Feb 4
Consistent Global States
(Part 2)

Vijay Chidambaram

Consistent observations

- A consistent observation is one that corresponds to a consistent run.
- It is the possibility of messages being reordered by channels that leads to undesirable observations
- We can restore order to messages between pairs of processes by defining a delivery rule for deciding when received messages are to be presented to the application process.

FIFO Delivery

- FIFO Delivery: sendi(m) -> sendi(m') => deliveri(m) -> deliveri(m')
- Clock Condition: e -> e' => Timestamp(e) < timestamp(e')
- Delivery Rule DR1: At time t, deliver all received messages with timestamps up to t - delta in increasing timestamp order

Gap Detection

- Given two events e and e′ along with their clock values LC(e) and LC(e′) where LC(e) < LC(e′) , determine whether some other event e″ exists such that LC(e) < LC(e″) < LC(e′)
- A message m received by process p is called stable if no future messages with timestamps smaller than TS(m) can be received by p.
- DR2: Deliver all received messages that are stable at p0 in increasing timestamp order.

Causal Delivery

- FIFO delivery is per-process
- Causal Delivery extends it across processes
- Causal Delivery: sendi(m) -> sendj(m') => deliveri(m) -> deliverj(m')
  - Note i and j can be different
- FIFO delivery between all pairs of processes not enough for causal delivery
- A -> B, A -> C; B->C
  - sendAB(M1) -> sendAC(M2)
  - B gets M1, sends it to C
  - C gets M2 before M1.
  - FIFO delivery is ensured, causal delivery is not.

Consistent Observations

- If the observer process uses a delivery rule that satisfies Causal Delivery, then all its observations will be consistent
- How do we build this in a practical distributed system?

Building the Observer

- Assume Observer has two parts: the Logic Controller and the Network Controller
- The Network Controller gets events sent by other nodes, decides in what order to show them to Logic Controller
  - Delivery rules are implemented here
- Logic Controller takes actions based on what it sees ("declare deadlock")

Building the Observer

- Network Controller gets two events E1 and E2
- Timestamp = TS
- TS(E1) < TS(E2)
- This doesn't mean E1 < E2
- Only this is true: E1 < E2 => TS(E1) < TS(E2)
- So we know E2 < E1 is false, E1 and E2 could still be concurrent

