Multicast for coordination

Marco Aiello

based on cdk5.net

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    - *delivery guarantees* e.g. can't make a guarantee if multicast is implemented as multiple sends and the sender fails. Can also do ordering

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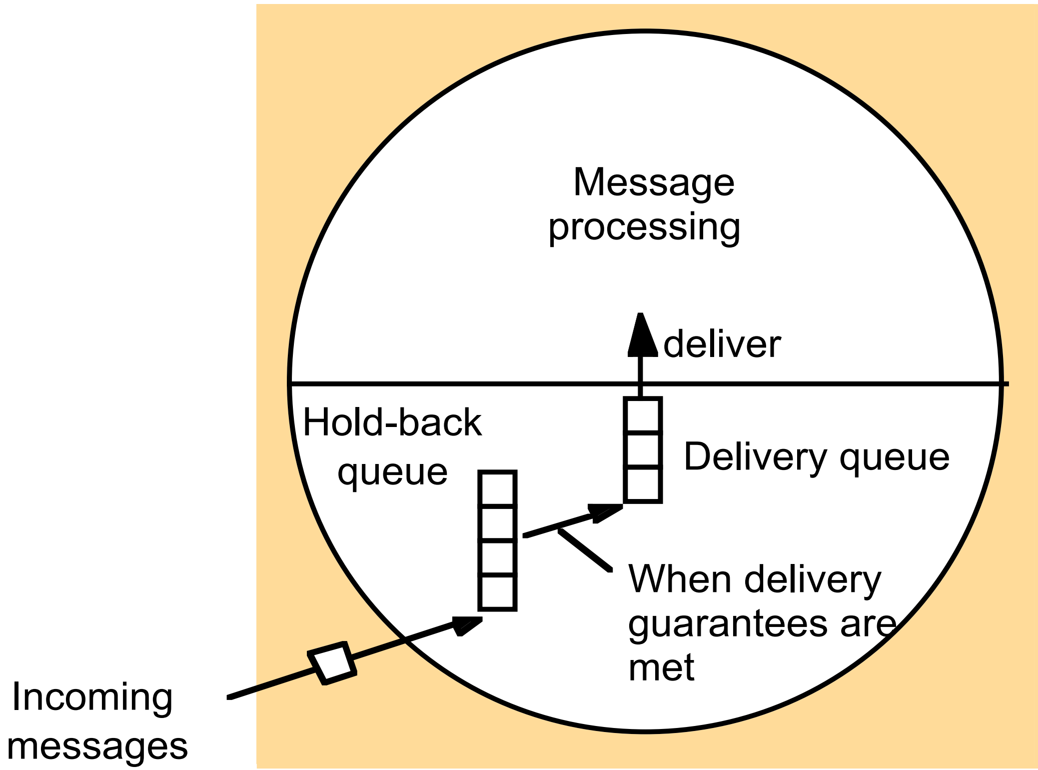
  - IP packets may not arrive in sender order, group members can receive messages in different orders

The hold-back queue for arriving multicast messages



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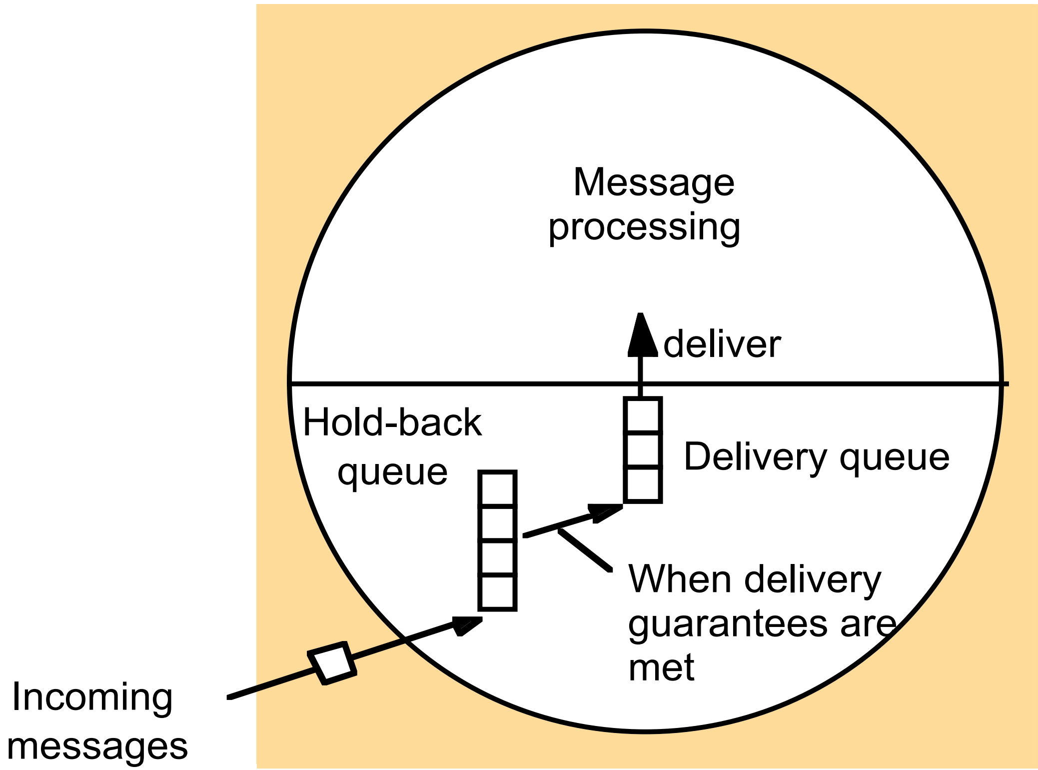

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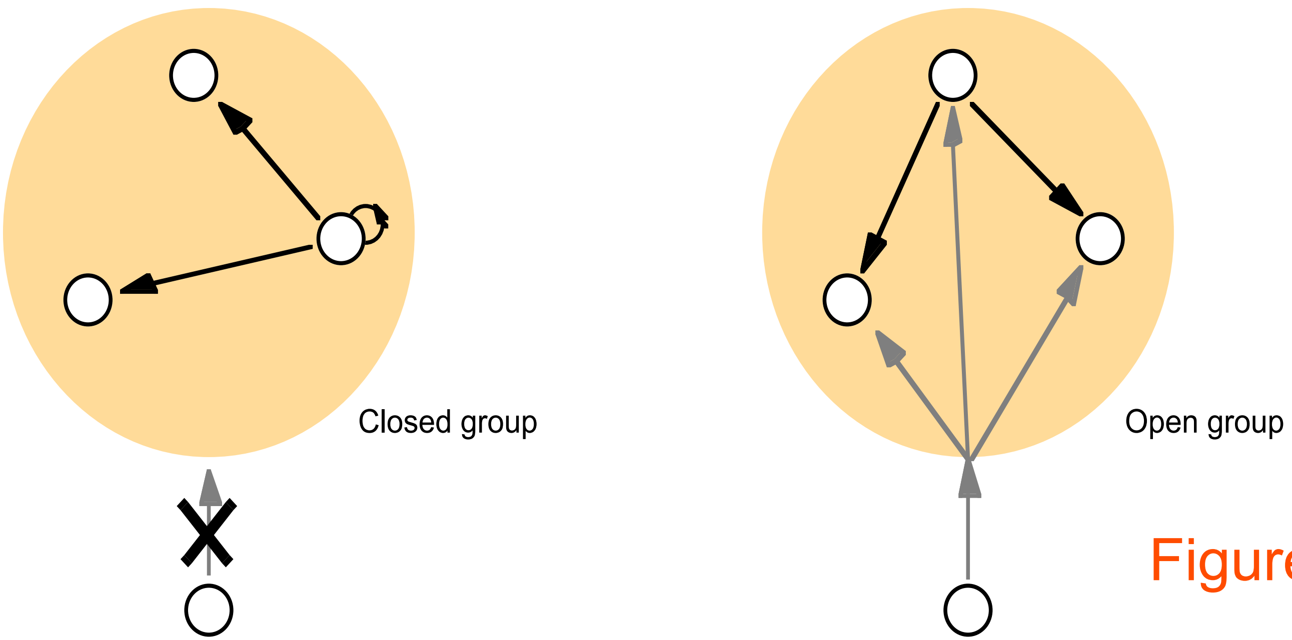
- We assume there is no falsification of the origin and destination of messages

