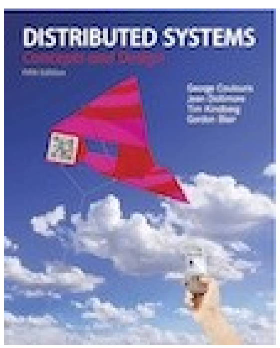
Slides for Chapter 15: Coordination and Agreement



From **Coulouris, Dollimore, Kindberg and Blair**

Distributed Systems: Concepts and Design

Figure 15.1
A network partition

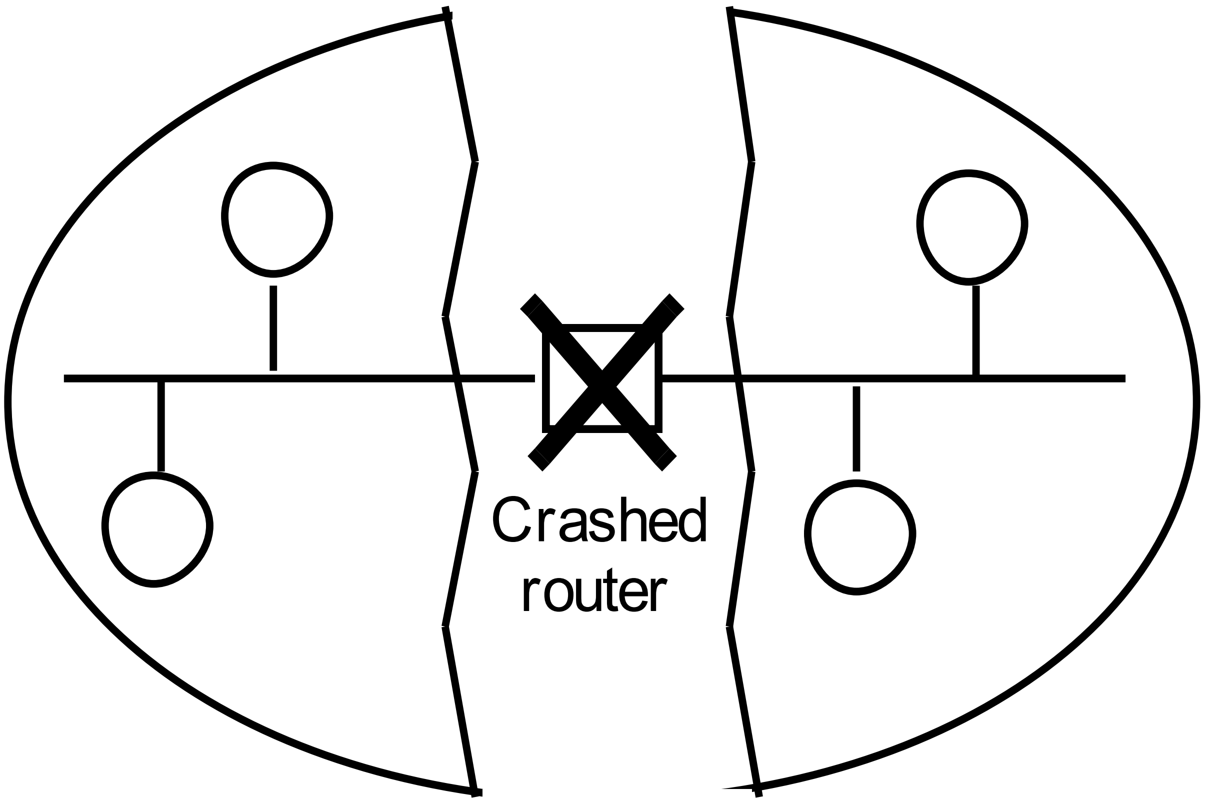


Figure 15.2
