Overview of Ordering and Logical Time

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Cpt. S 464/564 Lecture (partial)

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Context

- This material is NOT in CDKB5 textbook
- Rather, from second text by Verissimo and Rodrigues, chapters 1.4 & 2.7
- Do read the pertinent sections in CKDB5 Chapter 14, however!

Outline

- Logical Time
- Global States
- DS Properties

Logical Time

- Time in Distributed Systems
  - Computers can only be synchronized by network messages, but the latency can vary
  - We can not synchronize enough to be able to, in general, tell the ordering of two arbitrary events at different computers.
  - We can, however, establish an ordering on some of the events, and this can be used in many situations.
- **Logical Time**
  - Builds up a notion of what we can reason about w.r.t. the order of events
  - Defines the "Happened-before" relation
  - Source: Lamport, Leslie. "Time, Clocks and the Ordering of Event in a Distributed System", *Communications of the ACM*, Vol. 21, July 1978, pp. 558-565.
    - One of the seminal works in distributed systems…
    - **Assigned for 564 students to read (see web page)**

Happened-Before Relation

- <u>Happened-Before relation</u>, →, based on observations:
  1. If two events occur in the same process, then they occurred in the order in which that process observes them.
  2. The receipt of a message happens after its being sent.
  3. "Happened-before" is transitive
- Corresponding Rules for events *x*, *y*, *z*, process *p*, and message *m*

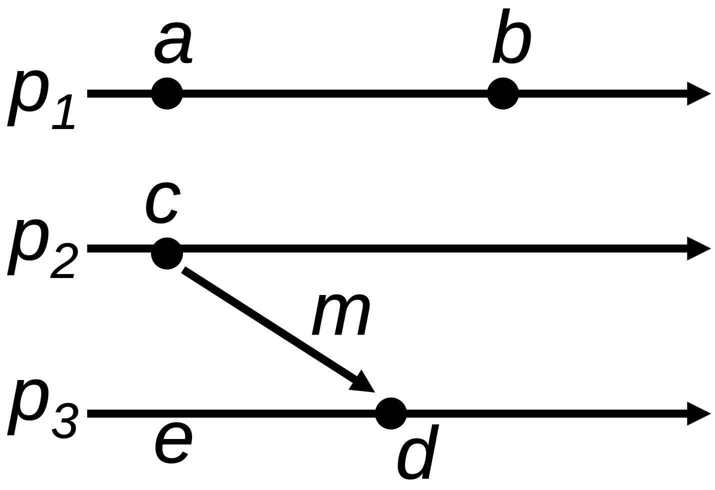
  <u>HB1</u>: $x \xrightarrow{}_{p} y$, then $x \rightarrow y$

  <u>HB2</u>: send(m) → recv(m)

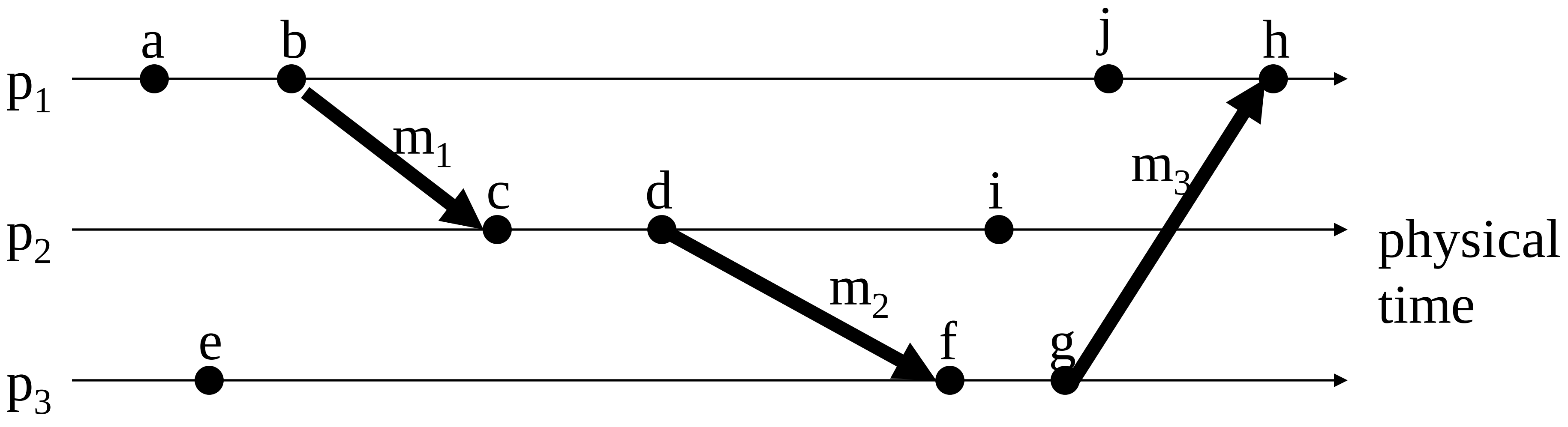
  <u>Transitivity</u>: x → y and y → z, then x → z
- <u>Concurrency</u>: If a ~→ b and b ~→ a, then a||b ("a is concurrent with b")'
- Note: if *x* → *y* ("*x* happened before *y*") then *y* ← *x* ("*y* happened after *x*"), notationally

