Time and Ordering of Events

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Partly based on material by
Sape Mullender and Ken Birman

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What time is it?

- Agree that update A occurred before update B
- Offer a “lease” on a resource that expires at time 10:10.0150
- Guarantee that a time critical event will reach all interested parties within 100ms

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What does time “mean”?

- Time on a global clock?
  - E.g. with GPS receiver
- Machine’s local clock
  - But was it set accurately?
  - And could it drift, e.g. run fast or slow?
  - What about faults, like stuck bits?
- Or try to agree on time

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LOGICAL TIME

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Lamport: Logical Time

- Time lets a system ask "Which came first: event A or event B?"
- Time is a means of labeling events so that…
  - If A happened before B, TIME(A) < TIME(B)
  - If TIME(A) < TIME(B), A happened before B

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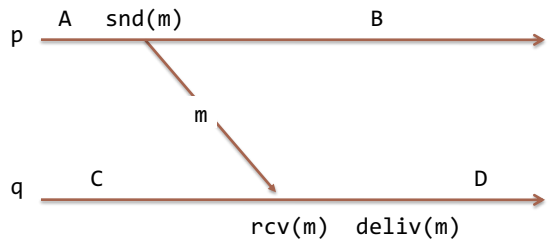
Drawing time-line pictures:



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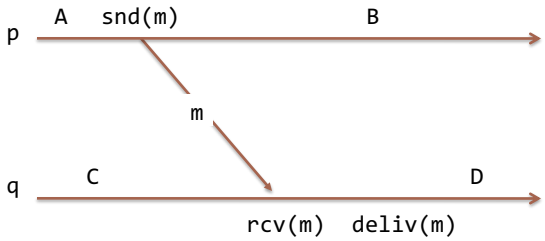
Drawing time-line pictures:



- A, B, C and D are "events".
  - So are snd(m) and rcv(m) and deliv(m)
- What ordering claims are meaningful?

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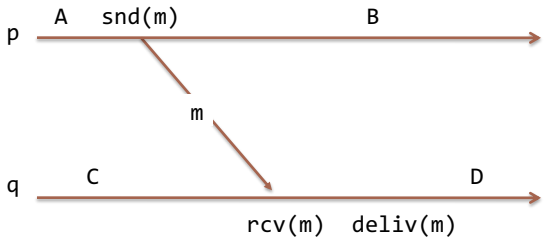
Drawing time-line pictures:



- A happens before B, and C before D
  - *Local ordering* at a single process
  - Write A $\rightarrow^{p}$ B and C $\rightarrow^{q}$ D

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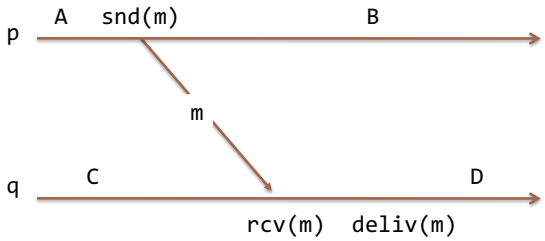
Drawing time-line pictures:



- snd(m) also happens before rcv(m)
  - *Distributed ordering* introduced by a message
  - Write snd(m) → recv(m)

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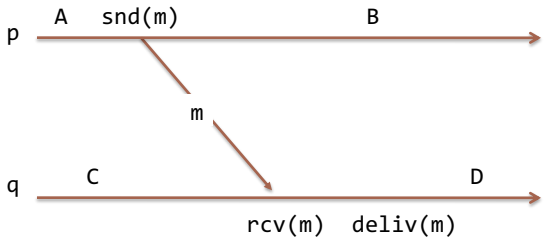
Drawing time-line pictures:



- A happens before D
  - *Transitivity:* A happens before snd(m), which happens before rcv(m), which happens before D

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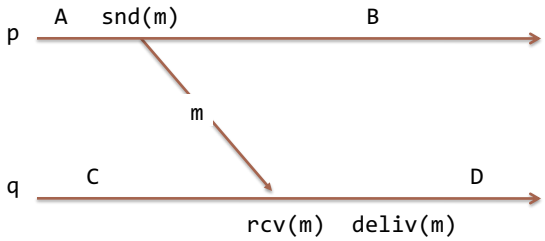
Drawing time-line pictures:



- B and D are concurrent
  - Looks like B happens first, but D has no way to know. No information flowed…

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"Happens before" relation

- We'll say that "*A happens before B*", written A→B, if
  - $A \rightarrow^{p} B$ according to the local ordering, or
  - A is snd(m) and B is rcv(m) and A→B, or
  - A and B are related under the transitive closure of rules (1) and (2)

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LOGICAL CLOCKS

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Logical clocks

- First version: uses just a single integer
  - Designed for big (64-bit or more) counters
  - Each process p maintains LT_p, a local counter
  - A message m will carry timestamp TS(m)

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Rules for managing logical clocks

- When an event happens at a process p it increments LT_p
  - Any event that matters to p
  - Normally, also snd and rcv events (since we want receive to occur "after" the matching send)
- When p sends m, set
  - $TS(m) = LT_p$
- When q receives m, set
  - $LT_q = \max(LT_q, TS(m))+1$

