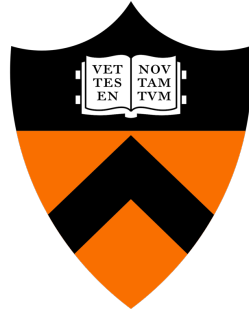


Distributed Snapshots

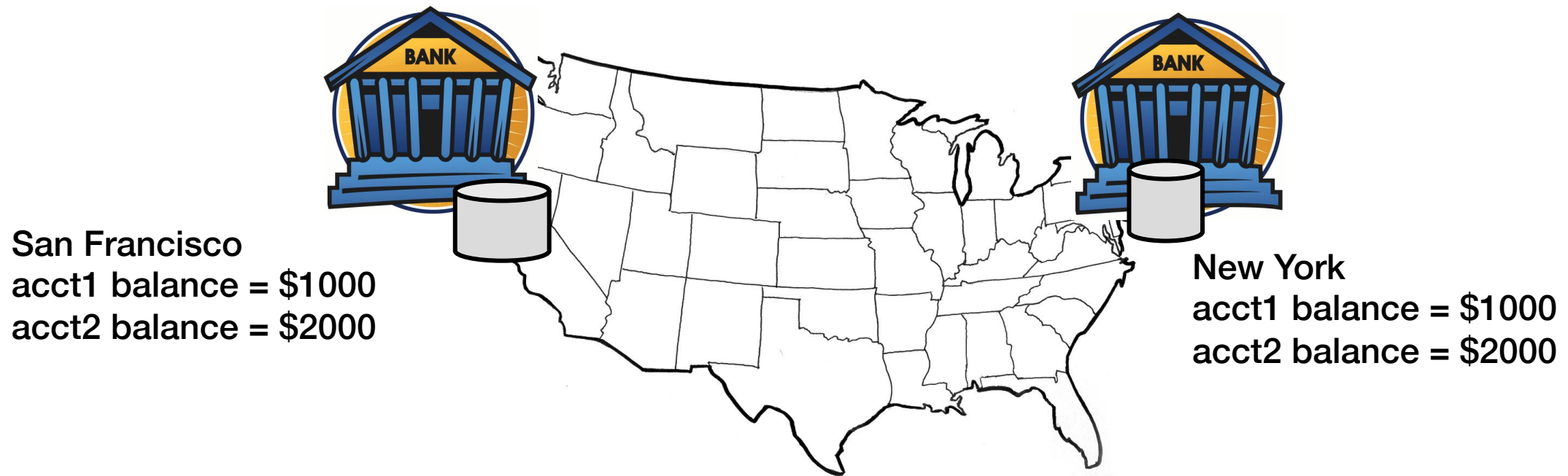


COS 418/518: Distributed Systems
Lecture 6

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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?
- TCP provides all of these when processes don't fail