Open and closed groups



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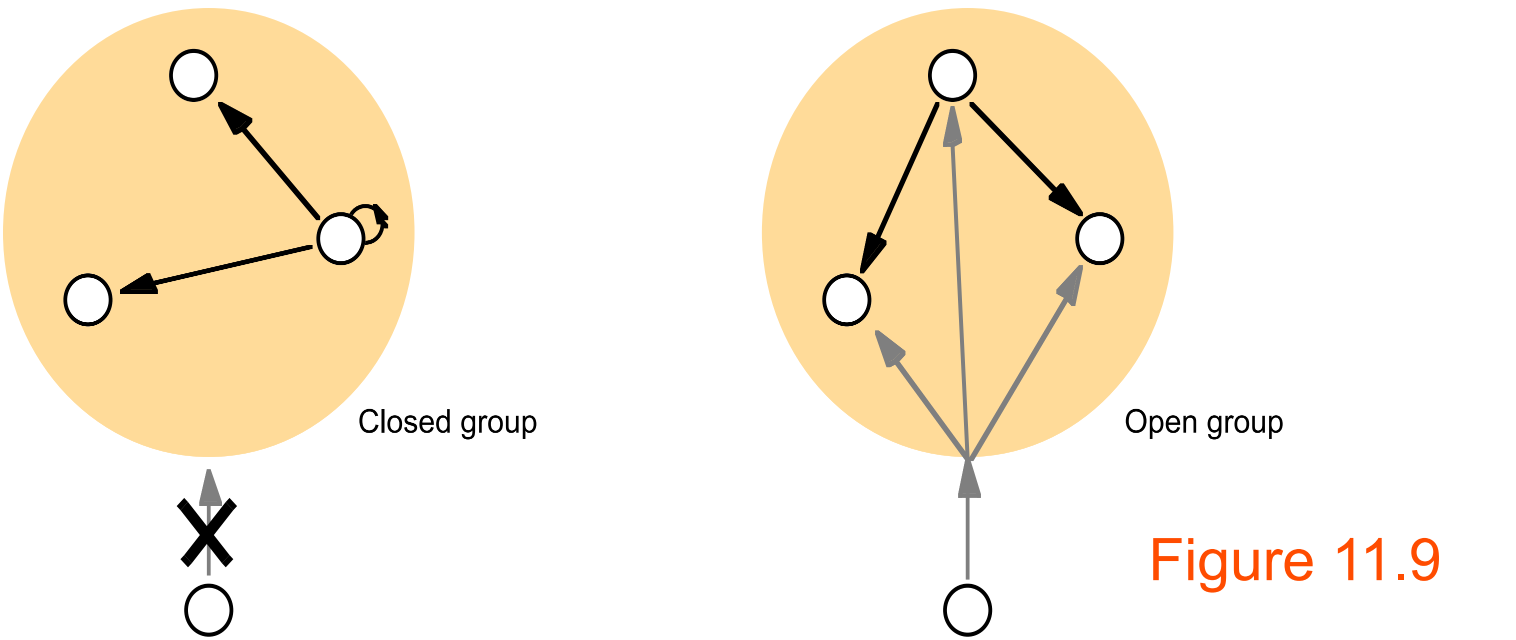

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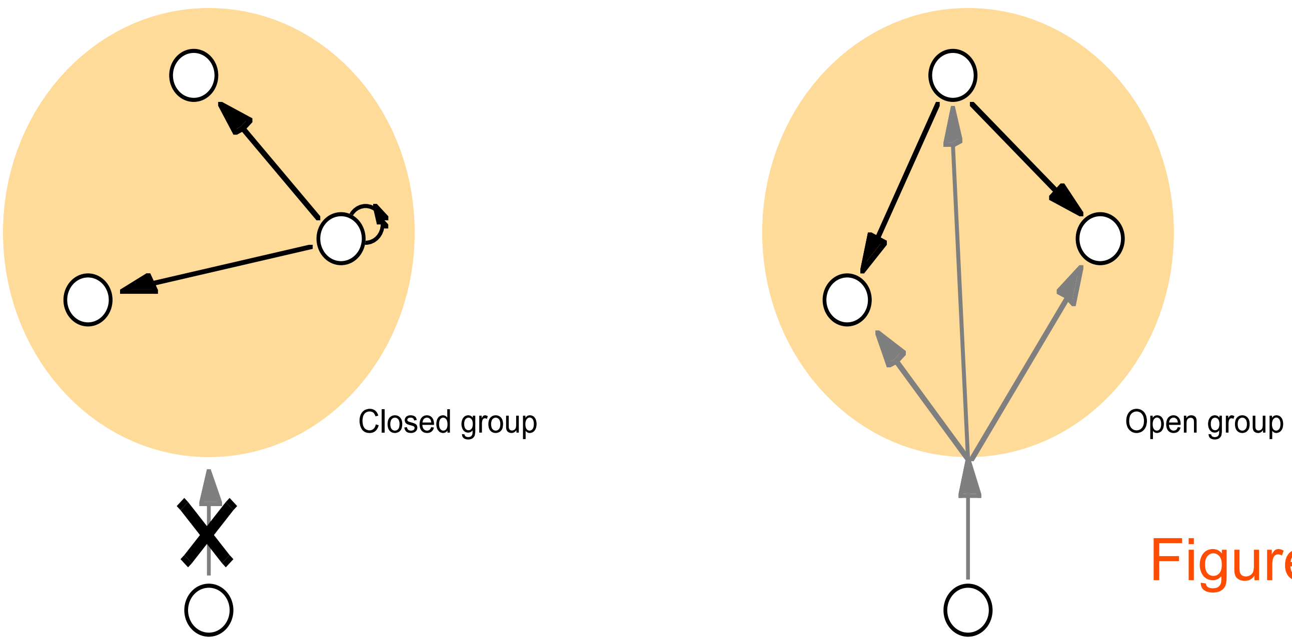

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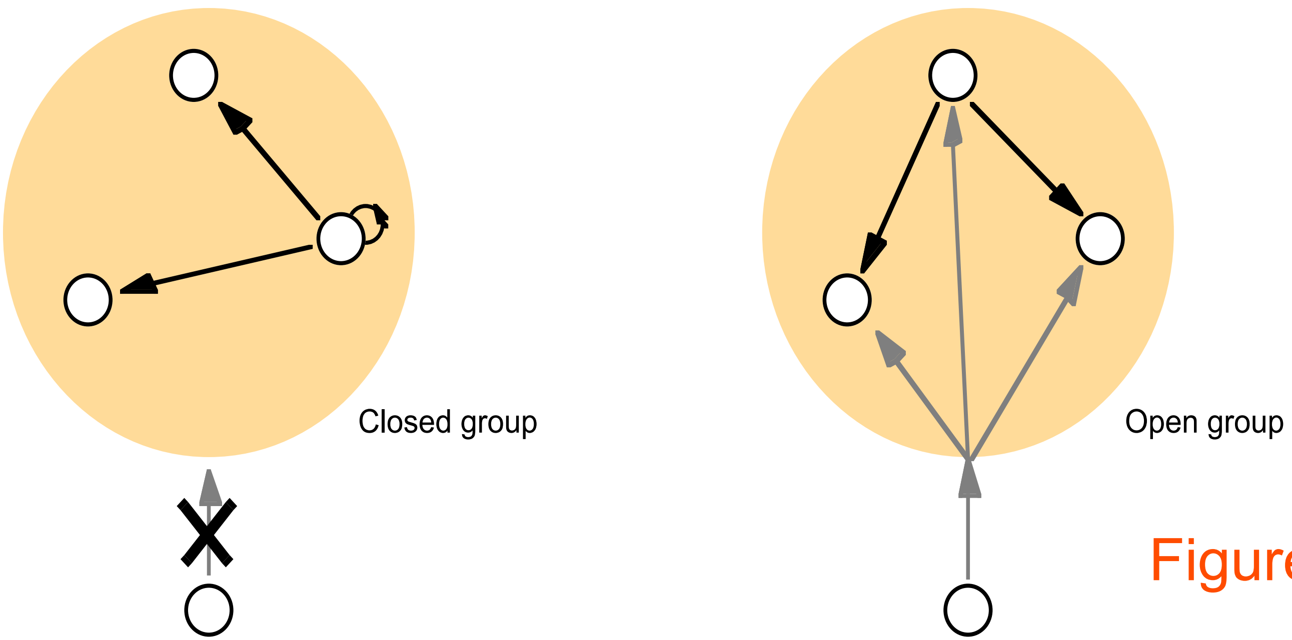

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- *by* use checksums, reject duplicates (e.g. due to retries).
- If considering malicious users in the system model, use security techniques

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A practical implementation of Basic Multicast may be achieved over IP multicast (on next slide, but not shown)

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- If the sender crashes, then a message may be delivered to some members of the group but not others.

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validity - simplify by choosing sender as the one process

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- *Agreement* - if a correct process delivers *m* then all correct processes in *group*(*m*) will eventually deliver *m*

integrity as for 1-1 communication

validity - simplify by choosing sender as the one process

agreement - all or nothing - atomicity, even if multicaster crashes

Reliable multicast algorithm over basic multicast

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On initialization
  Received := {};

For process p to R-multicast message m to group g
  B-multicast(g, m);   // $p \in g$ is included as a destination

On B-deliver(m) at process q with g = group(m)
  if ($m \notin$ *Received*)
  then
    Received := *Received* $\cup$ {*m*};
    if ($q \neq p$) *then B-multicast(g, m); end if*
    R-deliver m;
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Validity - a correct process will B-deliver to itself

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Integrity - because the reliable 1-1 channels used for *B-multicast* guarantee integrity

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What can you say about the performance of this algorithm?

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Is this algorithm correct in an asynchronous system? algorithm?

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Reliable multicast can be implemented efficiently over IP multicast by holding back messages until every member can receive them. We skip that.