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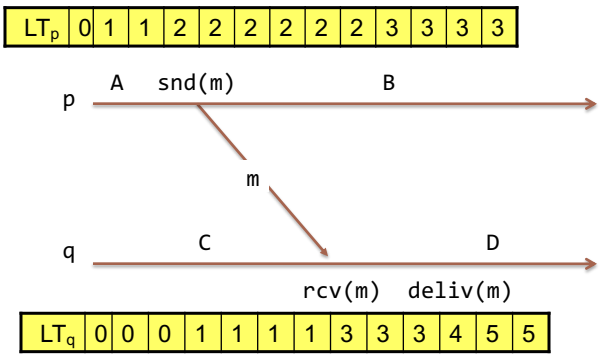
Time-line with LT annotations



- LT(A) = 1, LT(snd(m)) = 2, TS(m) = 2
- LT(rcv(m))=max(1,2)+1=3, etc…

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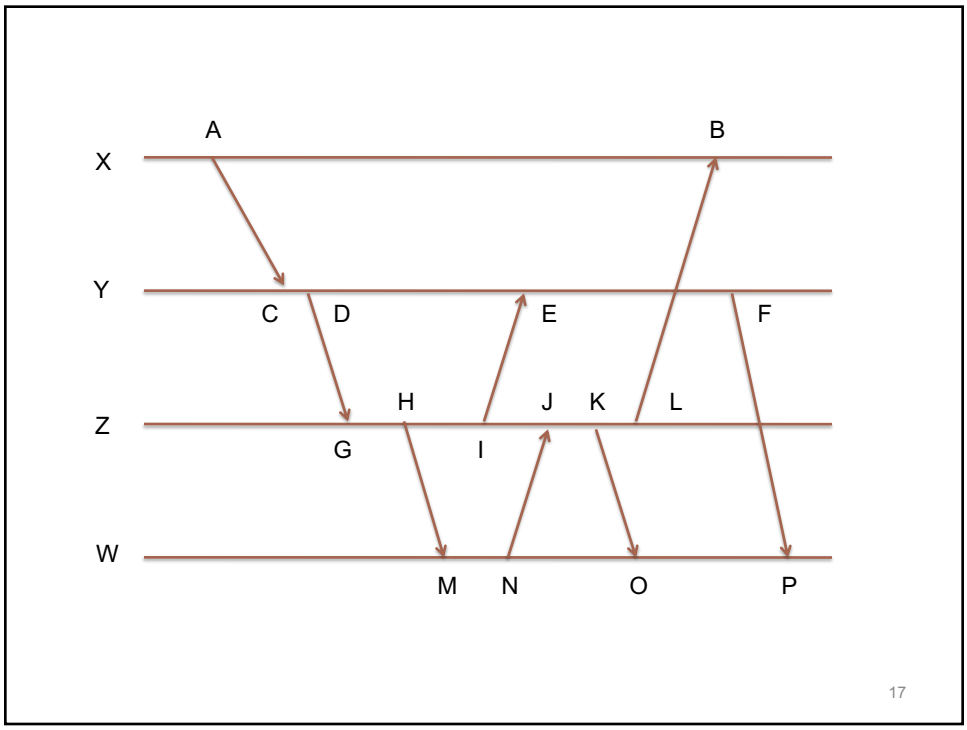

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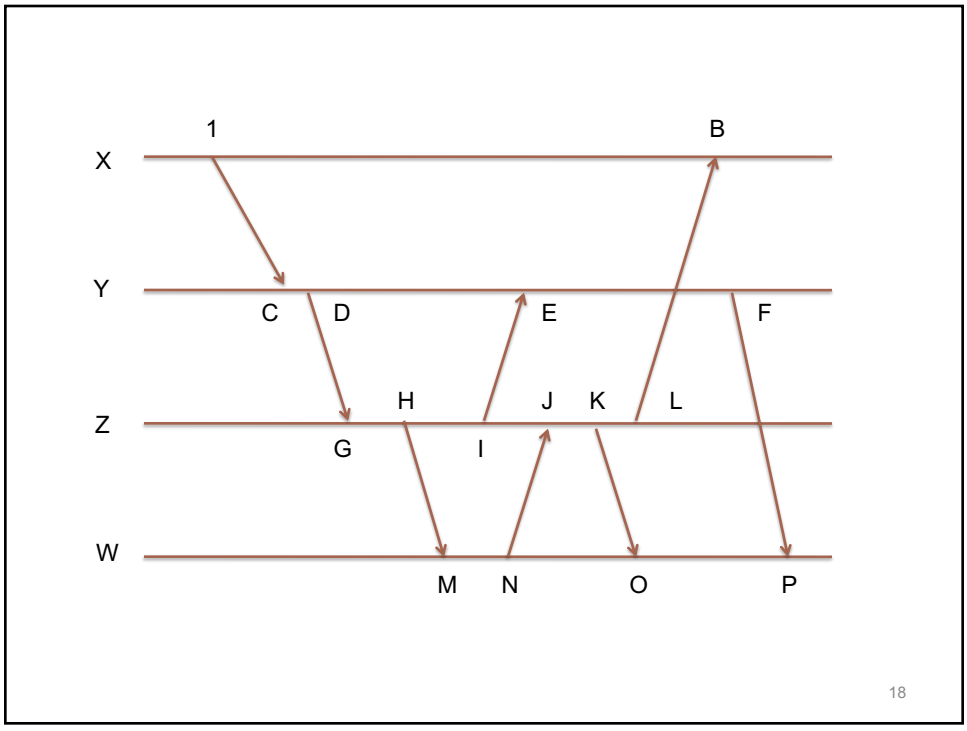

