Distributed snapshots

Doug Woos

Logistics notes

Problem Set 1 due Friday

- questions on Piazza—private, please!

Today

Chandy-Lamport snapshots

Some terms

Often useful: states, executions, reachability

- A state is a global state *S* of the system: states at all nodes + channels

- An execution is a series of states S_i s.t. the system is allowed to transition from S_i to S_{i+1}

- A state S_j is reachable from S_i if, starting in S_i, it's possible for the system to end up at S_j

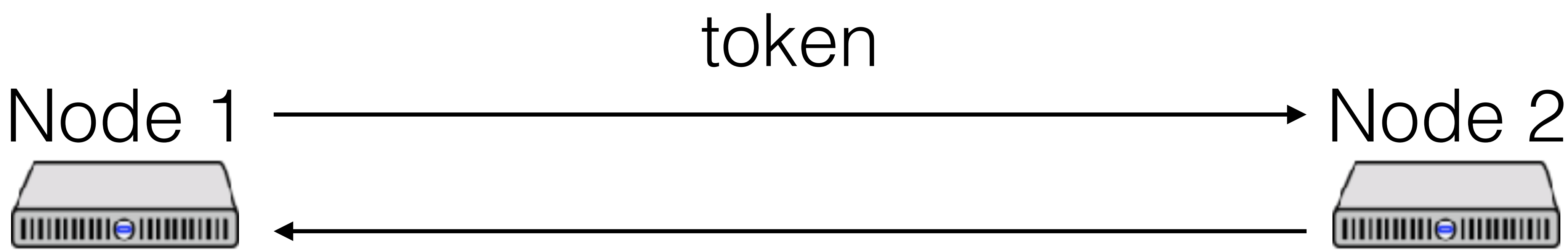
Types of properties: stable properties, invariants

- A property *P* is stable if

  $P(S_i) \rightarrow P(S_{i+1})$

- A property P is an invariant if it holds on all reachable states

Token conservation system



haveToken: bool

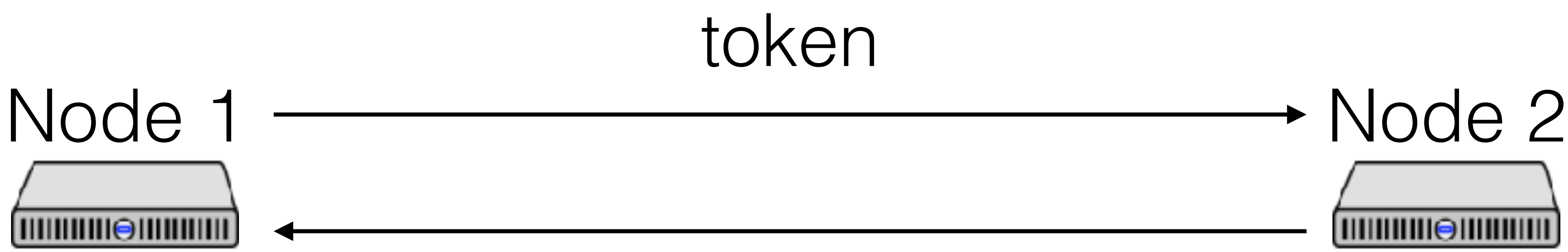
haveToken: bool

In S_o

- No messages
- Node 1 has haveToken = true
- Node 2 has haveToken = false

Nodes can send each other the token or “discard” the token

Token conservation system



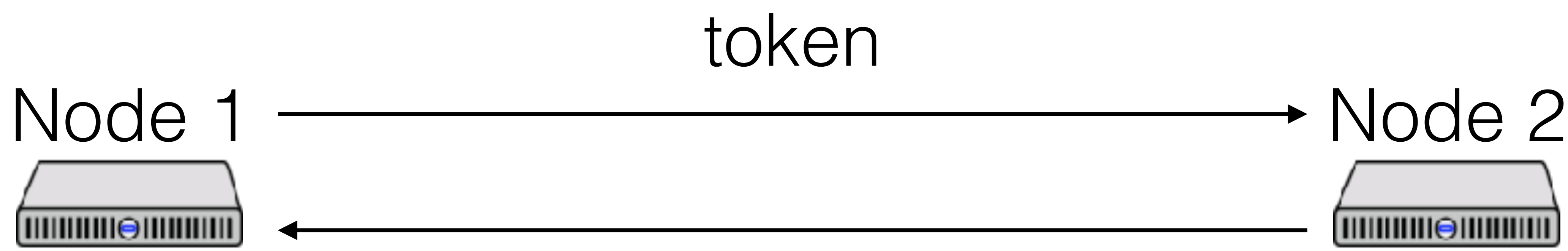
haveToken: bool

haveToken: bool

Invariant: token in at most one place

Stable property: no token

Token conservation system



haveToken: bool haveToken: bool

How can we check the invariant at runtime?

How can we check the stable property at runtime?

Distributed snapshots

Why do we want snapshots?

- Detect stable properties (deadlock)
- Phased computations (decentralized MapReduce)
- Diagnostics
- Invariant maintenance
- Other things?

Distributed snapshots

Problem: record global state of the system

- Global state: state of every node, every channel

Challenges:

- Physical clocks have skew
- State can't be an instantaneous snapshot, *but*
- State must be consistent (???)

Physical time algorithm

What if we could trust clocks?

Idea:

- Node: “hey, let’s take a snapshot @ noon”
- At noon, everyone records state
- How to handle channels?

Physical time algorithm

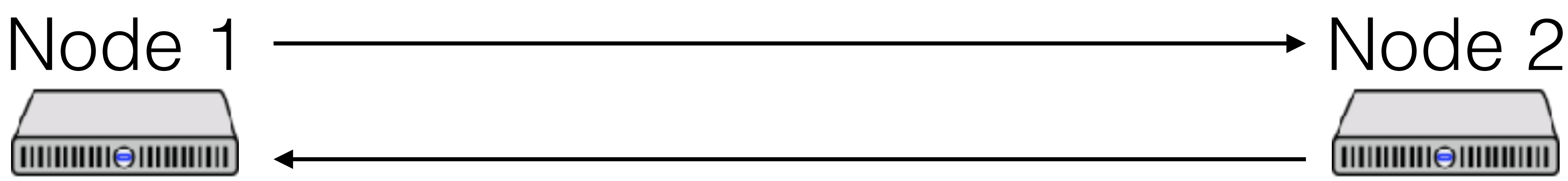
Channels:

- Timestamp all messages
- Receiver records channel state
- Channel state = messages received after noon but sent before noon

Example: is there <= 1 token in the system?