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  - ◆then it has missed messages and requests them with negative acknowledgements
  - ◆puts new message in hold-back queue for later delivery

The hold-back queue for arriving multicast messages

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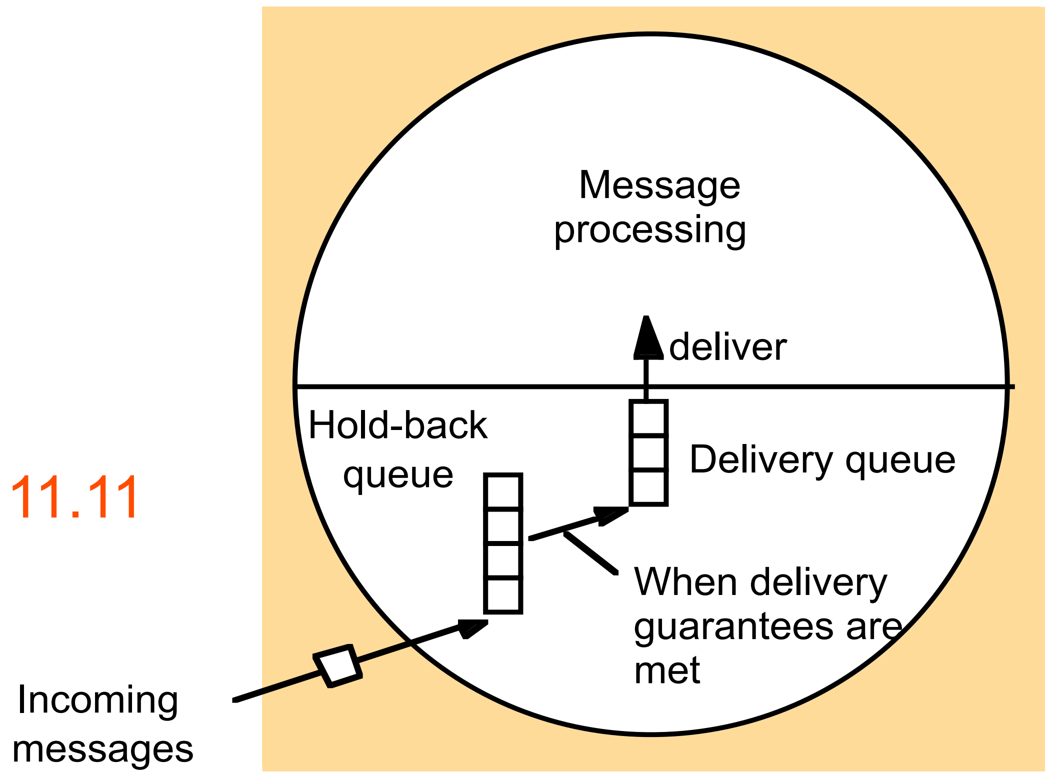
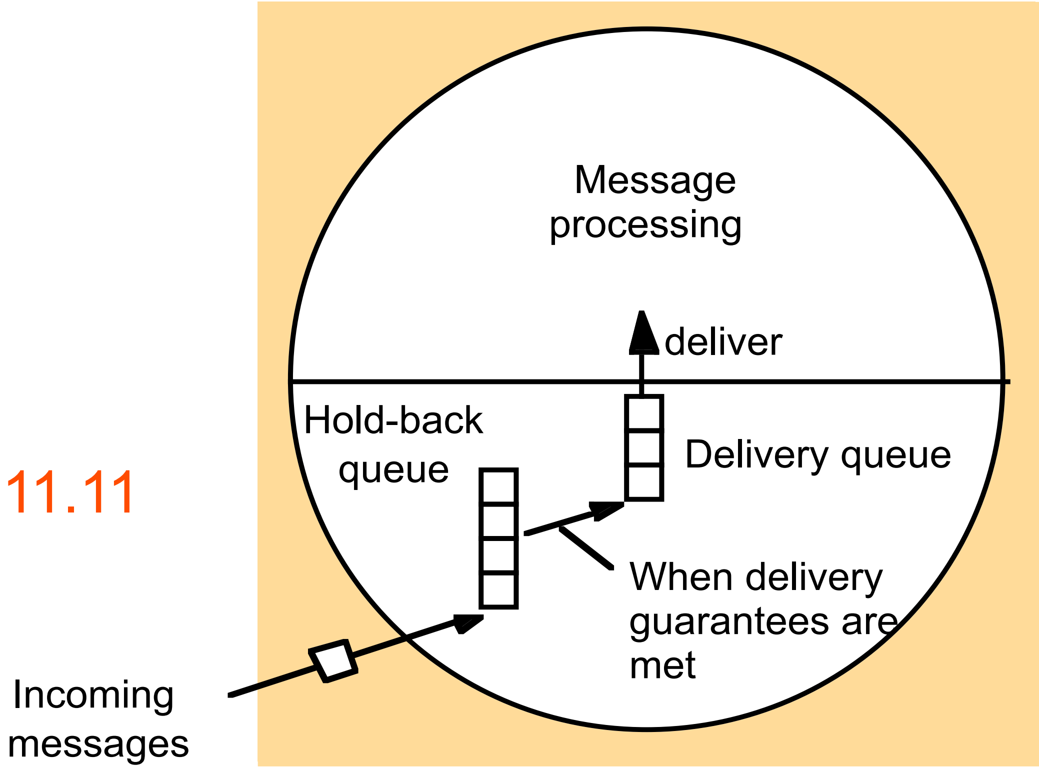
Figure 11.11



The hold-back queue for arriving multicast messages

- The hold back queue is not necessary for reliability as in the implementation using IP muilticast, but it simplifies the protocol, allowing sequence numbers to represent sets of messages. Hold-back queues are also used for ordering protocols.

Figure 11.11



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- *Agreement* - processes can detect missing messages. They must keep copies of messages they have delivered so that they can re-transmit them to others.
- discarding of copies of messages that are no longer needed :
  - when piggybacked acknowledgements arrive, note which processes have received messages. When all processes in *g* have the message, discard it.
  - problem of a process that stops sending - use ‘heartbeat’ messages.

Ordered multicast

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- Total ordering
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- Total ordering
  - If a correct process delivers message *m* before it delivers *m'*, then any other correct process that delivers *m'* will deliver *m* before *m'*.
- Ordering is expensive in delivery latency and bandwidth consumption

