Distributed Databases

CS347

Lecture 16

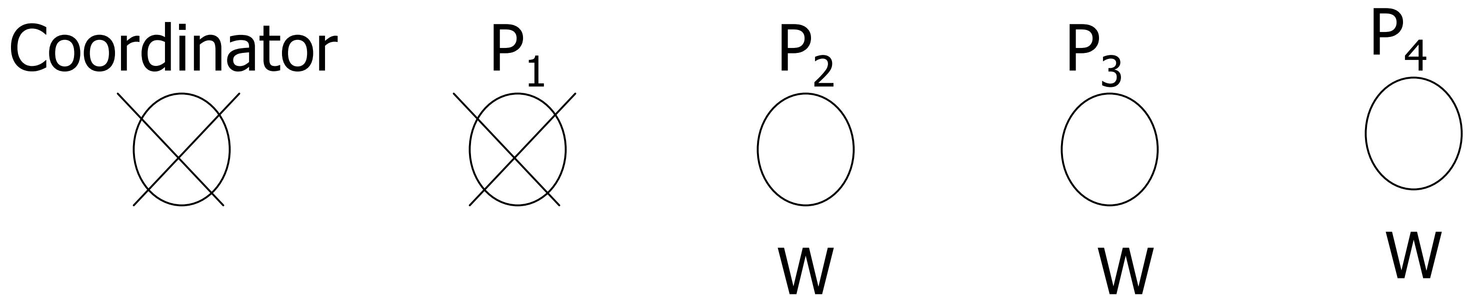
June 6, 2001

Topics for the day

- Reliability
  - Three-phase commit (3PC)
  - Majority 3PC

- Network partitions
  - Committing with partitions
  - Concurrency control with partitions

Recall - 2PC is blocking



Case I: P1 $\rightarrow$ "W"; coordinator sent commits

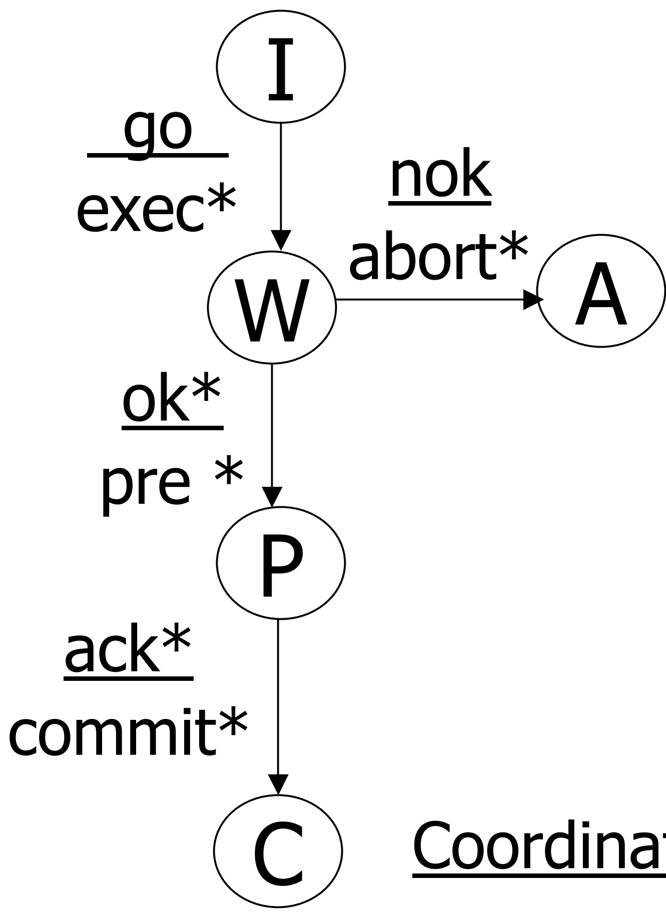
P1 $\rightarrow$ "C"

Case II: P1 $\rightarrow$ NOK; P1 $\rightarrow$ A

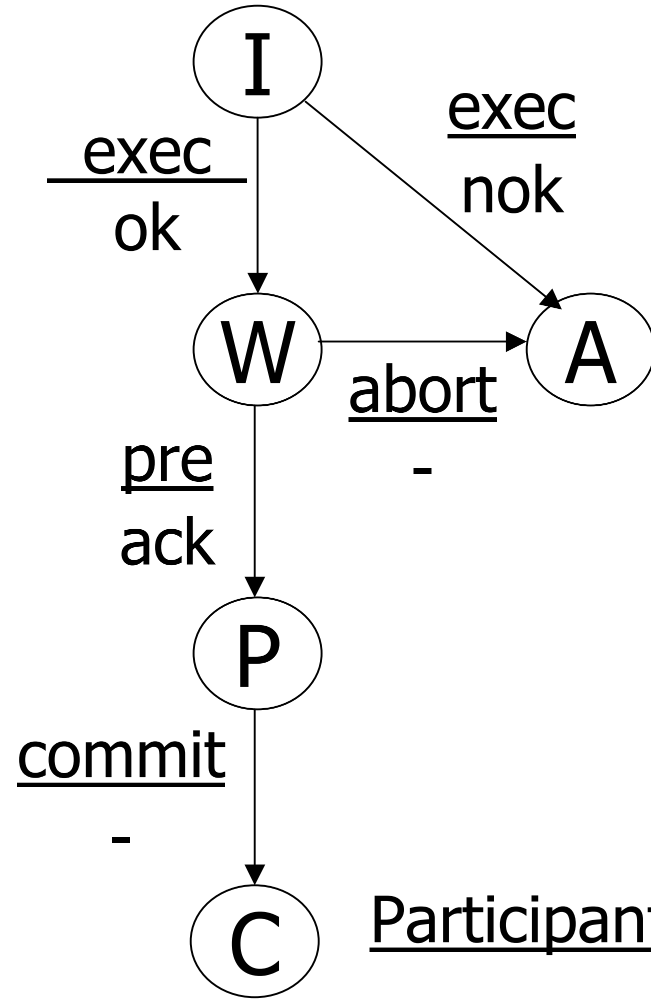
$\Rightarrow$ P2, P3, P4 (surviving participants) cannot safely abort or commit transaction

3PC (non-blocking commit)

- Assume: failed node is down forever
- Key idea: before committing, coordinator tells participants everyone is ok

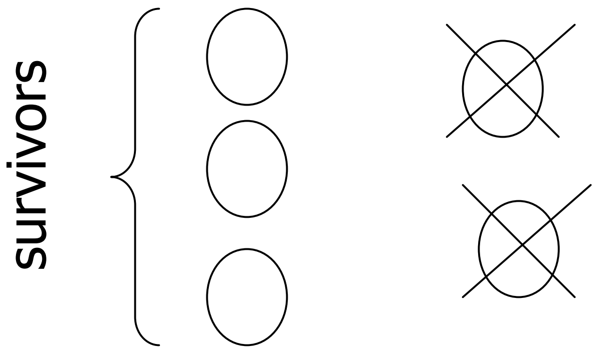


Coordinator



Participant

3PC recovery (termination protocol)



- Survivors try to complete transaction, based on their current states
- Goal:
  - If dead nodes committed or aborted, then survivors should not contradict!
  - Otherwise, survivors can do as they please...

Termination rules

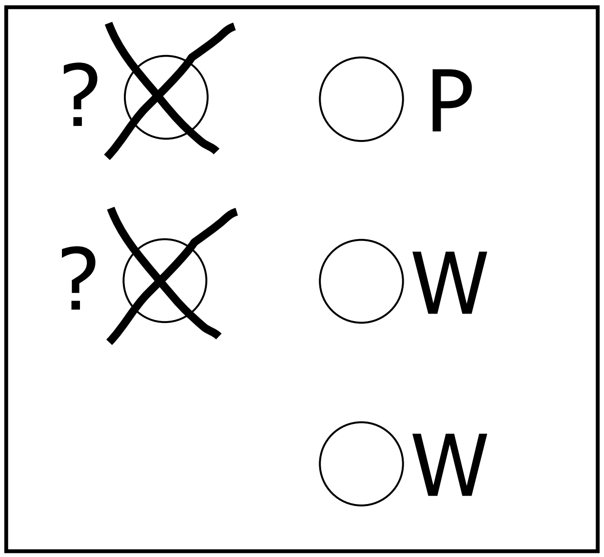
- Let $\{S_1, S_2, \ldots S_n\}$ be survivor sites. Make decision on commit/abort based on following rules:

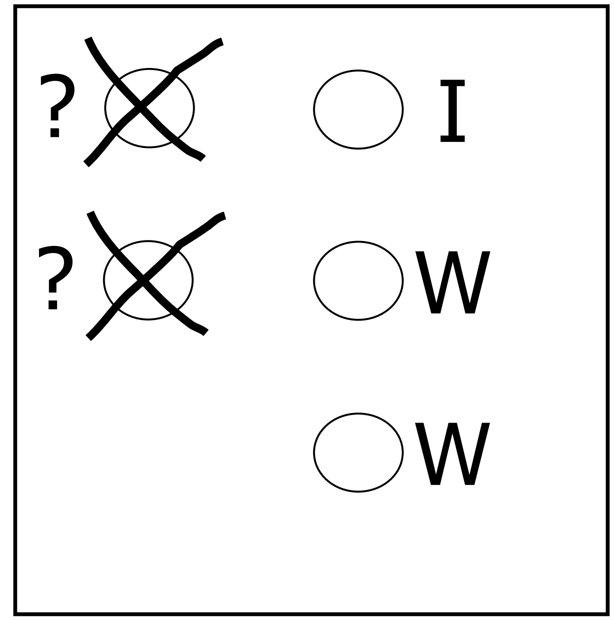
- If one or more S_i = COMMIT ⇒ COMMIT T
- If one or more S_i = ABORT ⇒ ABORT T
- If one or more S_i = PREPARE ⇒ COMMIT T