Representing Distributed Computations

- Events at a process can be
  - <u>execution events</u>: internal computations
  - <u>send events</u>: sending a message to another process
  - <u>receive events</u>: receiving a message from another process
- Message exchanges depicted with timelines: e.g.



Happened-Before Example

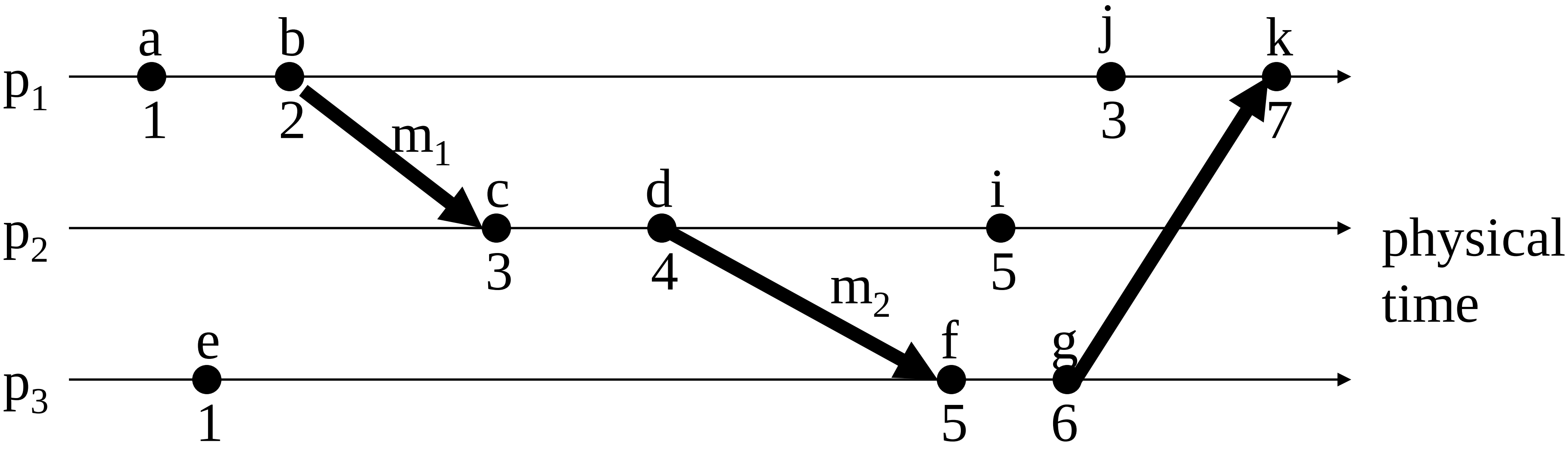


- Example table of →, ←, ||
- Limitations of Happened-Before
  - Covert channels
  - Too pessimistic: some things *a*→*b* did not have *a* causing *b*!
- Happened-before also called
  - Causal ordering
  - Potential causality
  - Lamport ordering
  - (irreflexive) partial ordering

Logical Clocks

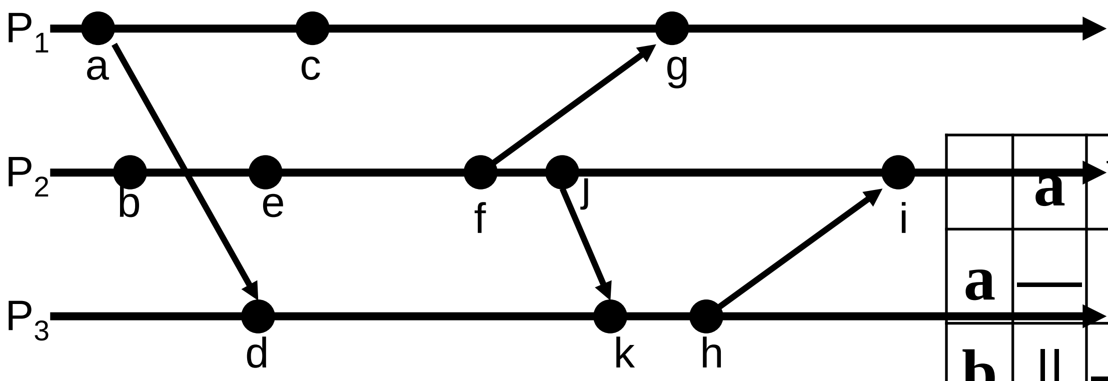
- How to implement “Happened Before”??
- <u>Logical Clock</u>, a monotonically increasing counter.
- Let
  - Each process *p* keeps its own logical clock, $C_{p,}$ which it uses to timestamp events
  - C_p (*a*) is the logical time at process *p* at which event *a* occurred
  - *C(a)* is the logical time at which event *a* occurred at the process it occurred at
- Processes keep their own logical clocks, initialized to 0. Updated by rules:
  - LC1: Before each event occurs, increment C_p
  - LC2:
    - When a process *p* sends a message *m*, it piggybacks on *m* value t= C_p
    - When process *q* receives <*m,t*>, *q* computes $C_q = \max(C_q, t) + 1$ then timestamps *m*