Physical time algorithm

11:59

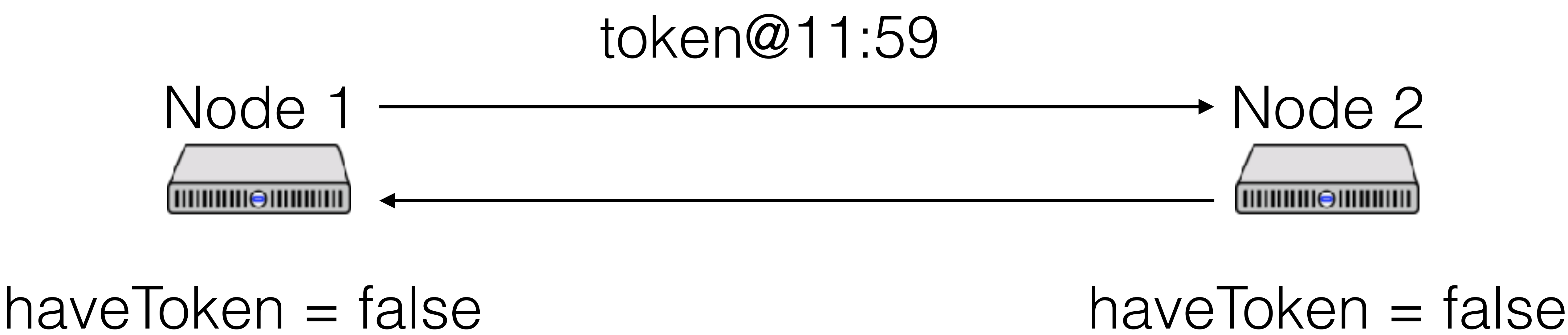


haveToken = true

haveToken = false

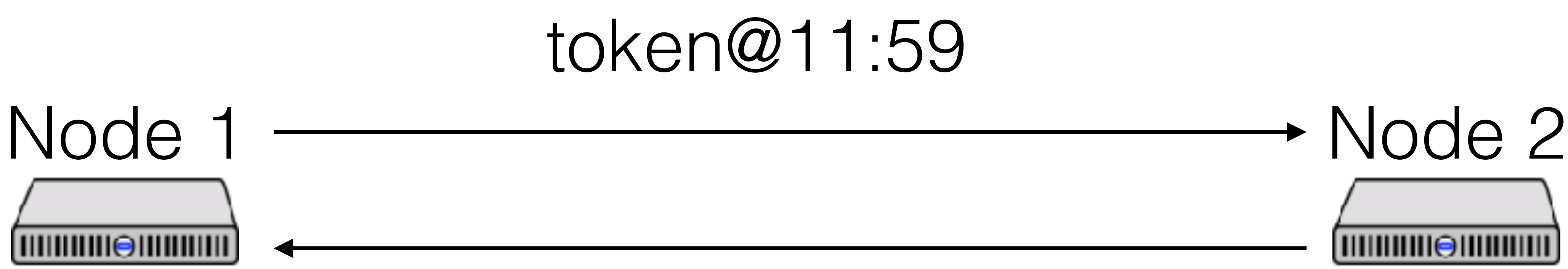
Physical time algorithm

11:59



Physical time algorithm

12:00



haveToken = false

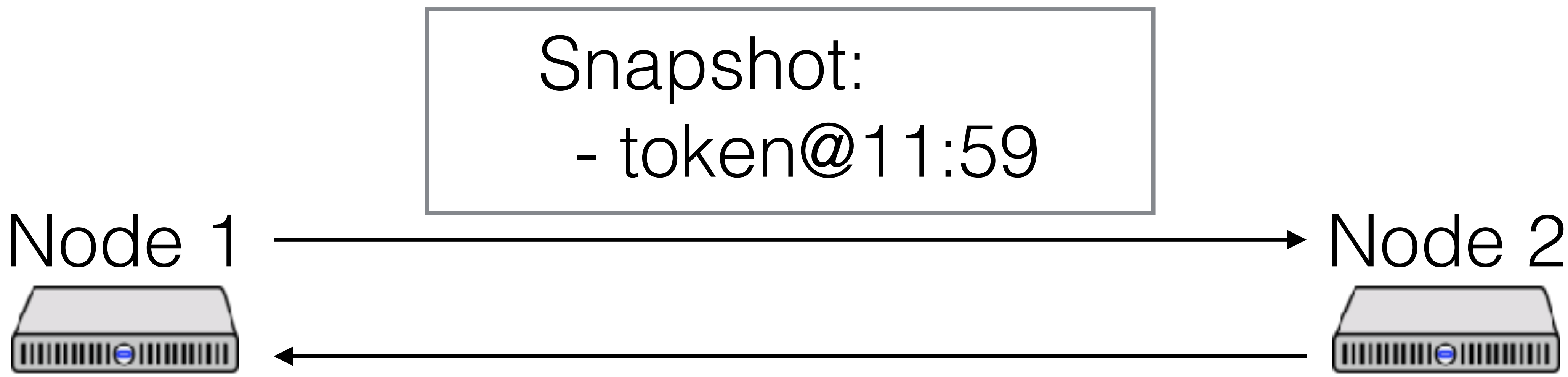
haveToken = false

Snapshot:
- haveToken = false

Snapshot:
- haveToken = false

Physical time algorithm

12:00



haveToken = false

haveToken = true

Snapshot:
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Snapshot:
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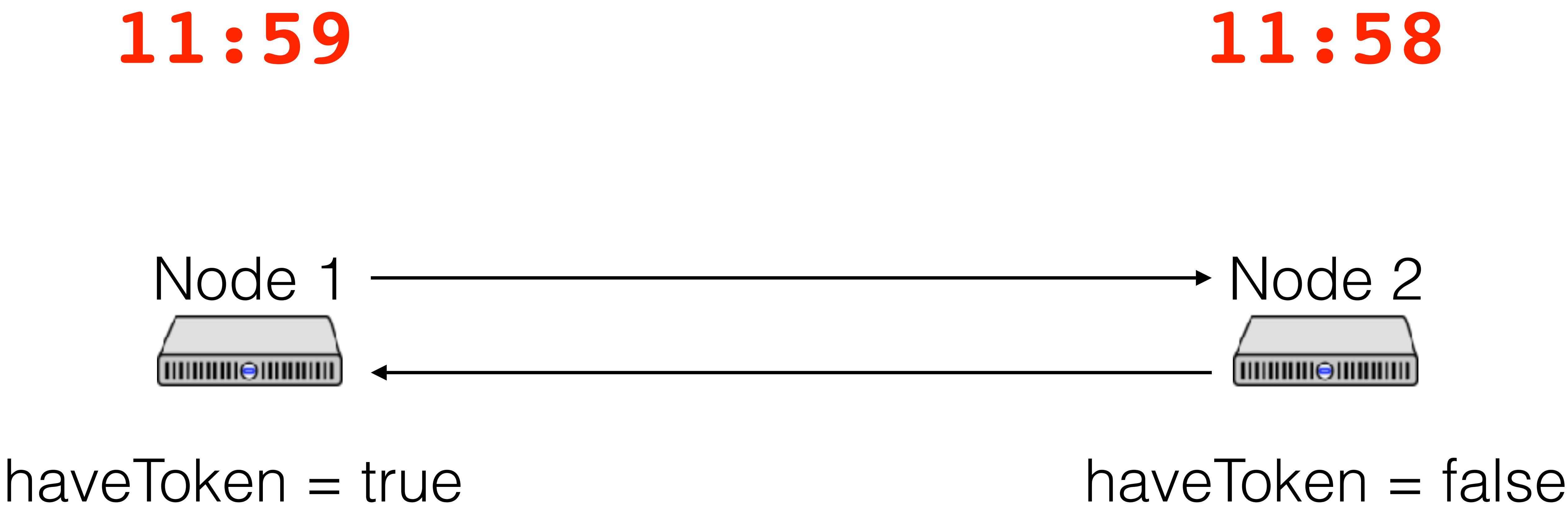