Strong Clock Condition

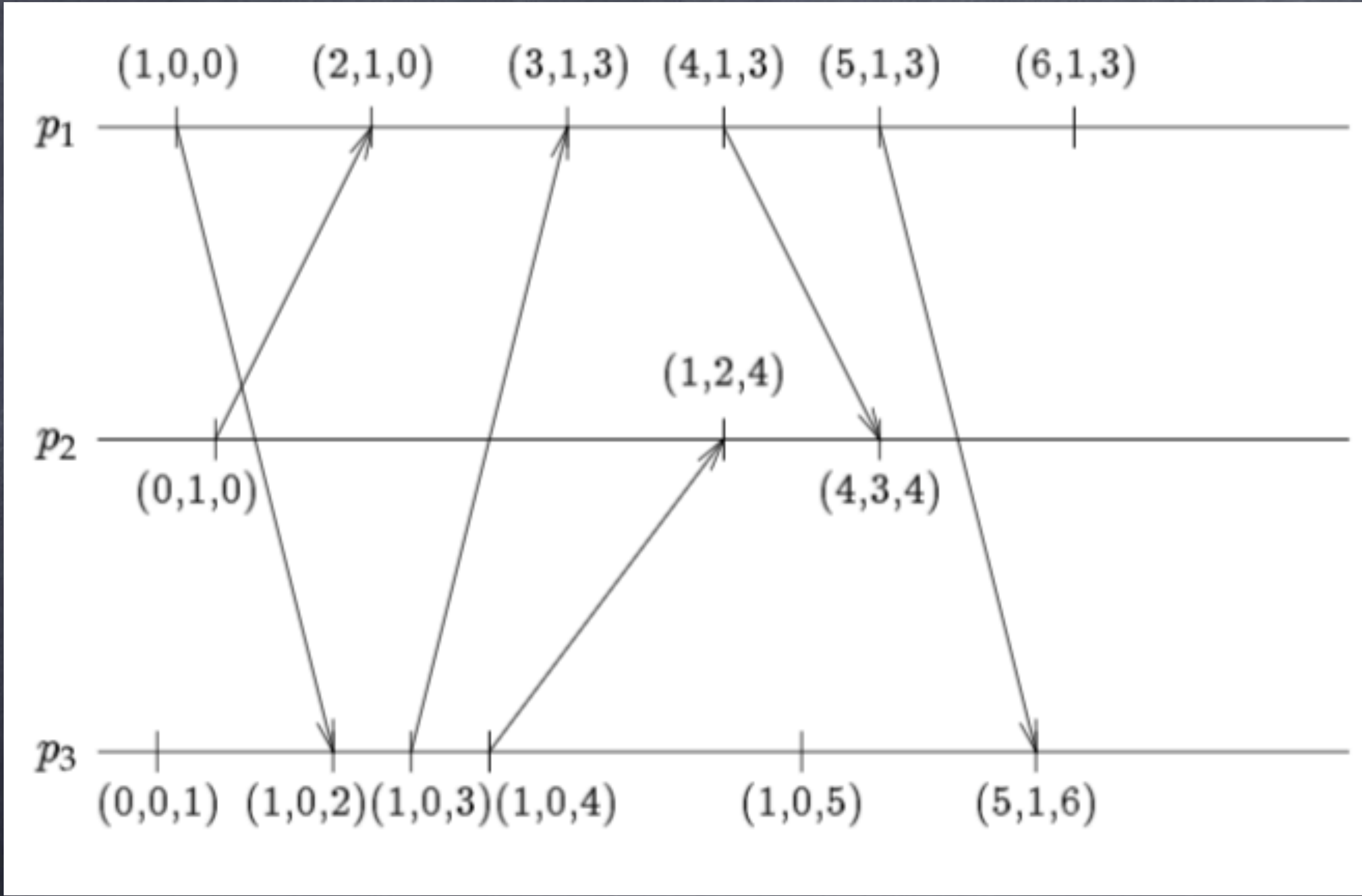
- Need stronger condition to implement Network Controller
- Strong Clock Condition:
  - E1 < E2 => TS(E1) < TS(E2)
  - TS(E1) < TS(E2) => E1 < E2

Implementing the Strong Clock Condition

- Brute force approach:
  - At each node, keep the Causal History C
  - Causal History C(e) is the set of all events e’ such that e’ < e
  - All previous local events at node are part of C(e)
  - When A sends a message to B, C(receipt of message M) = C(previous local event at B) union C(sending event at A)
  - E1 < E2 if C(E1) is a subset of C(E2)
- Problem: the set C grows too large too quickly, impractical to maintain

Vector Clocks

- Each node maintains a vector V[n] where there are n nodes
- V = 0 on initialization for all nodes
- For local event Ei at node i, update V[i] = V[i] + 1
- On receipt(M),
  - V = max(V, vector-TS(M)) for each element of V
  - V[i] +=1
- V[j] = number of events of j that casually precede this event (when this process is not j)
- V[i] = number of local events when this process is i


(1,0,0)
(2,1,0)
(3,1,3)
(4,1,3)
(5,1,3)
(6,1,3)
p1
(1,2,4)
p2
(0,1,0)
(4,3,4)
p3
(0,0,1)
(1,0,2)
(1,0,3)
(1,0,4)
(1,0,5)
(5,1,6)

Using Vector Clocks

- V1 < V2 if no element of V2 is bigger than its corresponding element in V1
- Strong Clock Condition: E1 < E2 <=> V(E1) < V(E2)
- V1 and V2 are concurrent if V1[i] > V2[i] for some i and V2[j] > V1[j] for some j

Using Vector Clocks in the Network Observer

- All events sent to observer have vector timestamps
- Network Observer obtains set of events M, then decides on order to deliver them
- A message can be delivered as soon as Network Observer determines there are no events that casually precede this message
- Consider message M from J
- M' is last message delivered from K (K != J)
- To deliver M, NO has to determine that:
  - There is no earlier message from J that is undelivered
    - if V(M)[J] -1 message have already been delivered, there cannot be an earlier message
  - There is no undelivered message M" such that sendK(M') < send (M") < sendJ(M)
    - V(M')[K] >= V(M)[K] for all K => V(M) < V(M')