Total, FIFO and causal ordering of multicast messages

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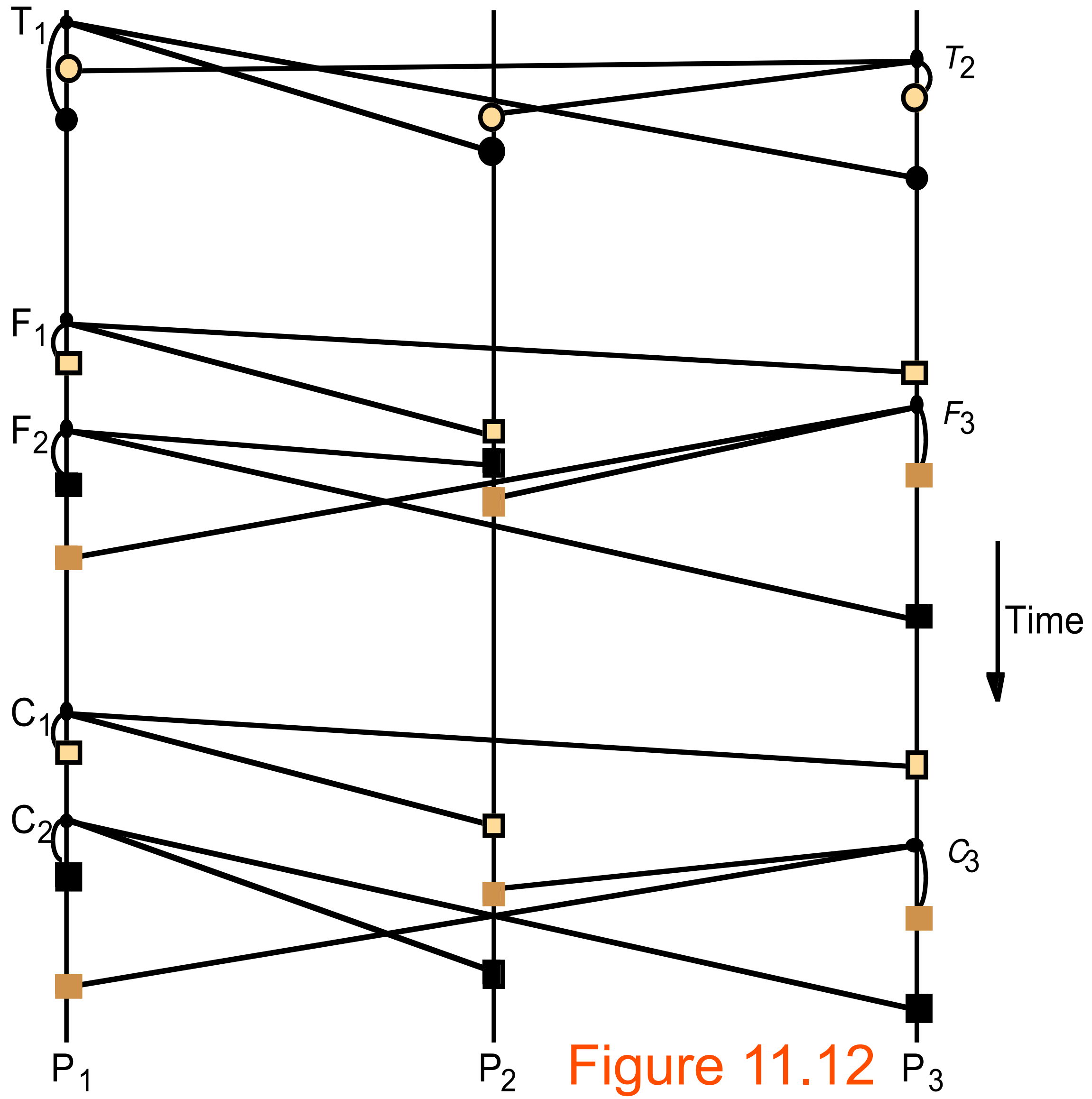
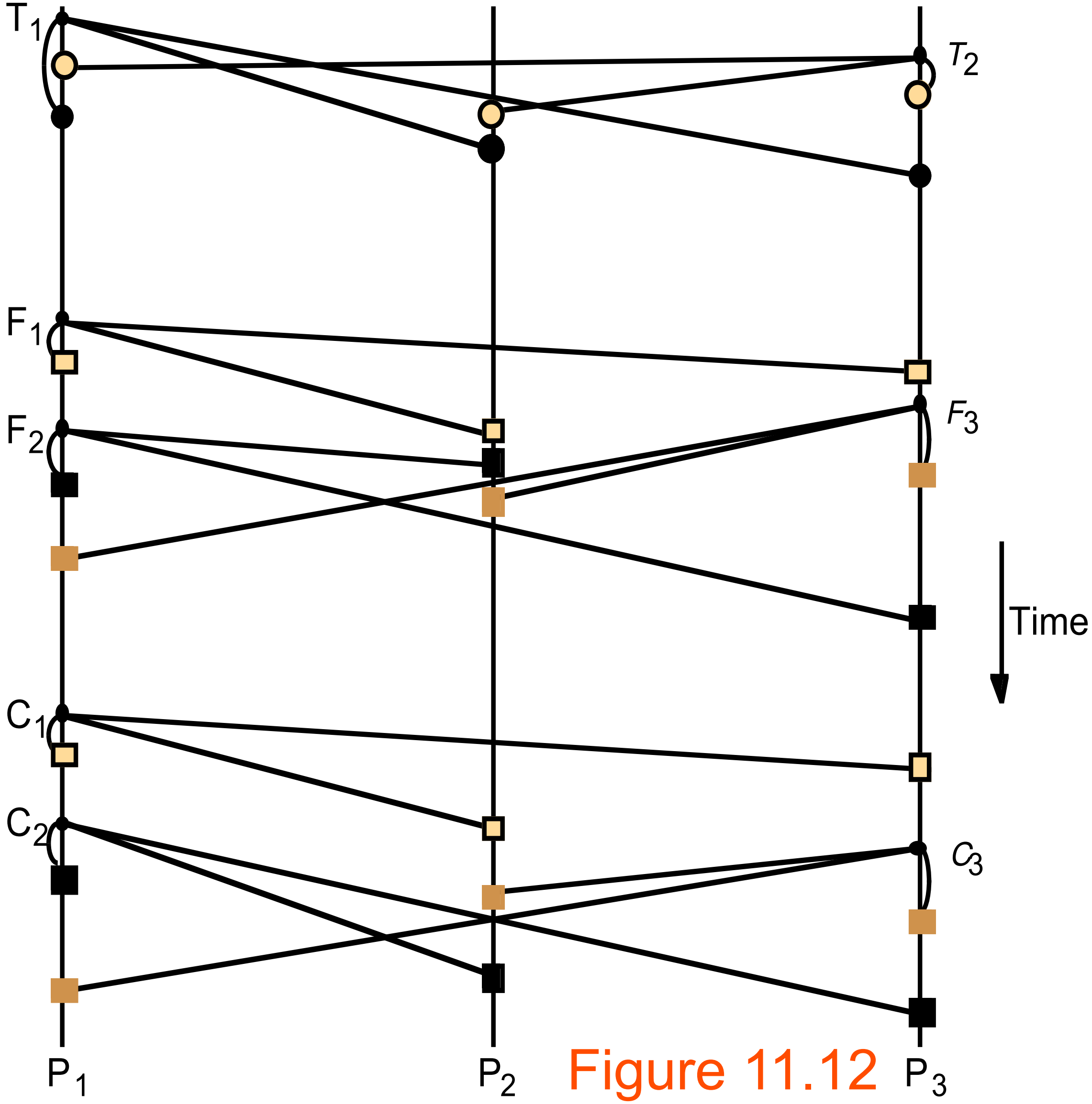


Figure 11.12

Total, FIFO and causal ordering of multicast messages

Notice the consistent ordering of totally ordered messages T_1 and T_2.
They are opposite to real time.
The order can be arbitrary it need not be FIFO or causal



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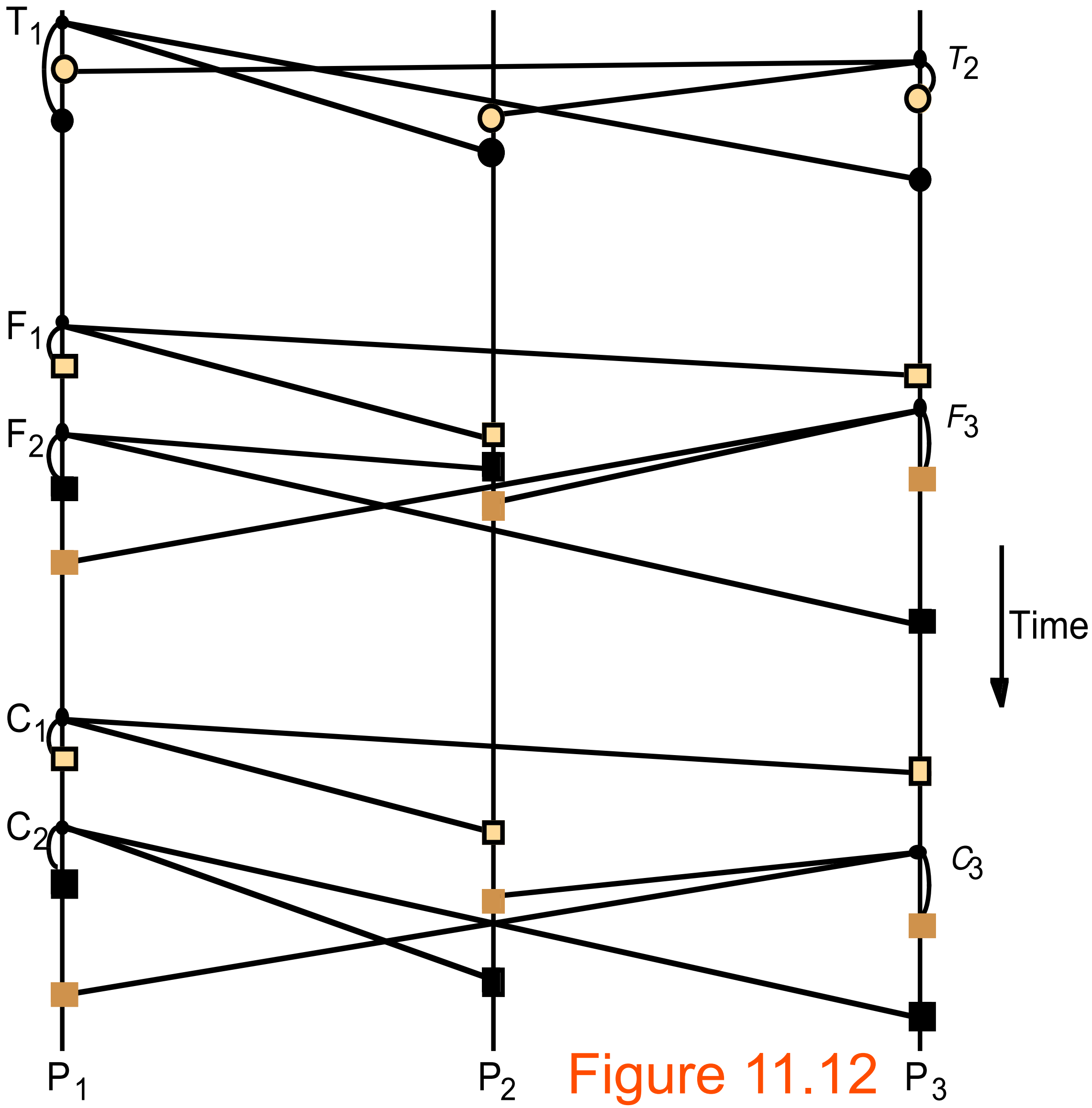