Server managing a mutual exclusion token for a set of processes

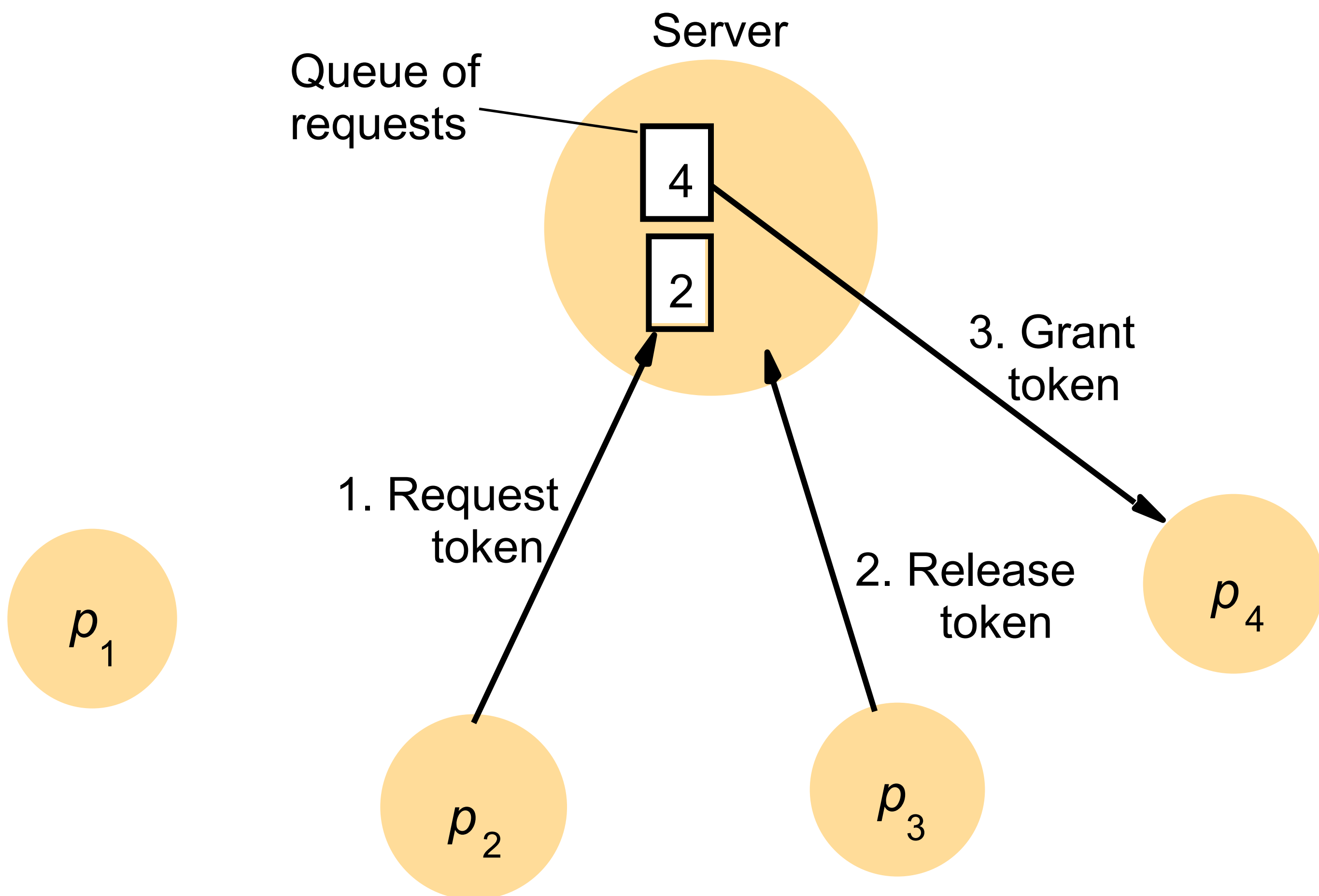


Figure 15.3
A ring of processes transferring a mutual exclusion token

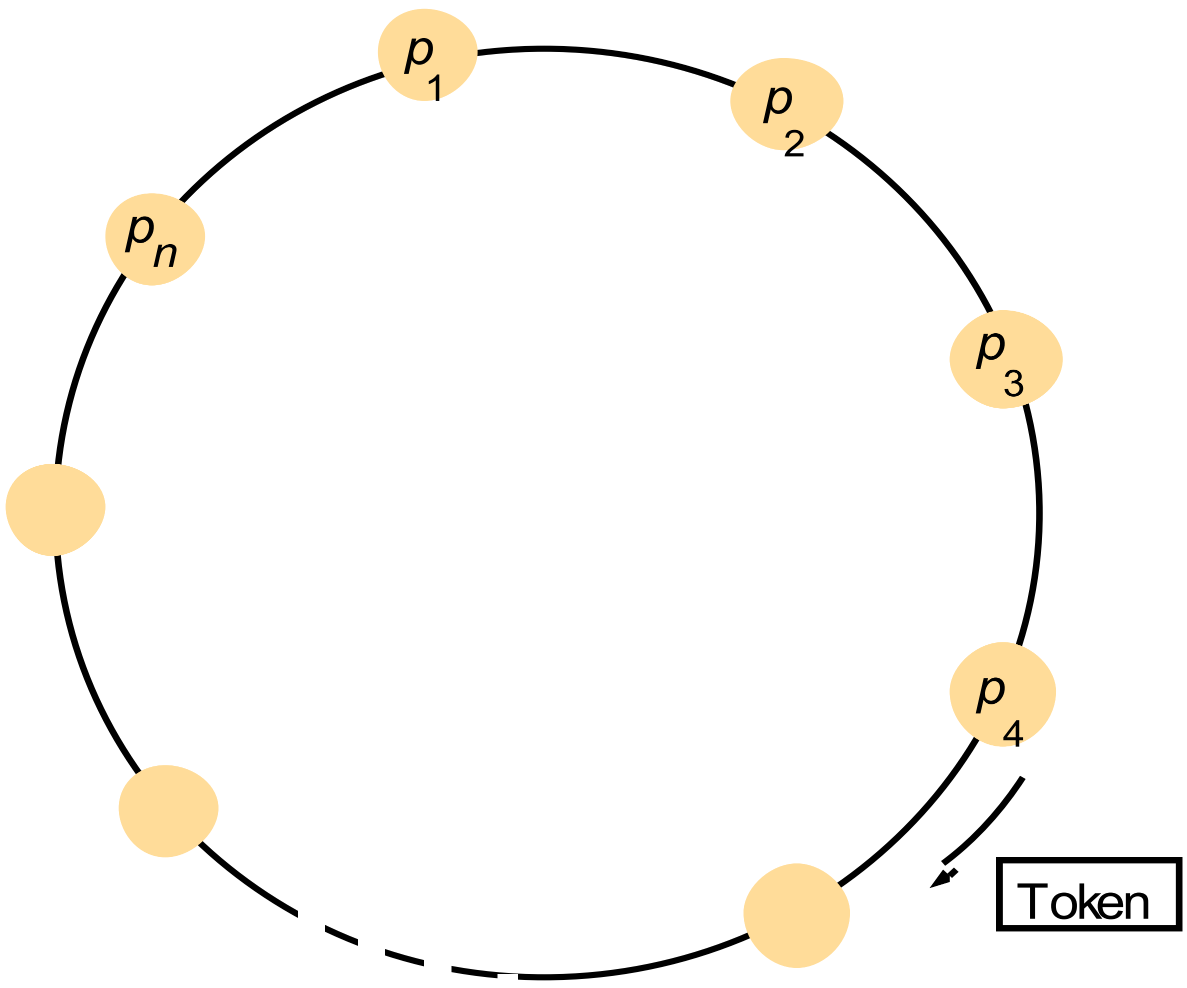


Figure 15.4
Ricart and Agrawala's algorithm

On initialization

    state := RELEASED;