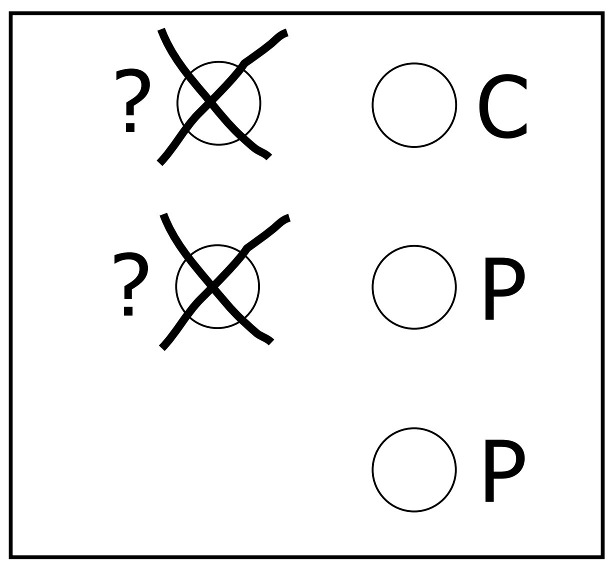
  (T could not have aborted)
- If no S_i = PREPARE (or COMMIT) ⇒ ABORT T

  (T could not have committed)

Examples

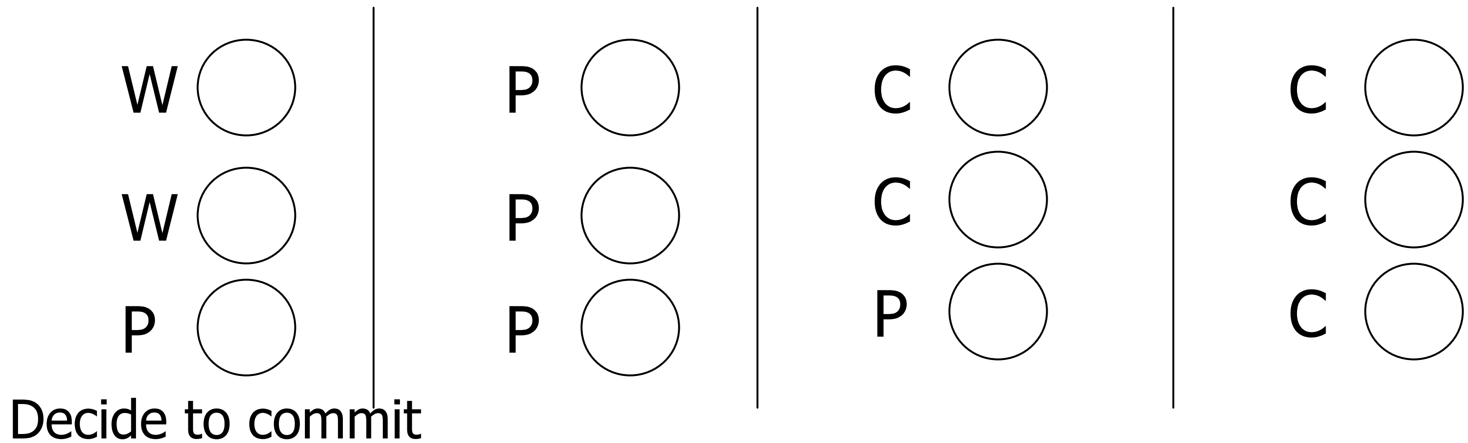






Points to Note

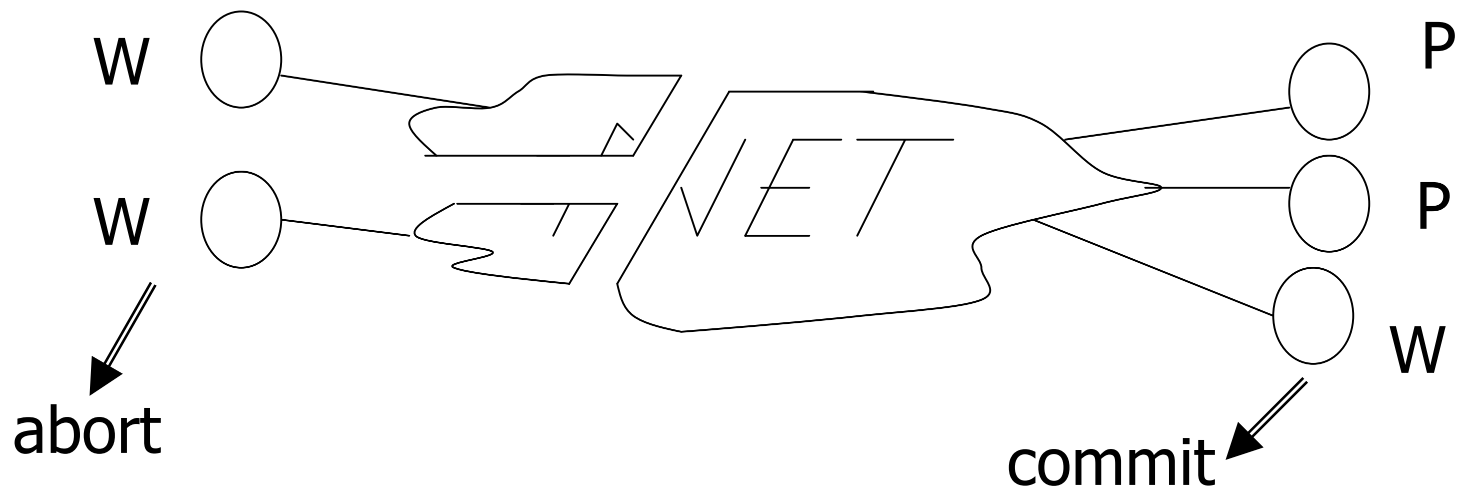
- Once survivors make a decision, they must elect a new coordinator and continue with 3PC.



- When survivors continue 3PC, failed nodes do not count.
  - Example: OK* = OK from every non-failed participant

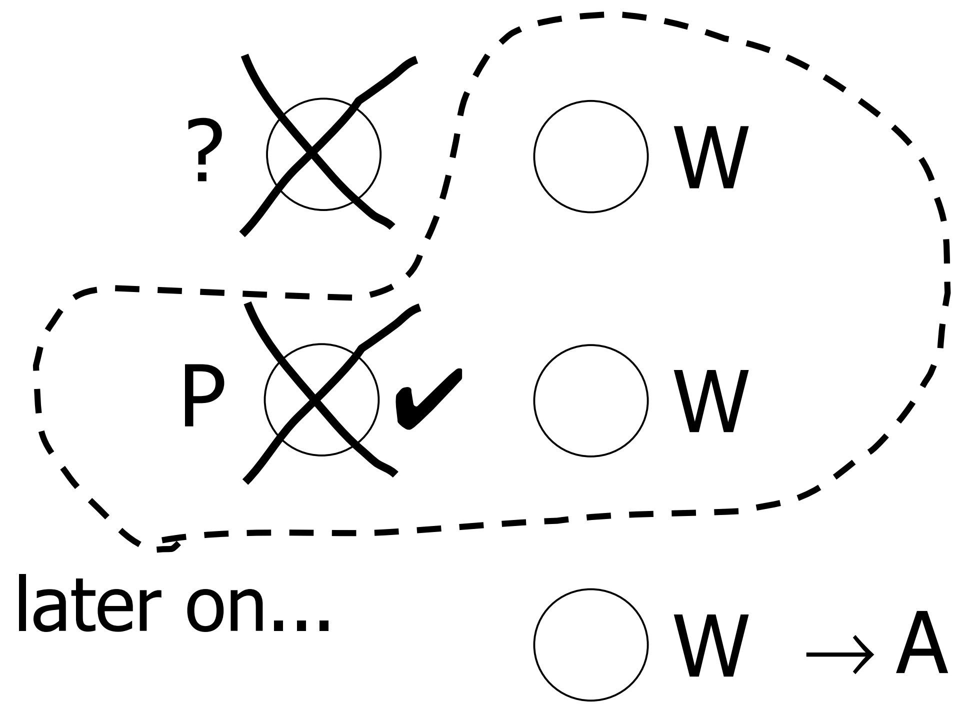
Points to Note

- 3PC unsafe with network partitions



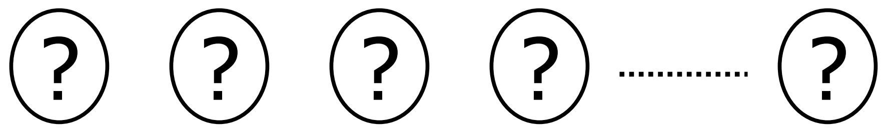
Node recovery

- After node N recovers from failure, what must it do?
  - N must not participate in termination protocol
  - Wait until it hears commit/abort decision from operational nodes



All-failed problem

Waiting for commit/abort decision is fine, unless all nodes fail.



