Figure 13.1 Distributed transactions

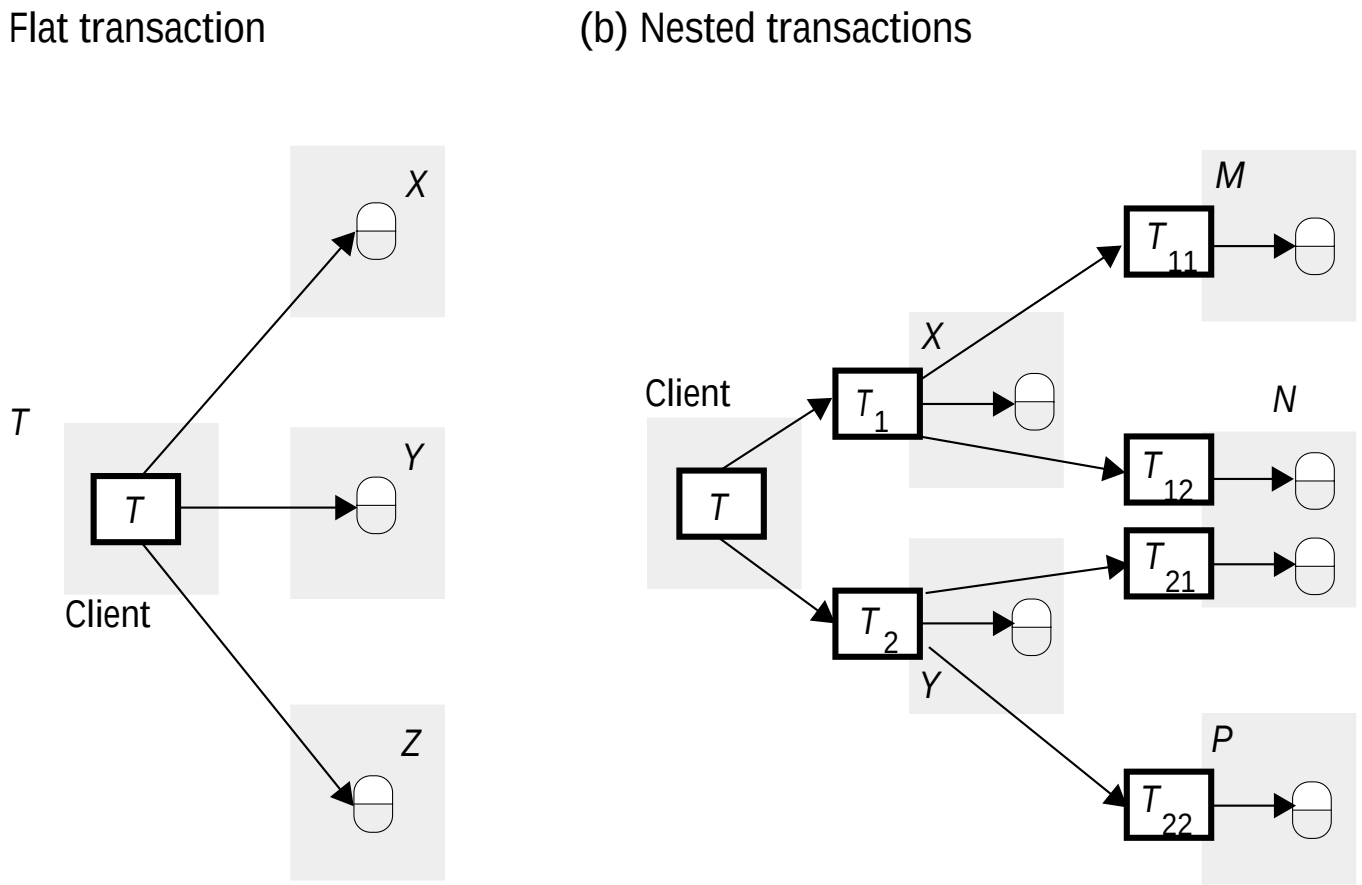


Figure 13.2 Nested banking transaction

```
T = openTransaction
      openSubTransaction
         a.withdraw(10);
      openSubTransaction
         b.withdraw(20);
      openSubTransaction
         c.deposit(10);
      openSubTransaction
         d.deposit(20);
      closeTransaction
```