Physical time algorithm

This seems like it works, right?

What could go wrong?

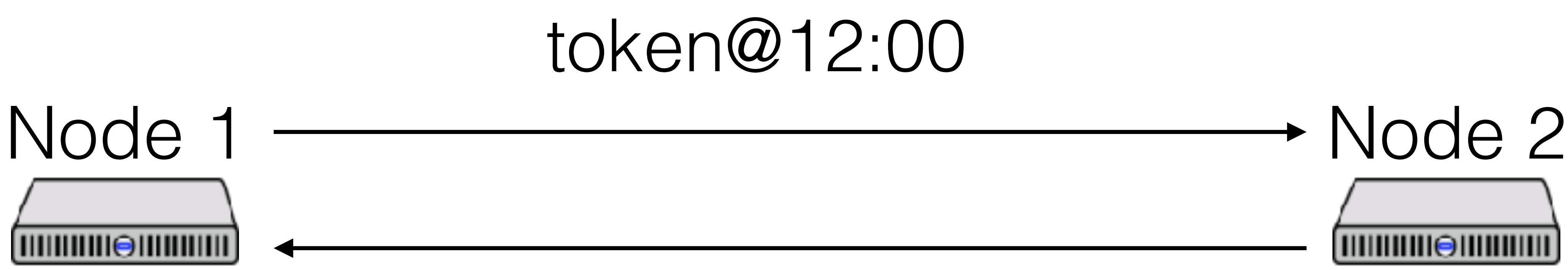
Physical time algorithm



Physical time algorithm

Physical time algorithm

12:00 **11:59**



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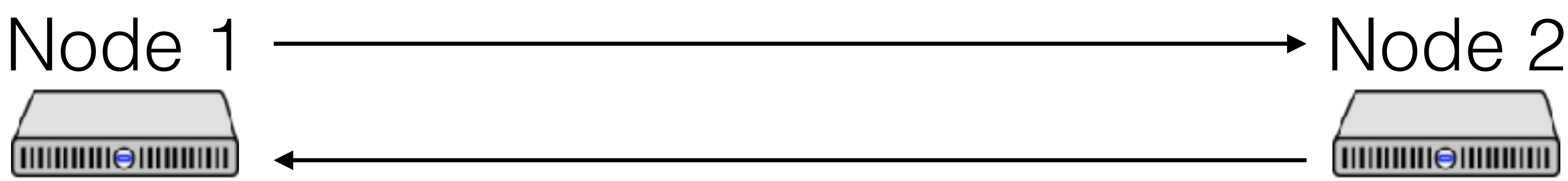
Physical time algorithm

12:00 **11:59**



haveToken = false haveToken = true

Snapshot:
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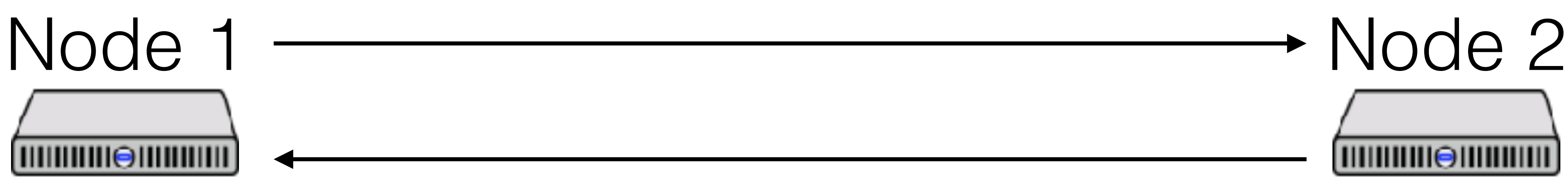
Physical time algorithm