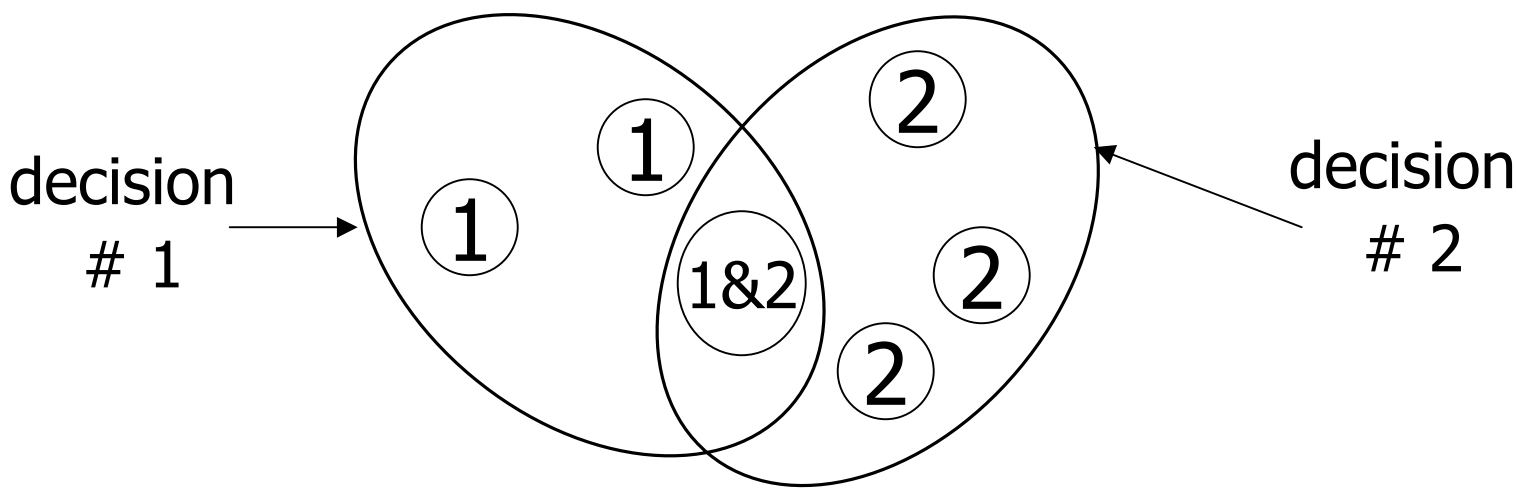
Two possible solutions:

- Option A: Recovering node waits for either
    - commit/abort outcome for T from some other node.
    - all nodes that participated in T are up and running. Then 3PC can continue

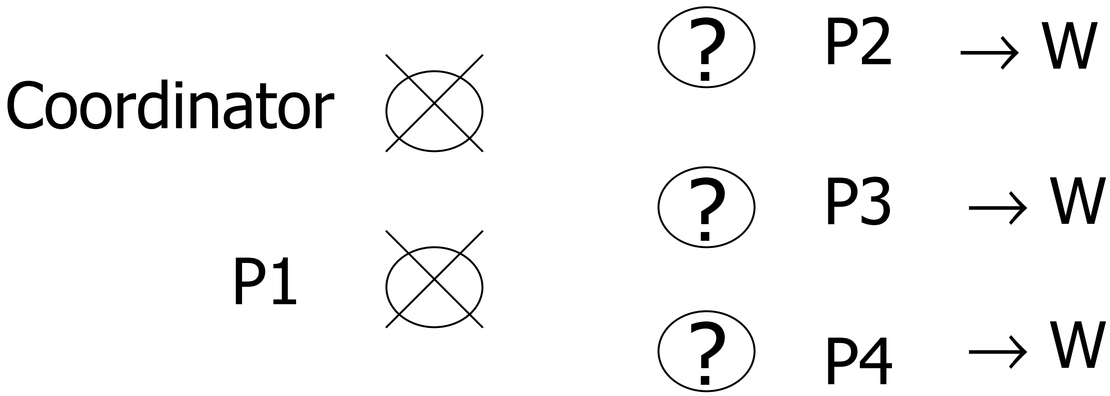
- Option B: Use Majority 3PC

Majority 3PC

- Nodes are assigned votes. Total votes = V. For majority, need $\lceil (V+1)/2 \rceil$ votes.
- Majority rule: For every state transition, coordinator requires messages from nodes with a majority of votes.
- Majority rule ensures that any decision (preparing, committing) is known to a future decision-making group.

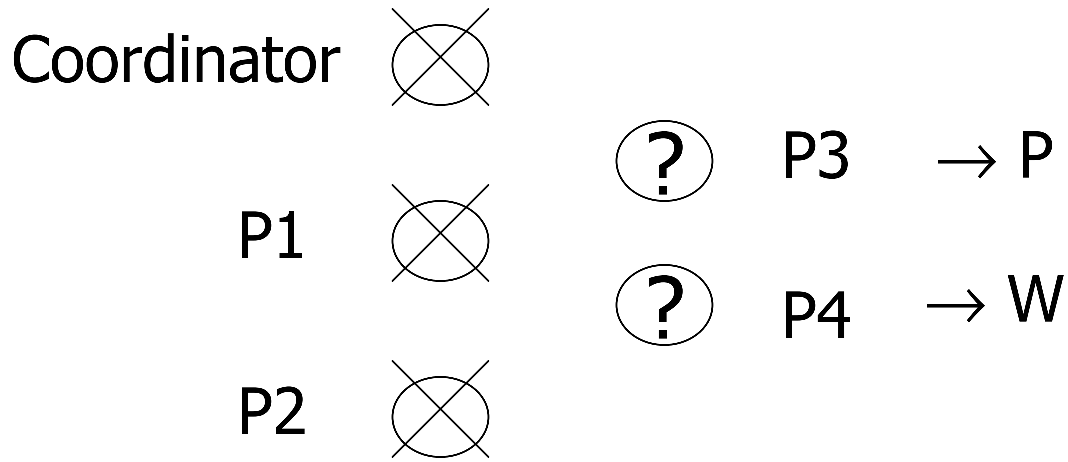


Example 1



- Each node has 1 vote, V=5
- Nodes P2, P3, P4 enter "W" state and fail
- When they recover, coordinator and P1 are down
- Since P2, P3, P4 have majority, they know coord. could not have gone to "P" without at least one of their votes
- Therefore, T can be aborted.