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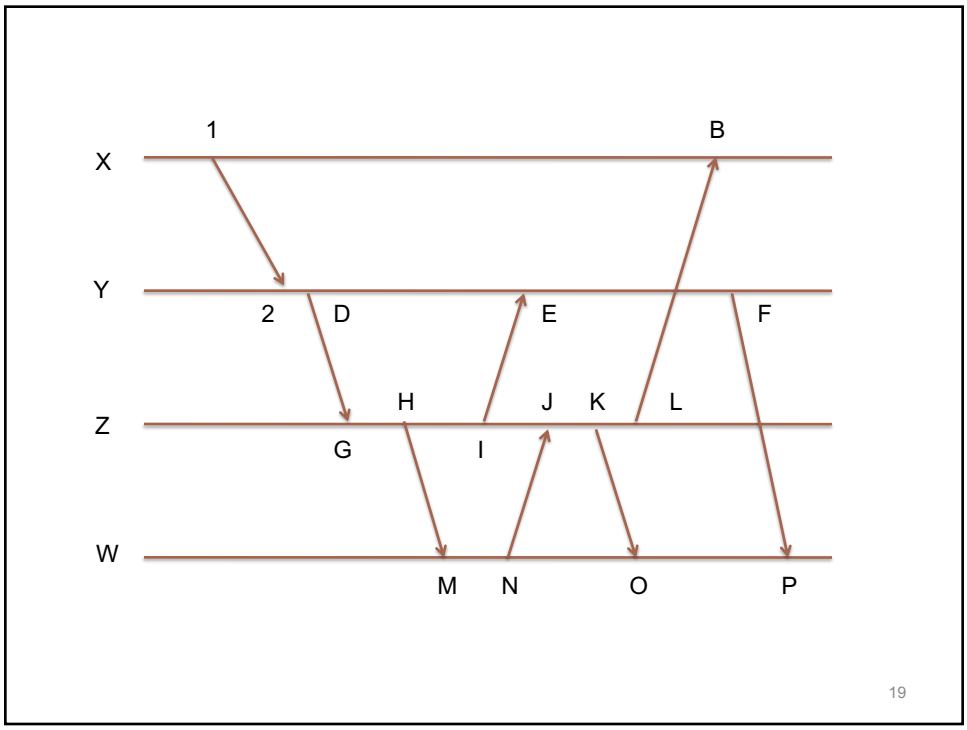

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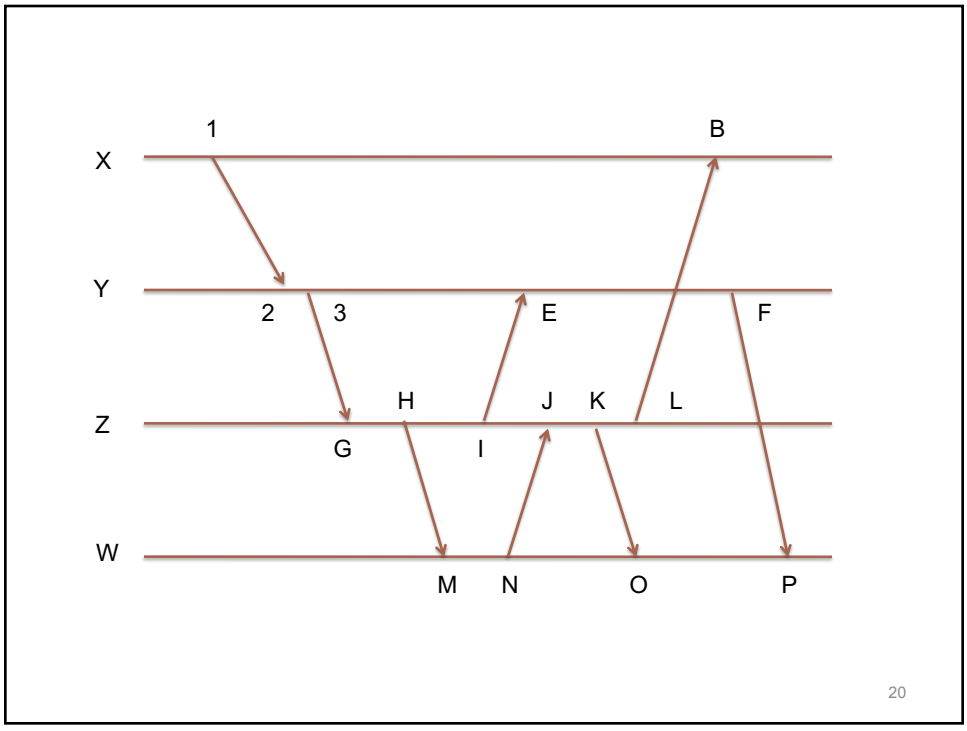

