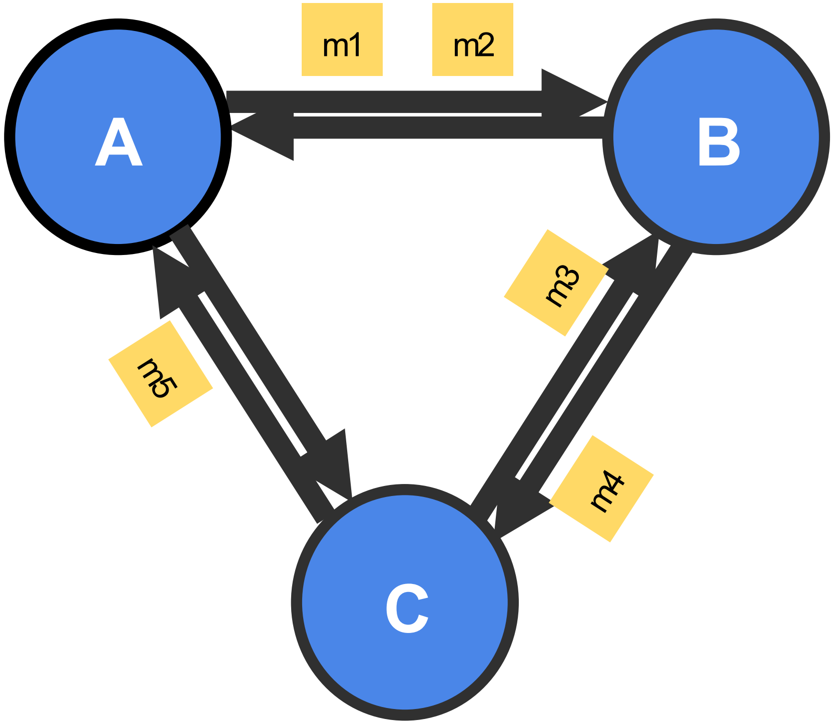
Distributed Snapshot

Feb 16th&17th, 2022

What is a Global Snapshot?

- A global snapshot captures the global state of a distributed system:
  - Local state of each process within the distributed system
  - Local state of each communication channel
- These local states are instantaneous
  - e.g messages in transit one node to another



Global Snapshots are Useful

- Checkpointing
  - Recover more quickly after failures
- Garbage Collection
  - Remove objects that are not referenced any more by other objects/processes at any other servers
- Deadlock Detection
  - Examine the global application state and identify any deadlocks, useful in transactional DB systems
- And many others …

System Model

- N processes in the system
  - Each process keeps track of some state
- There are two unidirectional communication channels between each pair of processes P and Q
  - FIFO-ordered (i.e first-in-first-out)
  - Message arrives intact and is unduplicated
  - Each channel also has some state
- No failures

Messages and States

- What are the messages?
  - Application messages that differ across systems (e.g "sending $10 from A to B", "read value at memory address X and write back with a new value")
  - Special messages (e.g marker message) that should not interfere with application messages

- What are the states?
  - Process state: application-defined state, or the classic notion of state which includes heap, registers, program counters and etc
  - Channel state: the set of messages inside

- Tips for Assignment 2
  - See `*.top`, `*.events`, `*.snap` files under ./test_data to understand what states and messages mean in this assignment
  - Read `test_common.go` to understand the syntax of the above files, and their relationships with the simulator

Distributed Snapshot

"Distributed Snapshots: Determining Global States of Distributed Systems" 1985, by K. Mani Chandy and Leslie Lamport

Key Idea: Servers send marker messages to each other

Marker messages

1. Mark the beginning of the snapshot process on the server
2. Act as a barrier (stopper) for recording messages

Chandy-Lamport Algorithm

Any process can initiate the snapshot

- Record local state
- Create marker messages and send them to all outbound channels
- Start recording messages from all incoming channels

Chandy-Lamport Algorithm Continued

When receiving a marker message from channel C

If this is the first marker message that this process has even seen:

- Record the local state
- Record the state of C as “empty sequence”
- Send out the marker message on all outbound channels
- Start recording messages from all of its other incoming channels

If it has already seen a marker message (e.g from some other channel)

- Record the state of C as the sequence of messages received since the process’s local state has been recorded
- Stop recording messages on C (i.e done with recording the channel’s state)

See **Section 3** of the original paper for more details

Chandy-Lamport Algorithm Continued

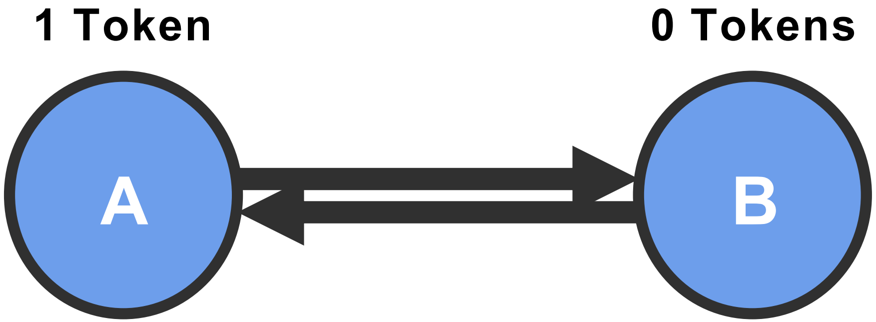
When is the algorithm terminated?

- All processes have received marker messages (i.e have recorded their local states)
- All processes have received marker messages from all of their incoming channels (i.e have recorded the local states of all channels)
- Both need to satisfy

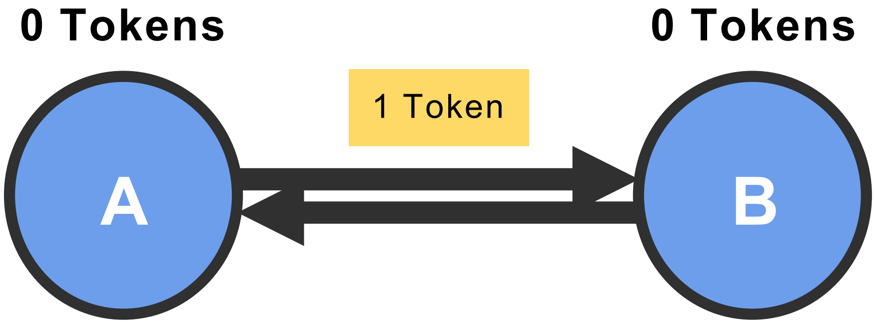
What happens after the termination?

- Optional and out of the scope of Chandy-Lamport algorithm
- Usually, there will be a central server that collects local snapshots from all servers to build a global snapshot (e.g the `simulator` in Assignment 2) and maybe run some computations (e.g deadlock detection) on it

Token passing example 1



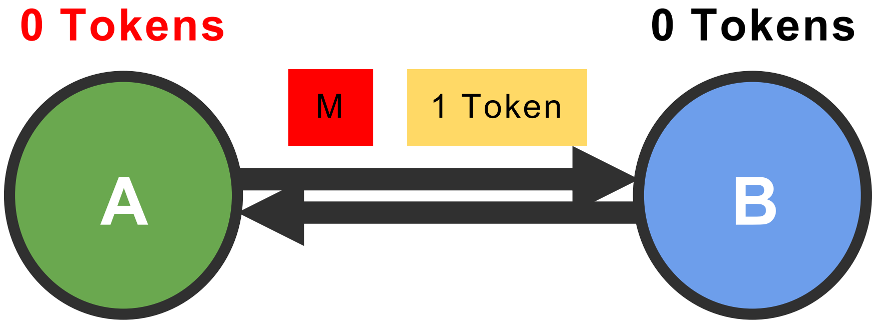
Token passing example 1



Event order:

1. *A* sends 1 token

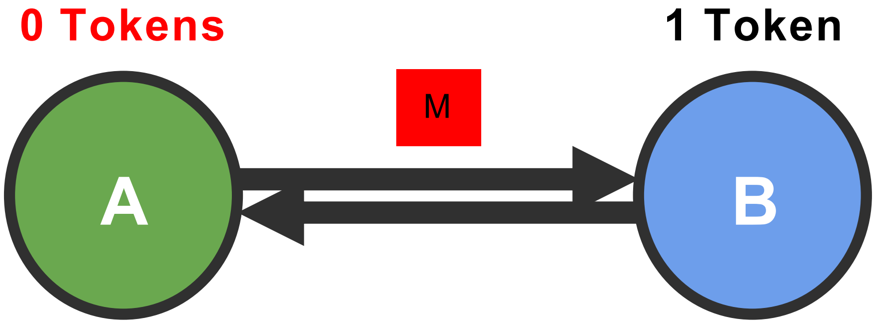
Token passing example 1



Event order:

1. *A* sends 1 token
2. *A* starts snapshot, sends marker

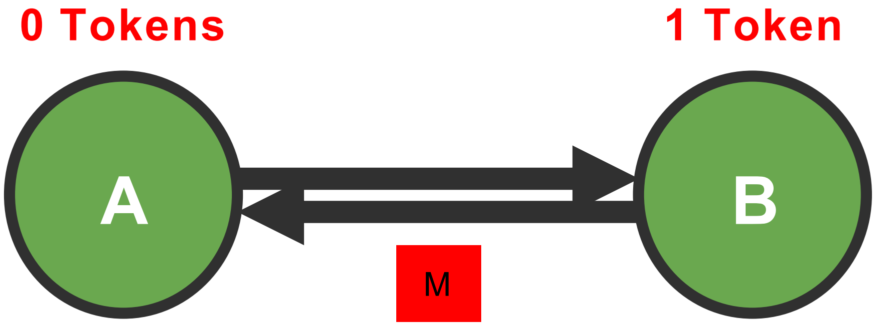
Token passing example 1



Event order:

1. *A* sends 1 token
2. *A* starts snapshot, sends marker
3. *B* receives 1 token

Token passing example 1



Event order:

1. *A* sends 1 token
2. *A* starts snapshot, sends marker
3. *B* receives 1 token
4. *B* receives marker, starts snapshot

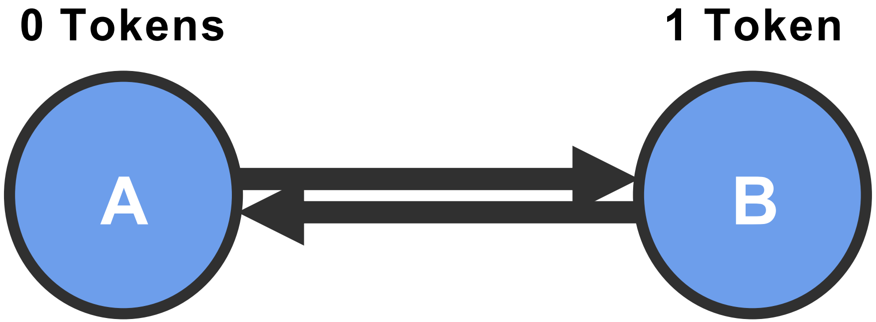
Token passing example 1

We did not record the token message because B received it before B started the snapshot process

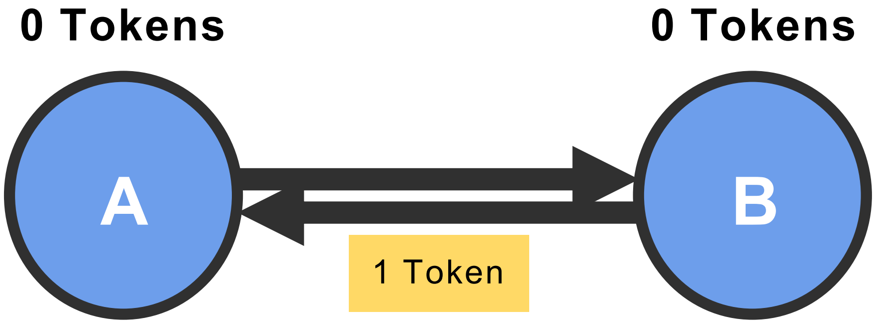
Event order:

1. *A* sends 1 token
2. *A* starts snapshot, sends marker
3. *B* receives 1 token
4. *B* receives marker, starts snapshot
5. *A* receives marker, ends snapshot

Token passing example 2



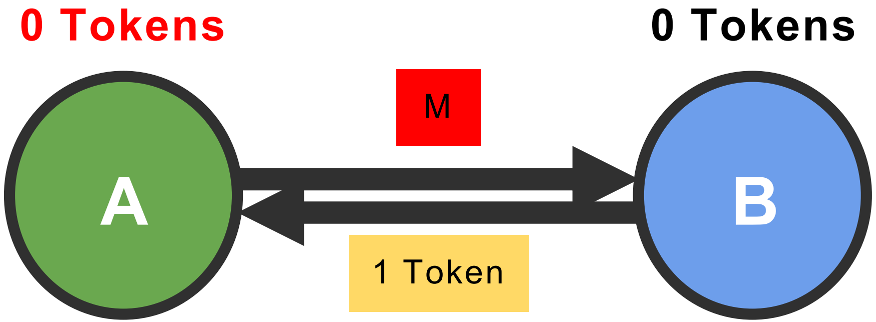
Token passing example 2



Event order:

1. *B* sends 1 token

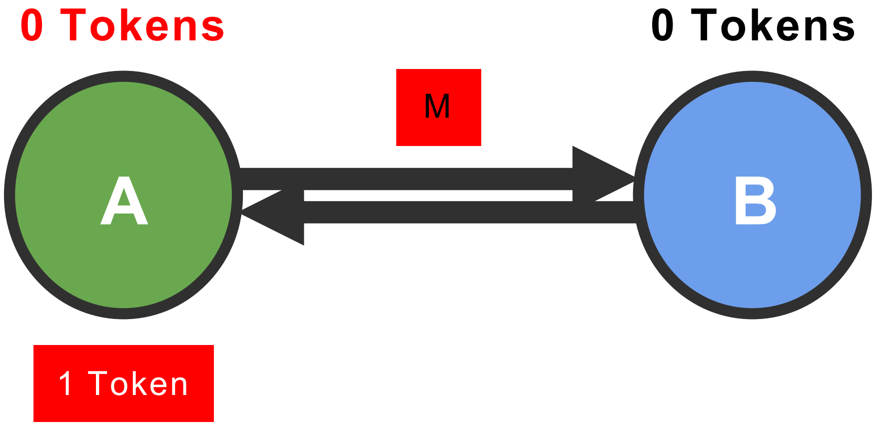
Token passing example 2



Event order:

1. *B* sends 1 token
2. *A* starts snapshot, sends marker

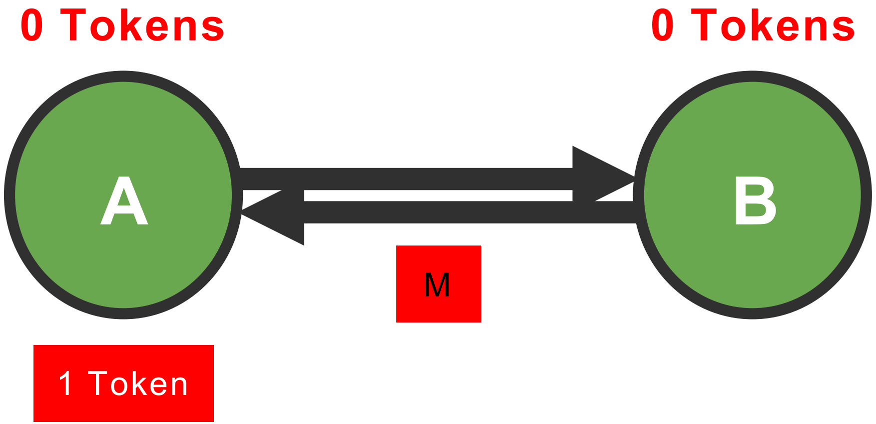
Token passing example 2



Event order:

1. *B* sends 1 token
2. *A* starts snapshot, sends marker
3. *A* receives 1 token, records message

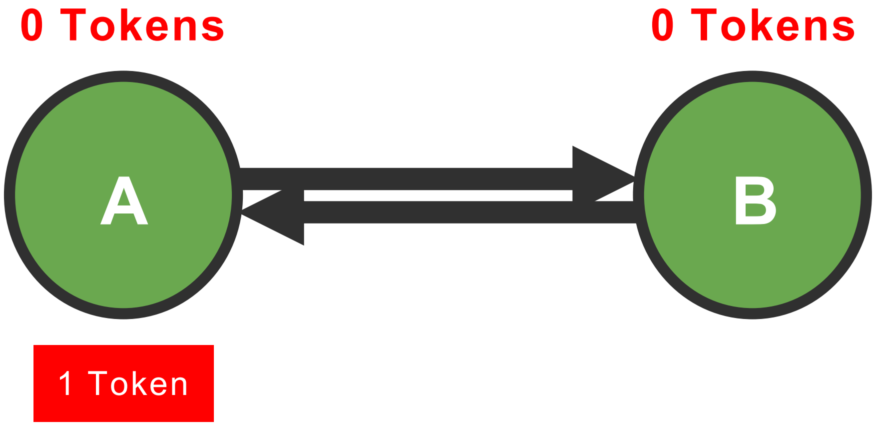
Token passing example 2



Event order:

1. *B* sends 1 token
2. *A* starts snapshot, sends marker
3. *A* receives 1 token, records message
4. *B* receives marker, starts snapshot

Token passing example 2

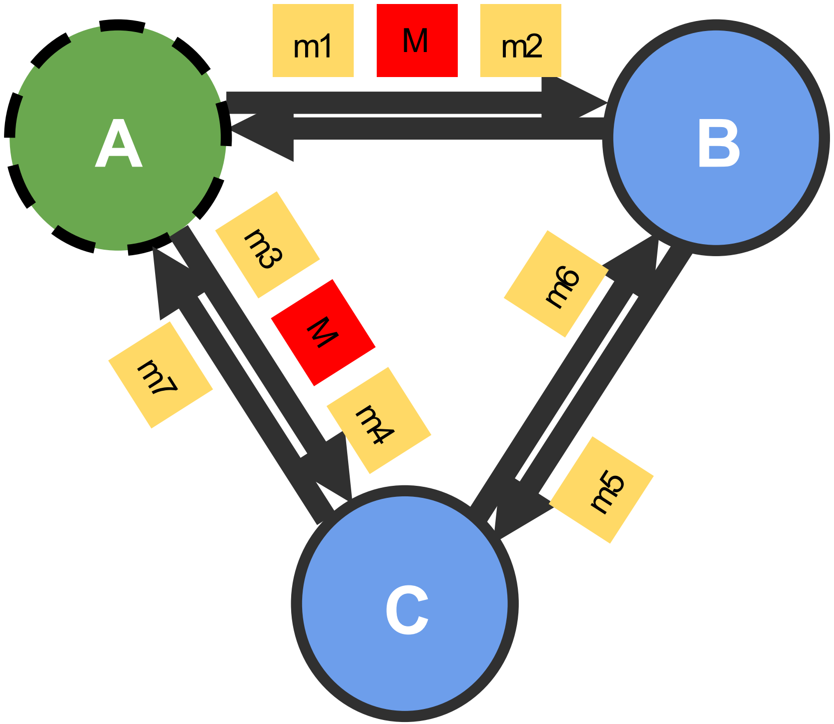


We recorded the token message because A received it ***after*** *it has already started the snapshot process*

Event order:

1. *B* sends 1 token
2. *A* starts snapshot, sends marker
3. *A* receives 1 token, records message
4. *B* receives marker, starts snapshot
5. *A* receives marker, ends snapshot