To enter the section

    state := WANTED;

    Multicast *request* to all processes;

    T := request's timestamp;

} request processing deferred here

    Wait until (number of replies received = $(N - 1)$);

    state := HELD;

On receipt of a request $<T_i, p_i>$ *at* p_j $(i \neq j)$

    if (*state* = HELD or (*state* = WANTED *and* $(T, p_j) < (T_i, p_i)$))

    then

        queue *request* from p_i without replying;

    else

        reply immediately to p_i;

    end if

To exit the critical section

    state := RELEASED;

    reply to any queued requests;

Figure 15.5
Multicast synchronization

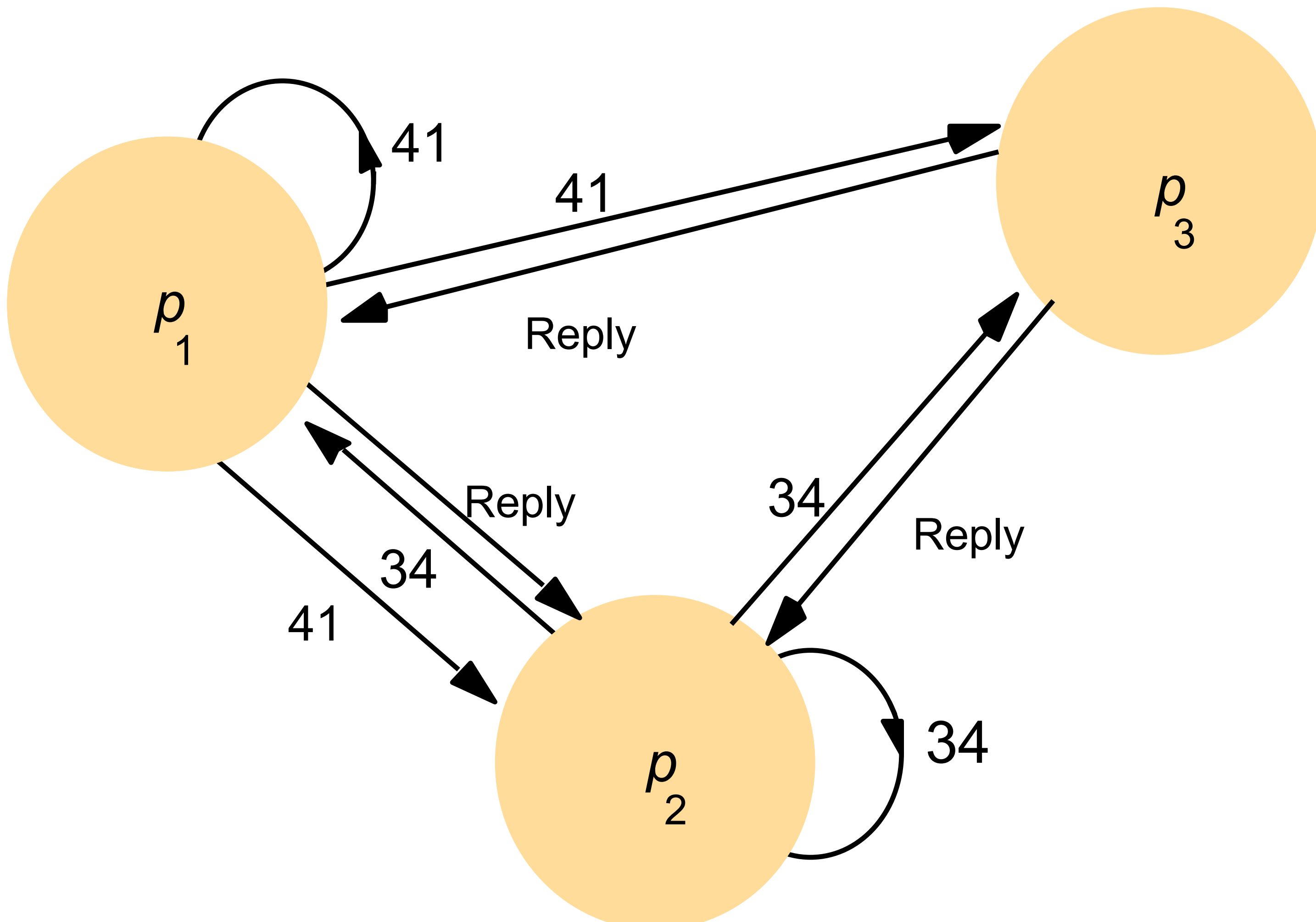


Figure 15.6
Maekawa's algorithm – part 1

On initialization
  state := RELEASED;
  voted := FALSE;

