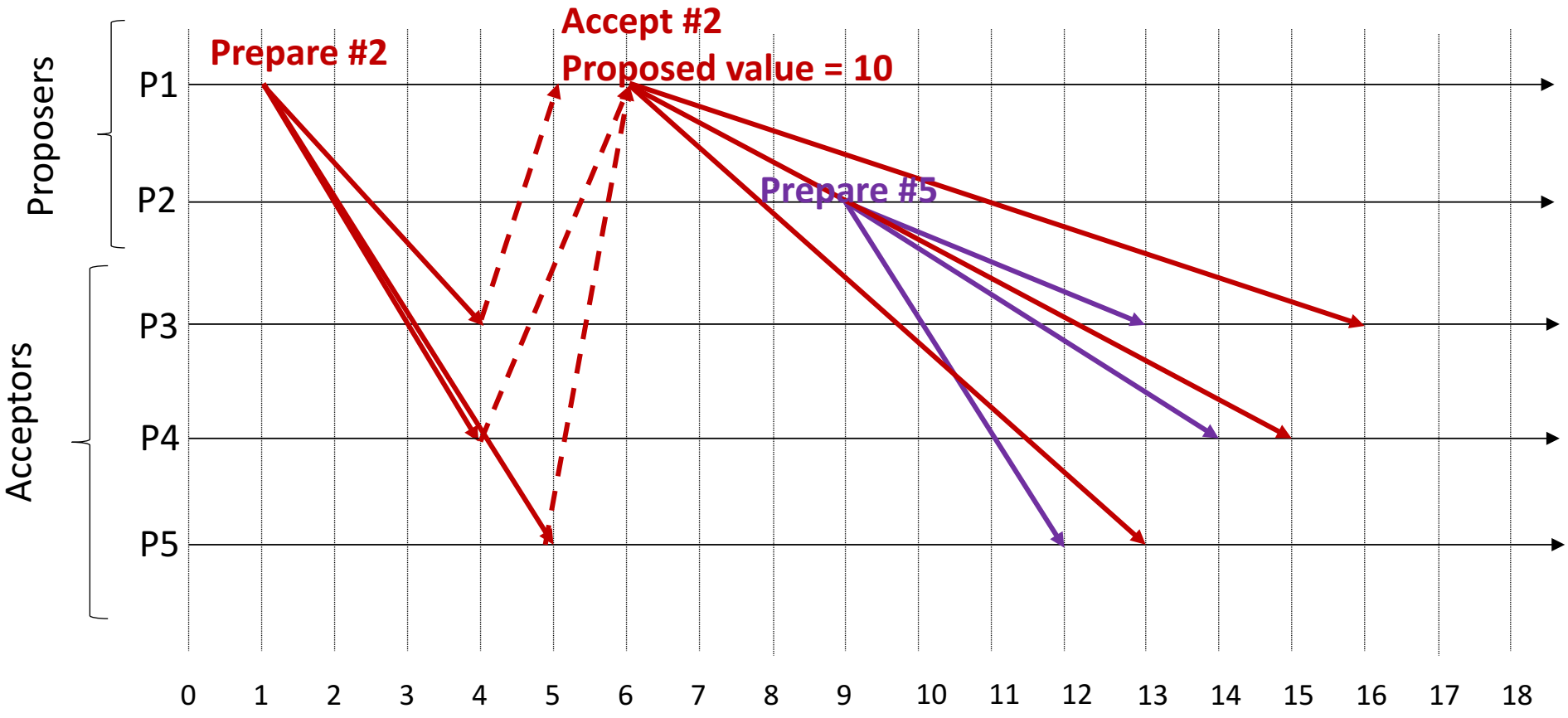


P2 intends to propose a value 15.