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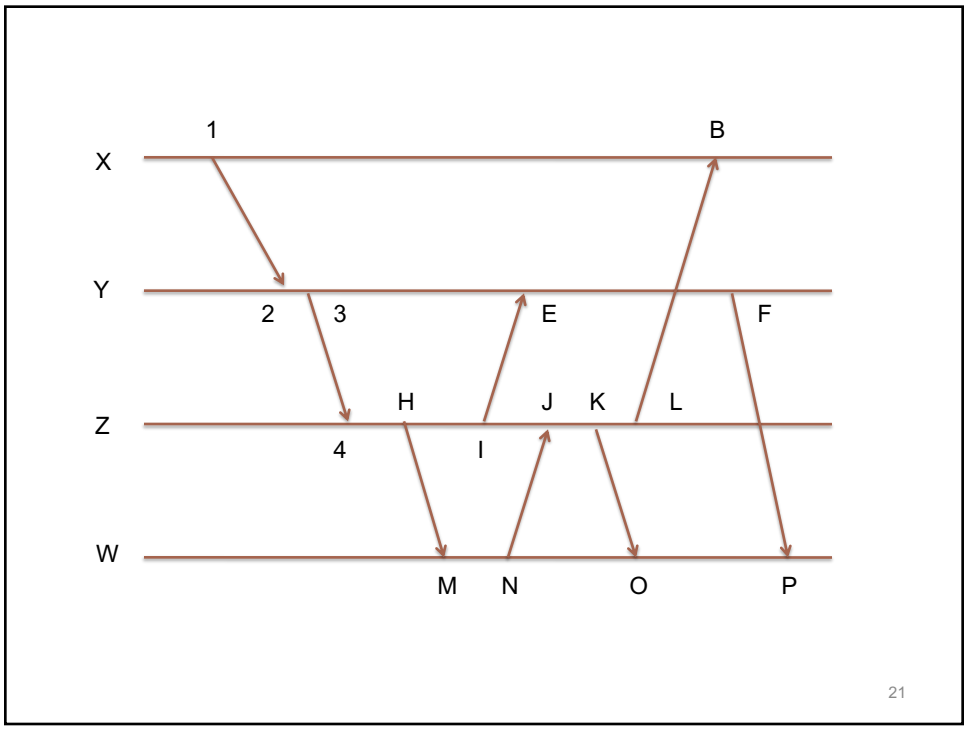

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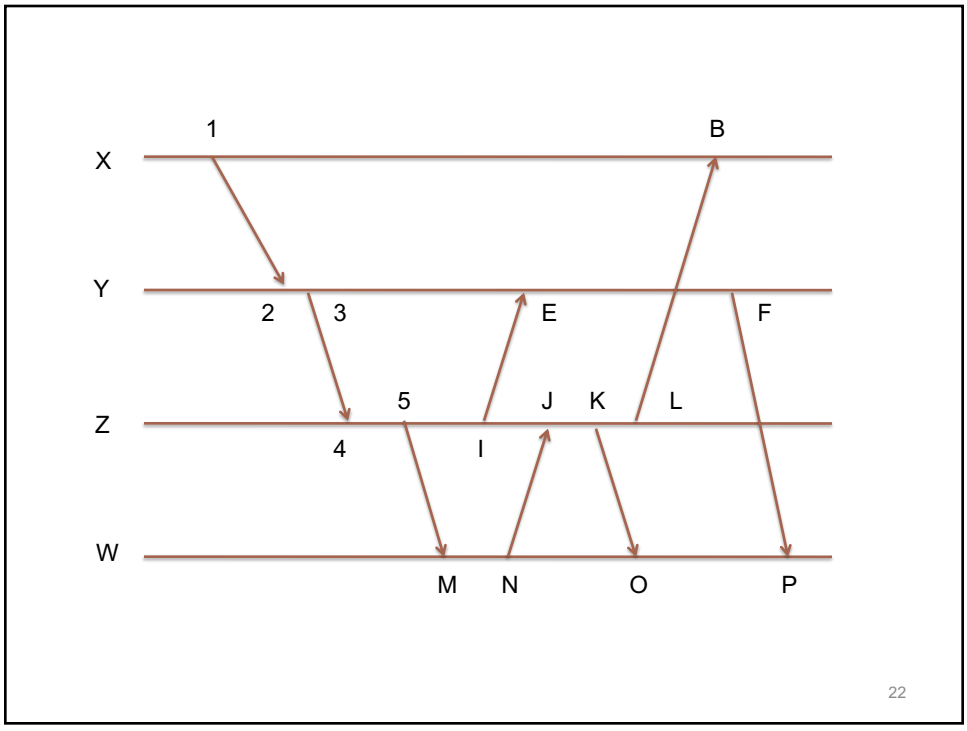