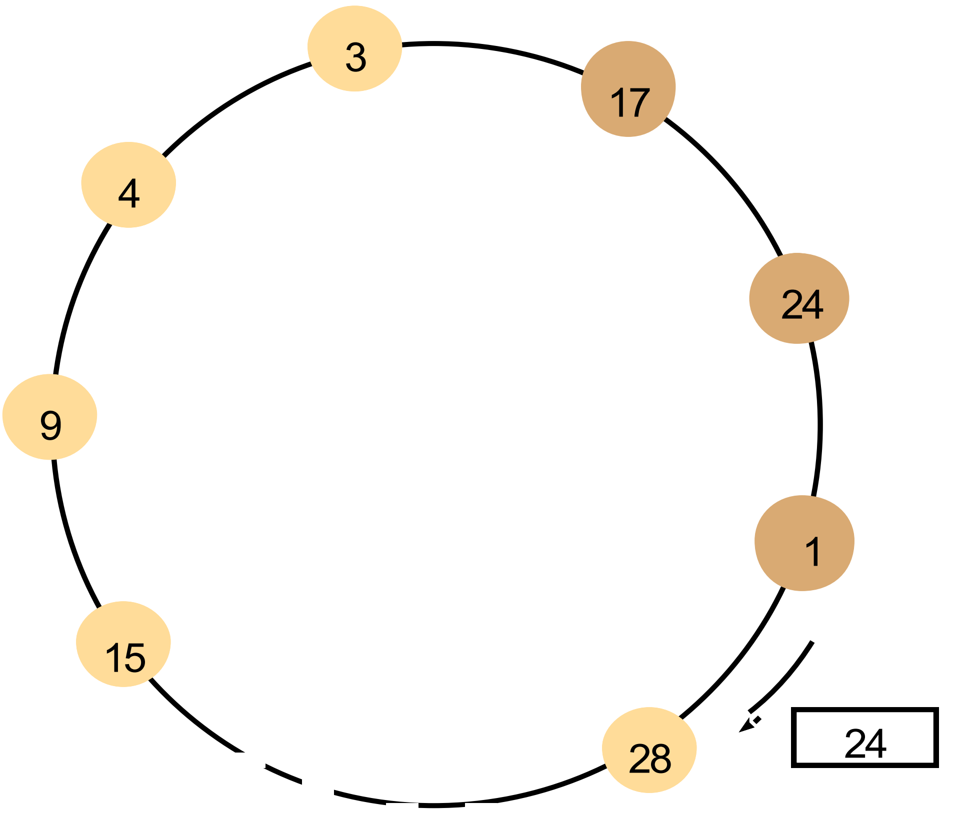
For p_i to enter the critical section
  state := WANTED;
  Multicast *request* to all processes in V_i;
  Wait until (number of replies received = K);
  state := HELD;

On receipt of a request from p_i at p_j
  if (*state* = HELD *or voted* = TRUE)
  then
    queue *request* from p_i without replying;
  else
    send *reply* to p_i;
    voted := TRUE;
  end if

For p_i to exit the critical section
  state := RELEASED;
  Multicast *release* to all processes in V_i;

On receipt of a release from p_i at p_j
  if (queue of requests is non-empty)
  then
    remove head of queue – from p_k, say;
    send *reply* to p_k;
    voted := TRUE;
  else
    voted := FALSE;
  end if

Figure 15.7
A ring-based election in progress



Note: The election was started by process 17.
The highest process identifier encountered so far is 24.
Participant processes are shown in a darker colour