Will P2 send an accept request? What value will it propose?

yes, 10

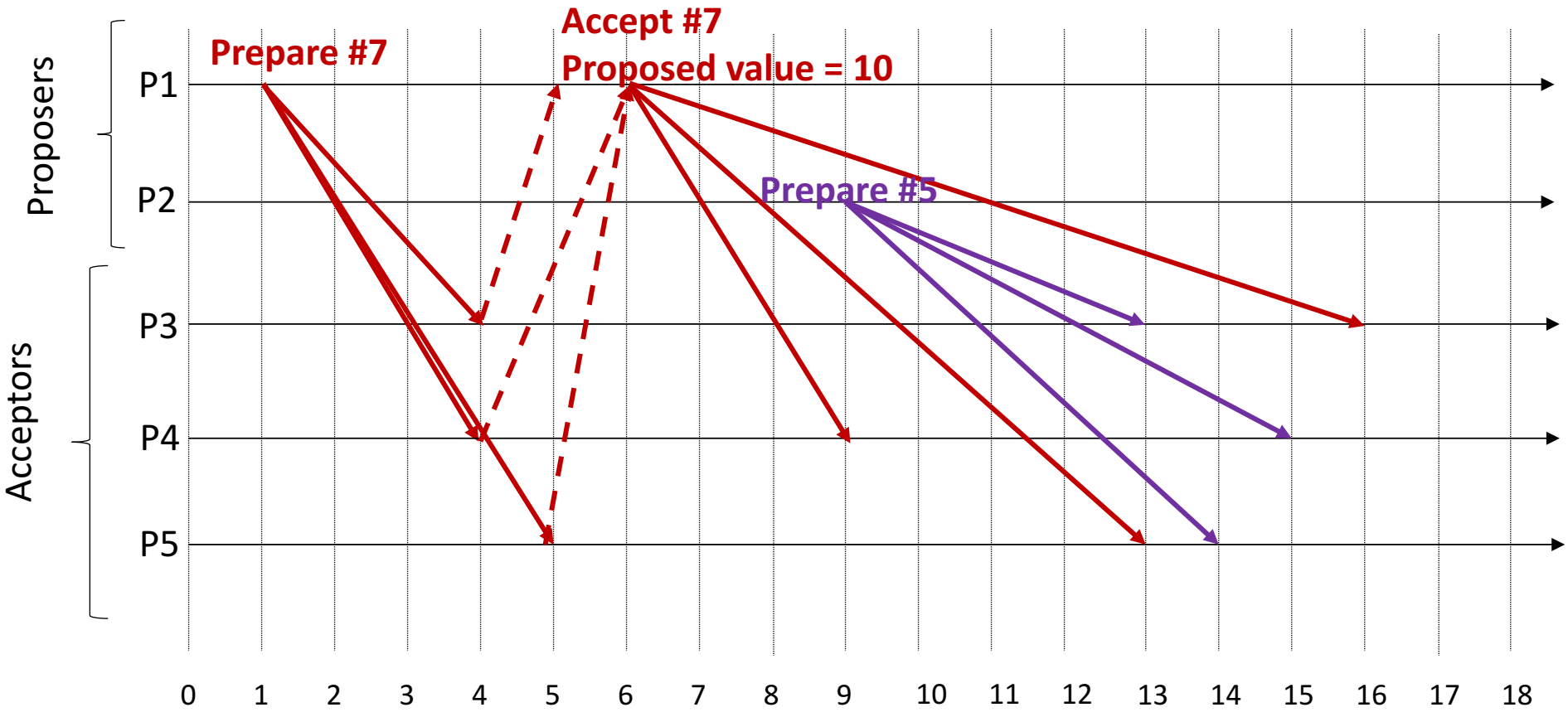
Paxos



How about now?

yes, 15

Paxos



How about now?

no

Raft

- Algorithm for log consensus. Designed for simplicity.

- What are the guarantees provided by Raft and how?
- How is leader elected?
  - Under what conditions will a process refuse to grant vote?
- What happens when a leader fails or gets disconnected?
- How are log entries appended?
- What leads to missing / extra entries in a server's log?
- When can log entries be overwritten?
- When can log entries be committed?

Raft

- Valid or not?
  - S1: 1, 1, 1
  - S2: 1, 2, 2
  - S3: 1, 2, 3

valid

- S1: 1, 1, 1
- S2: 1, 1, 2
- S3: 1, 1, 3

invalid

- S1: 1, 1, 3, 3
- S2: 1, 2, 2
- S3: 1, 1, 3

valid

S1: 1 1 3 3

S2: 1 2 2

S3: 1 1 3

Bitcoin / Blockchains

- How is a new transaction added to the log?
  - How is a block mined, and added to a chain?
- What factors determine the rate at which a block is mined?
- What happens if two nodes mine different versions of a block?
- How is information propagated in a Bitcoin network?