12:01 **12:00**



haveToken = false

haveToken = true

Snapshot:
- haveToken = true

Snapshot:
- haveToken = true

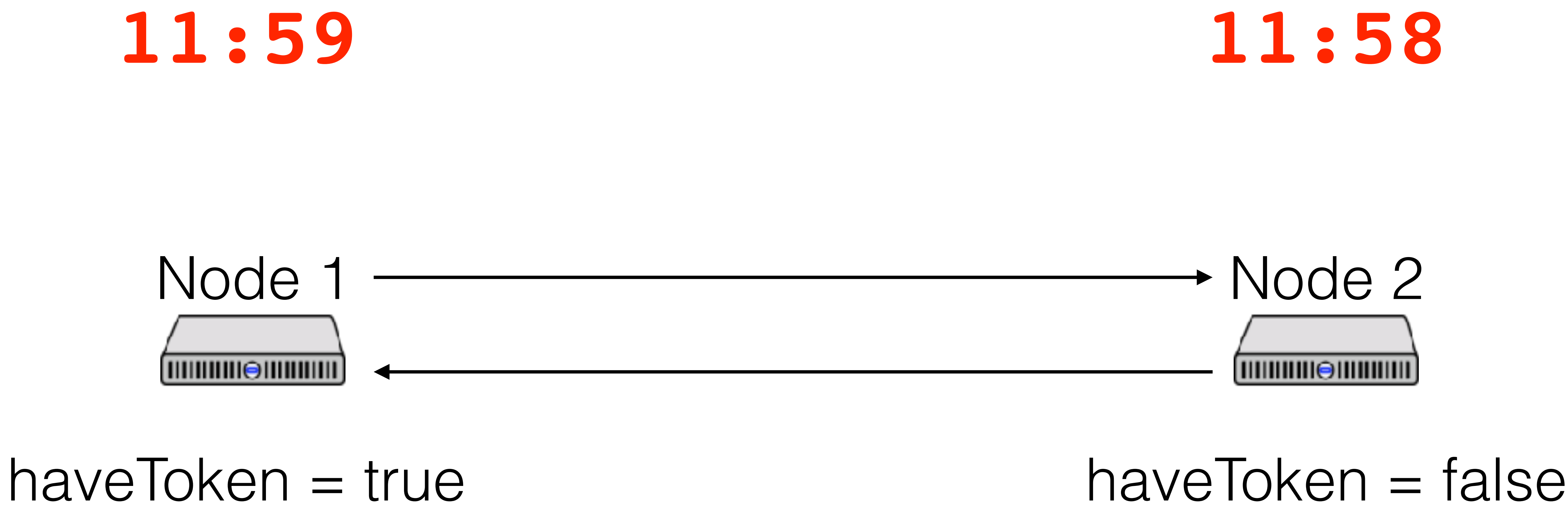
Avoiding inconsistencies

As we’ve seen, clocks won’t help us

Need to use messages to coordinate snapshot

Idea: what if we could make sure Node 2 took a snapshot before receiving the token?

Better algorithm



Better algorithm

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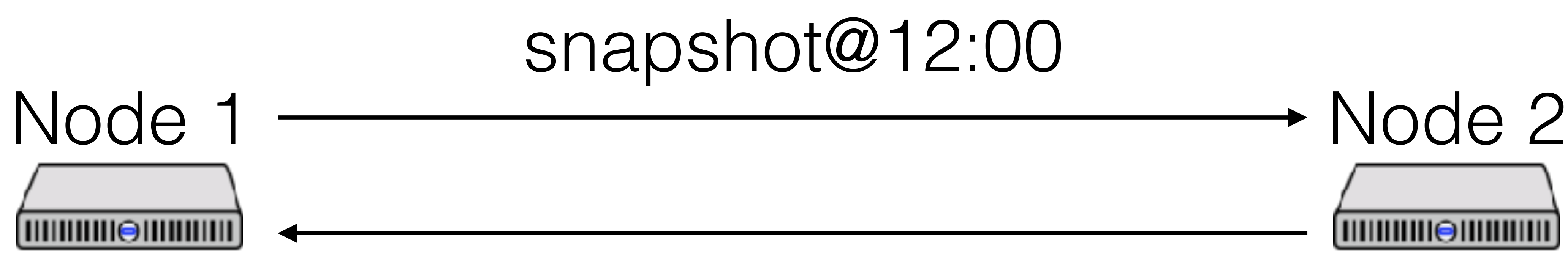

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Snapshot:
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Better algorithm

Better algorithm

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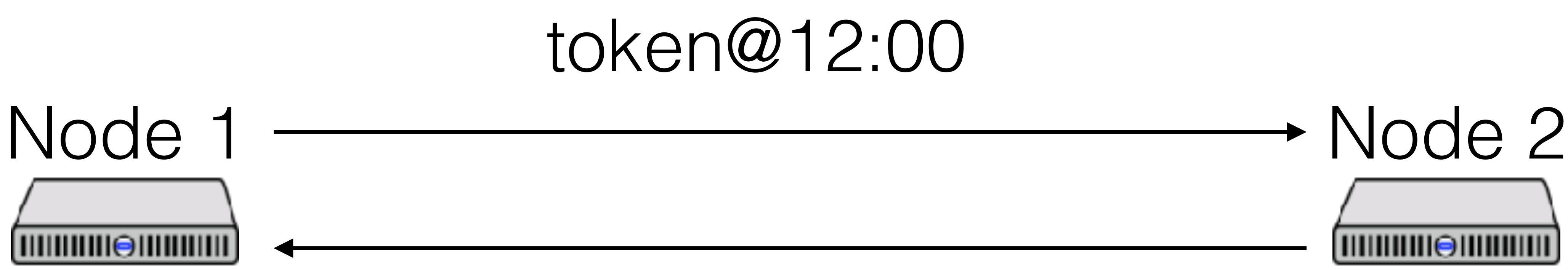

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Snapshot:
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Snapshot:
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Better algorithm

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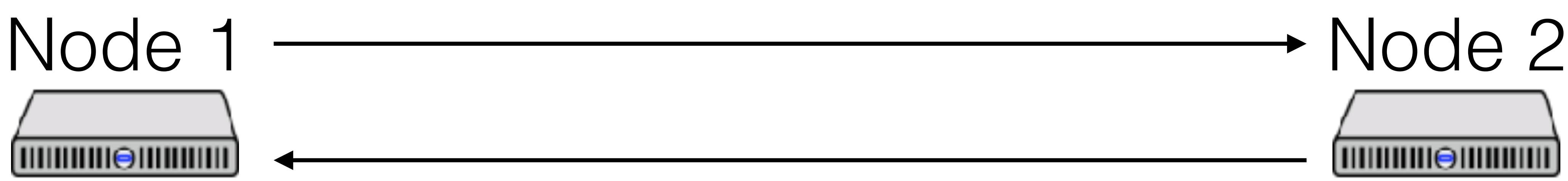