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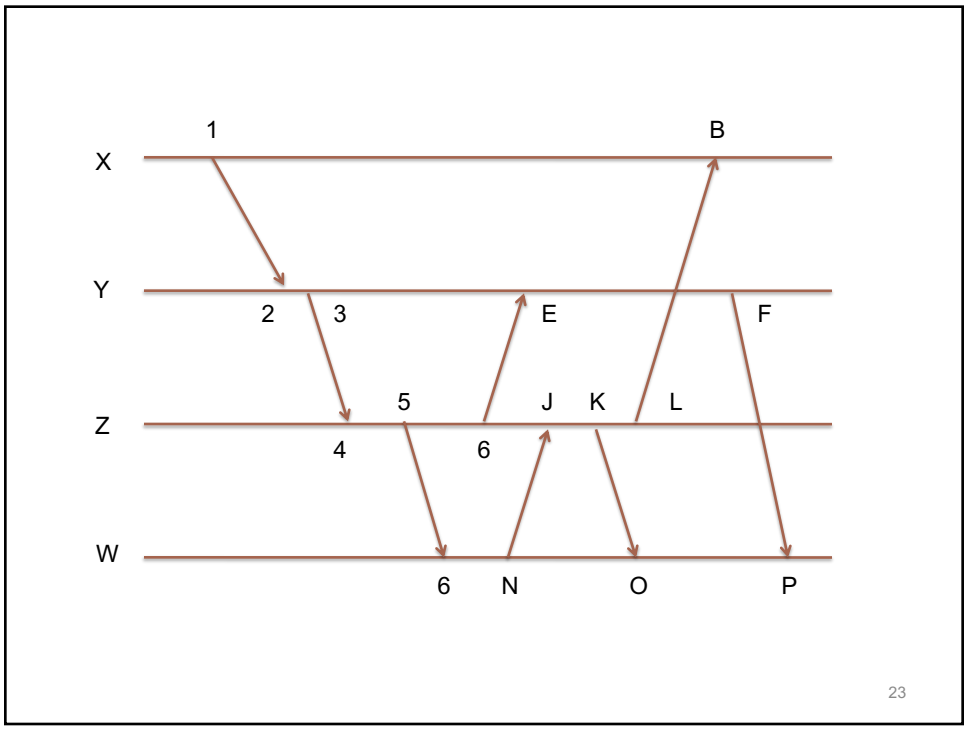

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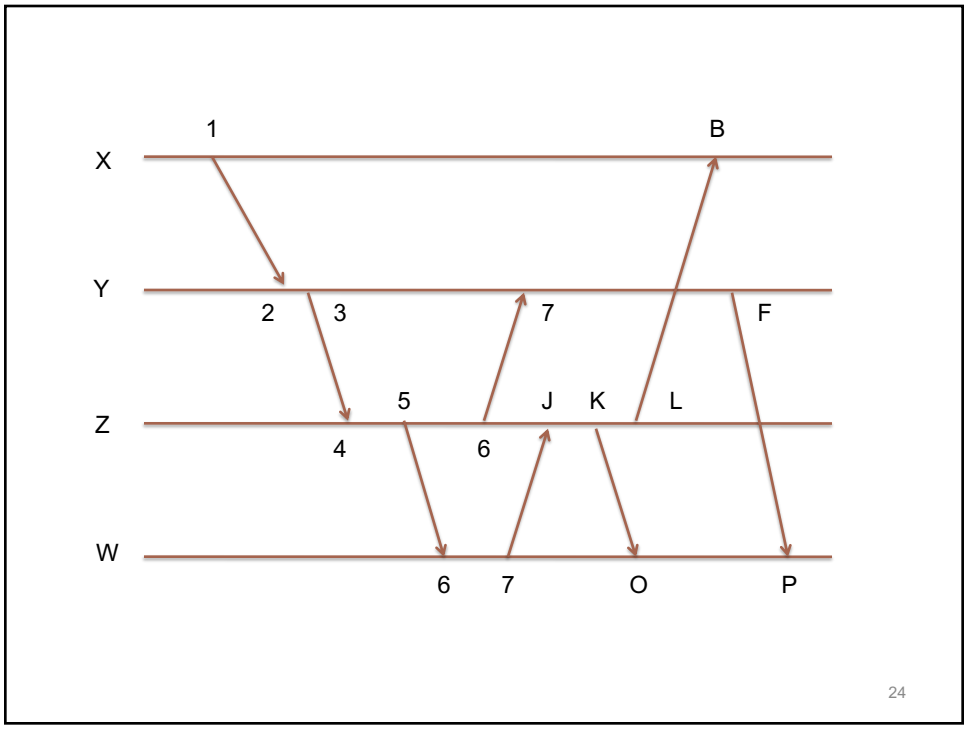