Logical Clock Example



- Note if *a* → *b* then *LC(a)* < *LC(b)*
- However, *LC(a)* < *LC(b)* does <u>not</u> imply *a* → *b*
  - Above, C(e) < C(b) yet *b* || *e*
  - Also note that concurrency is not transitive: *a*||*e* and *e*||*b* yet *a*→*b*

Logical Time & Clocks from 2003 Midterm



[22 points] On the diagram above, write the Logical Clock (LC) time at its processor for each event to the left of the dot for that event.

[45 points] Fill out the empty cells in the table to give the relations between each event: "→" denotes "happened before", "←" denotes "happened after", and "||" denotes "concurrent". (For examples of this notation, because there is a message from 'a' to 'd', it is filled in "→" in the [a,d] cell and "←" in the [d,a] cell. Also, 'b' and 'a' are concurrent, and are so marked.)

	a	b	c	d	e	f	g	h	i	j	k
a	—	||		→							
b	||	—									
c			—								
d	←			—							
e					—						
f						—					
g							—				
h								—			
i									—		
j										—	
k											—

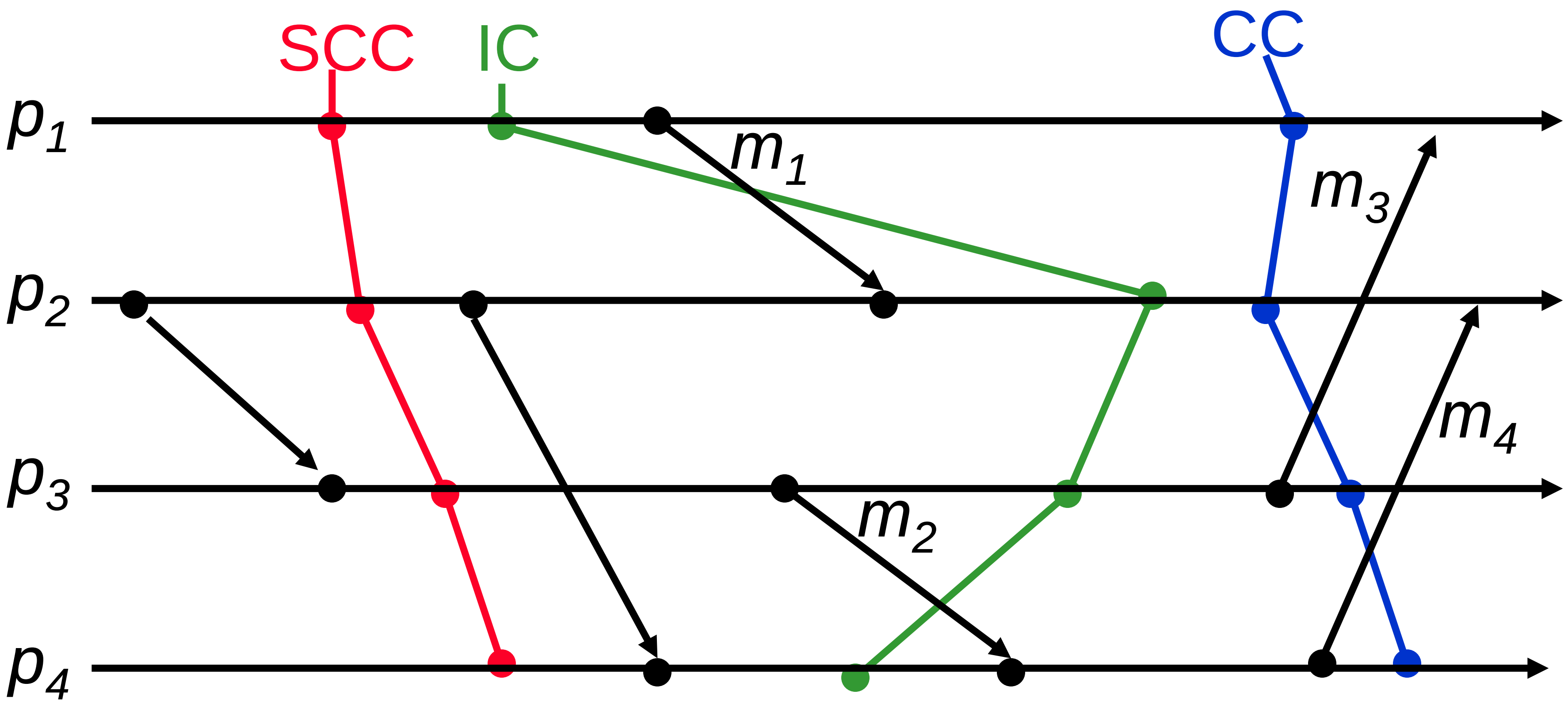
Global States

- Sometimes very useful to get a global “picture” of a distributed system
- **Global state** (GS) of a DS at any point is a vector of its individual process states: $S = \{S_1, S_2, \ldots, S_M\}$
- Two viewpoints of how a system evolves:
  - Interleaving view: system goes through a succession of states (like above)
  - Space-time view: system goes through a partially ordered set of events occuring in several processes in the system
- A **cut** (in space-time view) is a segment intersecting the timelines of all processes.
  - A cut involves coordination with computers across a DS
  - Many different ways to implement a cut in a DS that provide a range of properties and costs