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haveToken = true

Snapshot:
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Snapshot:
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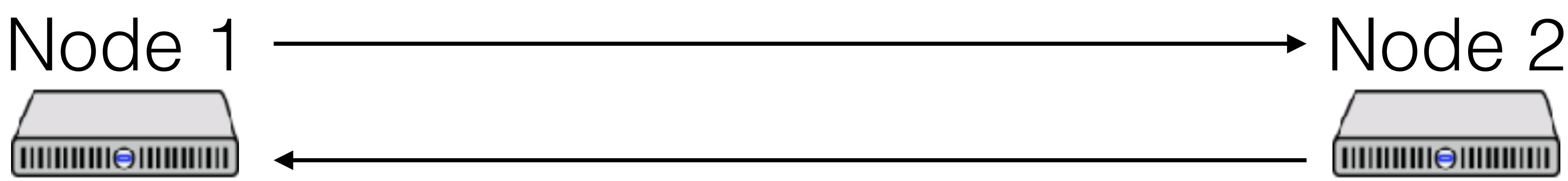
Better algorithm



haveToken = false

Snapshot:
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haveToken = true

Snapshot:
- haveToken = false

Chandy-Lamport Snapshots

At any time, a node can decide to snapshot

- Actually, multiple nodes can

That node:

- Records its current state
- Sends a “marker” message on all channels

When a node receives a marker, snapshot

- Record current state
- Send marker message on all channels

How to record channel state?

Chandy-Lamport Snapshots

Channel state recorded by the receiver

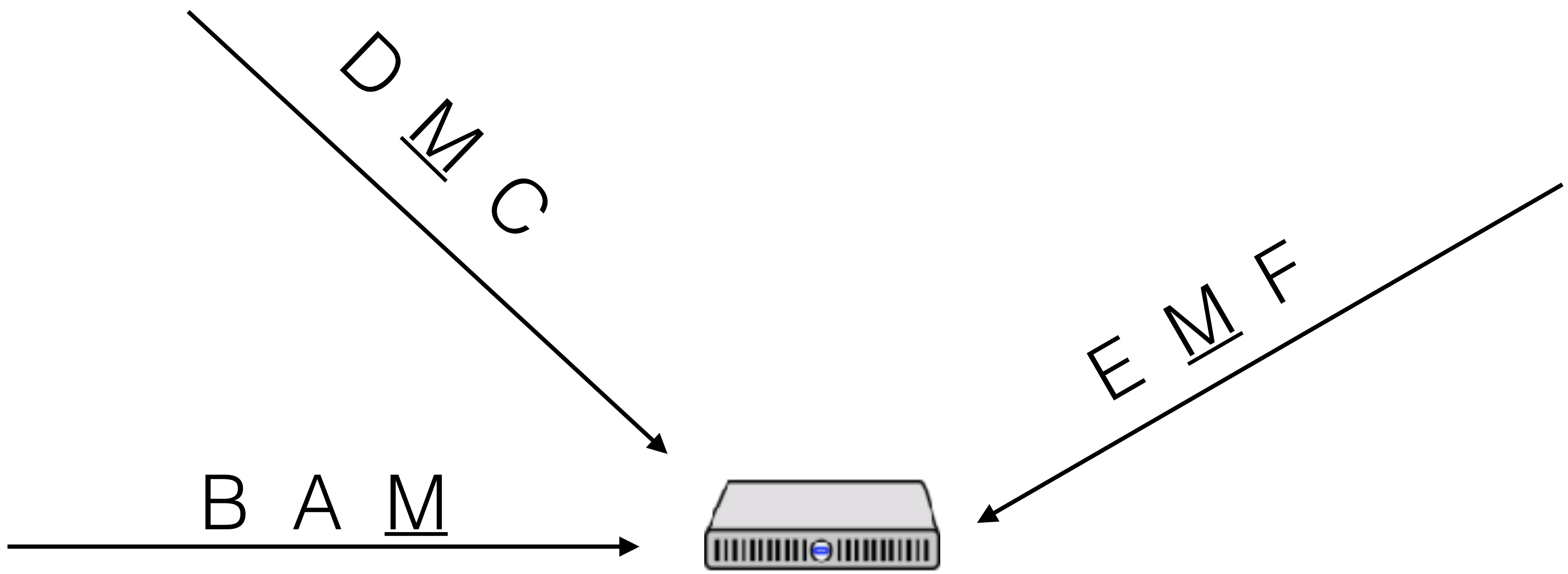
Recorded when marker received on that channel

When marker received on channel, record:

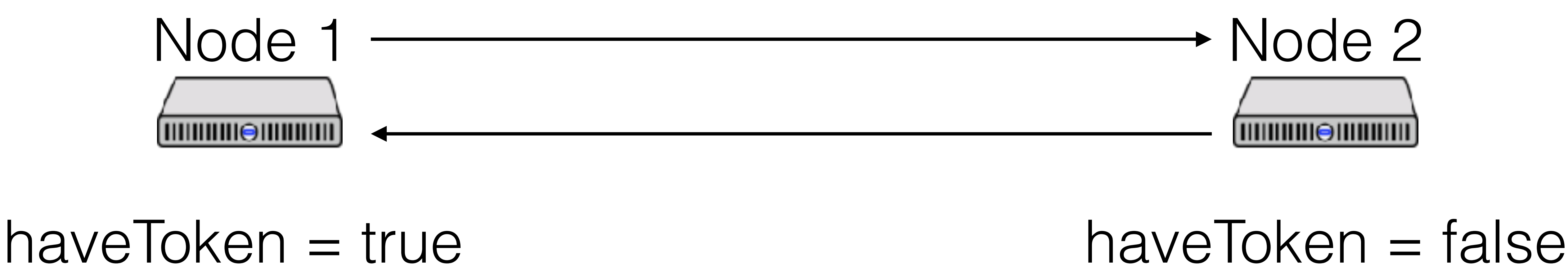
- Empty, if this is the first marker

- Messages received on channel since we snapshotted, otherwise

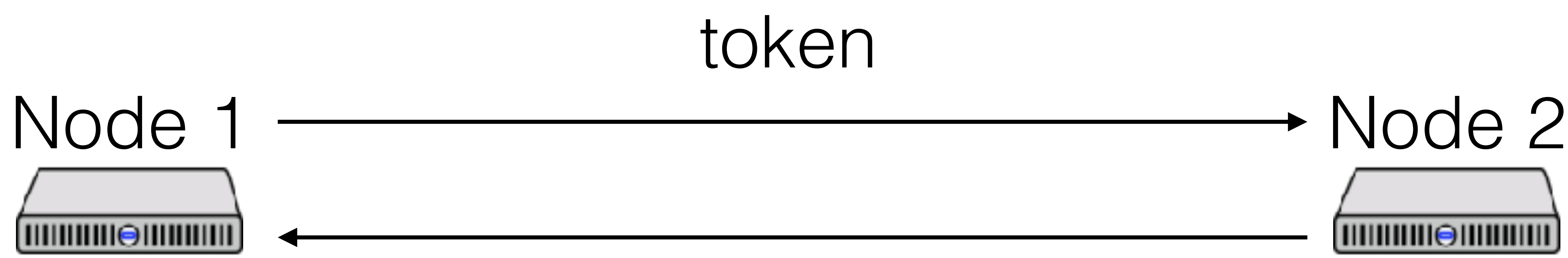
Chandy-Lamport Snapshots



Chandy-Lamport Snapshots



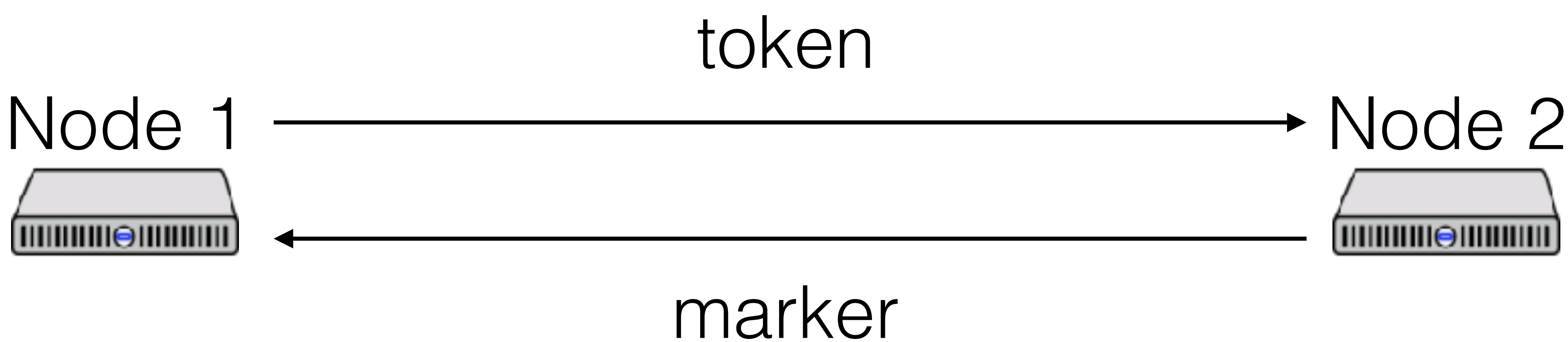
Chandy-Lamport Snapshots



haveToken = false

haveToken = false

Chandy-Lamport Snapshots



haveToken = false

haveToken = false

Snapshot:
- haveToken = false

Chandy-Lamport Snapshots

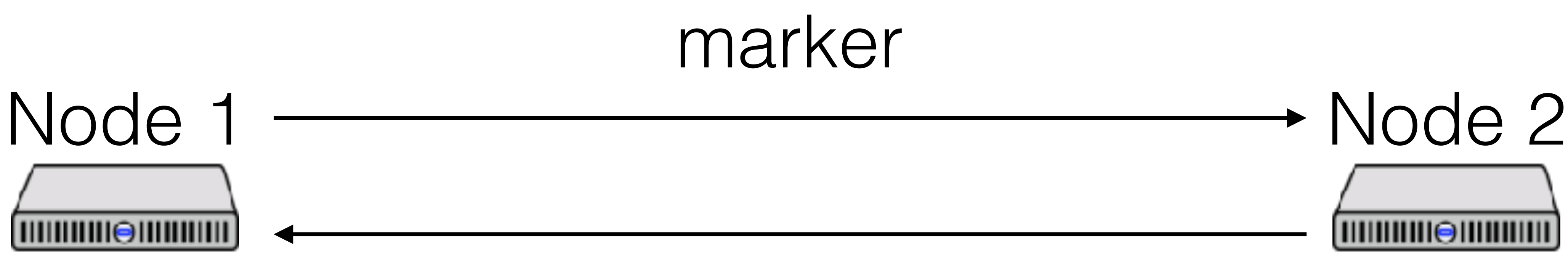
haveToken = false

Snapshot:
- haveToken = false

haveToken = false

Snapshot:
- haveToken = false