Global snapshot is global state

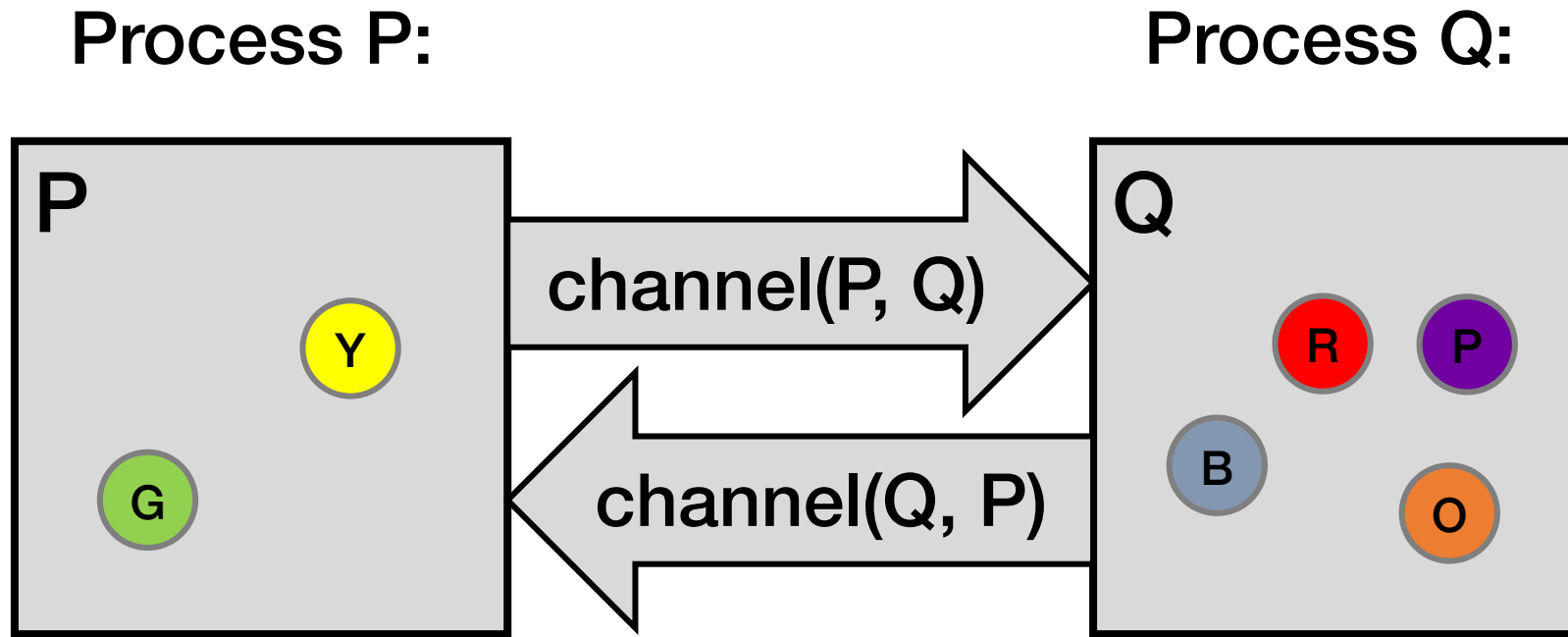
- Each distributed application has a number of processes running on a number of physical servers
- These processes communicate with each other via channels
- A **global snapshot** captures
 1. The local states of each process (e.g., program variables), and
 2. The state of each communication channel

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... ..

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

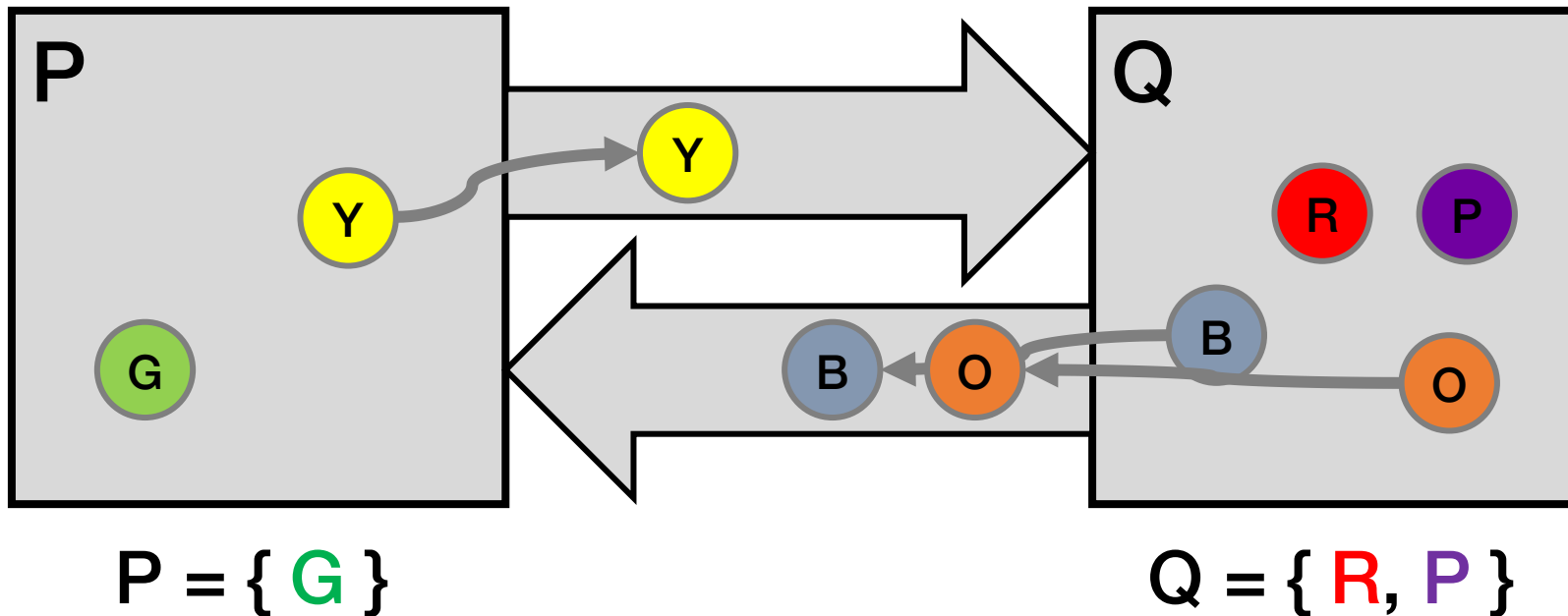
When is inconsistency possible?