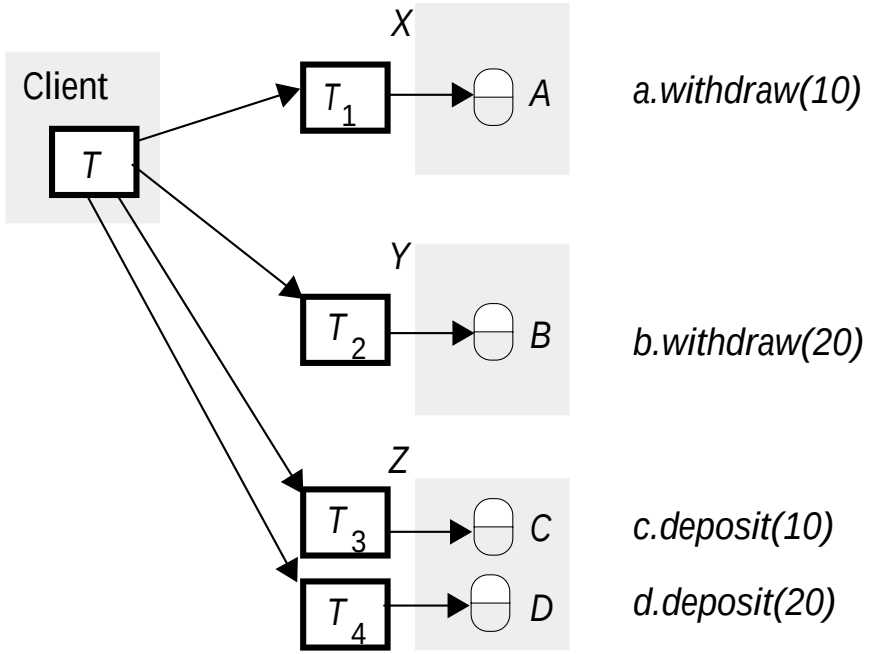
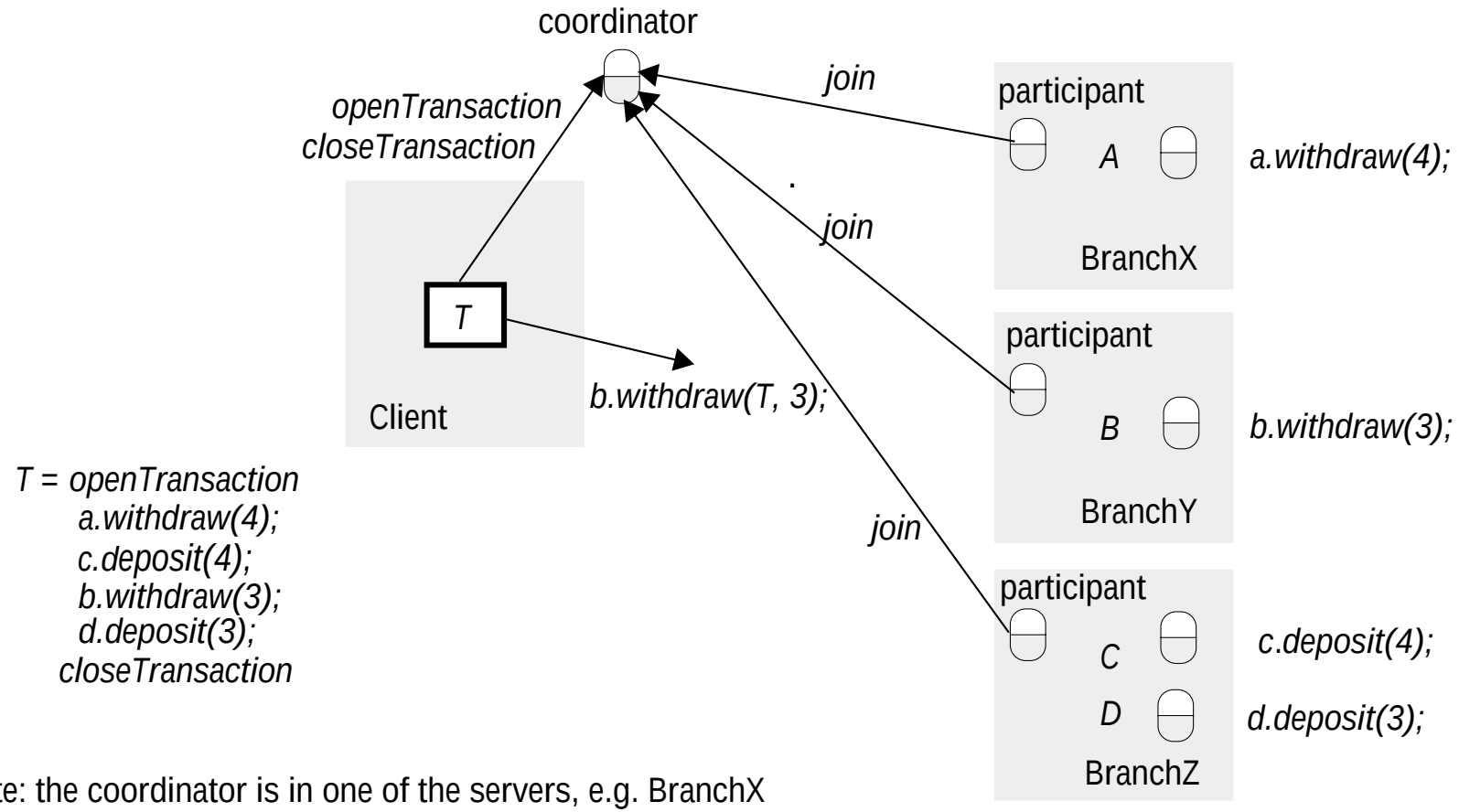