Using Vector Clocks in the Network Observer

- Network Observer maintains array D, initialized to 0
- Deliver message M with time stamp V from J as soon as:
  - D[J] = V[J] - 1
  - D[K] >= V[K], for all K != J
- When Network Observer delivers M, D is updated by setting D[j] = V[j]

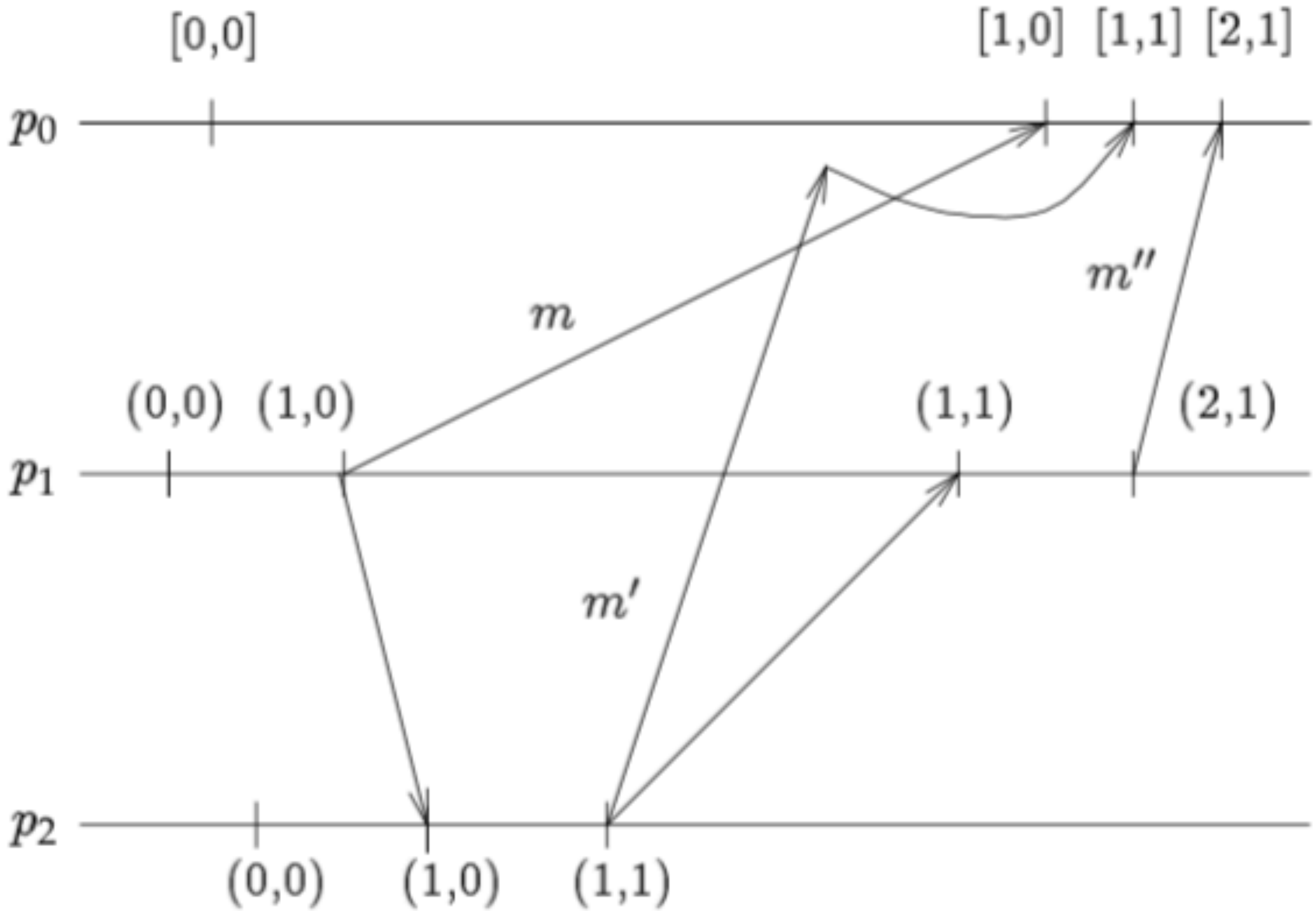


Figure 8. Causal Delivery Using Vector Clocks