- 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

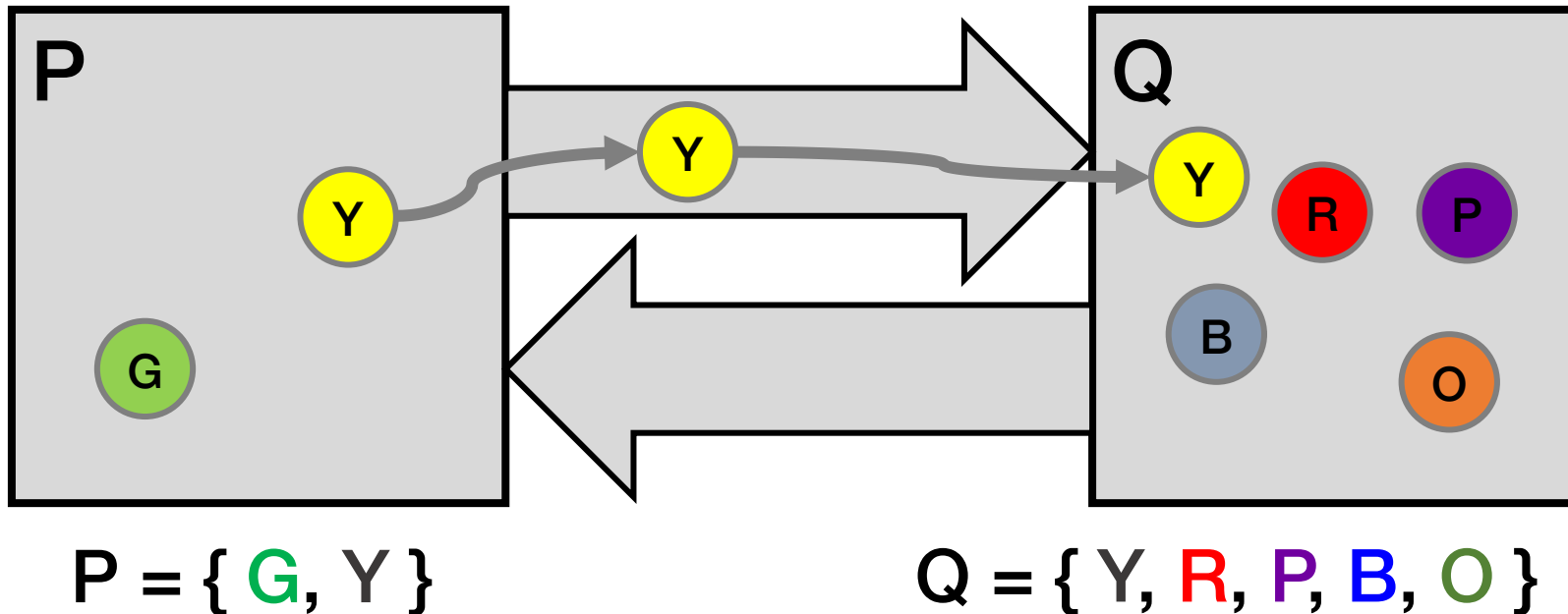
This snapshot **misses** Y, B, and O tokens