Figure 13.3 A distributed banking transaction




*T = openTransaction*
*a.withdraw(4);*
*c.deposit(4);*
*b.withdraw(3);*
*d.deposit(3);*
*closeTransaction*

Note: the coordinator is in one of the servers, e.g. BranchX

Figure 13.4 Operations for two-phase commit protocol

*canCommit?(trans)→ Yes / No*

Call from coordinator to participant to ask whether it can commit a transaction. Participant replies with its vote.

*doCommit(trans)*

Call from coordinator to participant to tell participant to commit its part of a transaction.

*doAbort(trans)*

Call from coordinator to participant to tell participant to abort its part of a transaction.

*haveCommitted(trans, participant)*

Call from participant to coordinator to confirm that it has committed the transaction.

*getDecision(trans) → Yes / No*

Call from participant to coordinator to ask for the decision on a transaction after it has voted *Yes* but has still had no reply after some delay. Used to recover from server crash or delayed messages.

Figure 13.5 The two-phase commit protocol

*Phase 1 (voting phase):*

1. The coordinator sends a *canCommit?* request to each of the participants in the transaction.

2. When a participant receives a *canCommit?* request it replies with its vote (*Yes* or *No*) to the coordinator. Before voting *Yes*, it prepares to commit by saving objects in permanent storage. If the vote is *No* the participant aborts immediately.

*Phase 2 (completion according to outcome of vote):*

3. The coordinator collects the votes (including its own).

   (a) If there are no failures and all the votes are *Yes* the coordinator decides to commit the transaction and sends a *doCommit* request to each of the participants.

   (b) Otherwise the coordinator decides to abort the transaction and sends *doAbort* requests to all participants that voted *Yes*.

4. Participants that voted *Yes* are waiting for a *doCommit* or *doAbort* request from the coordinator. When a participant receives one of these messages it acts accordingly and in the case of commit, makes a *haveCommitted* call as confirmation to the coordinator.