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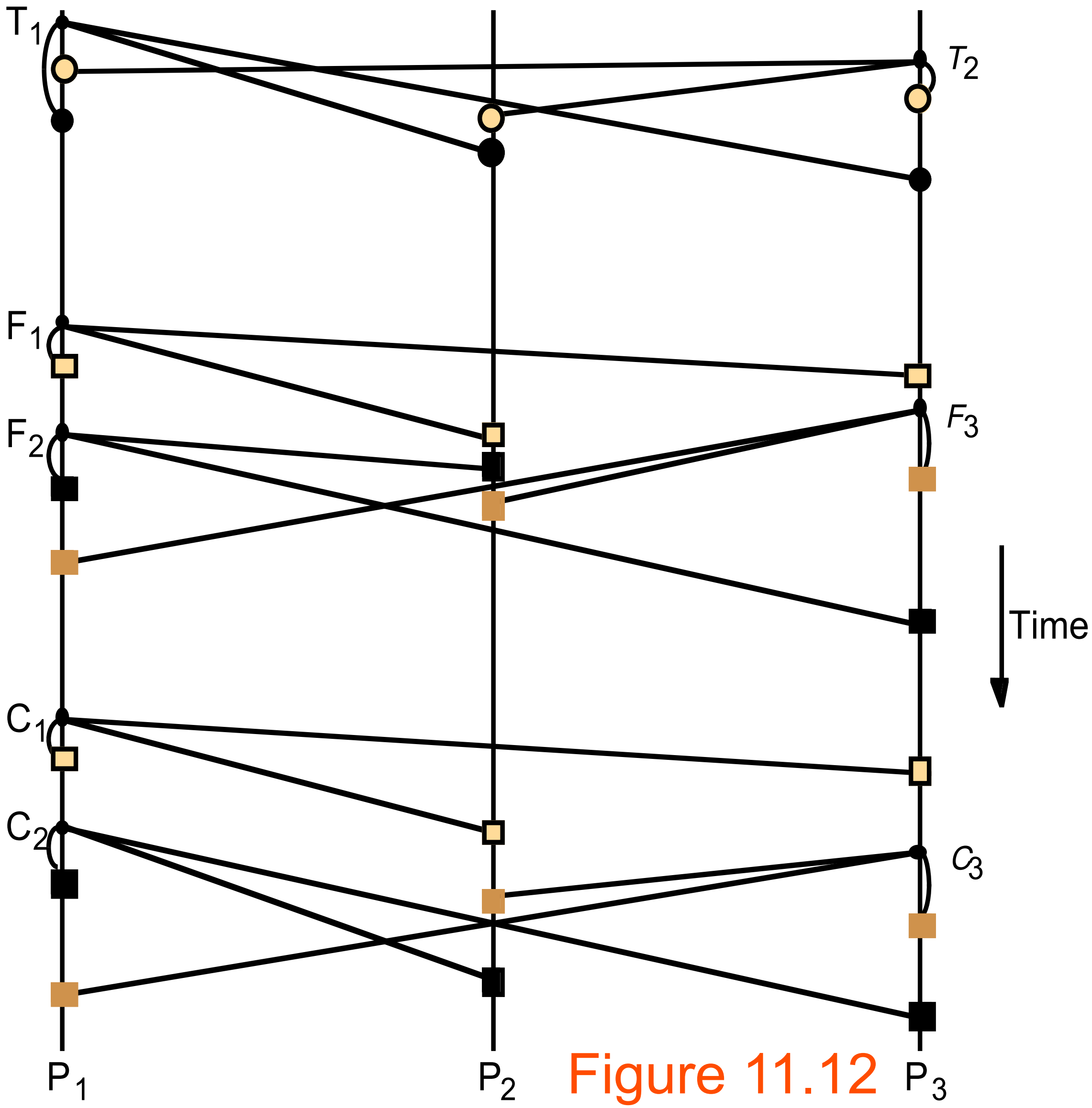

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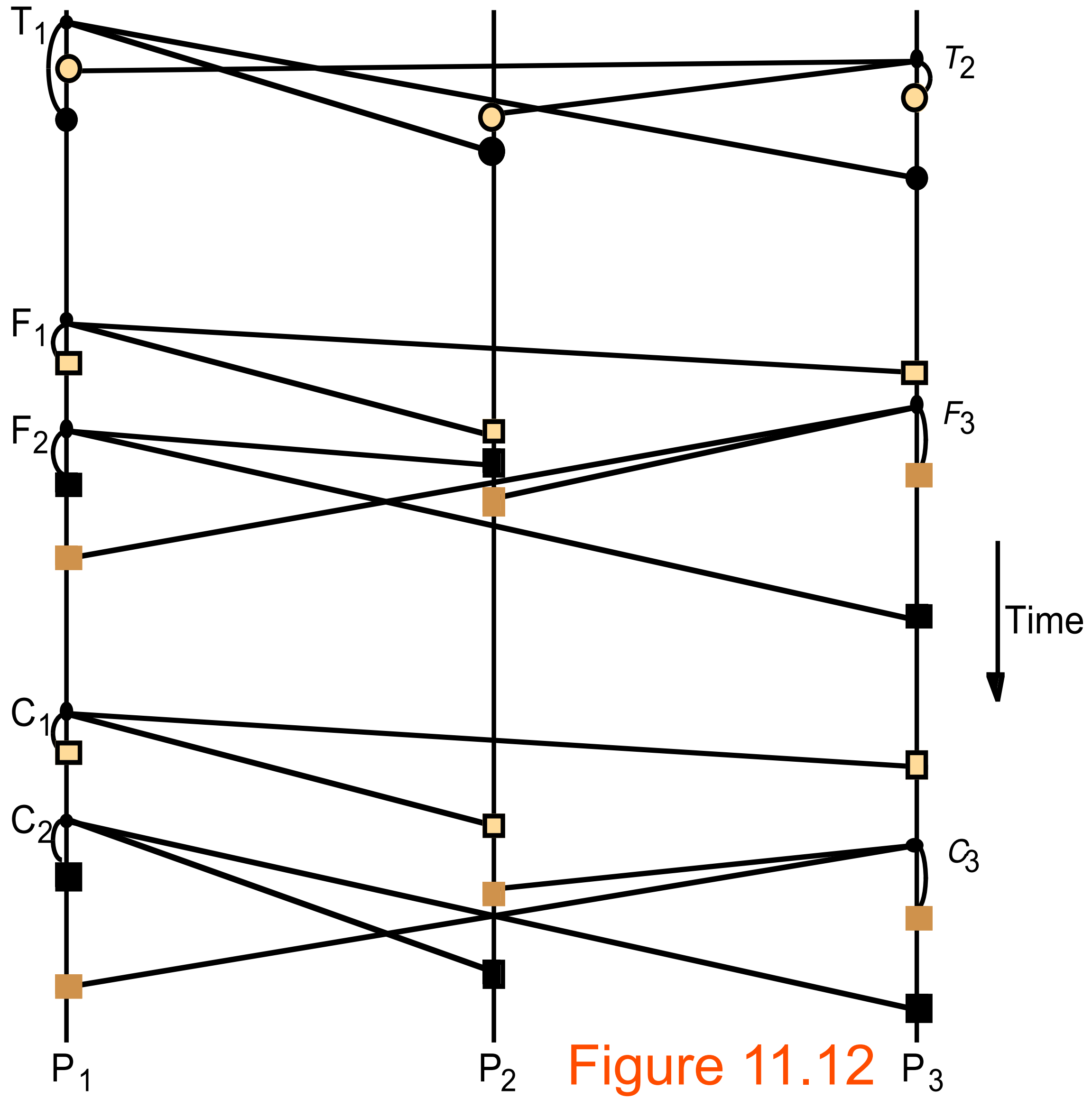