Problem: Duplicated tokens

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

This snapshot **duplicates** the Y token



Idea: “Marker” messages

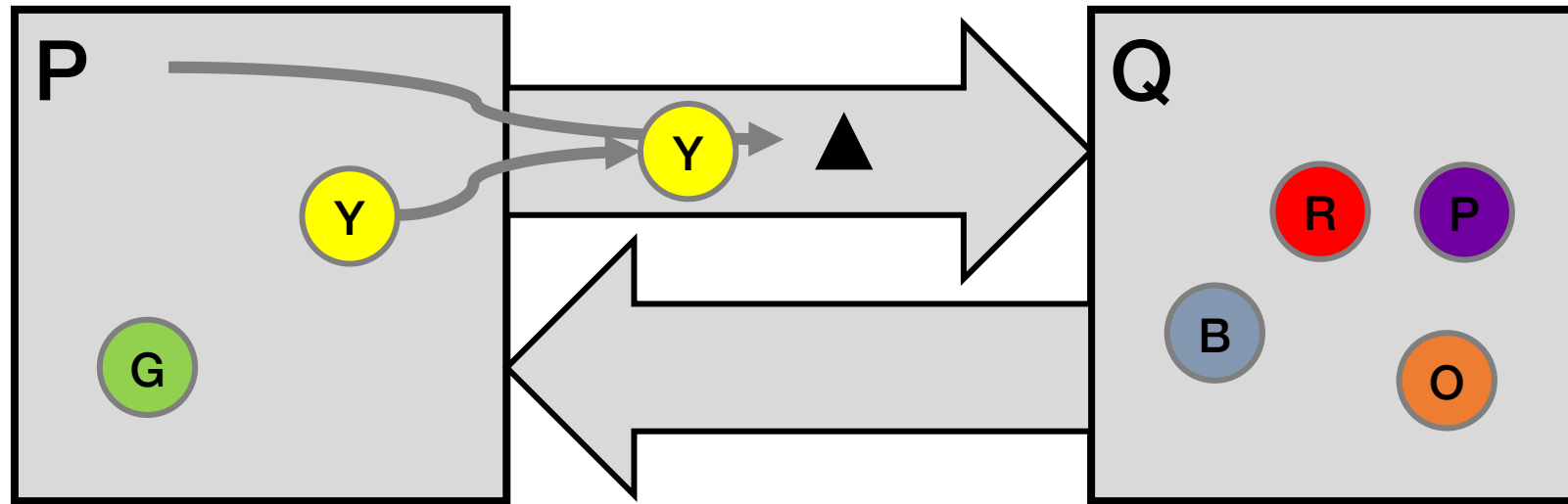
- What went wrong?
 - We should have captured the state of the **channels** as well
 - Avoids missing tokens
 - We should have coordinated snapshots at different processes
 - Avoids duplicate tokens
- Let's send a **marker message** ▲
 - Used to capture channel state and coordinate different processes
 - 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