Figure 15.8
The bully algorithm

The election of coordinator p_2,
after the failure of p_4 and then p_3

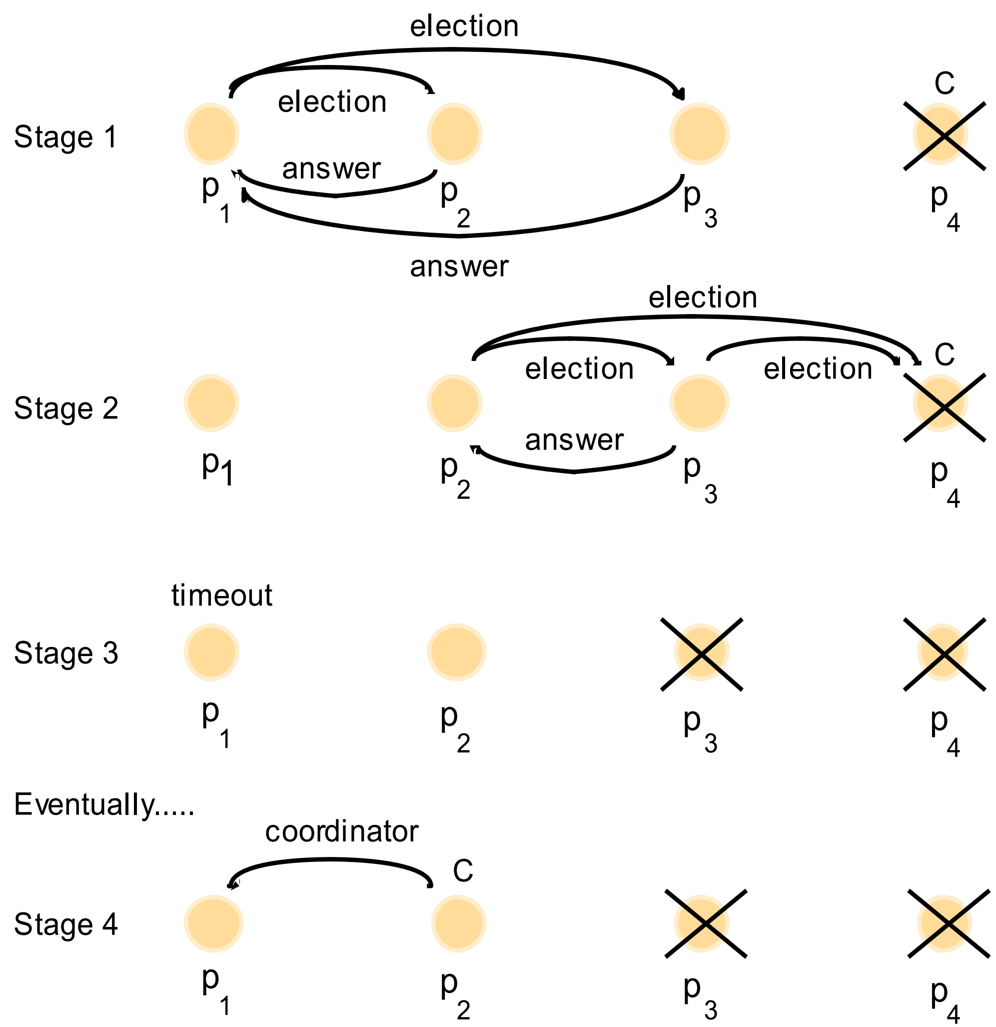


Figure 15.9
Reliable multicast algorithm

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;
    end if

Figure 15.10
The hold-back queue for arriving multicast messages

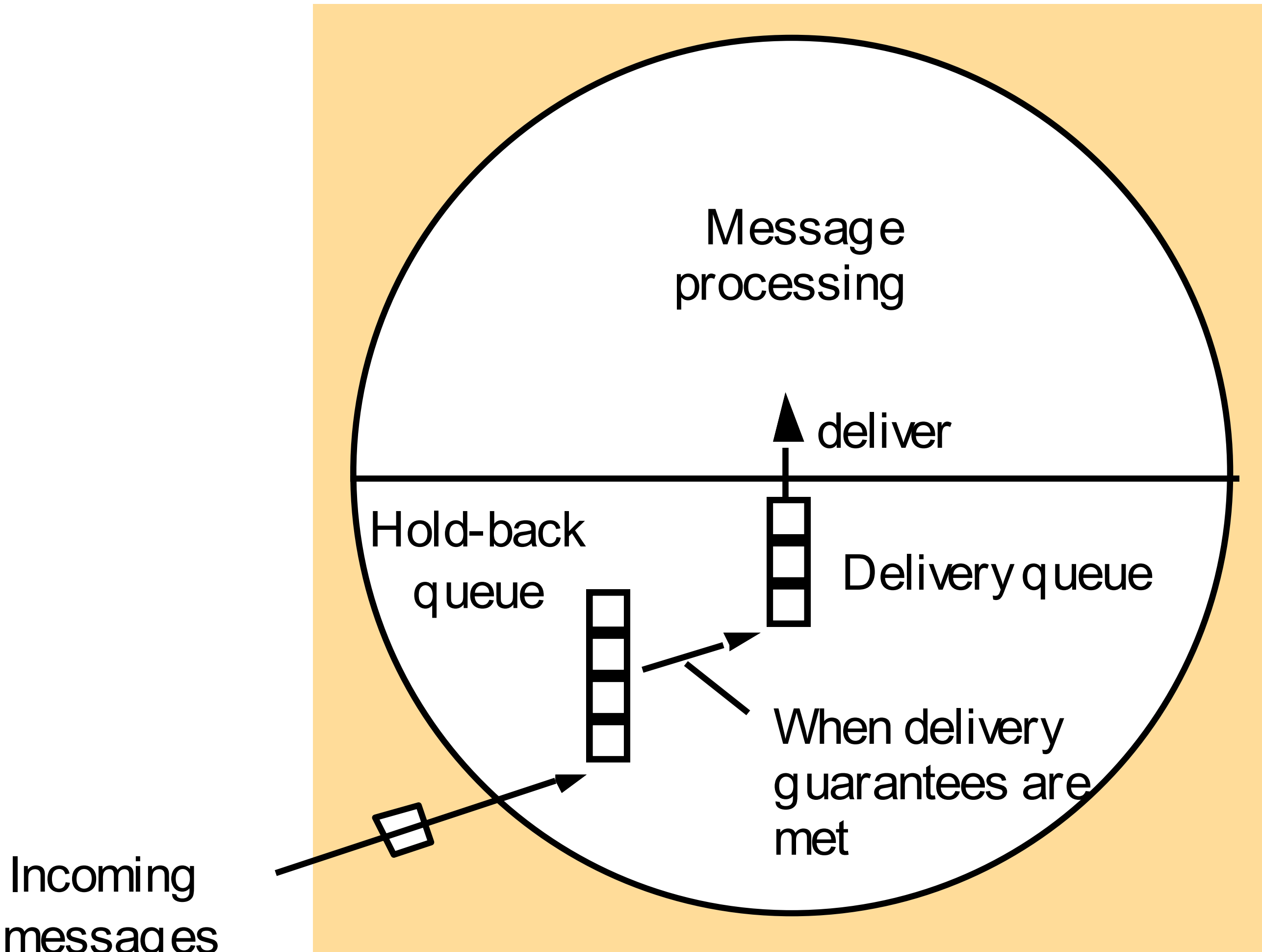


Figure 15.11
Total, FIFO and causal ordering of multicast messages

Notice the consistent ordering of totally ordered messages T_1 and T_2, the FIFO-related messages F_1 and F_2 and the causally related messages C_1 and C_3 – and the otherwise arbitrary delivery ordering of messages.