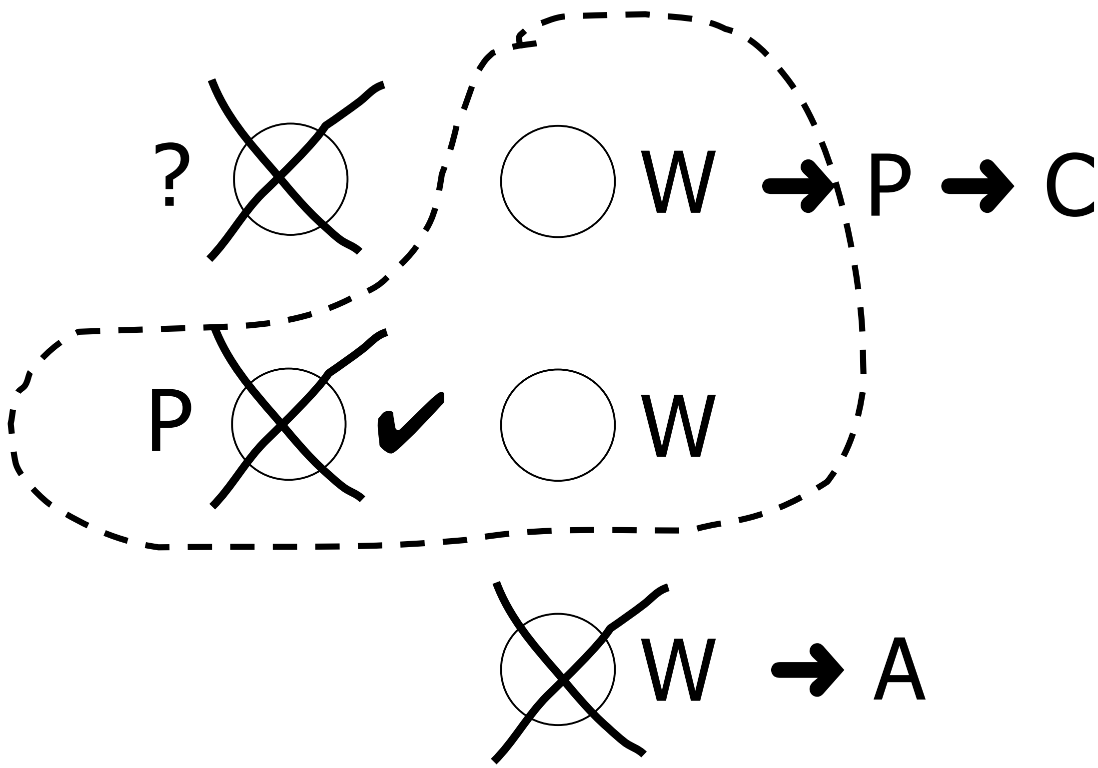
Example 2



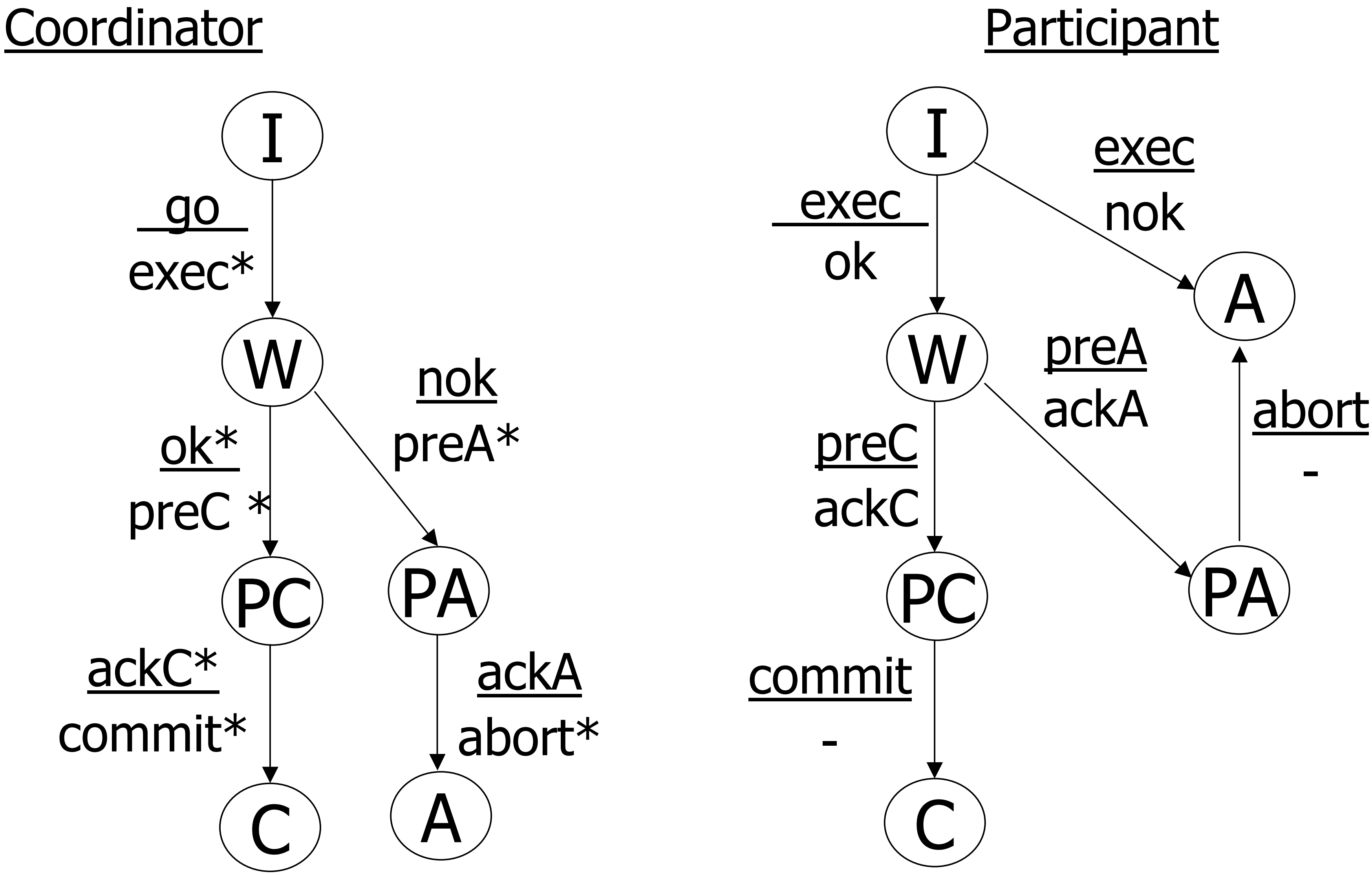
- Each node has 1 vote, V=5
- Nodes fail after entering states shown. P3 and P4 recover.
- Termination rule says {P3,P4} can commit. But {P3,P4} do not have majority – so block.
- Right thing to do, since {Coordinator,P1,P2} may later abort.

Problem!

- Previously, we disallowed recovering nodes from participating.
- Now any set of nodes with majority can progress.
- How do we fix the problem below?

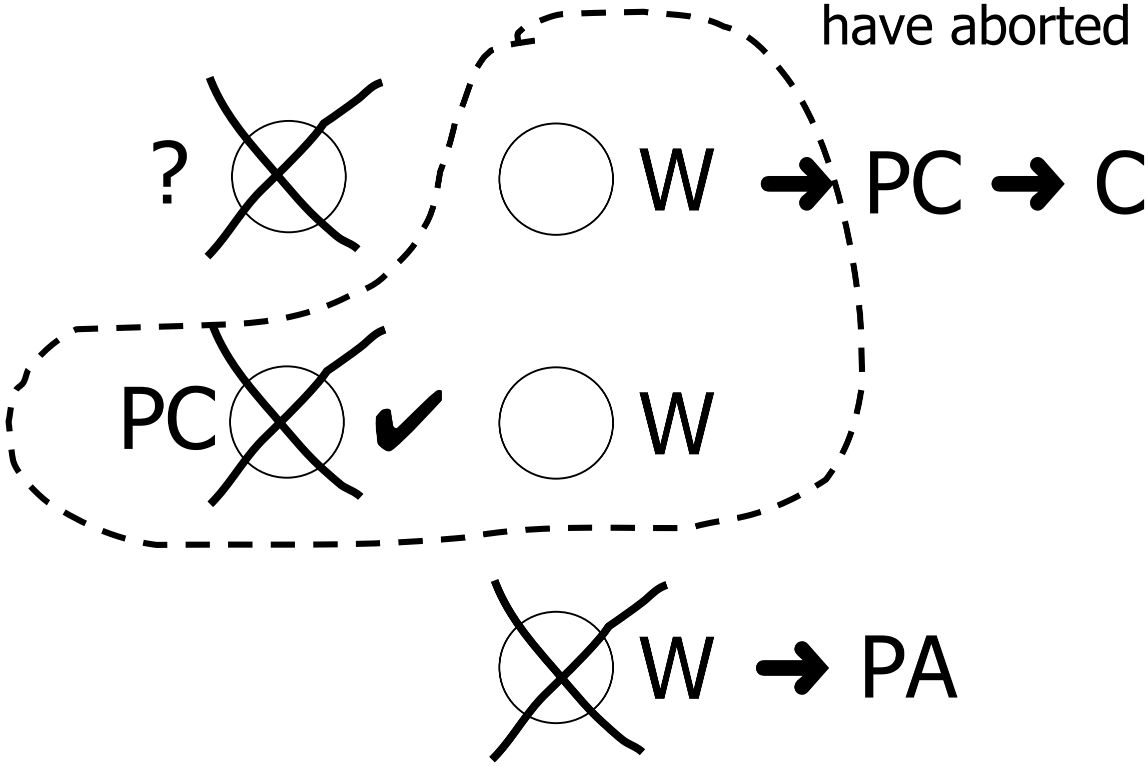


Majority 3PC (introduce "prepare to abort" state)



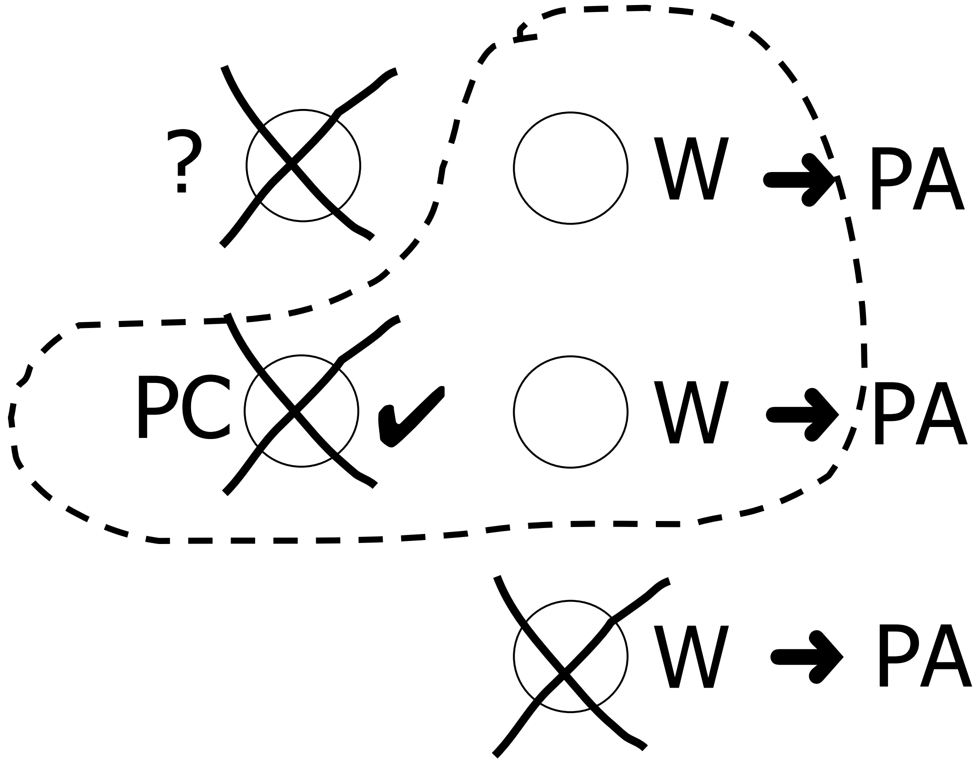
Example Revisited

OK to commit since transaction could not have aborted



Example Revisited -II

No decision:
Transaction could have aborted or could have committed... Block!



Majority 3PC Rules

- If survivors have majority and states in {W, PC, C} $\Rightarrow$ try to commit

- If survivors have majority and states in {W, PA, A} $\Rightarrow$ try to abort

- Otherwise block

Blocking Protocol !!