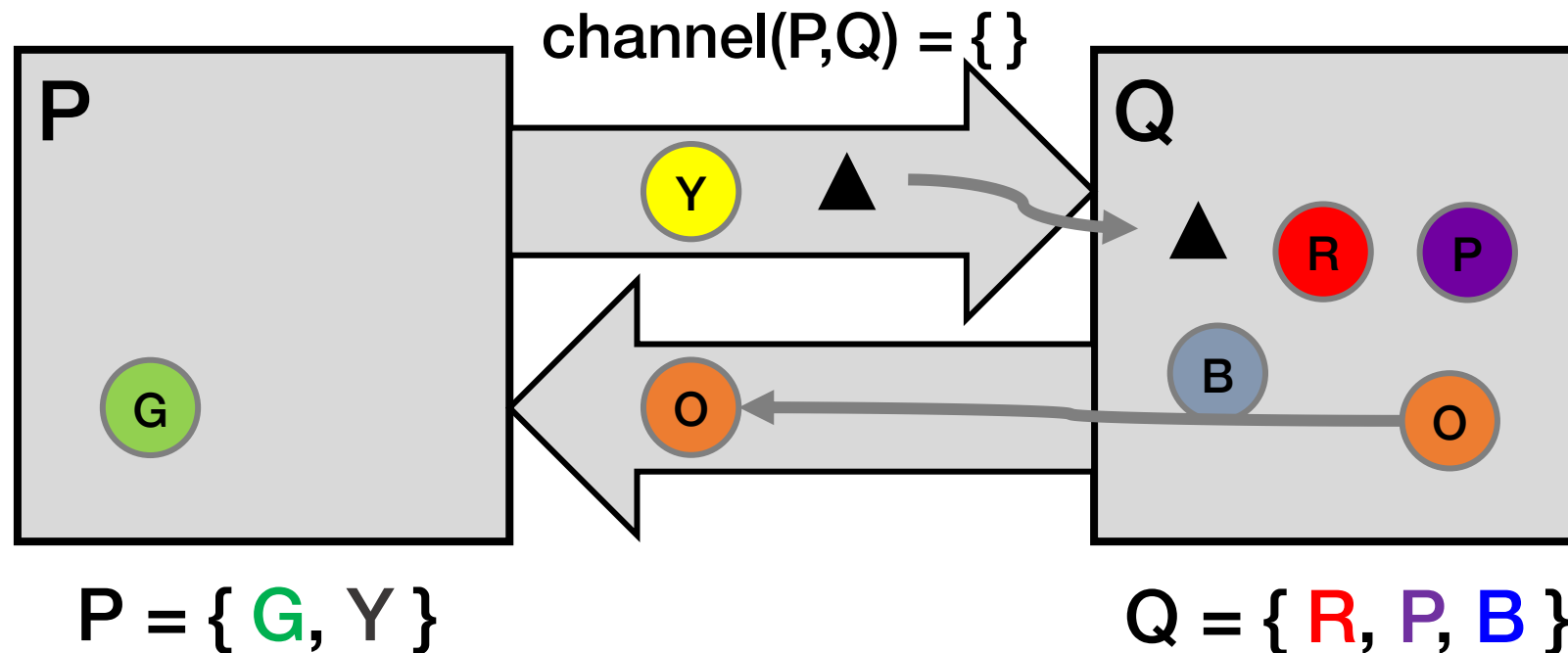
- P snapshots and sends marker, then sends Y
- **Send Rule:** Send marker on all outgoing channels
 - Immediately after snapshot
 - Before sending any further messages