Global States (cont.)

- Inconsistent cut (IC)
  - Snapshot gives invalid picture of the DS (a state that could never happen)
  - Example: message received but not sent in the snapshot
- Consistent cut (CC)
  - Snapshot gives correct (state that could have happened) but possibly incomplete picture of the DS
  - Example: messages in transit not accounted for in a snapshot
- Strongly consistent cut (SCC)
  - Snapshot is a faithful representation of an actual global state of the DS
  - No messages in transit when state read at each node, atomic checkpoints taken in that interval across nodes, …
- Note: TvS Chap6 has lots on consistency; we may cover some later in this class…

Example Cuts for Global States



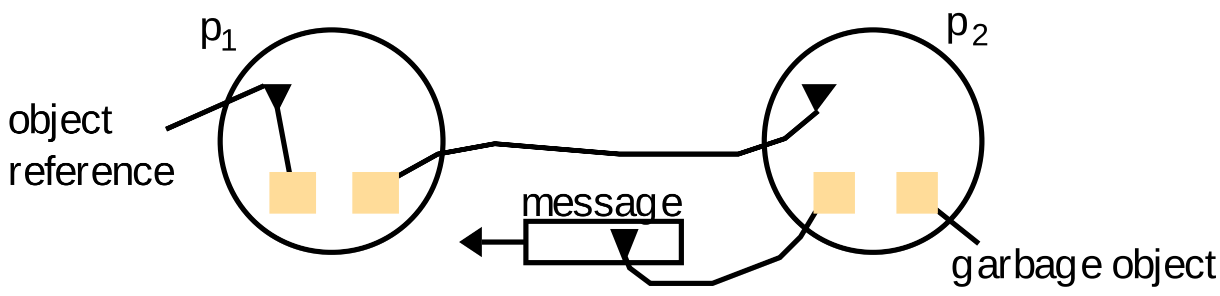
- Strongly consistent cut (SCC): faithfully represents GS of the system
- Inconsistent cut (IC): gives invalid picture of any GS
- Consistent cut (CC): gives valid but possibly incomplete picture of the GS of the system

DS Properties

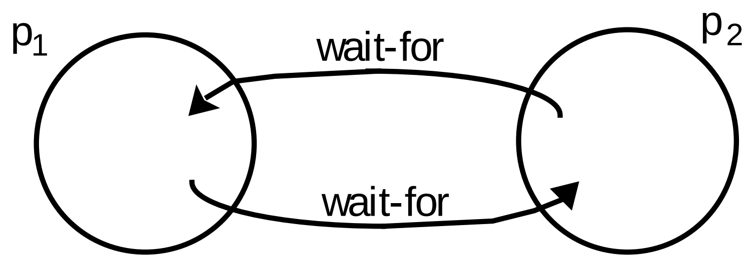
- Goal: specify a system with high-level properties
- **Safety properties**: something bad (wrong events) never take place
  - Specification: predicate *P* will never be true in the DS
- **Liveness properties**: something good (positive event) eventually takes place
  - Specification: predicate *P* will eventually be true in the DS
- "any delivered message is delivered to all correct participants": safety property (atomicity)
- "any message sent is delivered to at least one participant": liveness property
- **Timeliness properties** specify a time that a predicate will be true in the DS at a given instant in time

Examples of DS Properties (aux)

a. Garbage collection



b. Deadlock



c. Termination