Distributed Snapshots

COS 418/518: Distributed Systems
Lecture 7

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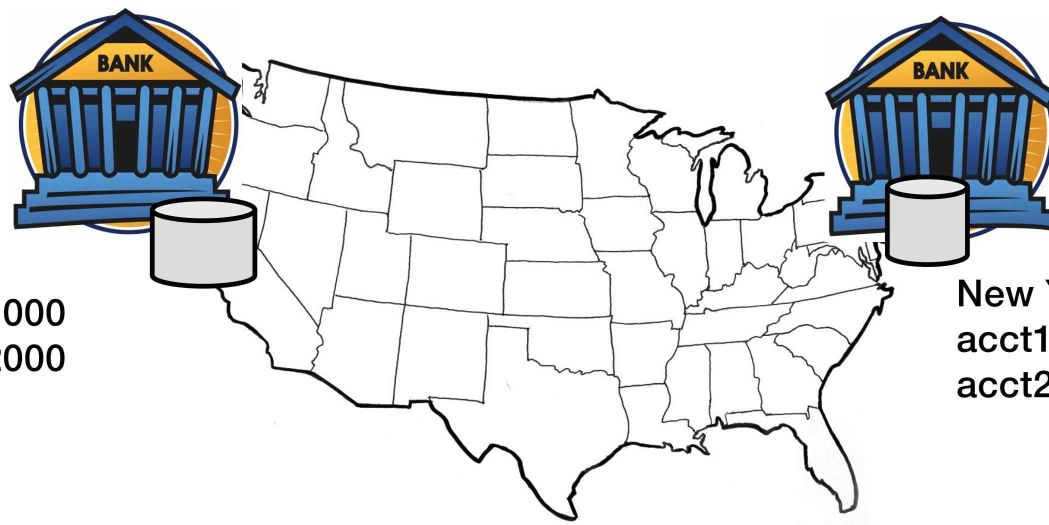
Distributed Snapshots

- What is the state of a distributed system?



System model

- N processes in the system with no process failures
  - Each process has some state it keeps track of
- There are two first-in, first-out, unidirectional channels between every process pair P and Q
  - Call them channel(P, Q) and channel(Q, P)
  - The channel has state, too: the set of messages inside
  - All messages sent on channels arrive intact, unduplicated, in order

Aside: FIFO communication channel

- “All messages sent on channels arrive intact, unduplicated, in order”

- Q: Arrive?
- Q: Intact?
- Q: Unduplicated?
- Q: In order?

- At-least-once retransmission
- Network layer checksums
- At-most-once deduplication
- Sender includes sequence numbers, receiver only delivers in sequence order

- TCP provides all of these when processes don’t fail

Global snapshot is global state

- Each distributed application has a number of processes running on a number of physical servers

- These processes communicate with each other via channels

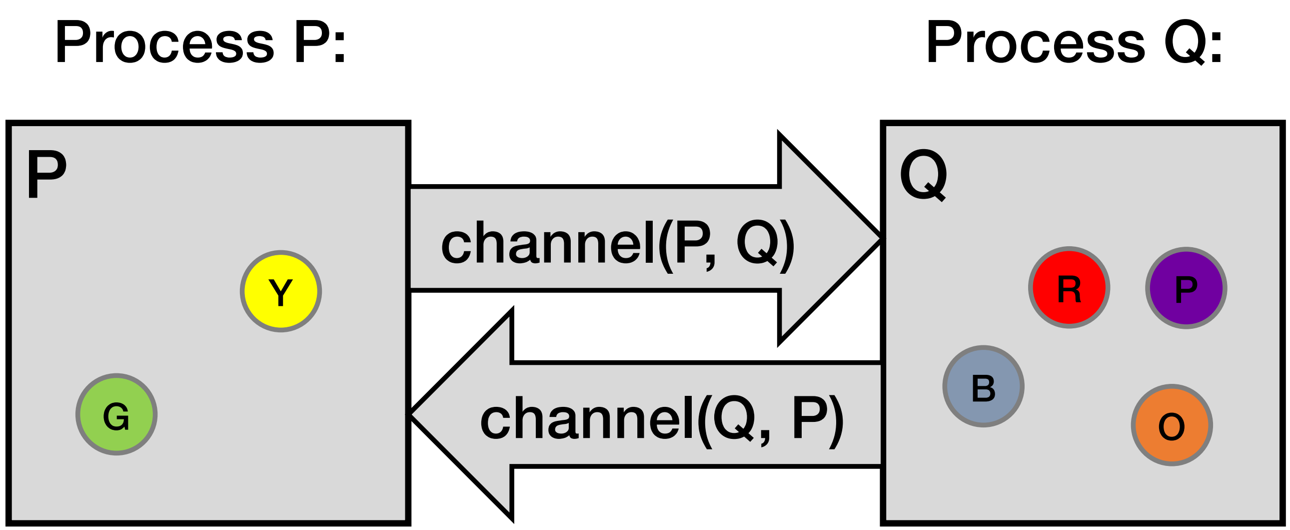
- A global snapshot captures
  1. The local states of each process (e.g., program variables), and
  2. The state of each communication channel