Transaction Processing

- What are the ACID properties?
  - How is atomicity achieved?
  - What does consistency mean in this context?
  - What does isolation mean, and how is it achieved?
  - What is durability?

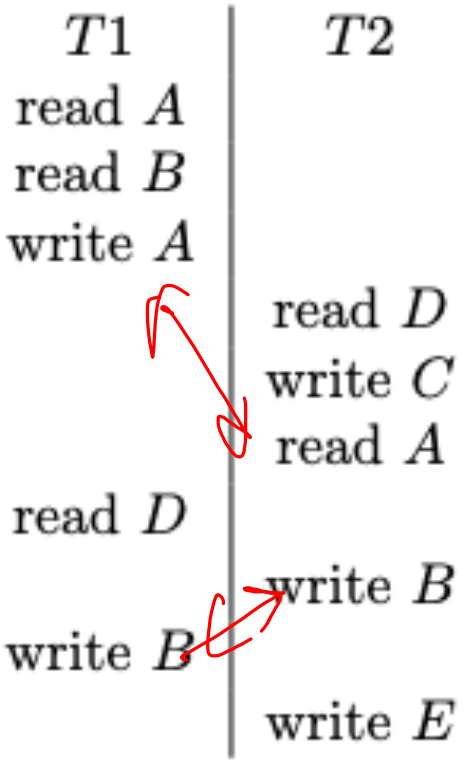
Concurrency Control

- What could go wrong if we don't have isolation?
  - Lost update problem
  - Inconsistent retrieval problem
- What are conflicting operations?
- What is serial equivalence?
- How can we check if an interleaving is serially equivalent?

Concurrency Control

- Pessimistic Concurrency Control
  - Global lock vs per-object locks vs per-object read/write locks
  - Two-phase locking
  - Deadlocks
- Optimistic Concurrency Control
  - Timestamped ordering

Concurrency Control



- Is this serially equivalent?

no

Concurrency Control

$T1$	$T2$
read A	
read B	
write A	
	read D
	write C
read D	
write B	
	read A
	write B
	write E

commit

commit

- What about this? serially equivalent
- Can it be achieved with strict two-phase locking? yes
- Can it be achieved with timestamp ordering? yes

Concurrency Control

$T1$	$T2$
read A	
read B	
write A	
	read D
	write C
	read A
read D	
write B	
	write B
	write E

- What about this? (Serial yes equivalent)
- Can it be achieved with strict two-phase locking? No
- Can it be achieved with timestamp ordering? No

Distributed Transactions

- Meeting ACID requirements for distributed transaction:
  - Two-phase commit for atomicity
  - Distributed deadlock detection with two-phase locking.

Distributed Hash Tables (Chord)

- What determines the placement of nodes in a Chord ring with m-bit key space?
- Which node is responsible for storing a given key?
- What are the routing table entries maintained by each node:
  - Finger tables
  - r successor entries
- What is the key lookup protocol in Chord?
- How does Chord handle churns?
  - Stabilization protocol.

MapReduce

- Map: creates intermediate key-value pairs
- Reduce: aggregate by key, and run some computation across all values for the key.
- A MapReduce chain may comprise multiple map-reduce pairs.
- Allows easier parallelization.
  - Multiple map/reduce tasks scheduled in parallel across the servers in a cluster.
- Barrier between a map stage and a reduce stage.
  - No reduce task starts before all map tasks are finished.

Distributed Datastores (Cassandra)

- What is CAP theorem?
  - Can only achieve two out of consistency, availability, and partition-tolerance.
- Cassandra: chooses availability, with *eventual* consistency
  - Key partitioning and replication strategies.
  - How is cluster membership updated?
  - How is a write query executed?
  - How is a read query executed?
  - What are the different consistency levels?
  - What is hinted-handoff and read repair?

Exam Syllabus

- **Pre-midterm**
  - System model and Failures
  - Failure Detection
  - Clock Synchronization
  - Event ordering and Logical Timestamps
  - Global Snapshot
  - Multicast
  - Mutual Exclusion
  - Leader Election
  - Synchronous Consensus
  - Paxos
- **Post-midterm (more weight)**
  - Raft
  - Blockchains
  - Transaction Processing and Concurrency Control
  - Distributed Transactions
  - ~~External consistency and Spanner~~
  - Distributed Hash Tables
  - MapReduce
  - Distributed Datastores

Good luck!