snap: P = { G, Y }

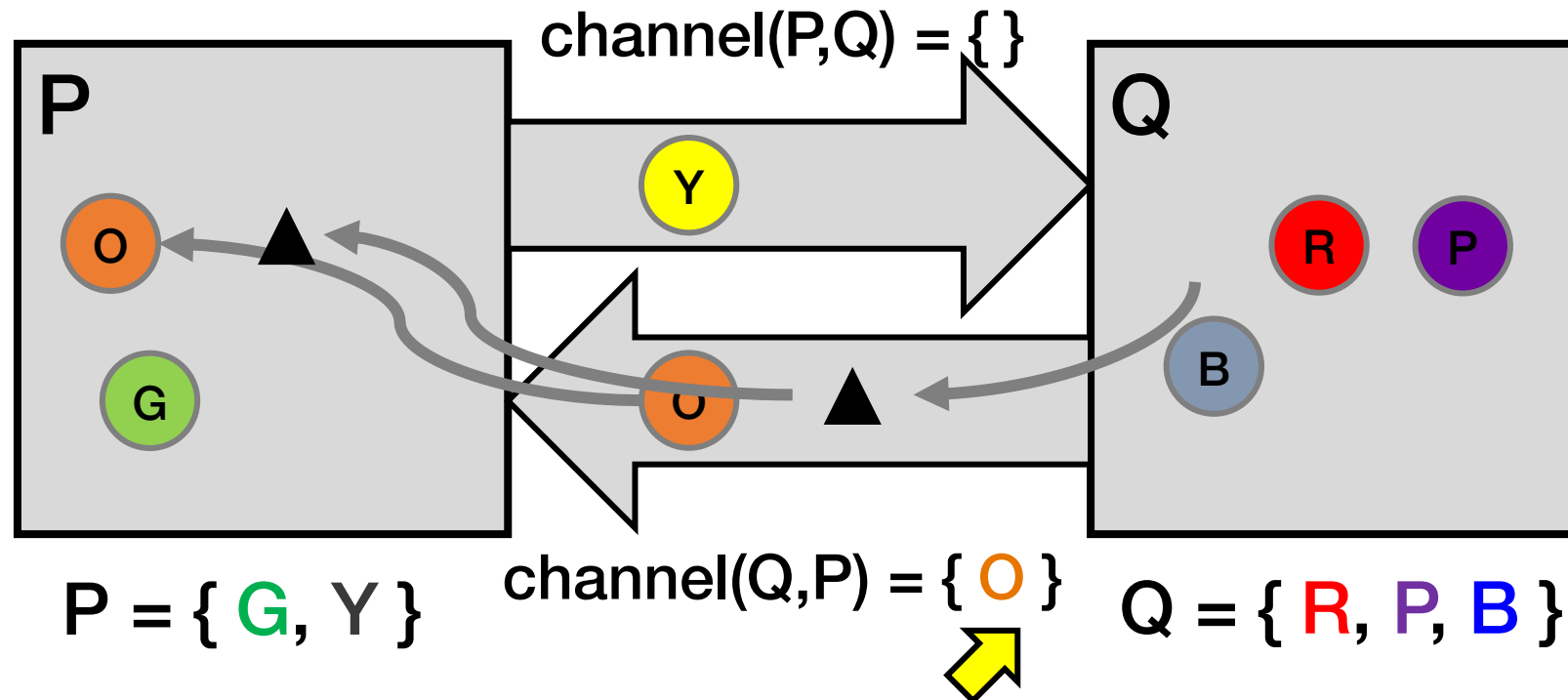
Chandy-Lamport: Receiving process (1/2)

- 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 $\bigcirc$, then marker $\blacktriangle$
- **Receive Rule (if already snapshotted):**
 - On receiving marker on c record c's state: all msgs from c since snapshot



Chandy-Lamport Algorithm: Details

- 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
 3. Starts recording messages on each inbound channel
- Nodes remember whether they have snapshotted
- On receiving a marker on channel c
 - If ($\neg$ snapshotted) then performs steps 1 — 3
 - 4. Stop recording messages on channel c

Chandy-Lamport Algorithm: Details

- Chandy-Lamport snapshot is a “consistent cut”
 - The snapshot’s state did not necessarily happen at any point in real time, but it could plausibly have happened
 - Guarantees that no effect is in the past while its cause is in the future
 - Cause = sending a message, effect = receiving the message
 - Prevents duplication (cannot receive a message at node B if it wasn’t sent yet at node A)

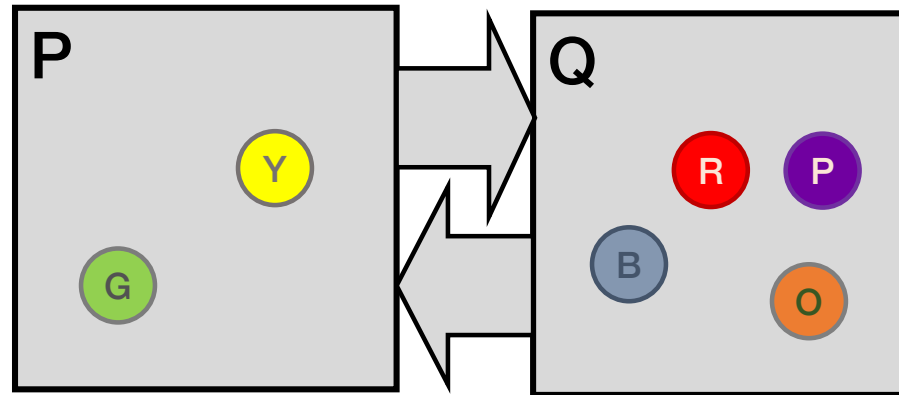
Chandy-Lamport Puzzle #1

Is this snapshot possible? And if so, how?

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

What if multiple nodes can initiate simultaneously for the same snapshot?