Why do we need snapshots?

- Checkpointing: Restart if the application fails
- Collecting garbage: Remove objects that aren't referenced
- Detecting deadlocks: The snapshot can examine the current application state
  - Process A grabs Lock 1, B grabs 2, A waits for 2, B waits for 1... ... ...
- Other debugging: A little easier to work with than printf…

System model: Graphical example

- Let's represent process state as a set of colored tokens
- Suppose there are two processes, P and Q:



Correct global snapshot = Exactly one of each token

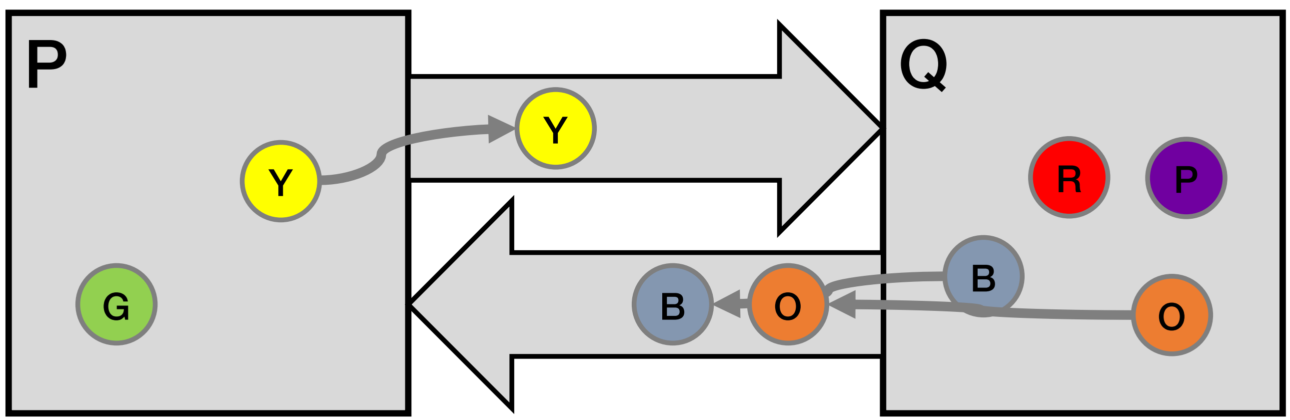
When is inconsistency possible?

- Suppose we take snapshots only from a process perspective
- Suppose snapshots happen independently at each process
- Let’s look at the implications...