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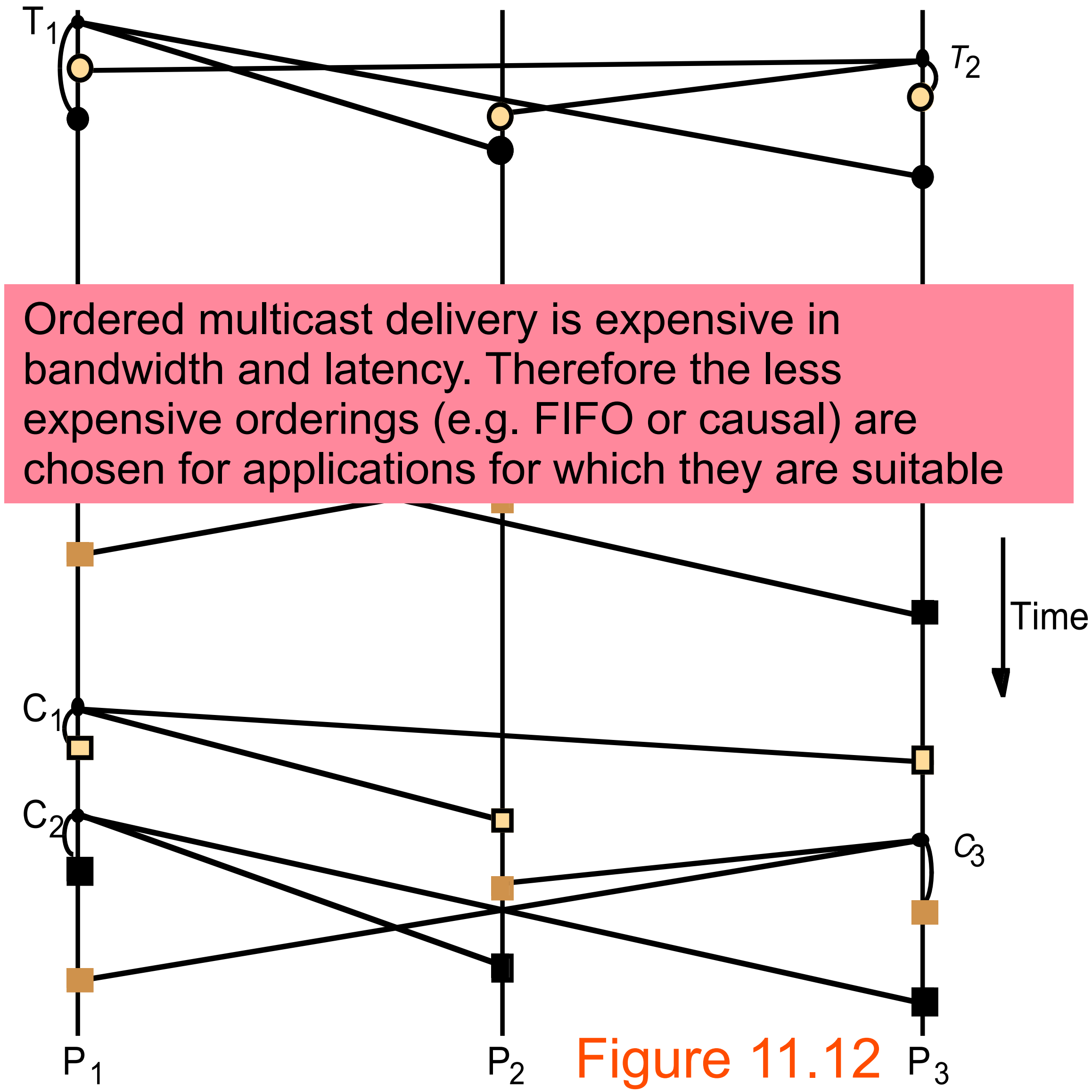

Ordered multicast delivery is expensive in bandwidth and latency. Therefore the less expensive orderings (e.g. FIFO or causal) are chosen for applications for which they are suitable

Figure 11.12

Display from a bulletin board program

Display from a bulletin board program

Bulletin board: os.interesting		
Item	From	Subject
23	A.Hanlon	Mach
24	G.Joseph	Microkernels
25	A.Hanlon	Re: Microkernels
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causal (makes replies come after original message)

FIFO (gives sender order

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- Users run bulletin board applications which multicast messages
- One multicast group per topic (e.g. *os.interesting*)
- Require reliable multicast - so that all members receive messages
- Ordering:

total (makes the numbers the same at all sites)

Bulletin board: os.interesting		
Item	From	Subject
23	A.Hanlon	Mach
24	G.Joseph	Microkernels
25	A.Hanlon	Re: Microkernels
26	T.L'Heureux	RPC performance
27	M.Walker	Re: Mach
end		

causal (makes replies come after original message)

FIFO (gives sender order

Figure 11.13

•

Implementation of FIFO ordering over basic multicast

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- On receipt of a message from *q* with sequence number *S*, *p* checks whether $S = R^q_g + 1$. If so, it *FO-delivers* it.
- if $S > R^q_g + 1$ then *p* places message in hold-back queue until intervening messages have been delivered. (note that *B-multicast* does eventually deliver messages unless the sender crashes)

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  1. using a sequencer (only for non-overlapping groups)
  2. the processes in a group collectively agree on a sequence number for each message

Total ordering using a sequencer

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1. Algorithm for group member p

On initialization: $r_g := 0$;

To TO-multicast message m to group g
B-multicast$(g \cup \{sequencer(g)\}, <m, i>)$;

On B-deliver$(<m, i>)$ *with* $g = group(m)$
Place $<m, i>$ in hold-back queue;

On B-deliver$(m_{order} = <\text{"order"}, i, S>)$ *with* $g = group(m_{order})$
wait until $<m, i>$ in hold-back queue and $S = r_g$;
TO-deliver m; // (after deleting it from the hold-back queue)
$r_g = S + 1$;

2. Algorithm for sequencer of g

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B-deliver order message, get *g* and *S* and *i* from order message
wait till <*m,i*> in queue and $S = r_g$,
TO-deliver *m* and set r_g to S+1

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  B-multicast(*g*, <"order", *i*, s_g>);
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Kaashoek's protocol uses hardware-based multicast

The sender transmits one message to sequencer, then

the sequencer multicasts the sequence number and the message

but IP multicast is not as reliable as B-multicast so the sequencer stores messages in its history buffer for retransmission on request

members notice messages are missing by inspecting sequence numbers

What can the sequencer do about its history buffer becoming full?

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Members piggyback on their messages the latest sequence number they have seen

full?

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What happens when some member stops multicasting?

full?

seen

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Members that do not multicast send heartbeat messages (with a sequence number)

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The ISIS algorithm for total ordering

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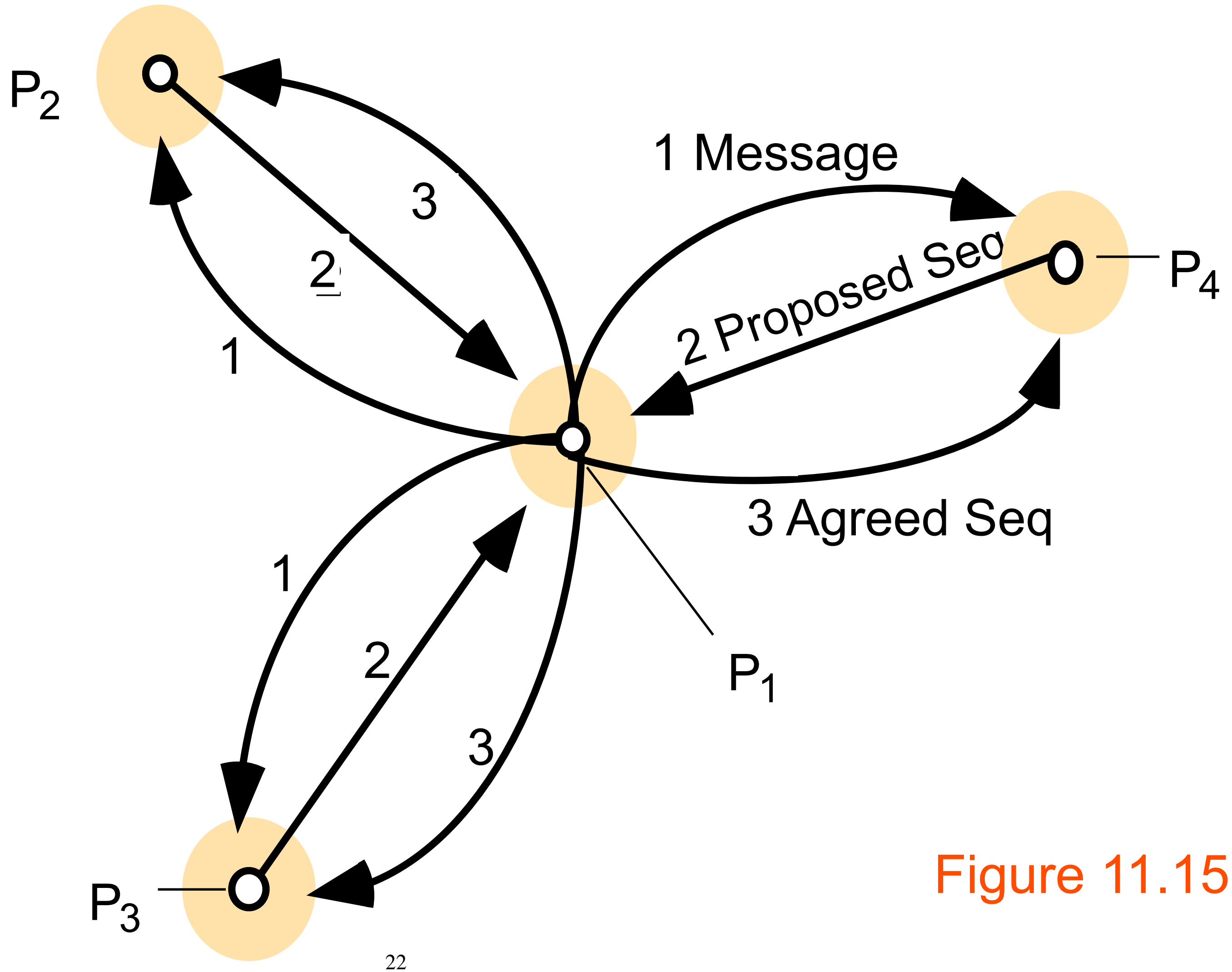
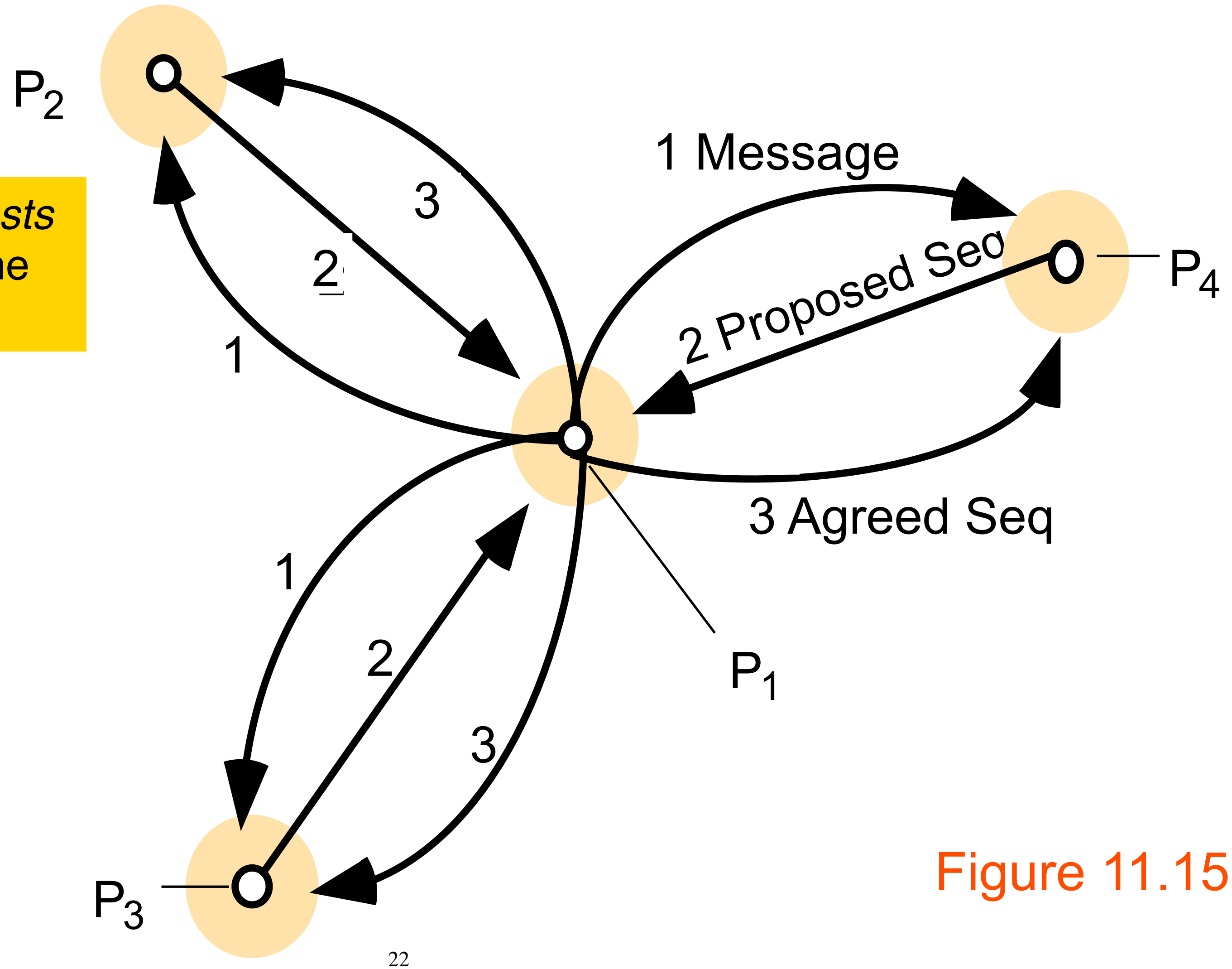