Token passing example 3



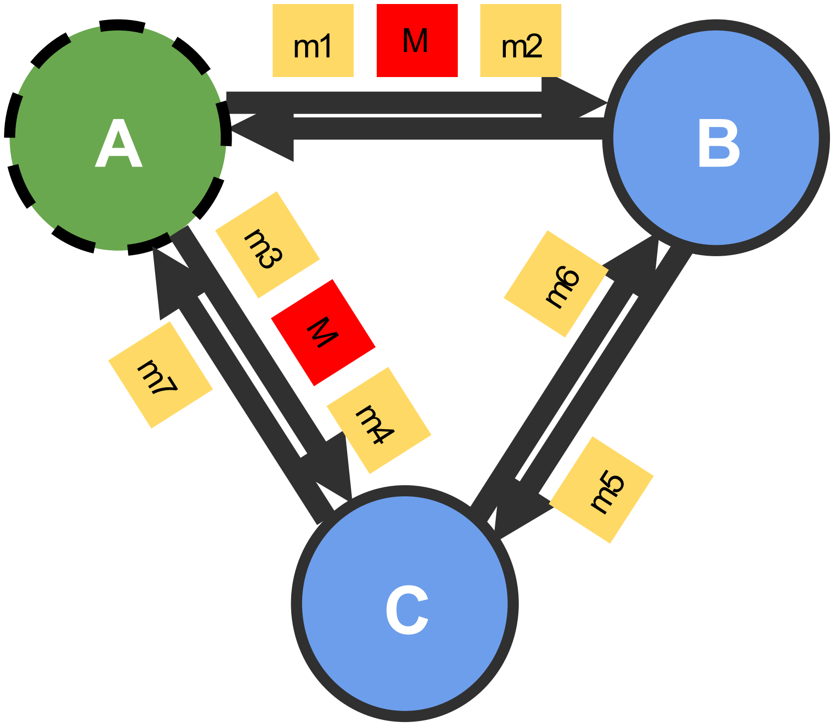
Which messages are definitely recorded*?

Which messages are definitely *not* recorded?

Which messages *might* be recorded?

* recorded as in-flight messages, i.e., as part of *channel state* rather than *process state*

Token passing example 3



Which messages are definitely recorded*?

m7

Which messages are definitely *not* recorded?

m1, m3

Which messages *might* be recorded?

m2, m4, m5, m6

*recorded as in-flight messages

Assignment 2 Overview

- You will implement the Chandy-Lamport snapshot algorithm
- Application is a token passing system
    - Number of tokens must be preserved in your snapshots
- Implementation uses *discrete time* simulator to order events
    - `Simulator` manages servers and injects events into the system
    - `Server` implements the snapshot algorithm (See slide 7 and 8)
- Allow multiple active snapshot processes
    - E.g, The second snapshot can start before the first snapshot completes in the system

Assignment 2 Interfaces

```
func (sim *Simulator) Tick()

func (sim *Simulator) StartSnapshot(serverId string)

func (sim *Simulator) NotifySnapshotComplete(serverId string, snapshotId int)

func (sim *Simulator) CollectSnapshot(snapshotId int) *SnapshotState
```

- What kind of state does the simulator need to keep track of?
  - Time
  - Topology
  - Channels to signal the completion of snapshots
  - ...

Assignment 2 Interfaces

```
func (server *Server) SendToNeighbors(message interface{})

func (server *Server) SendTokens(numTokens int, dest string)

func (server *Server) HandlePacket(src string, message interface{})

func (server *Server) StartSnapshot(snapshotId int)
```

- What kind of state does the server need to keep track of?
  - Local state
  - Neighbors
  - Which channels received markers
  - Recorded messages
  - ...

A Note on Channels and Goroutines

- Using channels is easy, debugging them is hard…

    Bullet-proof way: Keep track of how many things go in and go out

    Always ask yourself: is this channel buffered?

- In general, don't use locks or atomic operations with channels (awkward)
- Try not to nest goroutines (hard to reason about)

Assignment 2

Start Early ☺

Due 02/24 (Thursday) at 11:59pm!