Problem: Disappearing tokens

- P, Q put tokens into channels, then snapshot

This snapshot misses Y, B, and O tokens



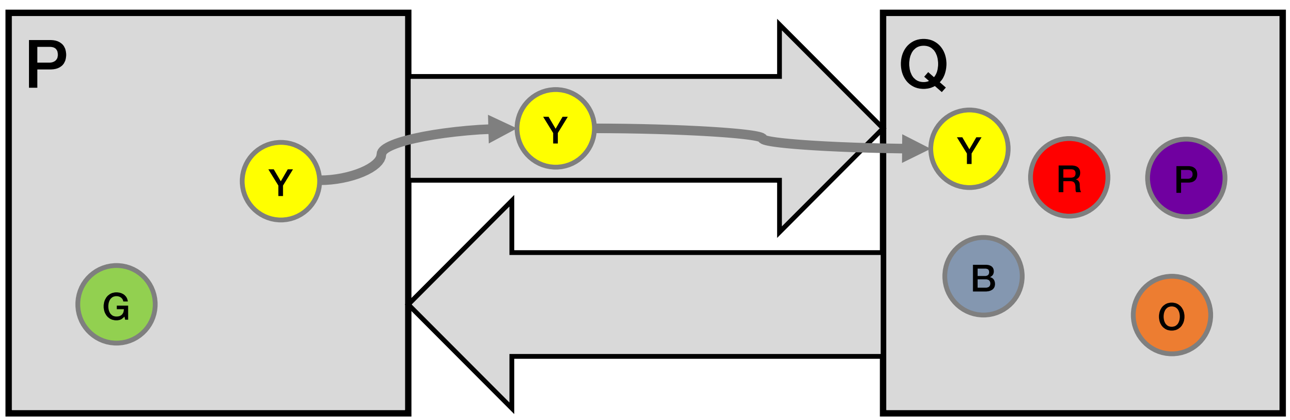
P = { G }

Q = { R, P }

Problem: Duplicated tokens

- P snapshots, then sends Y
- Q receives Y, then snapshots

This snapshot duplicates the Y token



P = { G, Y }

Q = { Y, R, P, B, O }

Idea: “Marker” messages

- What went wrong? We should have captured the state of the channels as well
- Let’s send a marker message ▲ to track this state
  - Distinct from other messages
  - Channels deliver marker and other messages FIFO

Chandy-Lamport Algorithm: Overview

- We’ll designate one node (say P) to start the snapshot
  - Without any steps in between, P:
    1. Records its local state (“snapshots”)
    2. Sends a marker on each outbound channel

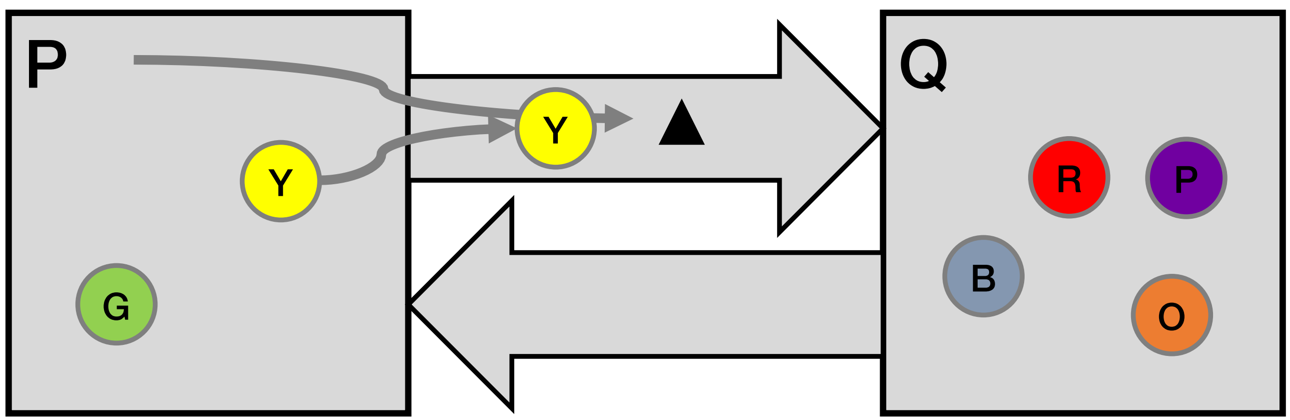
- Nodes remember whether they have snapshotted