Summarizing commit protocols

- 2PC
  - Blocking protocol
  - Key: coordinator does not move to "C" state unless every participant is in "W" state
- 3PC
  - Non-blocking protocol
  - Key: coordinator broadcasts that "all are ok" before committing. Failed nodes must wait.
  - Any set of non-failed nodes can terminate transaction (even a single node)
  - If all nodes fail, must wait for <u>all</u> to recover

Summarizing commit protocols

- Majority 3PC
  - Blocking protocol
  - Key: Every state transition requires majority of votes
  - Any majority group of active+recovered nodes can terminate transaction

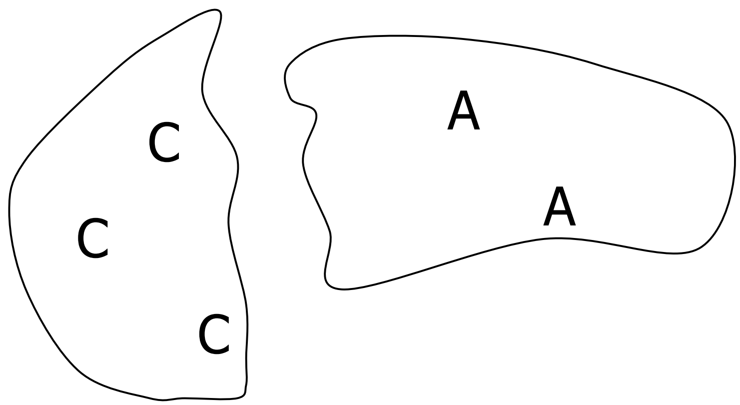
Network partitions

- Groups of nodes may be isolated or may be slow in responding

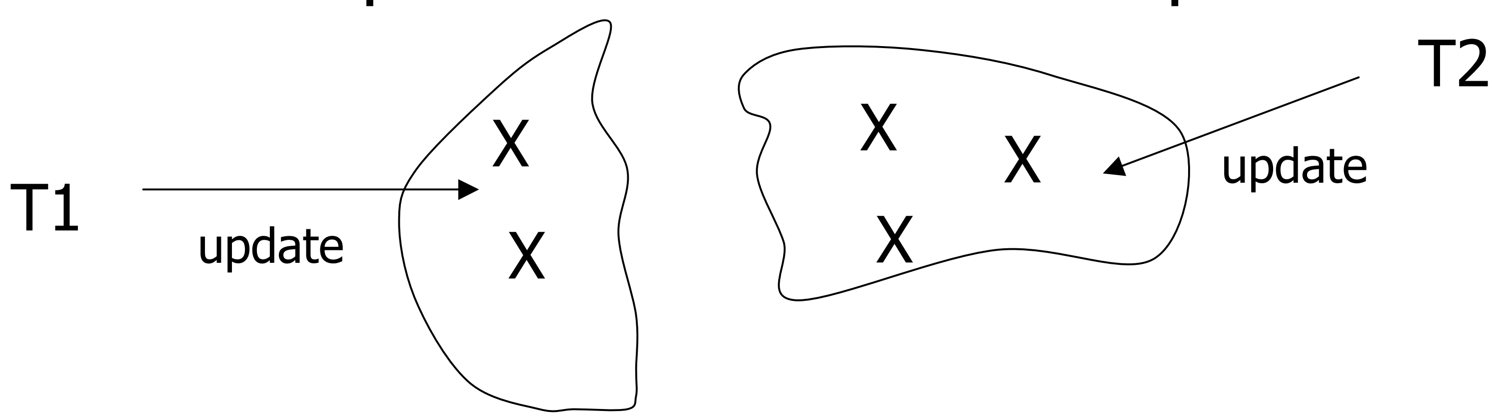
- When are partitions of interest?
  - True network partitions (disaster)
  - Single node failure cannot be distinguished from partition (e.g., NIC fails)
  - Loosely-connected networks
    - Phone-in, wireless

Problems

- Partitions during commit



- Updates to replicated data in isolated partitions



Quorums

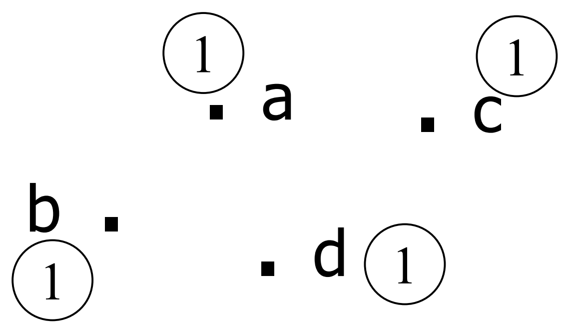
- <u>Commit and Abort Quorums:</u> Given set S of nodes, define
  - Commit quorum $C \subseteq 2^S$, Abort quorum $C \subseteq 2^S$
  - $X \cap Y \neq \emptyset \ \forall X, Y$ such that $X \in C$ and $Y \in A$

- Example: S = {a,b,c,d}

  C = {{a,b,c}, {a,b,d}, {a,c,d}, {b,c,d}}

  A = {{a,b}, {a,c}, {a,d}, {b,c}, {b,d}, {c,d}}

- Quorums can be implemented with vote assignments
  - $V_a = V_b = V_c = V_d = 1$
  - To commit $\geq$ 3 votes
  - To abort $\geq$ 2 votes

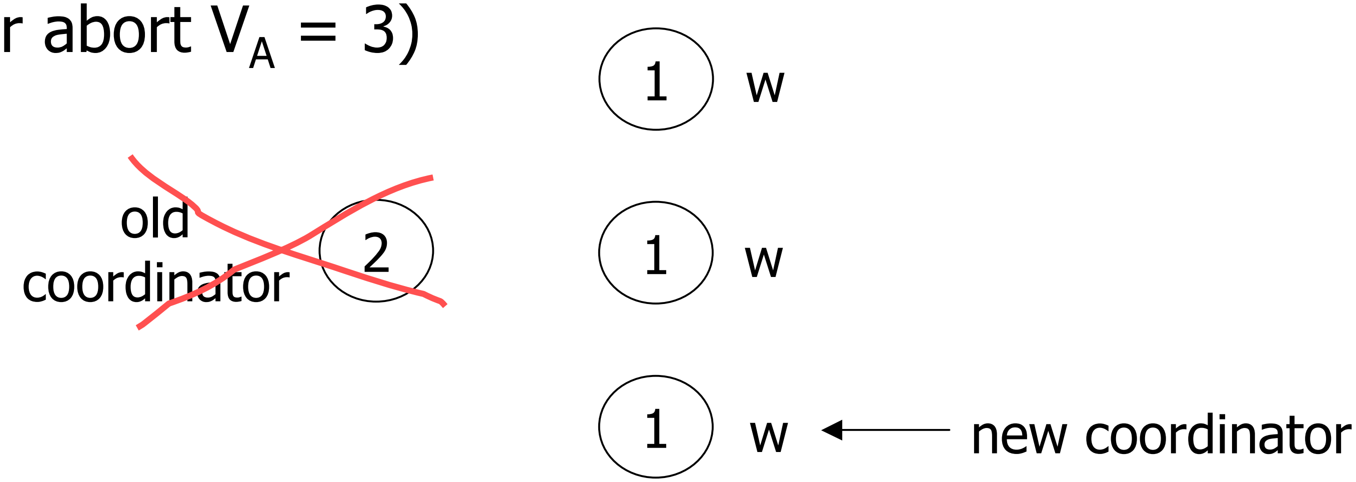


Quorums

- However, not all quorums can be implemented with votes
  C = {{a,b}, {c,d}}   A = {{a,c}, {a,d}, {b,c}, {b,d}}
- Commit protocol must enforce quorum
- Quorum condition is in addition to whatever rules the commit protocol might have
- If node knows transaction could have committed (aborted), if cannot abort (commit) even if abort (commit) quorum available
- With network partitions, all commit protocols are blocking.

3PC Example

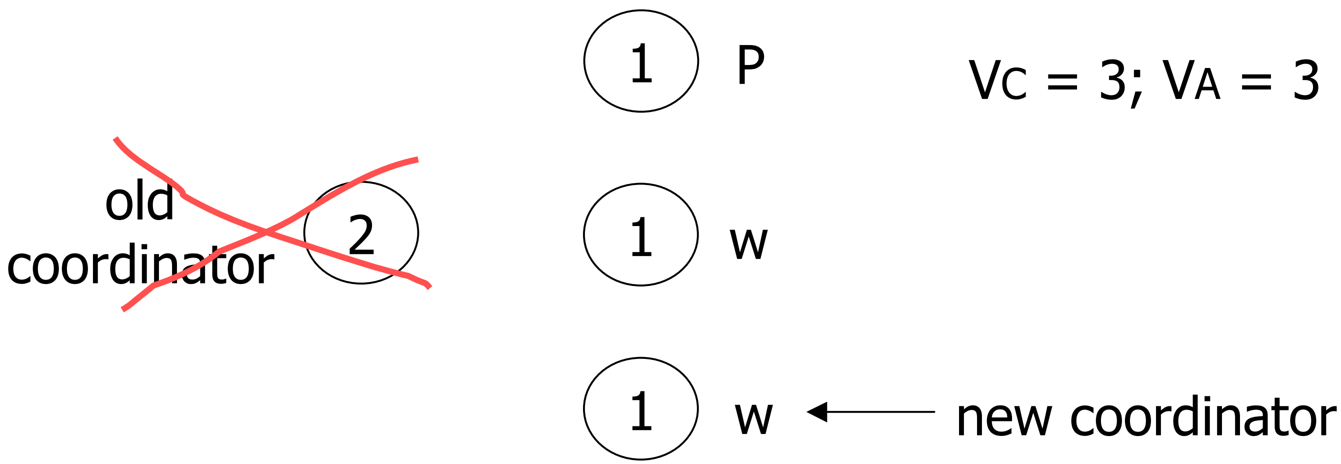
- To make commit decision: commit quorum (votes for commit $V_C = 3$)
- To make abort decision: abort quorum (votes for abort $V_A = 3$)



- Old coordinator could not have committed since all other nodes are in "W" state.
- Surviving nodes have abort quorum