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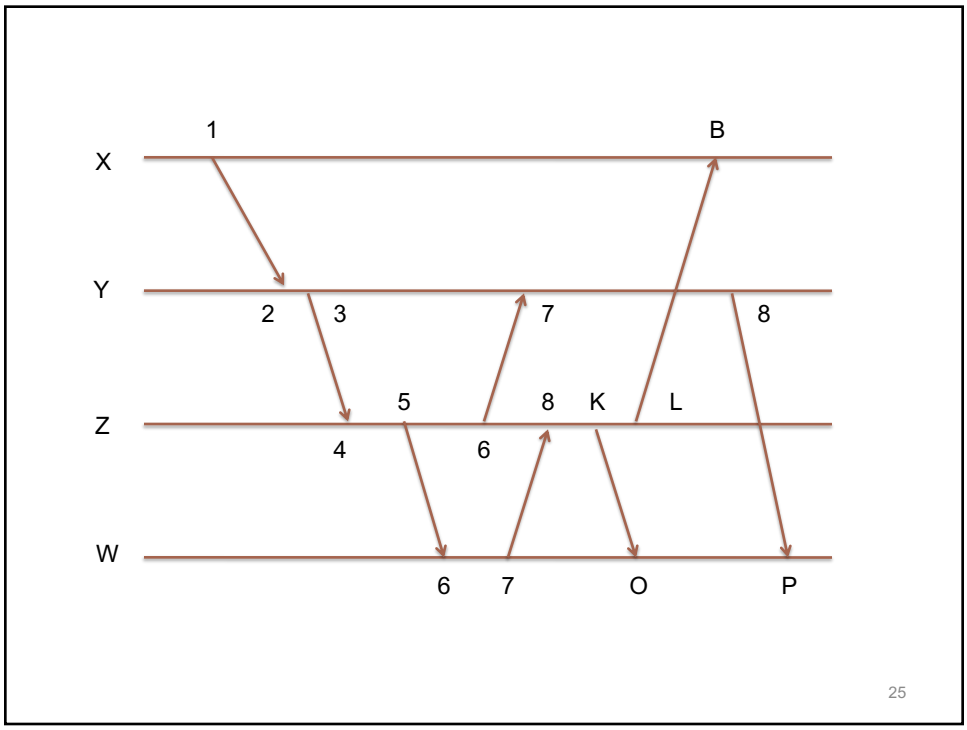

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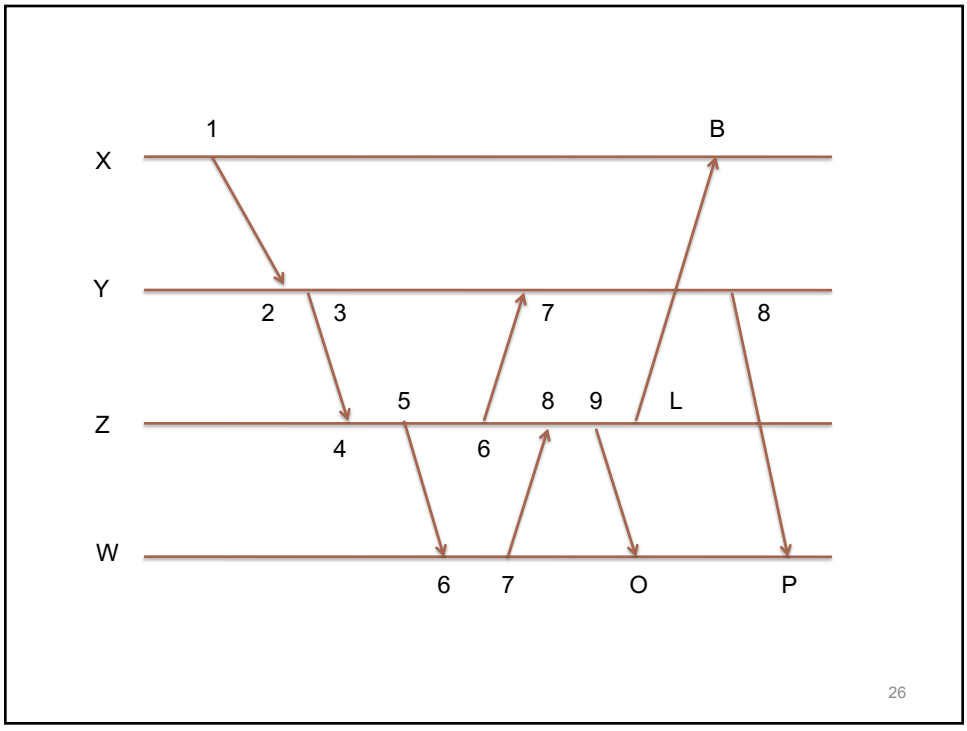