- On receiving a marker, a non-snapshotted node performs steps (1) and (2) above

Chandy-Lamport: Sending process

- P snapshots and sends marker, then sends Y

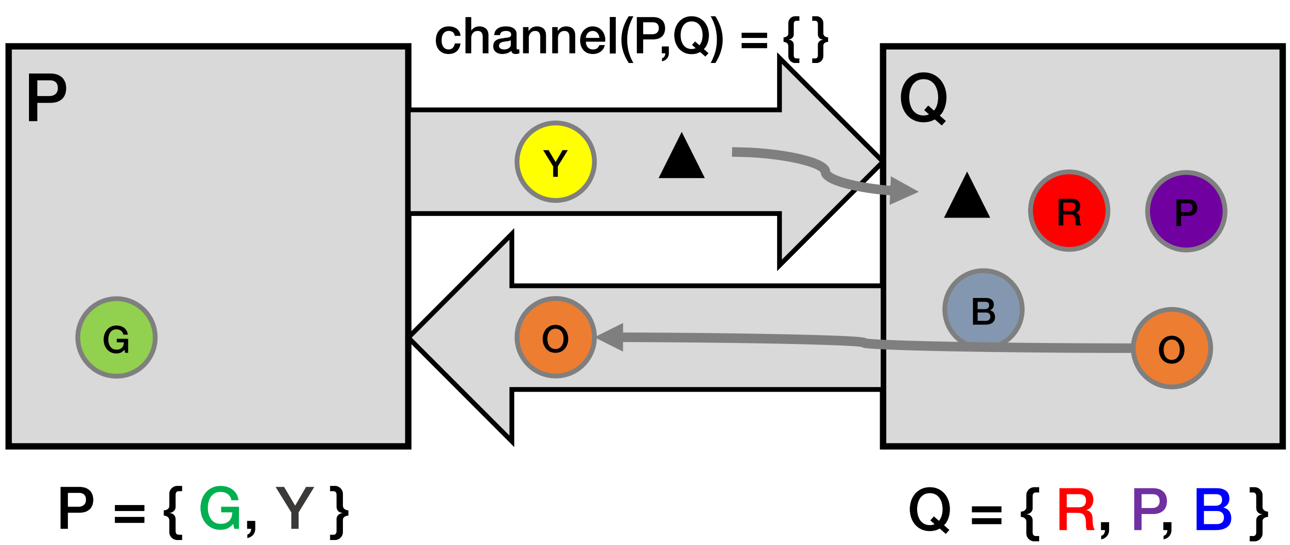
- Send Rule: Send marker on all outgoing channels
  - Immediately after snapshot
  - Before sending any further messages



snap: P = { G, Y }

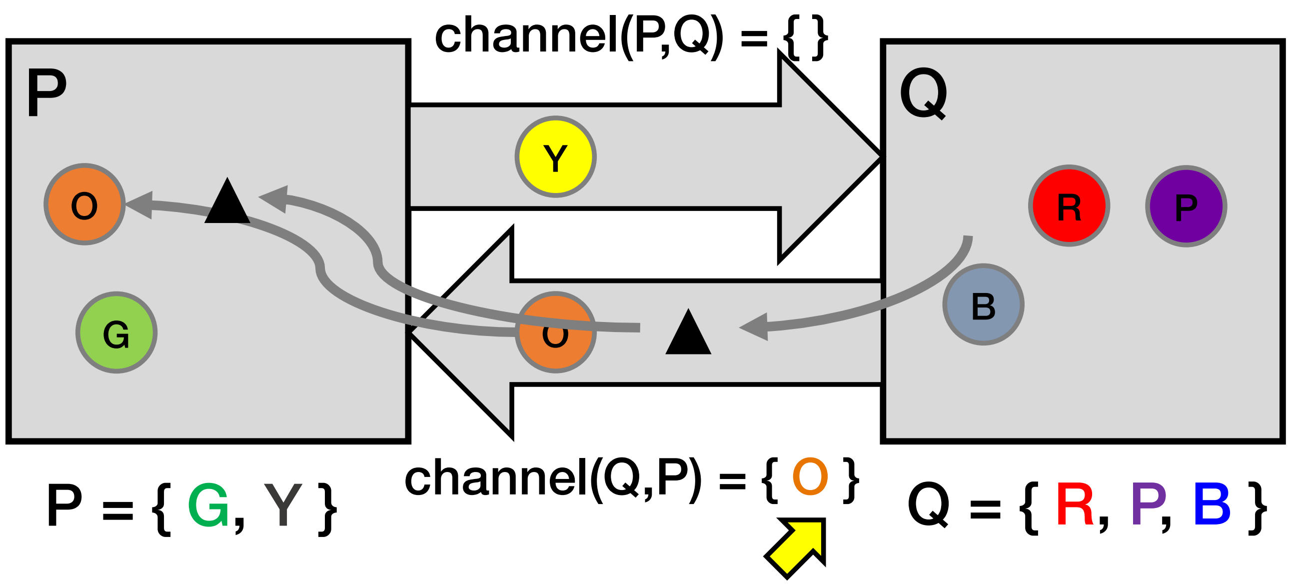
Chandy-Lamport: Receiving process (1/2)