Attempt to abort

Another 3PC Example

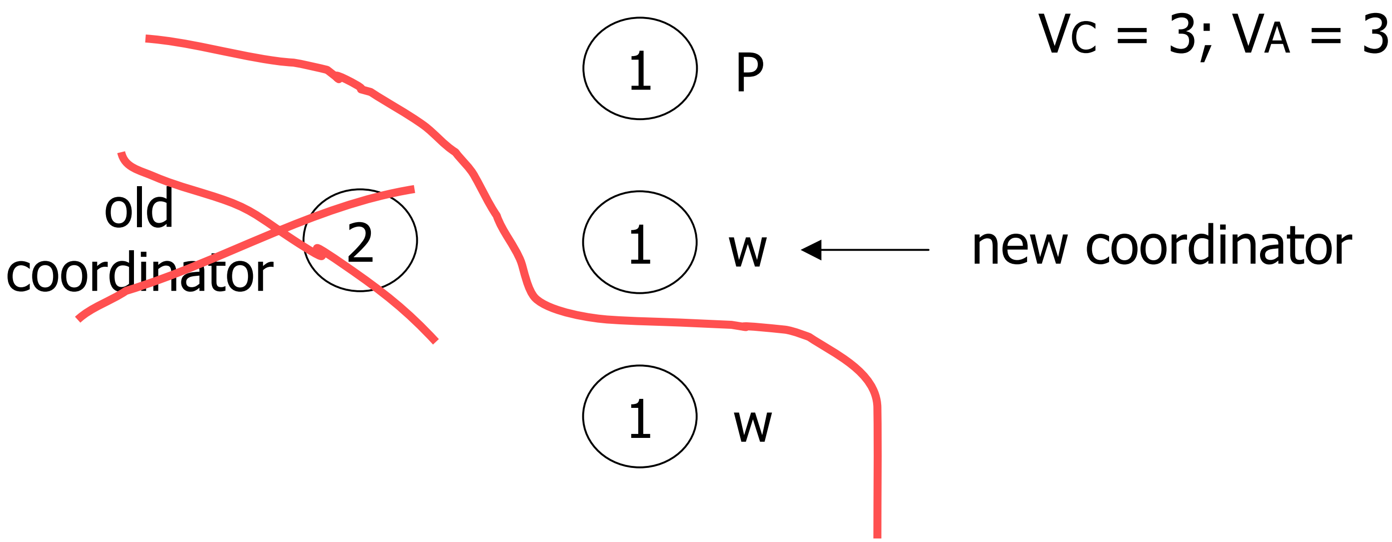


- Old coordinator could not have aborted since one node is in "P" state.
- Surviving nodes have commit quorum

} Attempt to commit

Note: When using 3PC with quorums, we must use the "Prepare to Abort" (PA) state as in majority commit (for the same reasons).

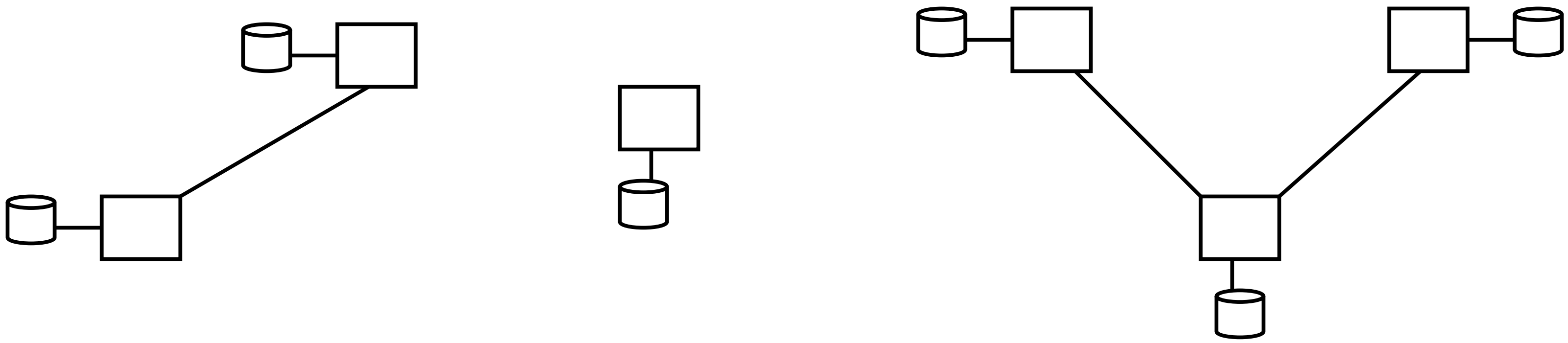
Yet Another 3PC Example



- Old coordinator could not have aborted since one node is in “P” state.
- However, surviving nodes do not have commit quorum

Block

Partitions and data replication

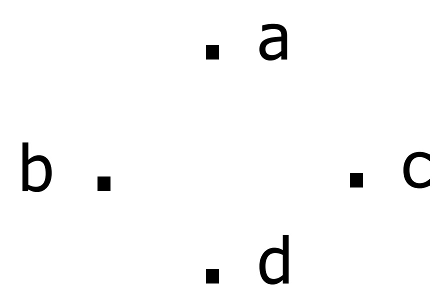


Options:

1. All copies required for updates
2. At most one group may update, at any time
3. Any group may update (potentially more than one can update simultaneously)

Coteries

- Used to enforce updates by at most one group
- Given a set S of nodes at which an element X is replicated, define a coterie C such that
  - $C \subseteq 2^S$
  - $A_1 \cap A_2 \neq \emptyset$, for $\forall\ A_1, A_2 \in C$



- Examples:

$C_1 = \{\{a,b,c\}, \{a,b,d\}, \{a,c,d\}, \{b,c,d\}\}$

$C_2 = \{\{a,b\}, \{a,c\}, \{a,d\}, \{b,c,d\}\}$

$C_3 = \{\{a,b\}, \{c,d\}\}$ not a valid coterie

Accessing Replicated Elements

- Element X replicated at a set S of sites.
- Specify two sets R (for "read") and W (for "write") with the following properties:
  - R, W $\subseteq 2^S$
  - W is a coterie over S
  - R and W are read and write quorums respectively over S i.e., $A \cap B \neq \emptyset \;\; \forall$ A,B such that $A \in R$ and $B \in W$

  (similar to commit and abort quorums)

Accessing replicated elements

- X replicated at S = {a,b,c,d}

- Example 1:

  W = {{a,b,c}, {a,b,d}, {a,c,d}, {b,c,d}}

  R = {{a,b}, {a,c}, {a,d}, {b,c}, {b,d}, {c,d}}

- Example 2:

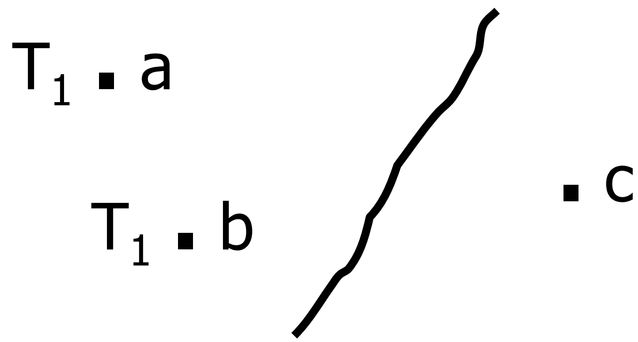
  R = W = {{a,b}, {a,c}, {a,d}, {b,c,d}}

- Can be implemented using vote assignments. For example 1:
  - $V_a = V_b = V_c = V_d = 1$; Total = 4
  - To write, get 3 votes (V_w)
  - To read, get 2 votes (V_r)

$$2\,V_w > T$$
$$V_w + V_r > T$$

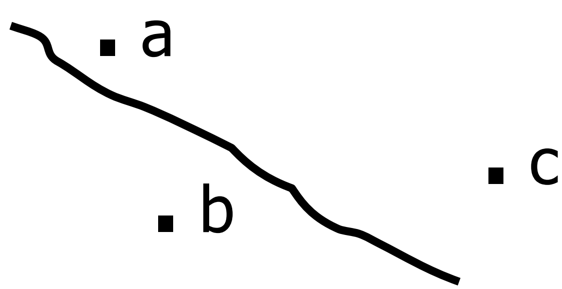
Missing Writes

Example: a 3 node system, 1 vote for each node



T_1 commits at {a,b}.

Partition changes. T_2 comes along. Verifies read and write quorum {a,c}.