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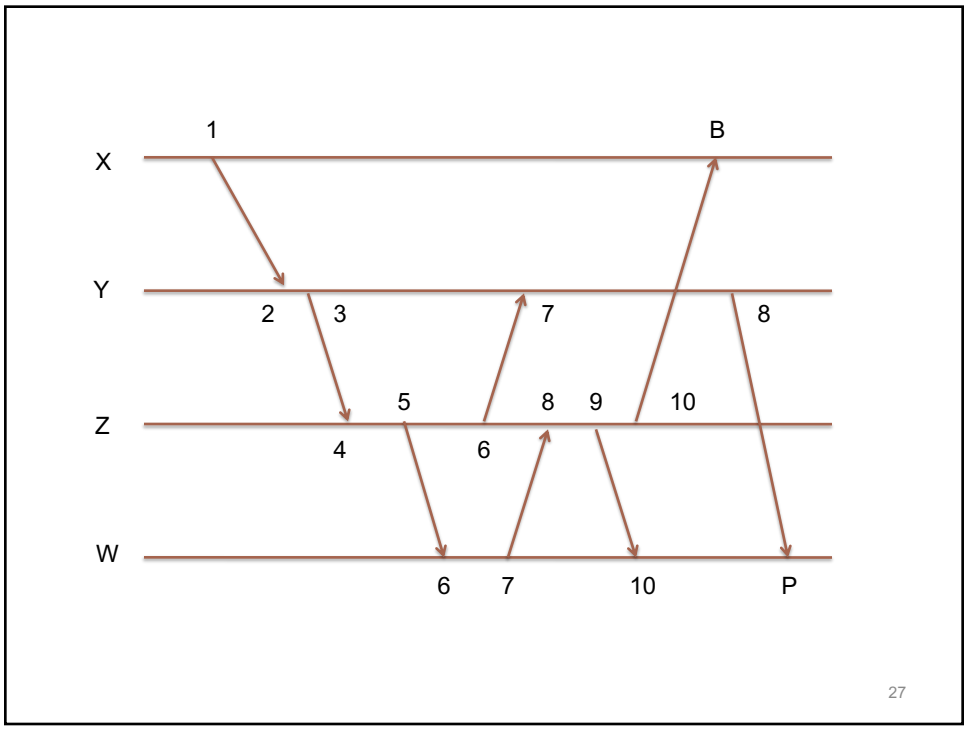
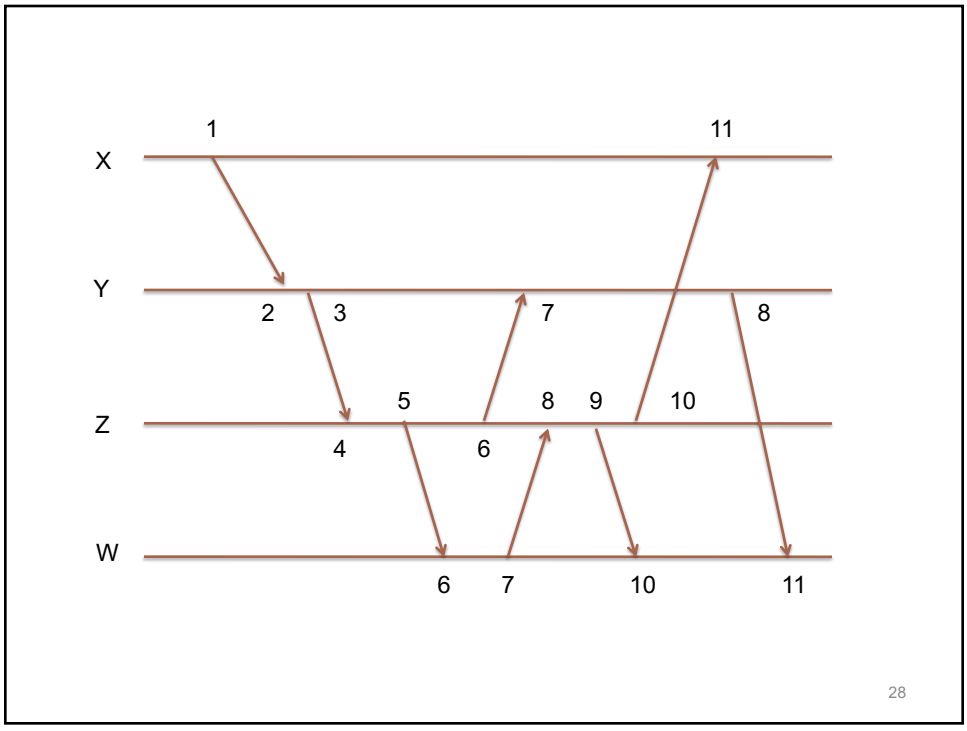

1
B
X
Y
2
3
7
8
5
8
9
10
Z
4
6
W
6
7
10
P
27

27


1
11
X
Y
2
3
7
8
5
8
9
10
Z
4
6
W
6
7
10
11
28

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DISTRIBUTED MUTUAL EXCLUSION

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Distributed Mutual Exclusion

- Idea: purely distributed protocol for mutually exclusive access to a resource
  - No central coordinator

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Distributed Mutual Exclusion

- Idea: purely distributed protocol for mutually exclusive access to a resource
  - No central coordinator
- Requests are ordered using logical time
  - Use (ts, pid) with pid to break ties
  - (m, p) < (n, q) if m < n or (m = n and p < q)

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Distributed Mutual Exclusion

- Idea: purely distributed protocol for mutually exclusive access to a resource
  - No central coordinator
- Requests are ordered using logical time
  - Use (ts, pid) with pid to break ties
  - (m, p) < (n, q) if m < n or (m = n and p < q)
- Data structures
  - Logical time LT_p
  - Request queue, ordered by request timestamp
  - LT[i], timestamp of last message received from process p_i

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Request a Resource

- Process p_i
  - Increments its logical clock
  - Adds request m (TS(m)=LT_i) to its request queue
  - Broadcasts request to every other process

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- Process p_j ($j \neq i$)
  - Acknowledges receipt of request (TS(ack)=LT_j)

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Request a Resource

- Process p_i
  - Increments its logical clock
  - Adds request m (TS(m)=LT_i) to its request queue
  - Broadcasts request to every other process
- Process p_j ($j \neq i$)
  - Acknowledges receipt of request (TS(ack)=LT_j)
- Process pi has access when:
  - Its request is in the front of its request queue
  - LT[i] $\geq$ TS(m) for all i=1,…,n