Usually, each initiator will assign a unique ID to its snapshot



Chandy-Lamport Puzzle #2

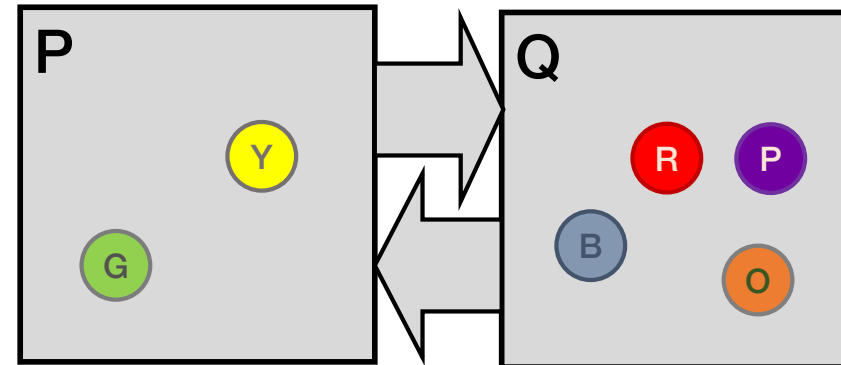
Is this snapshot possible? And if so, how?

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

$\text{chan}(P, Q) = \{ \}$

$Q = \{ \}$

$\text{chan}(Q, P) = \{ \}$



Chandy-Lamport Puzzle #3

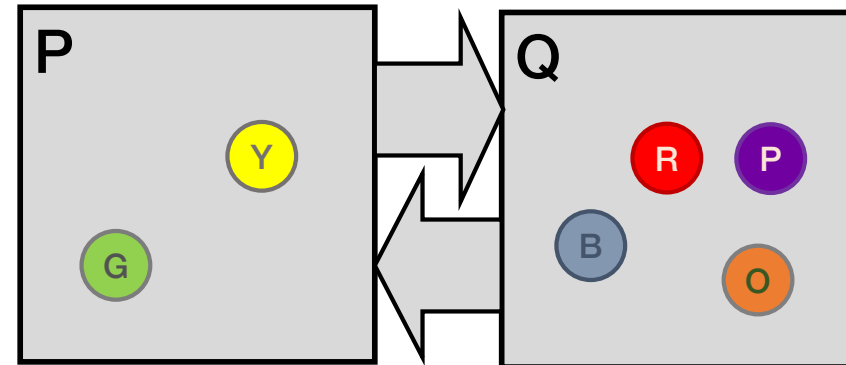
Is this snapshot possible? And if so, how?

$P = \{\}$

$\text{chan}(P, Q) = \{\}$

$Q = \{\}$

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



Chandy-Lamport Puzzle #4

Is this snapshot possible? And if so, how?

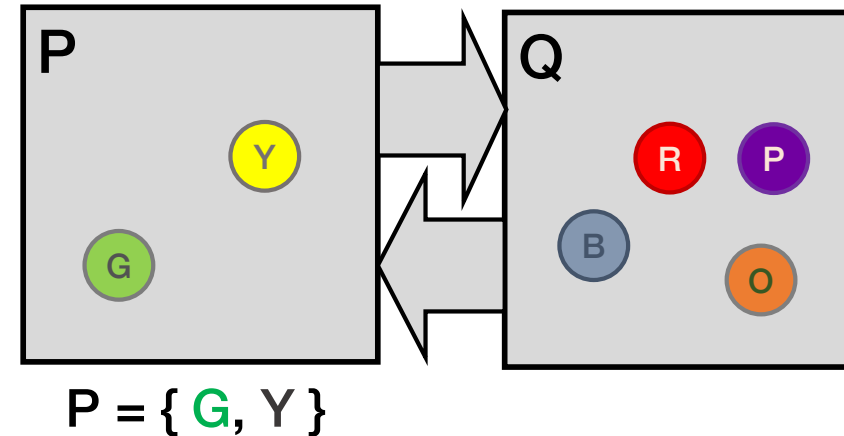
$P = \{ G, Y, \}$

$\text{chan}(P, Q) = \{ R \}$

$Q = \{ B, O \}$

$\text{chan}(Q, P) = \{ P \}$

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



Chandy-Lamport Puzzle #5

Is this snapshot possible? And if so, how?