Chandy-Lamport Snapshots



haveToken = false

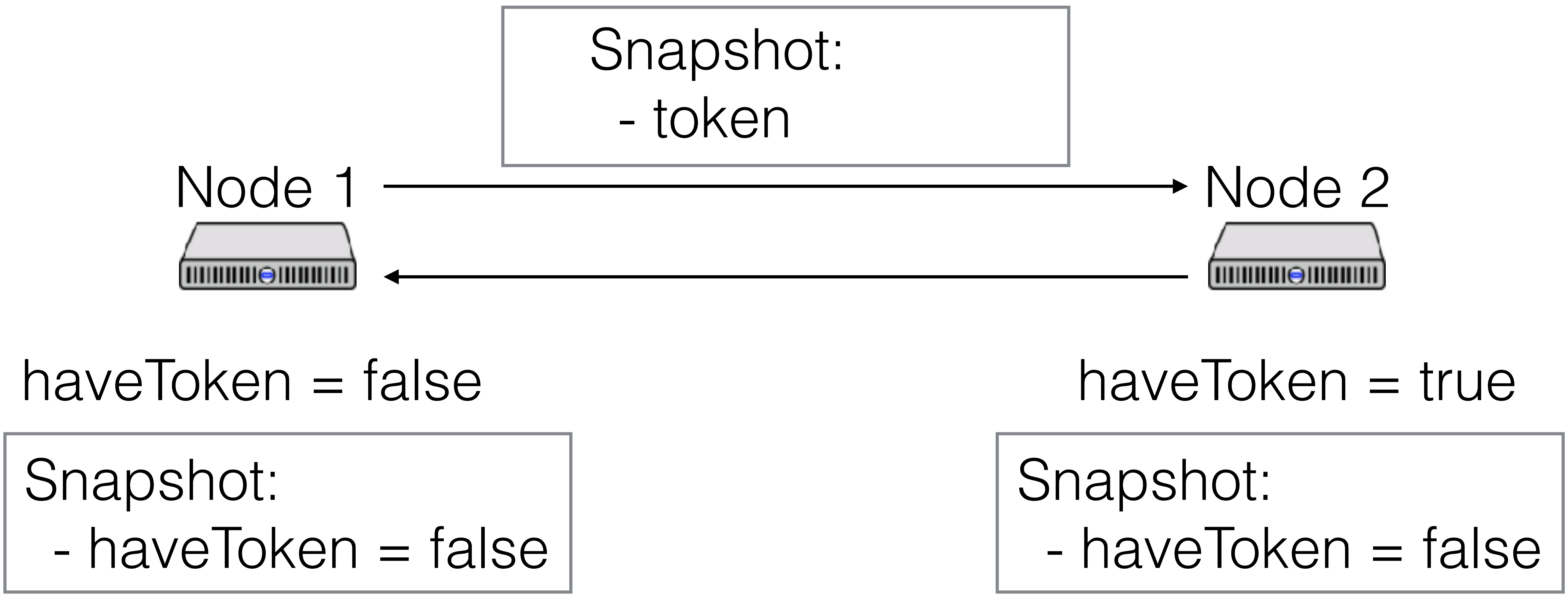
Snapshot:
- haveToken = false

haveToken = true

Snapshot:
- haveToken = false

In-flight:
- token

Chandy-Lamport Snapshots



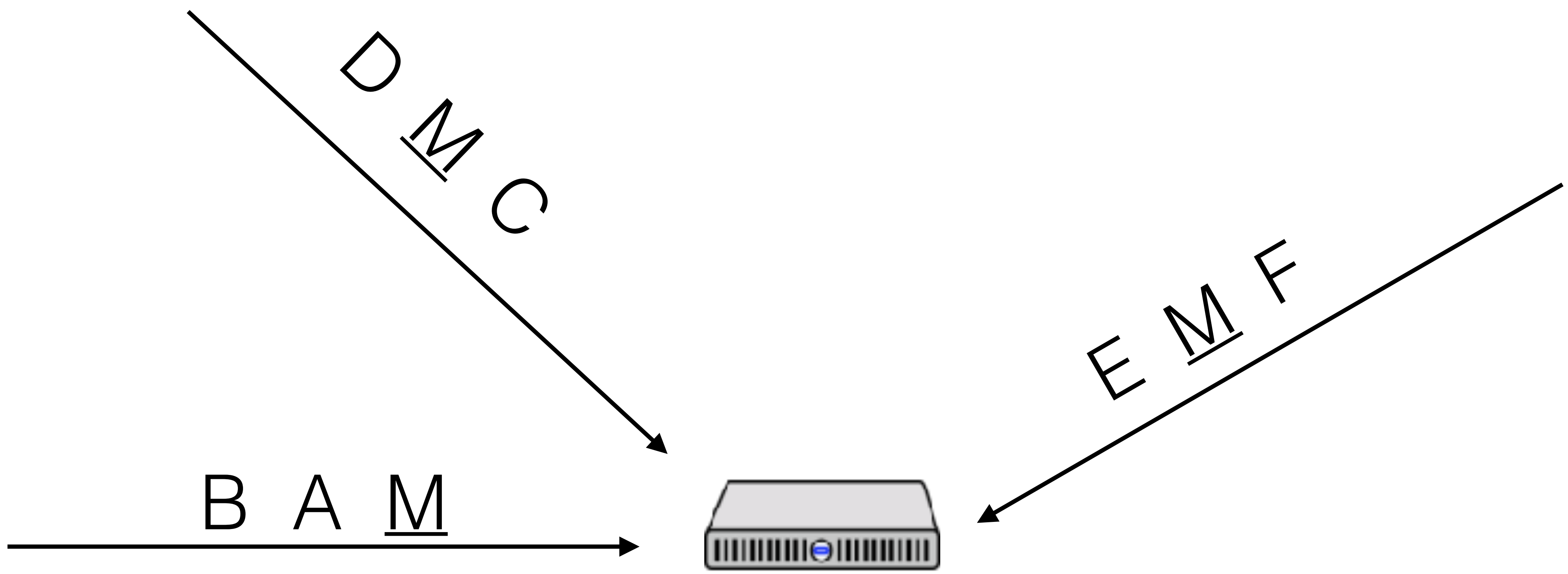
Chandy-Lamport Snapshots

Multiple nodes can initiate the snapshot

- Follow same rules: send markers on all channels

- Intuition: either initiate and include in-flight messages, or don't and exclude them

Chandy-Lamport Snapshots



Which state is snapshotted?

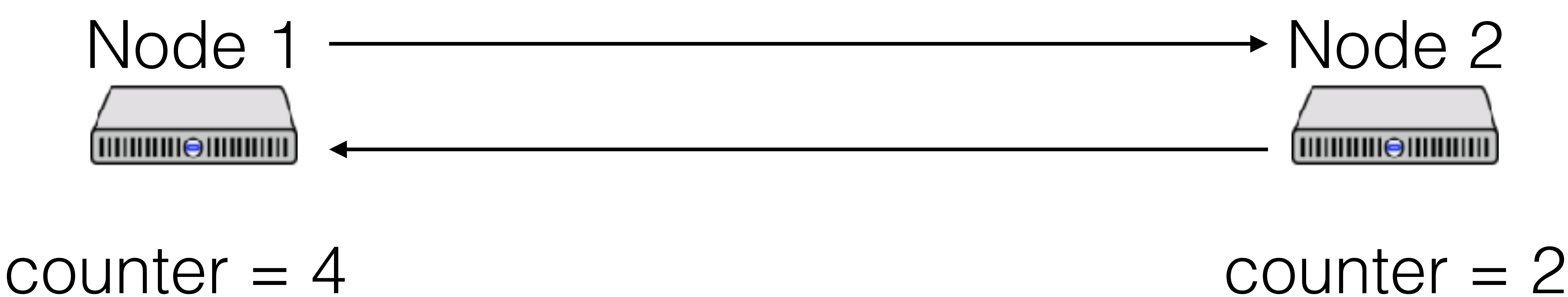
Let's say we have an execution S_0, S_1, …