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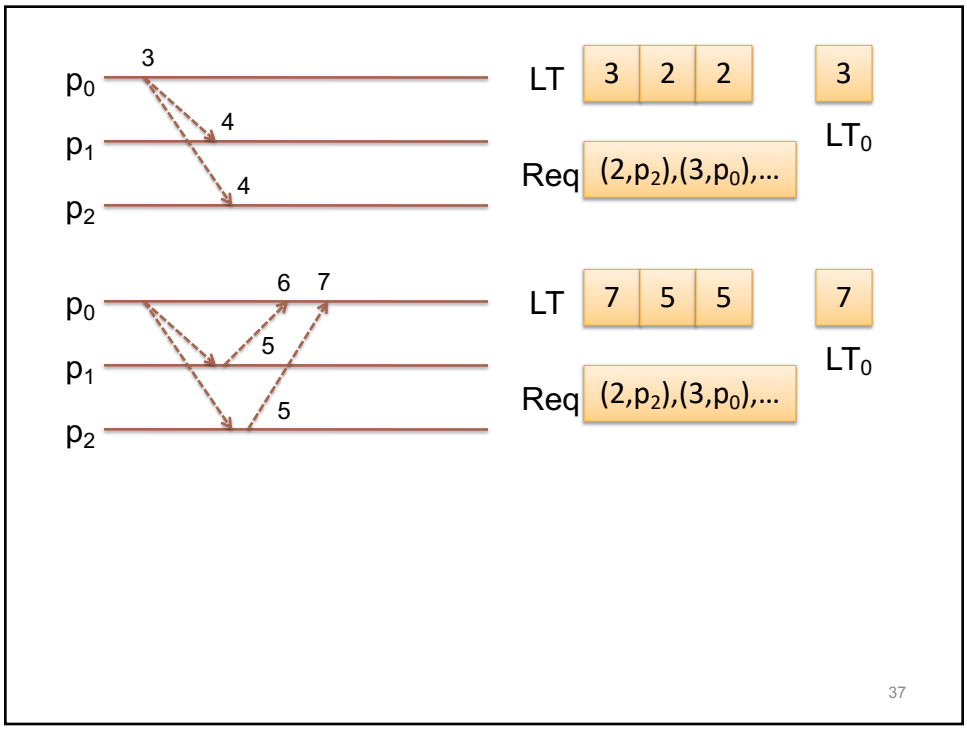
p0
p1
p2
3
4
4
LT
3 2 2
3
LT0
Req
(2,p2),(3,p0),...
6 7
5
5
LT
7 5 5
7
LT0
Req
(2,p2),(3,p0),...
37

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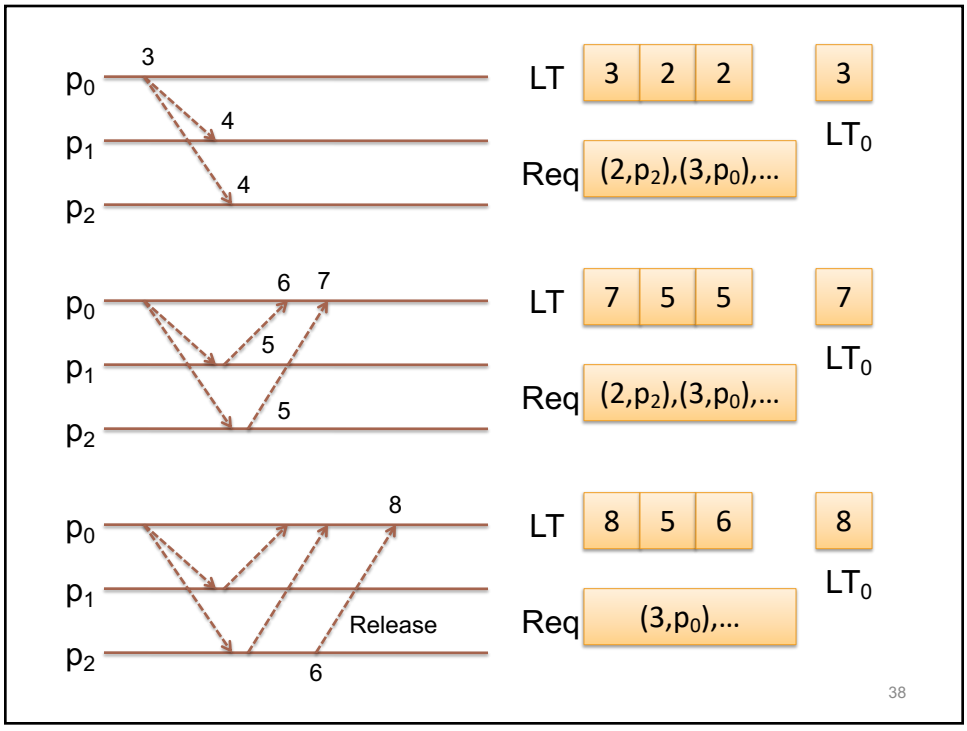
p0
p1
p2
3
4
4
LT
3 2 2
3
LT0
Req
(2,p2),(3,p0),...
6 7
5
5
LT
7 5 5
7
LT0
Req
(2,p2),(3,p0),...
8
Release
6
LT
8 5 6
8
LT0
Req
(3,p0),...
38

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