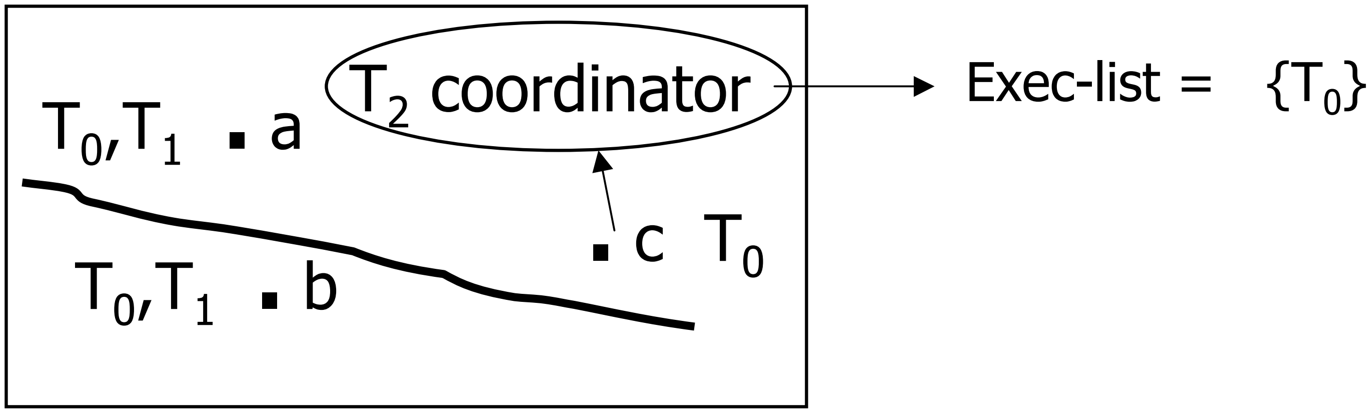


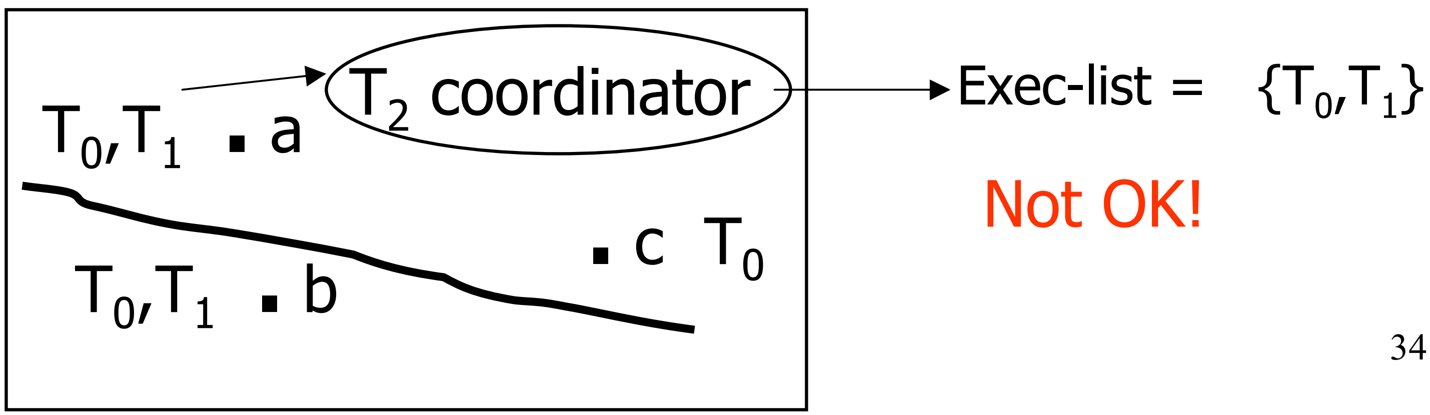
T_2 reads at c. Writes and commits at {a,c}.

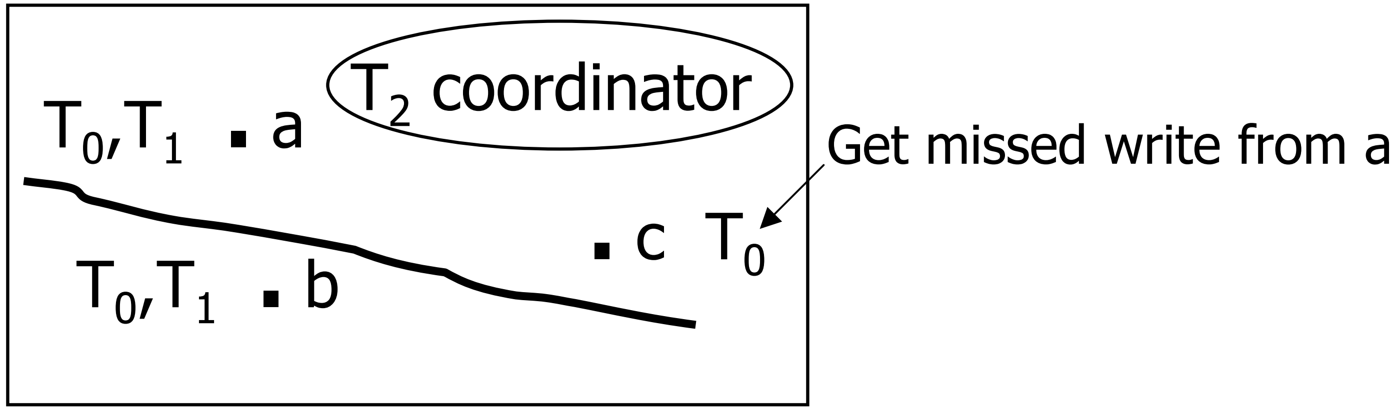
Unserializable

Solution

- Each node maintains list of committed transactions
- Compare list at read site with those at write sites
- Update sites that missed transactions







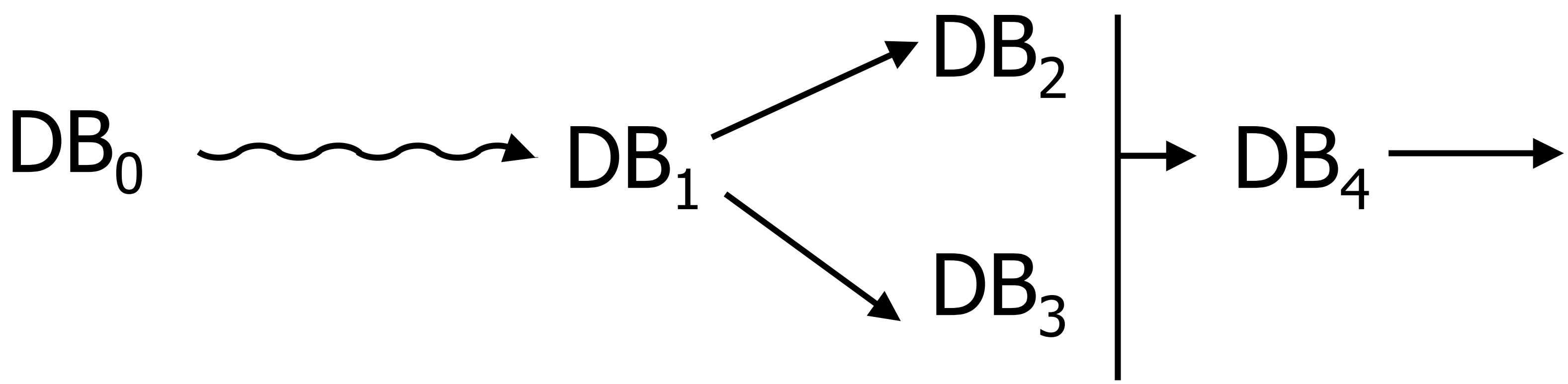
- Details are tricky
- Maintaining list of updates until <u>all</u> nodes have seen them
  - interesting problem
- See resource ("Missing Writes" algorithm) for details

Partitions and data replication

Options:

1. All copies required for updates
2. At most one group may update, at any time
3. Any group may update

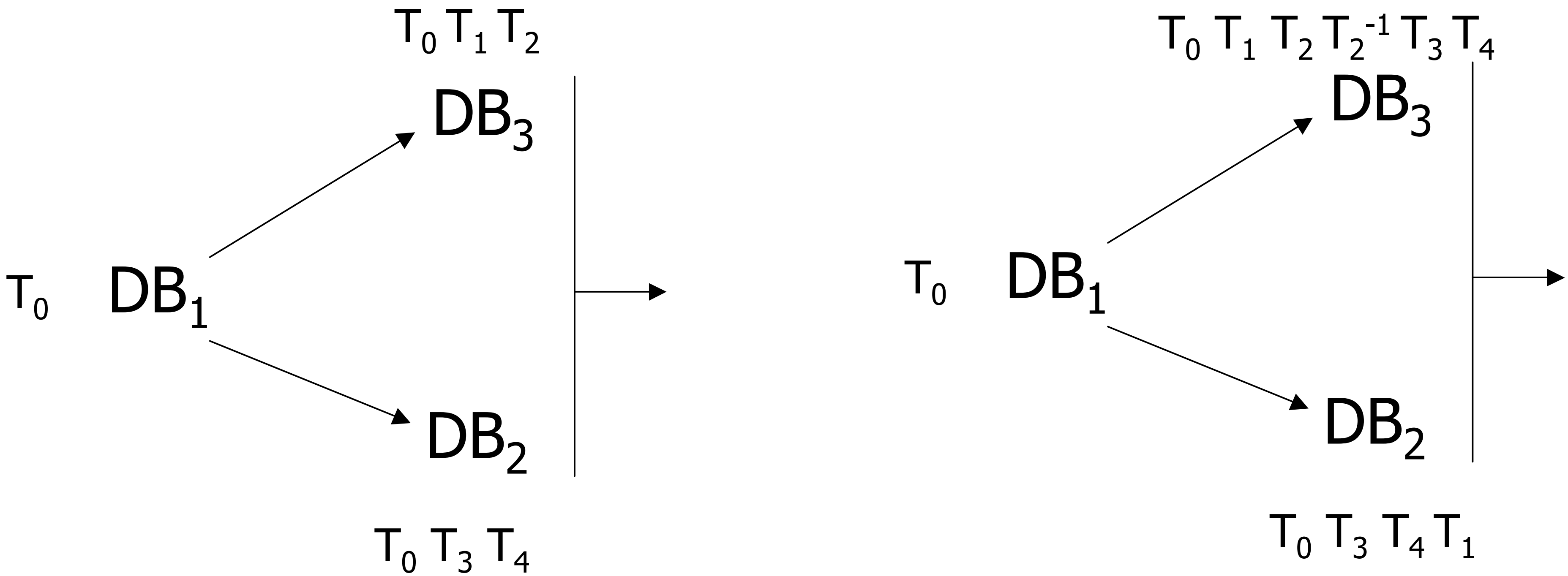
Separate Operational Groups



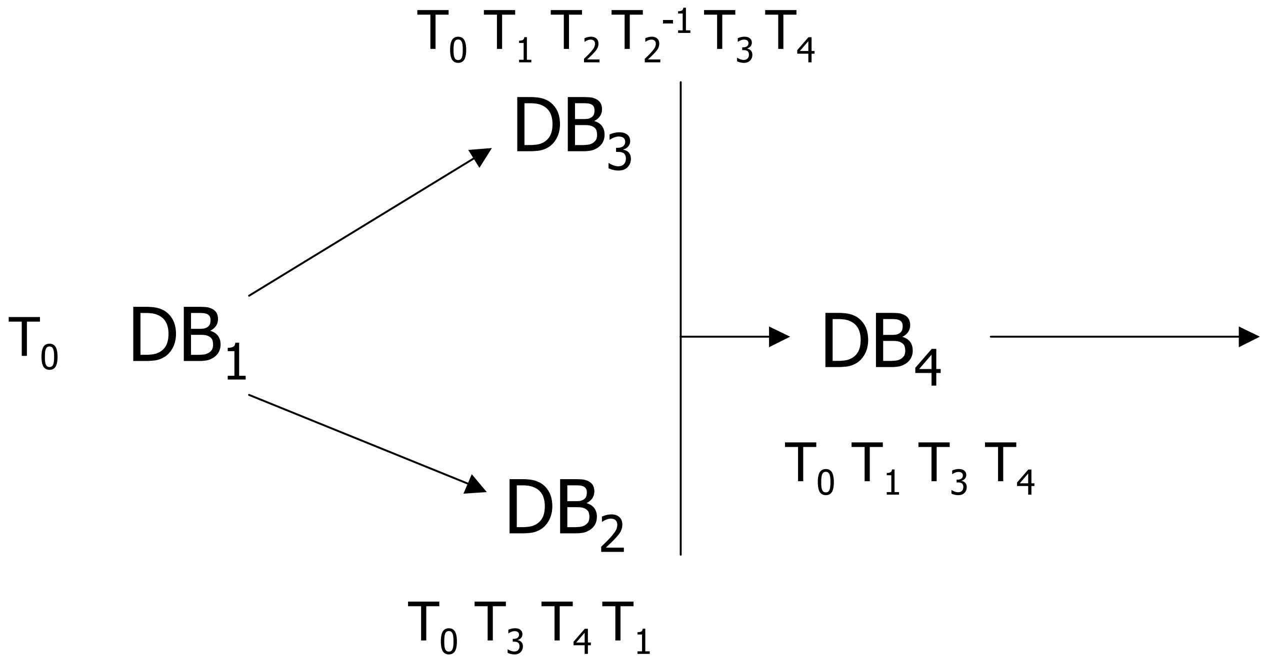
Integrating Diverged DBs

1. Compensate transactions to make schedules equivalent
2. Data-patch: semantic fix

Compensation Example



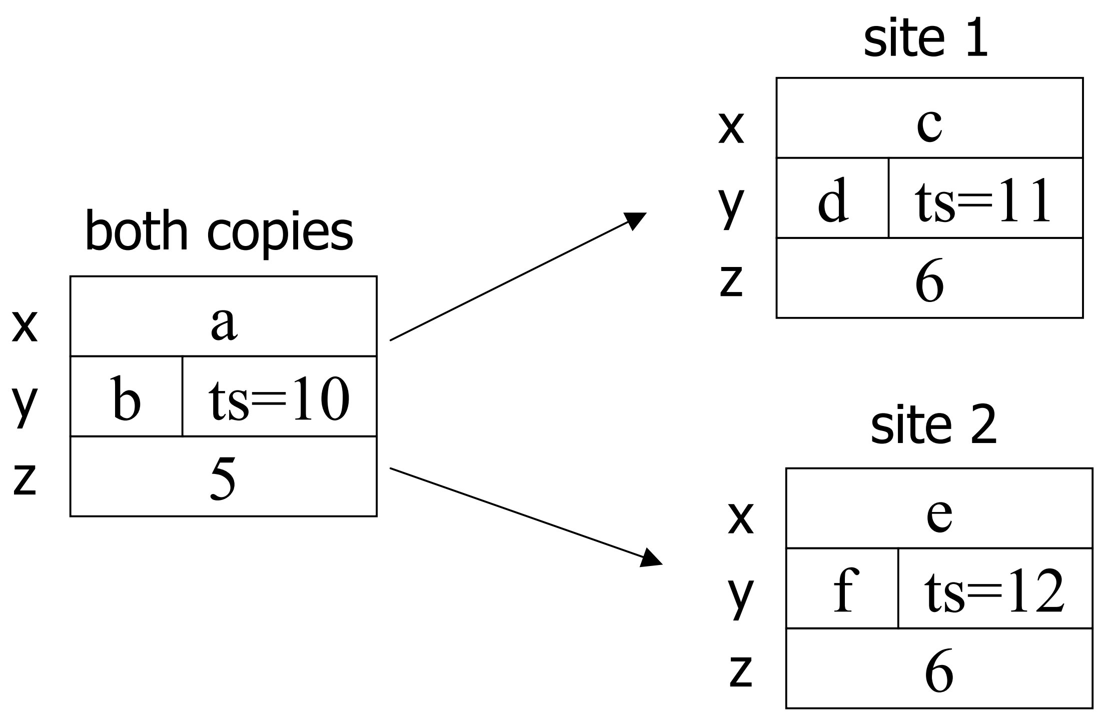
- Assume T_1 commutes with T_3 and T_4 (for example, no conflicting operations)
- Also assume that it is possible to come up with T_2^{-1} to undo the effect of T_2 on the database.



<u>In general:</u> Based on the characteristics of transactions, can "merge" schedules

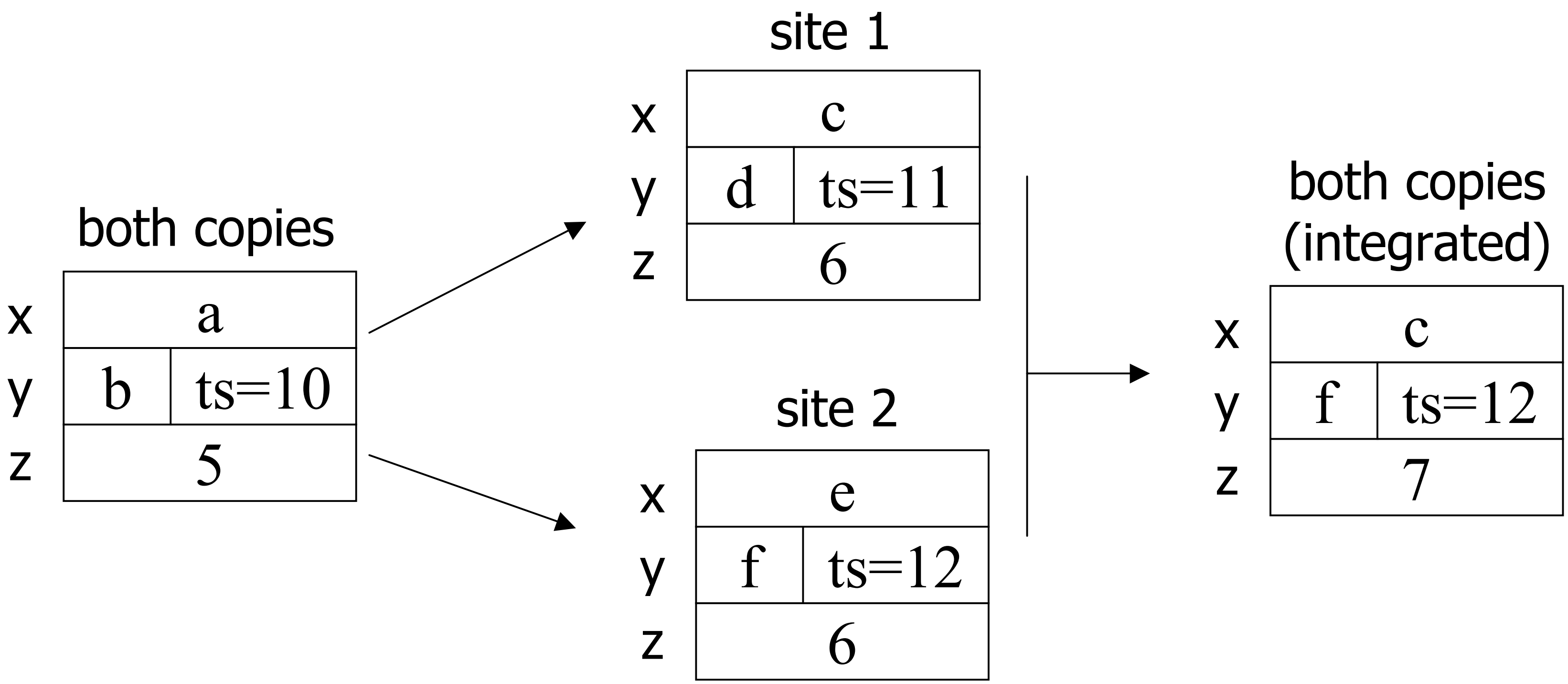
Data Patch Example

- Forget schedules
- Integrate differing values via human-supplied "rules"



Rules

For X: site 1 wins
For Y: latest timestamp wins
For Z: add increments



for Z: 7 = 5 + site 1 increment + site 2 increment
= 5 + 1 + 1

Resources

- “Concurrency Control and Recovery” by Bernstein, Hardzilacos, and Goodman
  - Available at http://research.microsoft.com/pubs/ccontrol/