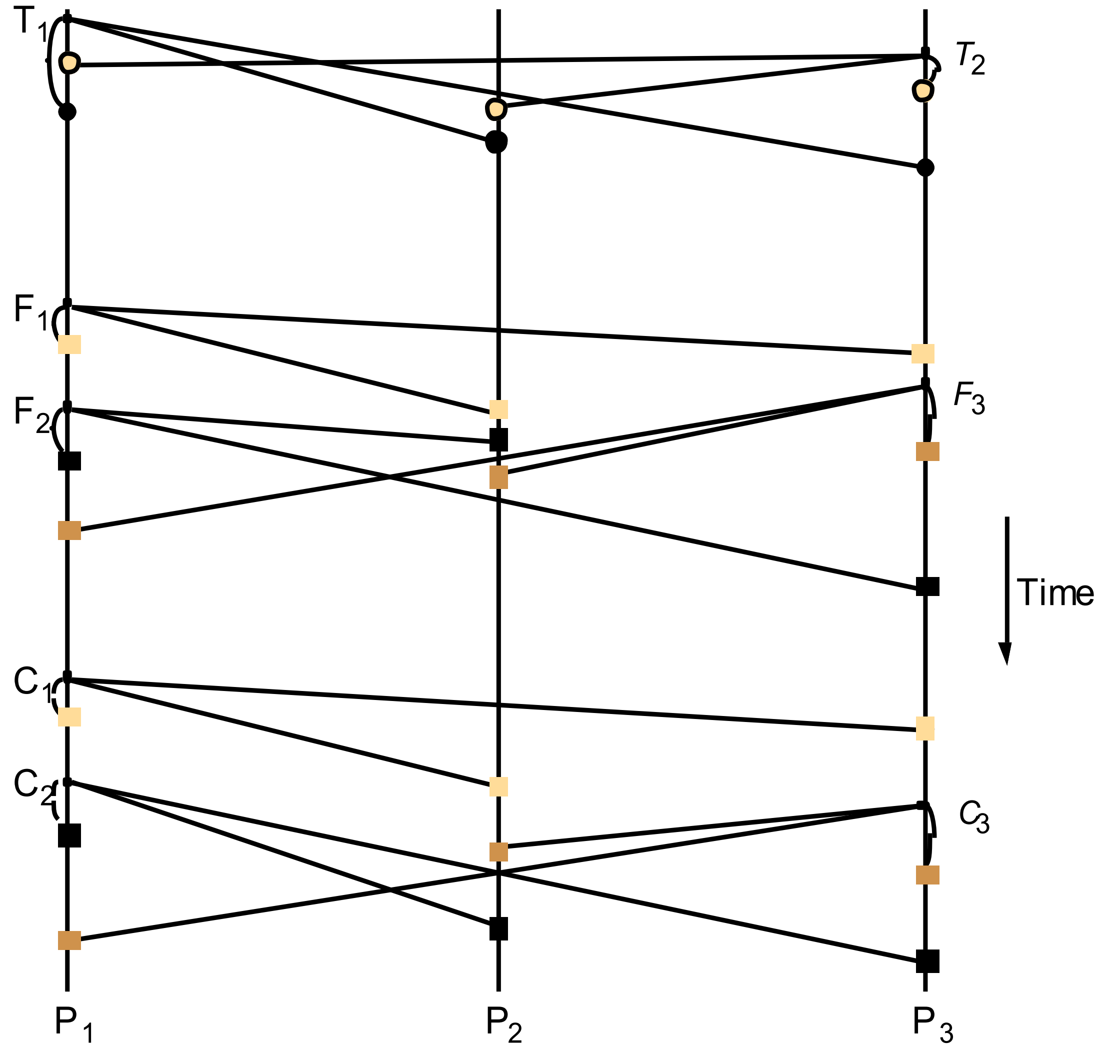


Figure 15.12
Display from bulletin board program

	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		

Figure 15.13
Total ordering using a sequencer

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} = <“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*

On initialization: $s_g := 0;$

On B-deliver(<*m, i*>) *with g = group*(*m*)
    B-multicast(*g*, <“order”, *i*, s_g>);
    $s_g := s_g + 1$;