Figure 13.6 Communication in two-phase commit protocol

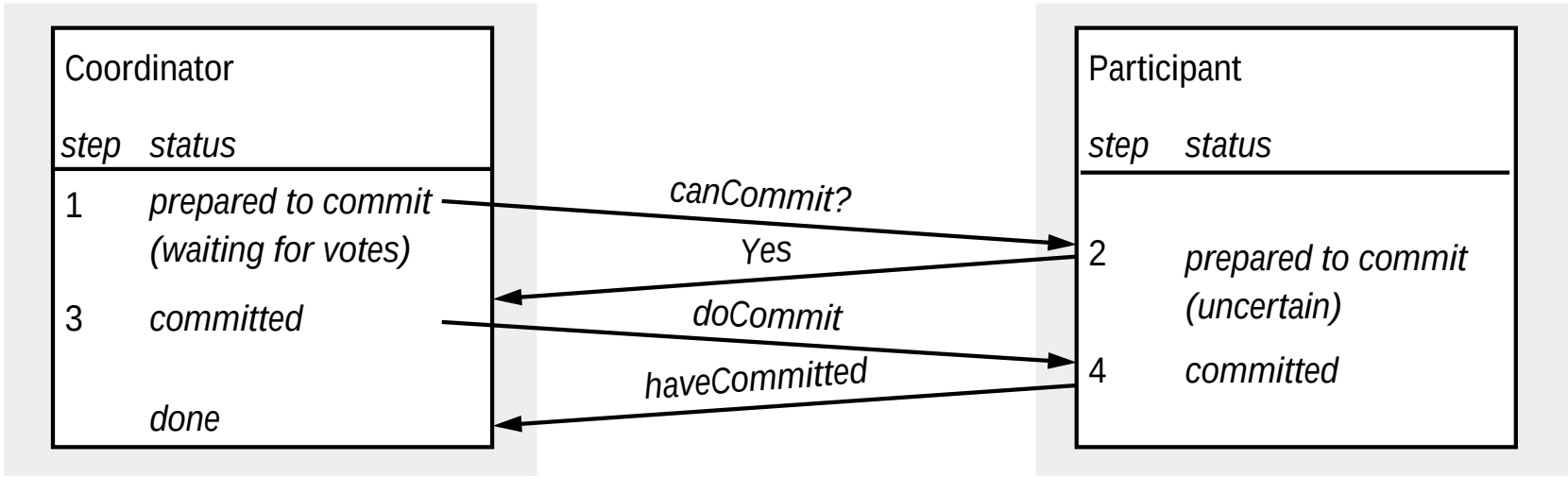


Figure 13.7 Operations in coordinator for nested transactions

*openSubTransaction(trans)* $\rightarrow$ *subTrans*

Opens a new subtransaction whose parent is *trans* and returns a unique subtransaction identifier.

*getStatus(trans)*$\rightarrow$ *committed, aborted, provisional*

Asks the coordinator to report on the status of the transaction *trans*. Returns values representing one of the following: *committed*, *aborted*, *provisional*.