- At the same time, Q sends orange token O
- Then, Q receives marker ▲
- Receive Rule (if not yet snapshotted)
  - On receiving marker on channel c record c's state as empty



Chandy-Lamport: Receiving process (2/2)

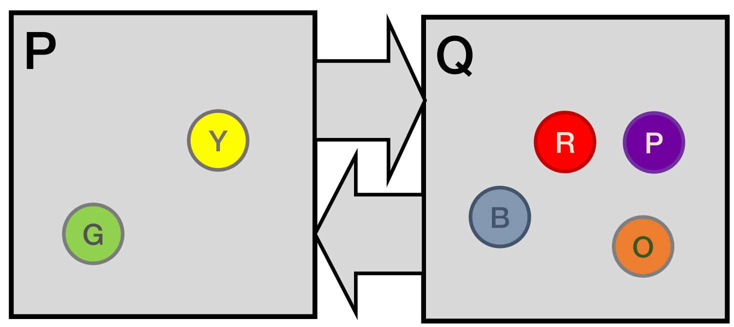
- Q sends marker to P
- P receives orange token O, then marker ▲
- Receive Rule (if already snapshotted):
  - On receiving marker on c record c's state: all msgs from c since snapshot



Chandy-Lamport Puzzle #1

Is this snapshot possible? And if so, how?

P = { G },
chan(P, Q) = { Y },
Q = { R, P },
chan(Q, P) = { B, O },



Chandy-Lamport Puzzle #2

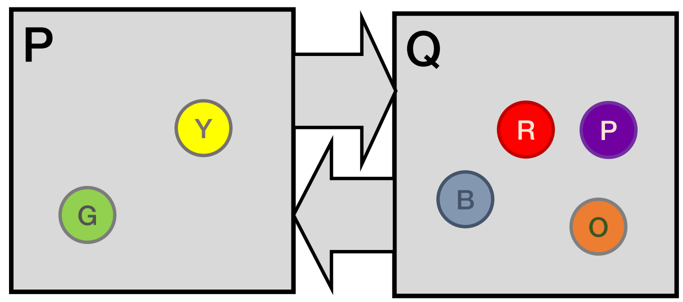
Is this snapshot possible? And if so, how?

P = { G, Y, R, P, B, O }

chan(P, Q) = { }

Q = { }

chan(Q, P) = { }



Chandy-Lamport Puzzle #3

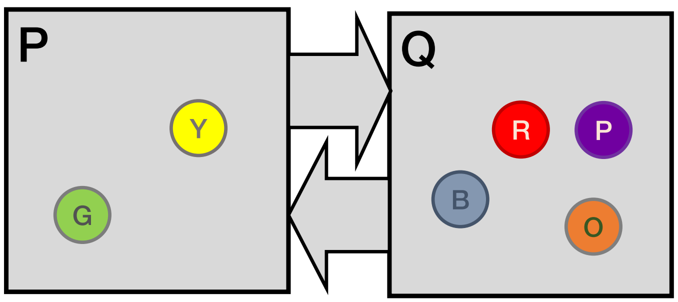
Is this snapshot possible? And if so, how?

P = { }

chan(P, Q) = { }

Q = { }

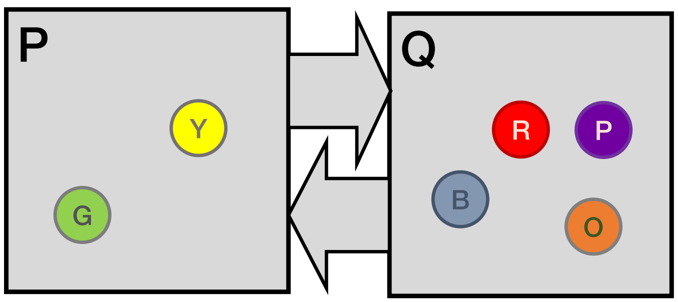
chan(Q, P) = { G, Y, R, P, B, O }



Chandy-Lamport Puzzle #4

Is this snapshot possible? And if so, how?