Figure 11.15

The ISIS algorithm for total ordering

1. the process *P1 B-multicasts* a message to members of the group



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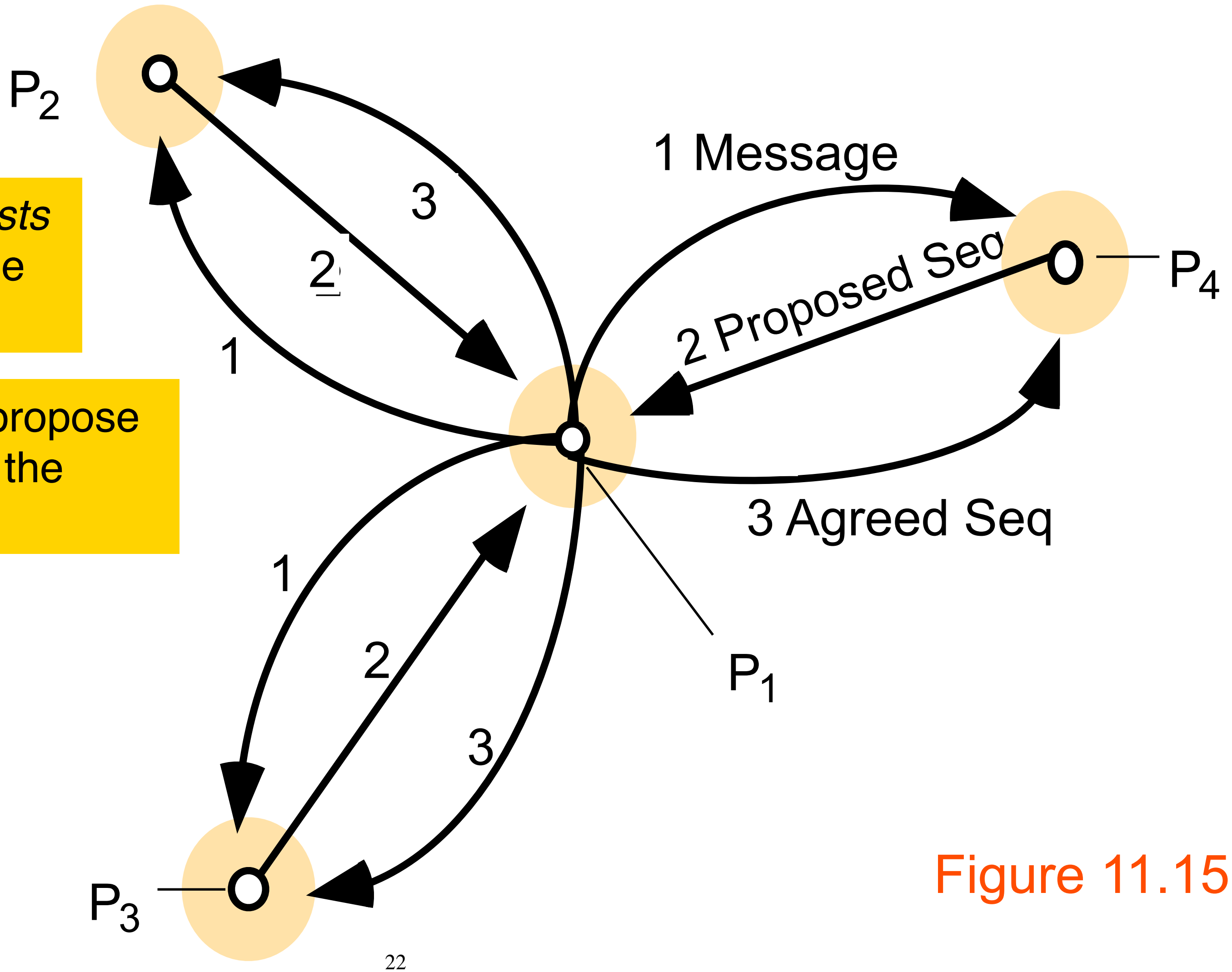

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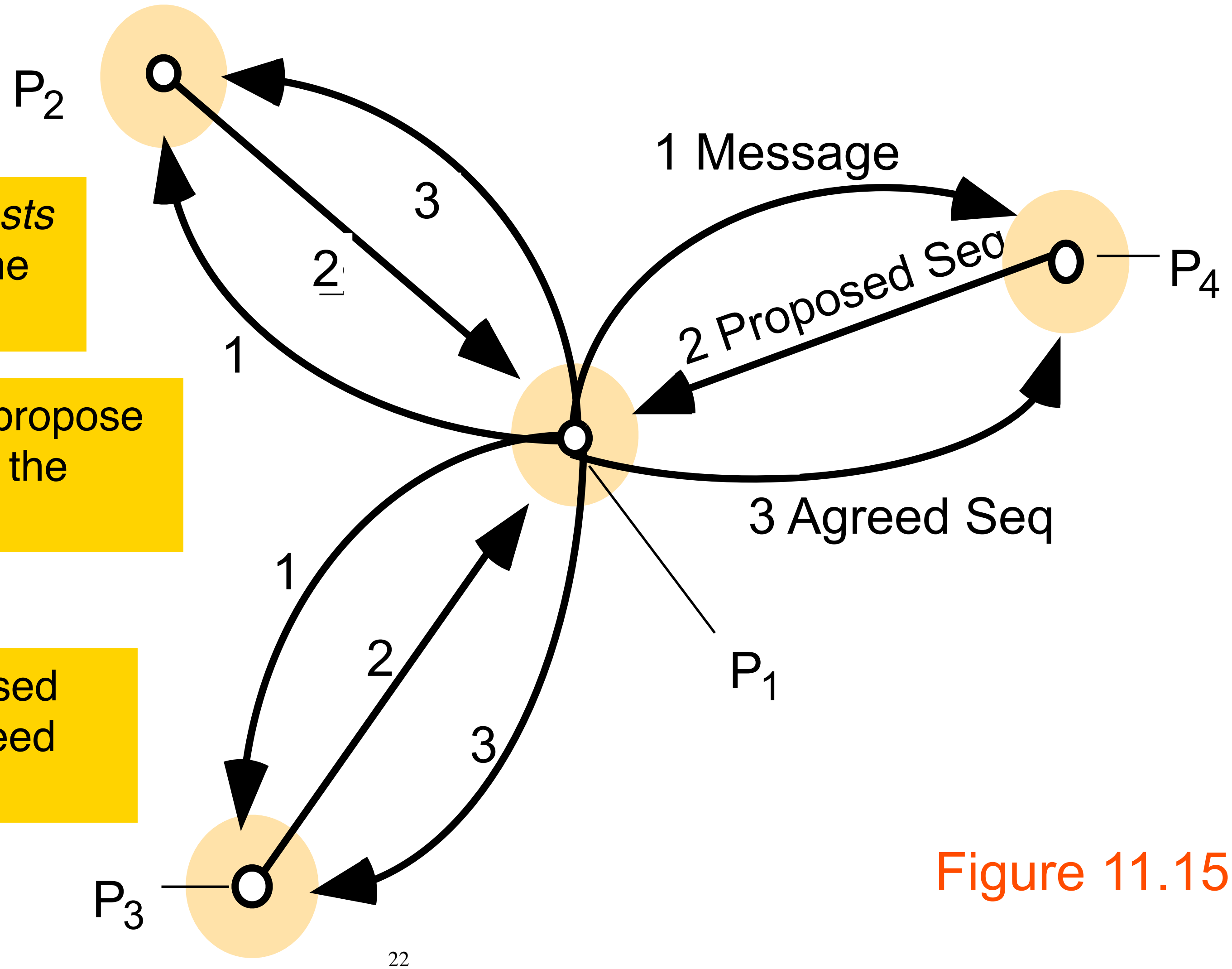