Figure 13.8 Transaction *T* decides whether to commit

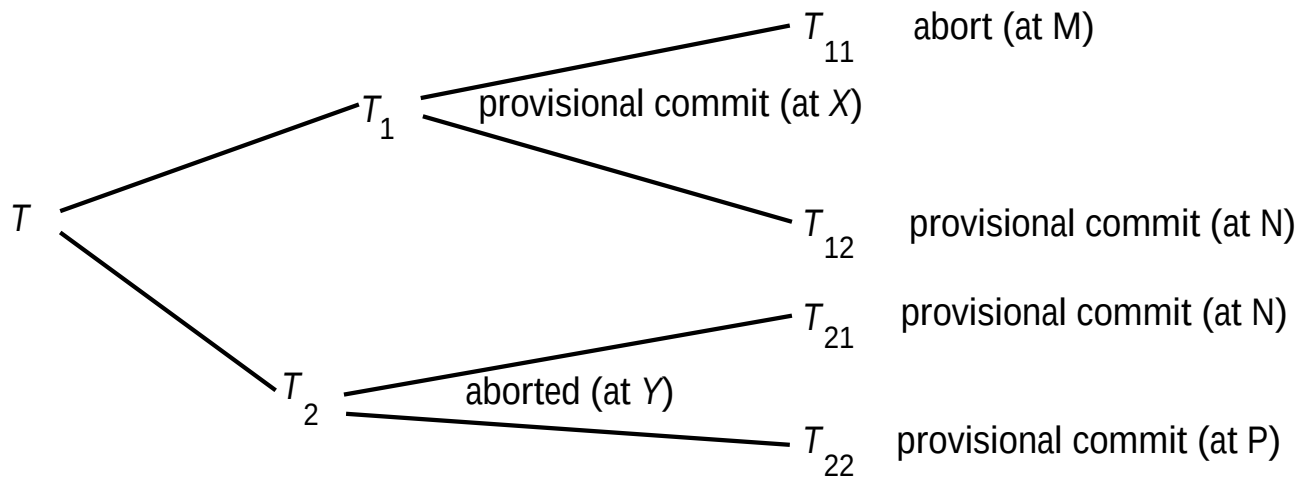


Figure 13.9 Information held by coordinators of nested transactions:

| *Coordinator of transaction* | *Child transactions* | *Participant* | *Provisional commit list* | *Abort list* |
|---|---|---|---|---|
| $T$ | $T_1$, $T_2$ | yes | $T_1$, $T_{12}$ | $T_{11}$, $T_2$ |
| $T_1$ | $T_{11}$, $T_{12}$ | yes | $T_1$, $T_{12}$ | $T_{11}$ |
| $T_2$ | $T_{21}$, $T_{22}$ | no (aborted) | | $T_2$ |
| $T_{11}$ | | no (aborted) | | $T_{11}$ |
| $T_{12}$, $T_{21}$ | | $T_{12}$ but not $T_{21}$ | $T_{21}$, $T_{12}$ | |
| $T_{22}$ | | no (parent aborted) | $T_{22}$ | |

Figure 13.10 *canCommit?* for hierarchic two-phase commit protocol

*canCommit?(trans, subTrans)* → *Yes / No*

Call a coordinator to ask coordinator of child subtransaction whether it can commit a subtransaction *subTrans*. The first argument *trans* is the transaction identifier of top-level transaction. Participant replies with its vote *Yes / No.*

Figure 13.11 *canCommit?* for flat two-phase commit protocol

*canCommit?(trans, abortList)* → *Yes / No*

Call from coordinator to participant to ask whether it can commit a transaction. Participant replies with its vote *Yes / No.*

Figure 13.12 Interleavings of transactions *U*, *V* and *W*

| *U* | | *V* | | *W* | |
|---|---|---|---|---|---|
| *d.deposit(10)* | lock *D* | | | | |
| | | *b.deposit(10)* | lock *B* | | |
| *a.deposit(20)* | lock *A* | | at *Y* | | |
| | at *X* | | | | |
| | | | | *c.deposit(30)* | lock *C* |
| *b.withdraw(30)* | wait at *Y* | | | | at *Z* |
| | | *c.withdraw(20)* | wait at *Z* | | |
| | | | | *a.withdraw(20)* | wait at *X* |