P = { G, Y, }
chan(P, Q) = { R }
Q = { B, O }
chan(Q, P) = { P }



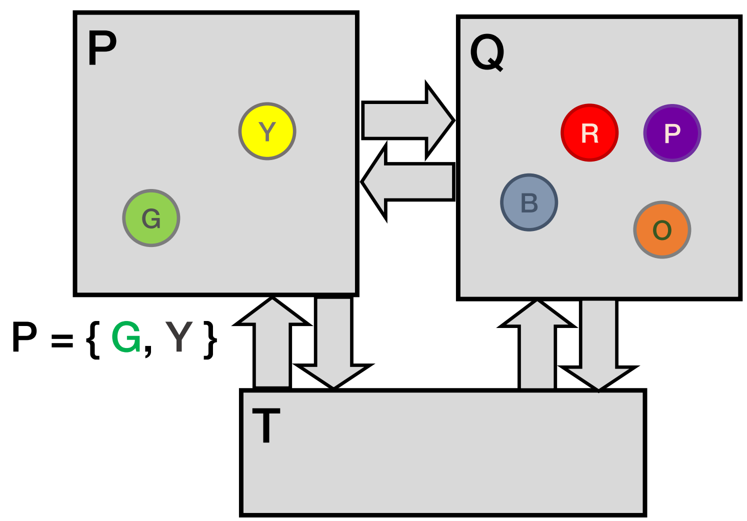
P = { G, Y }

- Is it possible (and how) if we add:
  - A process T and just a chan(T,P)?
  - T, chan(T,P) and chan (T,Q)?

Chandy-Lamport Puzzle #5

Is this snapshot possible? And if so, how?

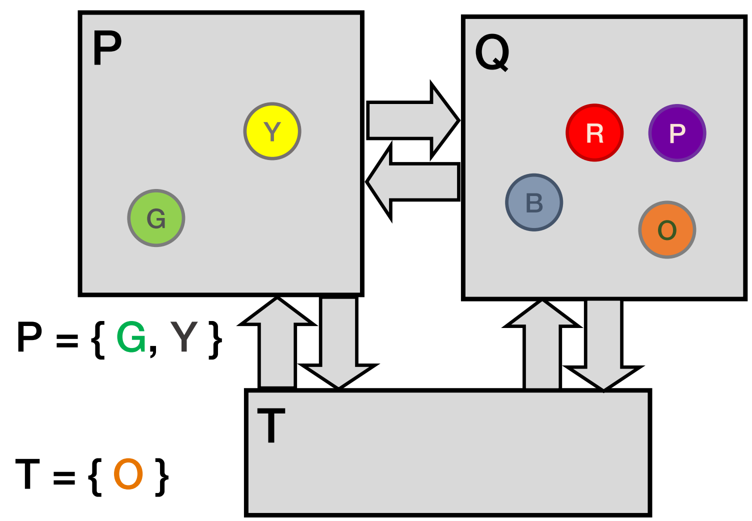
P = { G, Y, }
chan(P, Q) = { }
chan(P, T) = { }
Q = { B, O }
chan(Q, P) = { P }
chan(Q, T) = { R }
T = { }
chan(T, P) = { }
chan(T, Q) = { }



Chandy-Lamport Puzzle #6

Is this snapshot possible? And if so, how?

P	= { G, Y, }
chan(P, Q)	= { }
chan(P, T)	= { }
Q	= { B }
chan(Q, P)	= { P }
chan(Q, T)	= { R }
T	= { O }
chan(T, P)	= { }
chan(T, Q)	= { }



Terminating a Snapshot

- Distributed algorithm: No one process decides when it terminates
- Eventually, all processes have received a marker (and recorded their own state)
- All processes have received a marker on all the N–1 incoming channels (and recorded their states)
- Later, a central server can gather the local states to build a global snapshot

Take-away points

- Distributed Global Snapshots
  - FIFO Channels: we can do that!
  - Chandy-Lamport algorithm: use marker messages to coordinate
- Reasoning about concurrency
  - You’re doing it!
  - Use trickier and trickier puzzle methodology to understand how (and if) systems really work