Figure 15.14
The ISIS algorithm for total ordering

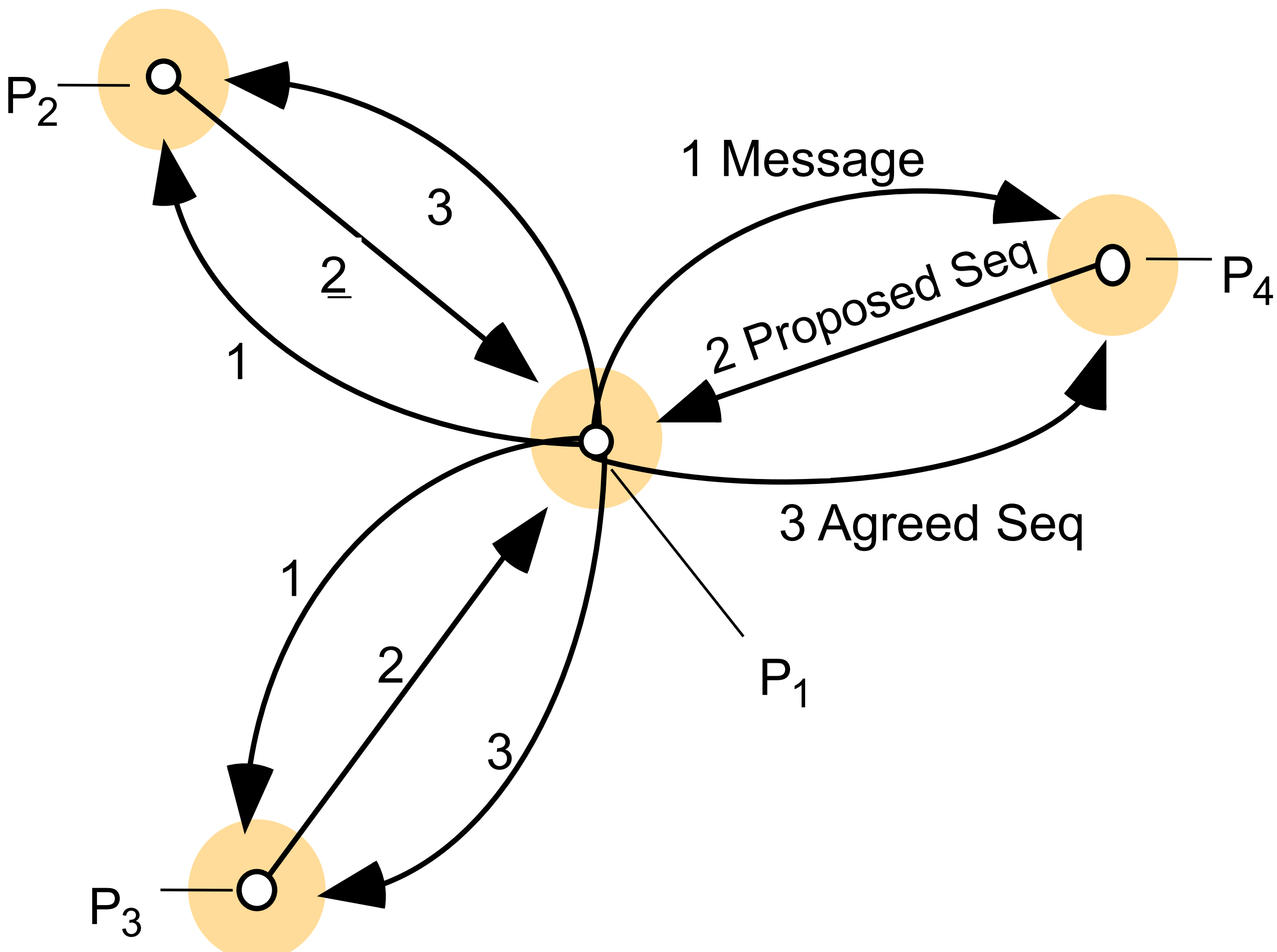


Figure 15.15
Causal ordering using vector timestamps

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

On initialization

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

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 $V_j^g[k] \leq V_i^g[k] \ (k \neq j);$

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

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

Figure 15.16
Consensus for three processes

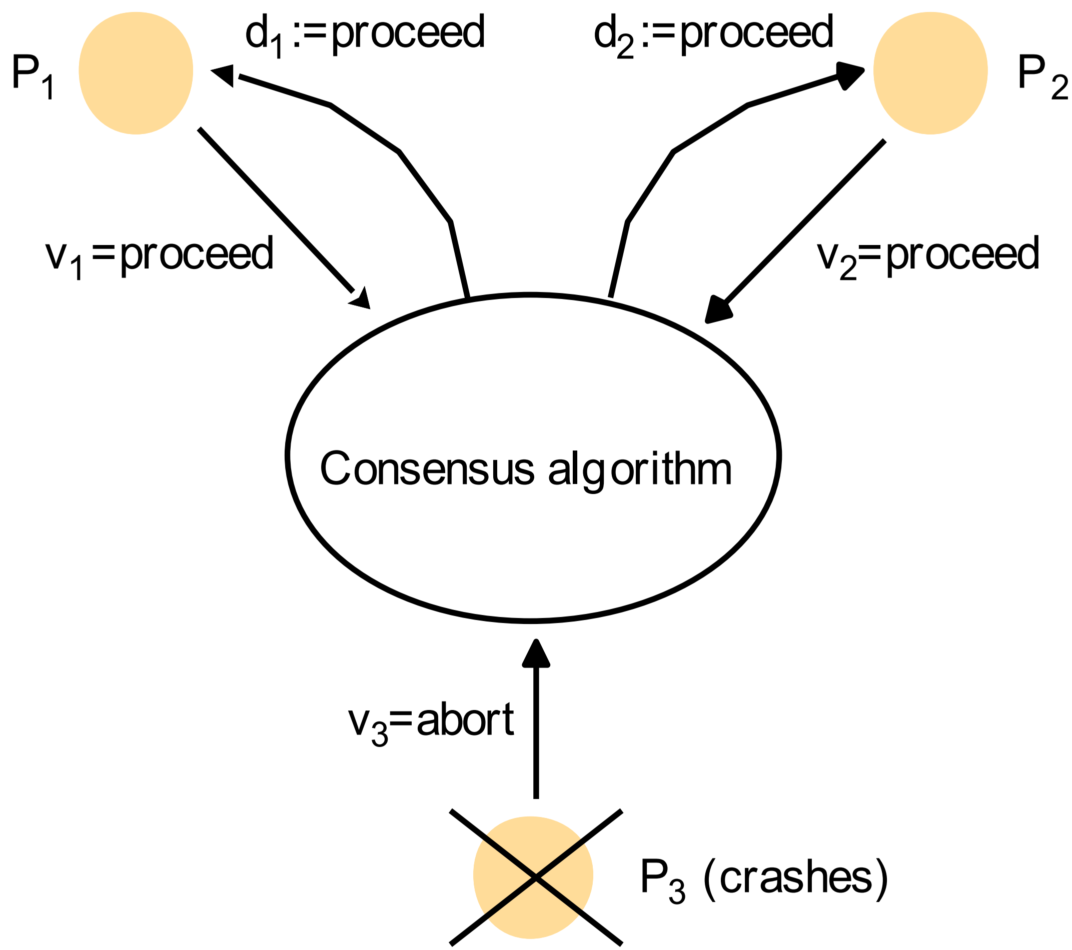


Figure 15.17
Consensus in a synchronous system

Algorithm for process $p_i \in g$; algorithm proceeds in $f + 1$ rounds

On initialization

$Values_i^1 := \{v_i\}$; $Values_i^0 = \{\}$;

In round r $(1 \leq r \leq f + 1)$

B-multicast$(g, Values_i^r - Values_i^{r-1})$; // Send only values that have not been sent

$Values_i^{r+1} := Values_i^r$;

while (in round r)