Figure 13.13 Distributed deadlock

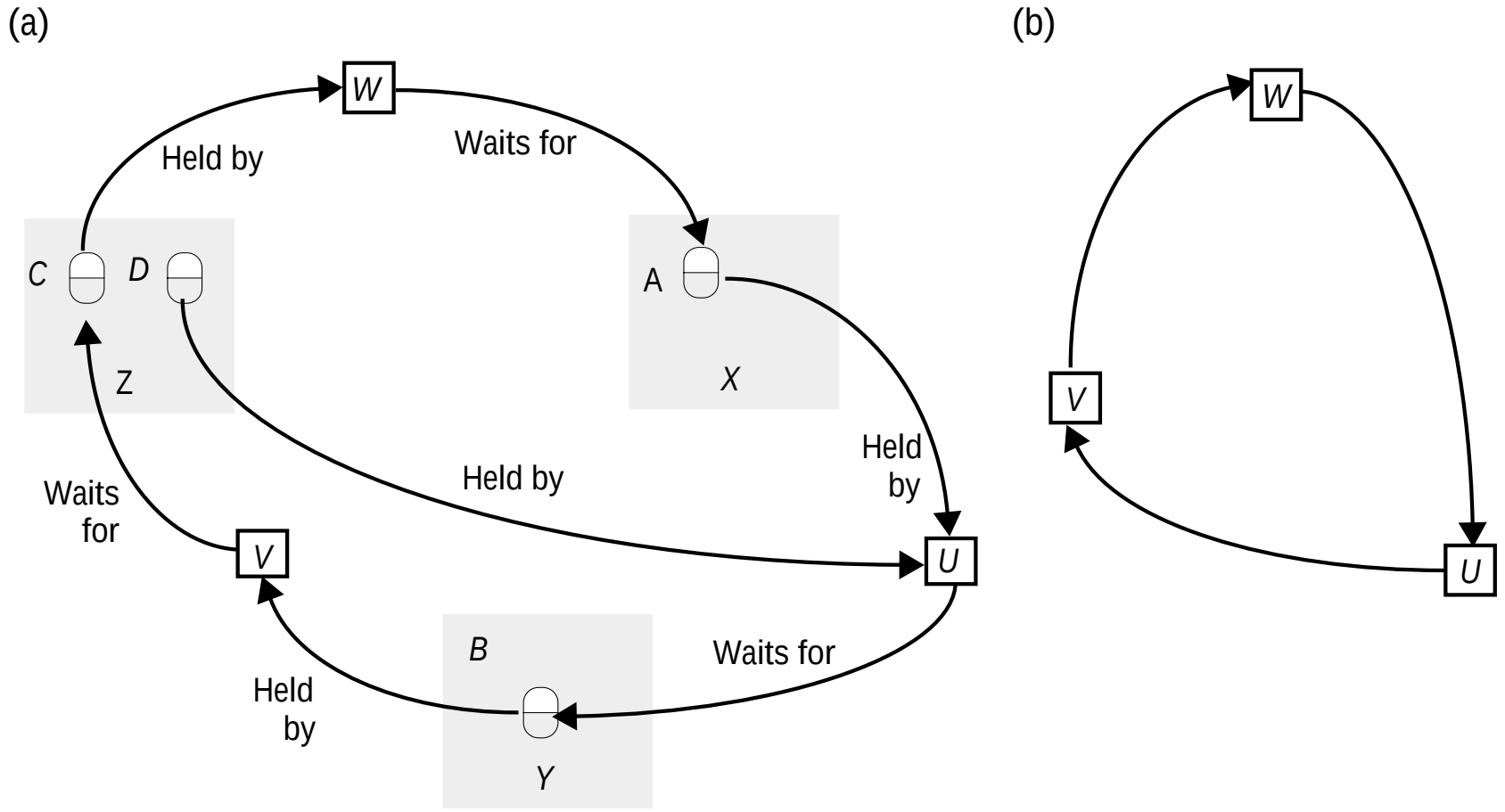


Figure 13.14 Local and global wait-for graphs

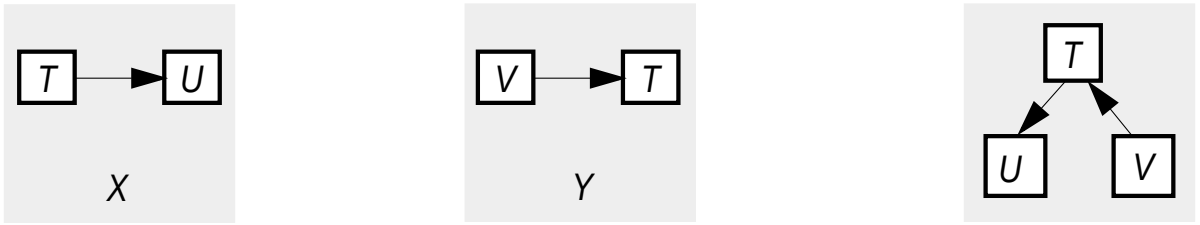


Figure 13.15 Probes transmitted to detect deadlock

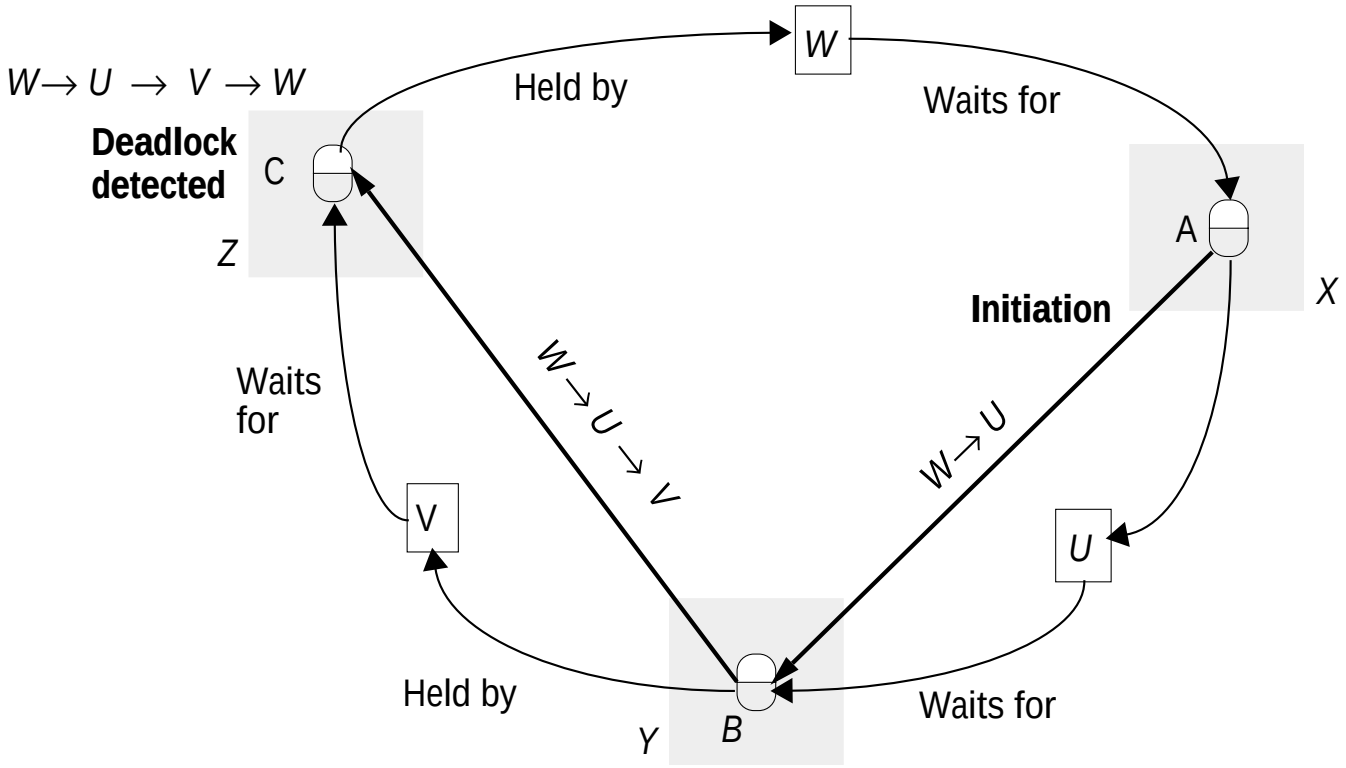


Figure 13.16 Two probes initiated