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The ISIS algorithm for total ordering

- this protocol is for open or closed groups

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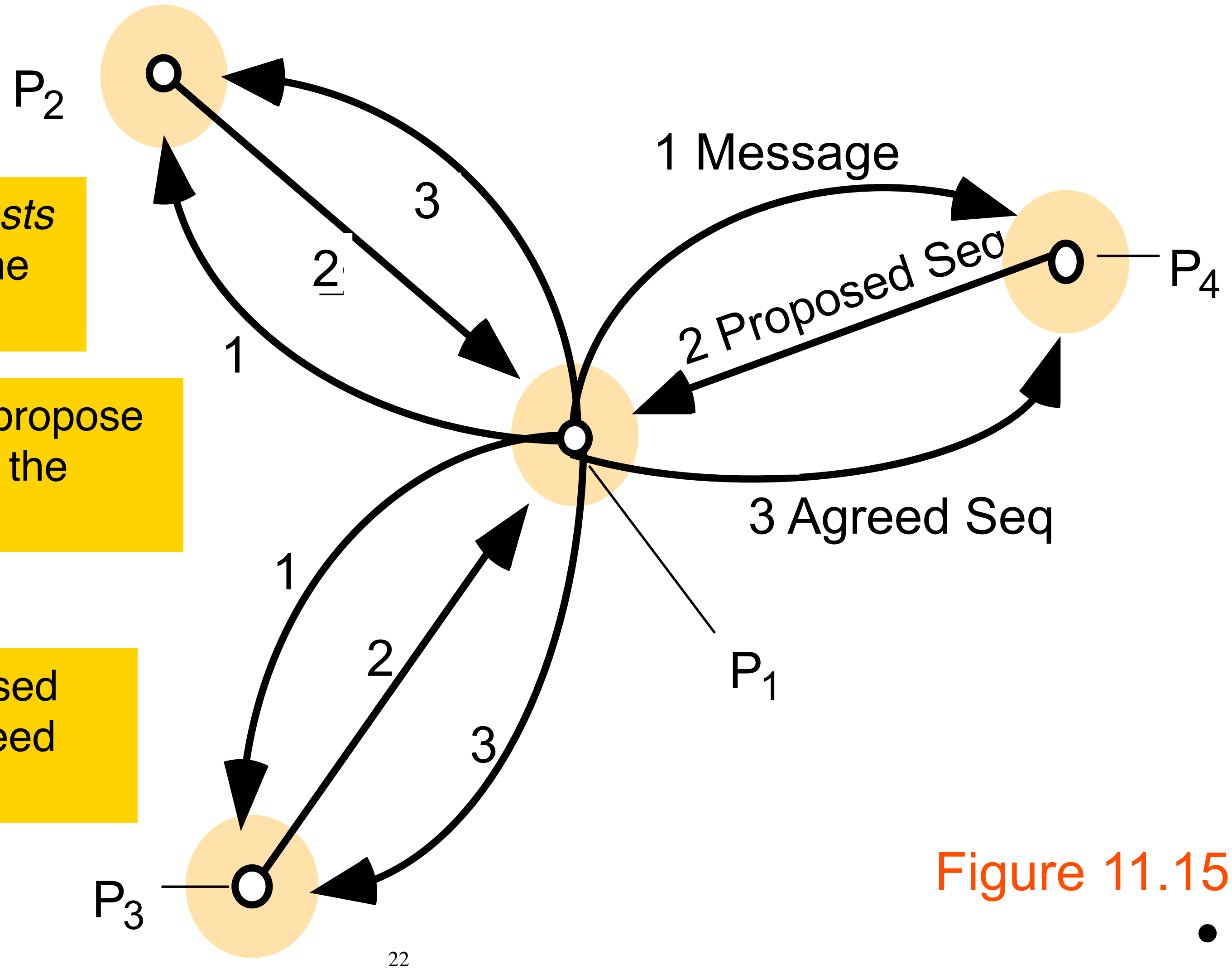

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- 3. *p* collects all the proposed sequence numbers and selects the largest as the next agreed sequence number, *a*.
  It *B-multicast*s <*i*, *a*> to *g*. Recipients set $A^q_g := \text{Max}(A^q_g, a)$, attach *a* to the message and re-order hold-back queue.

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- every process agrees on the same order and delivers messages in that order, therefore we have total ordering.
- Latency
  - 3 messages are sent in sequence, therefore it has a higher latency than sequencer method
  - this ordering may not be causal or FIFO

Causally ordered multicast

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- We present an algorithm of Birman 1991 for causally ordered multicast in non-overlapping, closed groups. It uses the *happened before* relation (on multicast messages only)
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  - that is, ordering imposed by one-to-one messages is not taken into account
- It uses vector timestamps - that count the number of multicast messages from each process that happened before the next message to be multicast

Causal ordering using vector timestamps

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Algorithm for group member p_i $(i = 1, 2..., N)$

On initialization

$V_i^g[j] := 0 \ (j = 1, 2..., N);$

To CO-multicast message m to group g

$V_i^g[i] := V_i^g[i] + 1;$

B-multicast$(g, <V_i^g, m>);$

On B-deliver$(<V_j^g, m>)$ *from* p_j, *with* $g = group(m)$

place $<V_j^g, m>$ in hold-back queue;

wait until $V_j^g[j] = V_i^g[j] + 1$ and $V_j^g[k] \le V_i^g[k] \ (k \ne j);$

CO-deliver m;   // after removing it from the hold-back queue

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Causal ordering using vector timestamps

each process has its own vector timestamp

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wait until $V_j^g[j] = V_i^g[j] + 1$ and $V_j^g[k] \le V_i^g[k] \; (k \ne j);$

CO-deliver m; // after removing it from the hold-back queue

$V_i^g[j] := V_i^g[j] + 1;$

Figure 11.16

then it CO-delivers the message and updates its timestamp

Causal ordering using vector timestamps

each process has its own vector timestamp

To *CO-multicast m* to *g*, a process adds 1 to its entry in the vector timestamp and *B-multicasts m* and the vector timestamp

Algorithm for group member p_i

On initialization

$V_i^g[j] := 0 \ (j = 1, 2 \ldots, N);$

To CO-multicast message m to gr

$V_i^g[i] := V_i^g[i] + 1;$

B-multicast$(g, <V_i^g, m>);$

When a process *B-delivers m*, it places it in a hold-back queue until messages earlier in the causal ordering have been delivered:-

a) earlier messages from same sender have been delivered

b) any messages that the sender had delivered when it sent the multicast message have been delivered

On B-deliver$(<V_j^g, m>)$ *from*

place $<V_j^g, m>$ in hold-bac

wait until $V_j^g[j] = V_i^g[j] + 1$ and $V_j^g[k] \le V_i^g[k] \ (k \ne j);$

CO-deliver m; // after removing it from the hold-back queue

$V_i^g[j] := V_i^g[j] + 1;$

Figure

then it CO-delivers the message and updates its timestamp

Note: a process can immediately *CO-deliver* to itself its own messages (not shown)

Comments

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- after delivering a message from p_j, process p_i updates its vector timestamp
  - by adding 1 to the *j*th element of its timestamp

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  - in this algorithm we know that only the jth element will increase
- for an outline of the proof see page 449
- if we use *R-multicast* instead of *B-multicast* then the protocol is reliable as well as causally ordered.
- If we combine it with the sequencer algorithm we get total and causal ordering