P = { G, Y, }

chan(P, Q) = { }

chan(P, T) = { }

Q = { B, O }

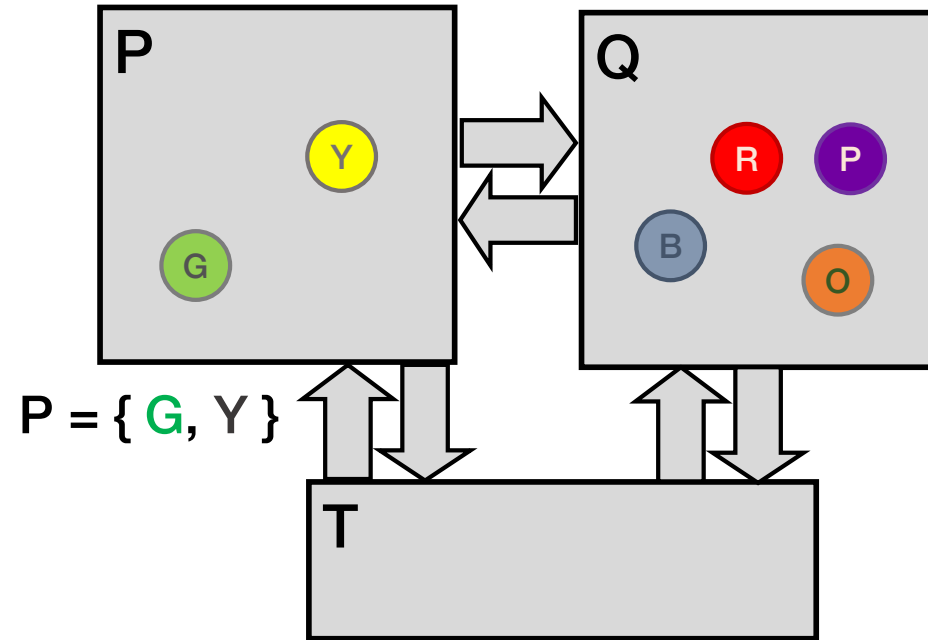
chan(Q, P) = { P }

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 }

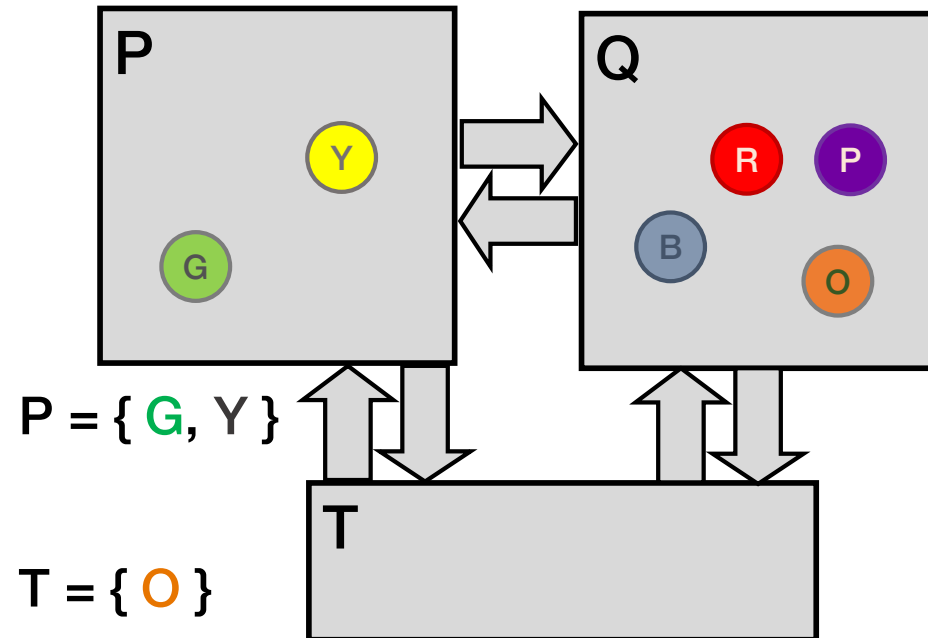
chan(Q, P) = { P }

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