{

On B-deliver(V_j) *from some* p_j

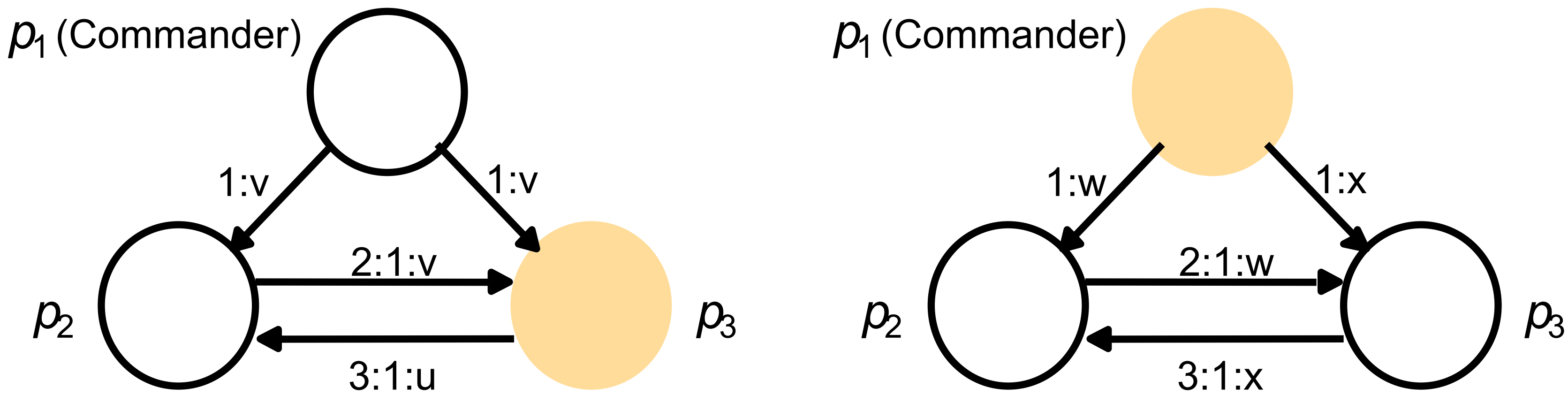
$Values_i^{r+1} := Values_i^{r+1} \cup V_j$;

}

After $(f + 1)$ *rounds*

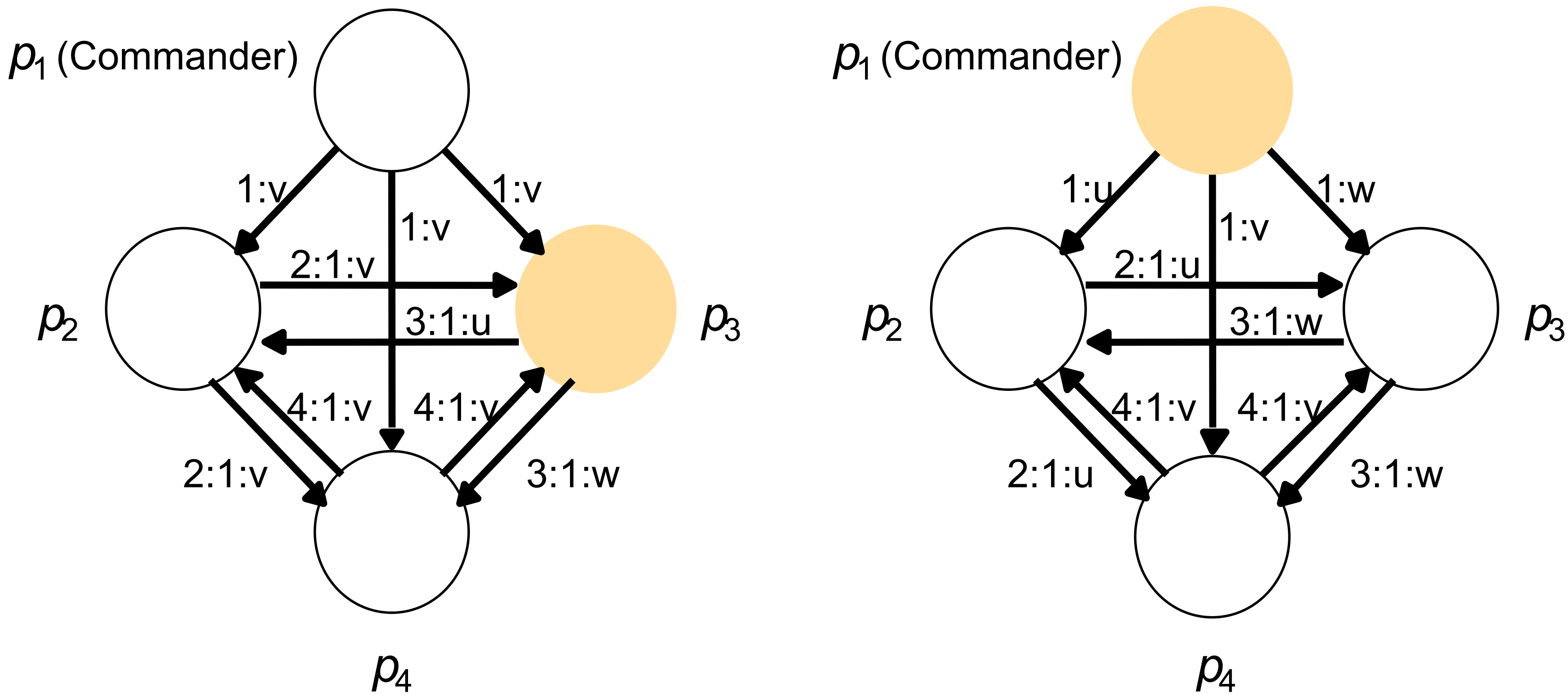
Assign $d_i = minimum(Values_i^{f+1})$;

Figure 15.18
Three Byzantine generals



Faulty processes are shown coloured

Figure 15.19
Four Byzantine generals



Faulty processes are shown coloured