Some node starts the snapshot in S_b

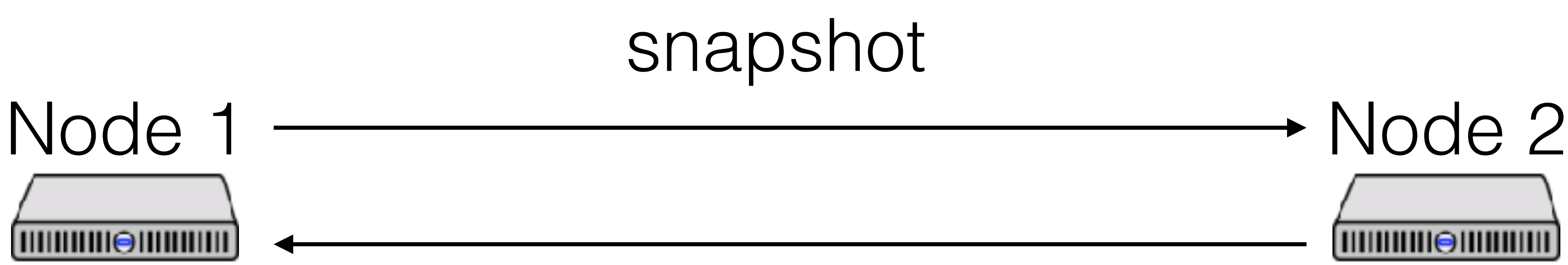
The snapshot finishes in S_e

Which state did we snapshot?

Which state is snapshotted?



Which state is snapshotted?

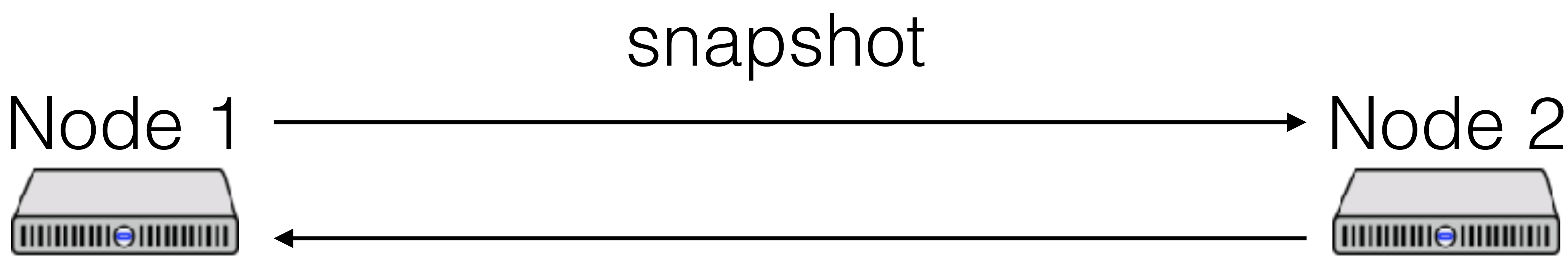


counter = 4

counter = 2

Snapshot:
- counter = 4

Which state is snapshotted?

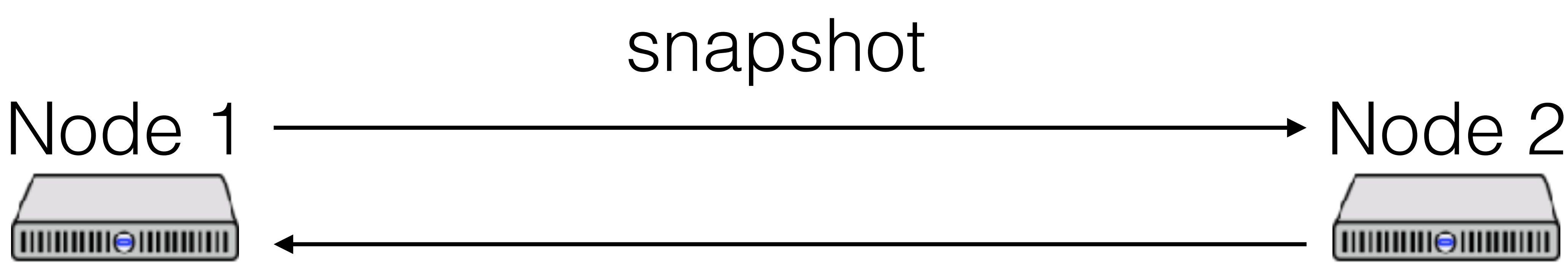


counter = 5

counter = 2

Snapshot:
- counter = 4

Which state is snapshotted?

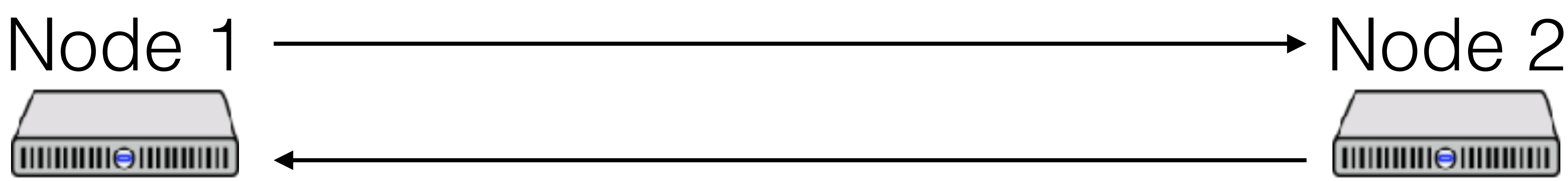


counter = 5

counter = 3

Snapshot:
- counter = 4

Which state is snapshotted?



counter = 5

counter = 3

Snapshot:
- counter = 4

Snapshot:
- counter = 3

Which state is snapshotted?

What *can* we say about this snapshotted state?

Two things:

- Reachable from S_b
- Can reach S_e

Proof is in the paper

- Intuition: state is “consistent” with what actually happened

So, why does this make sense for stable properties?

Discussion

What’s cool about this?

What’s the deal with phases?

What about dropped markers?