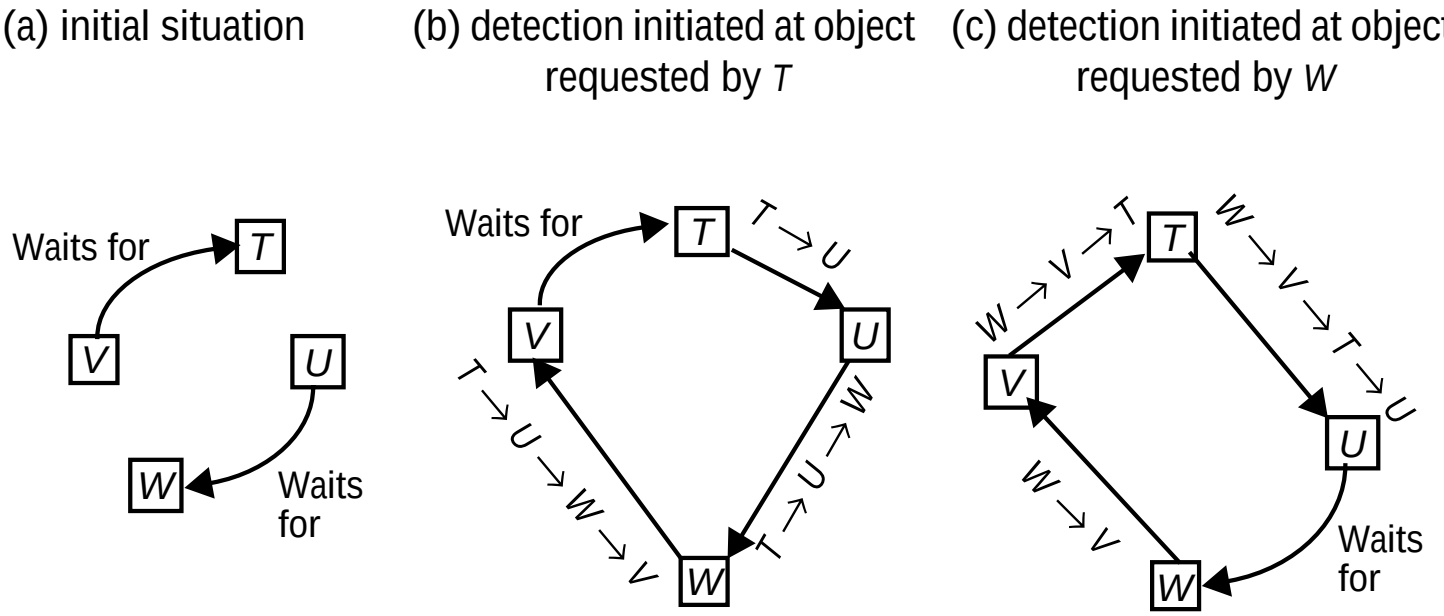


Figure 13.17 Probes travel downhill

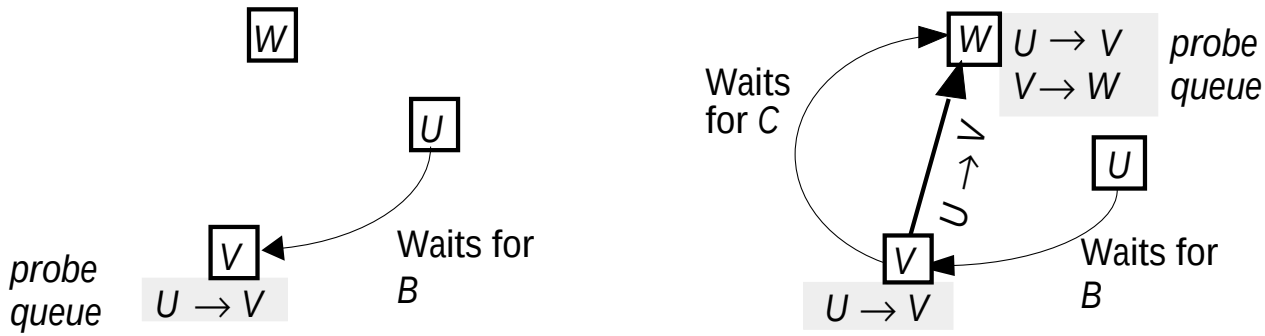


Figure 13.18 Types of entry in a recovery file

| *Type of entry* | *Description of contents of entry* |
|---|---|
| Object | A value of an object. |
| Transaction status | Transaction identifier, transaction status (*prepared*, *committed*, *aborted*) – and other status values used for the two-phase commit protocol. |
| Intentions list | Transaction identifier and a sequence of intentions, each of which consists of <identifier of object>, <position in recovery file of value of object>. |

Figure 13.19 Log for banking service

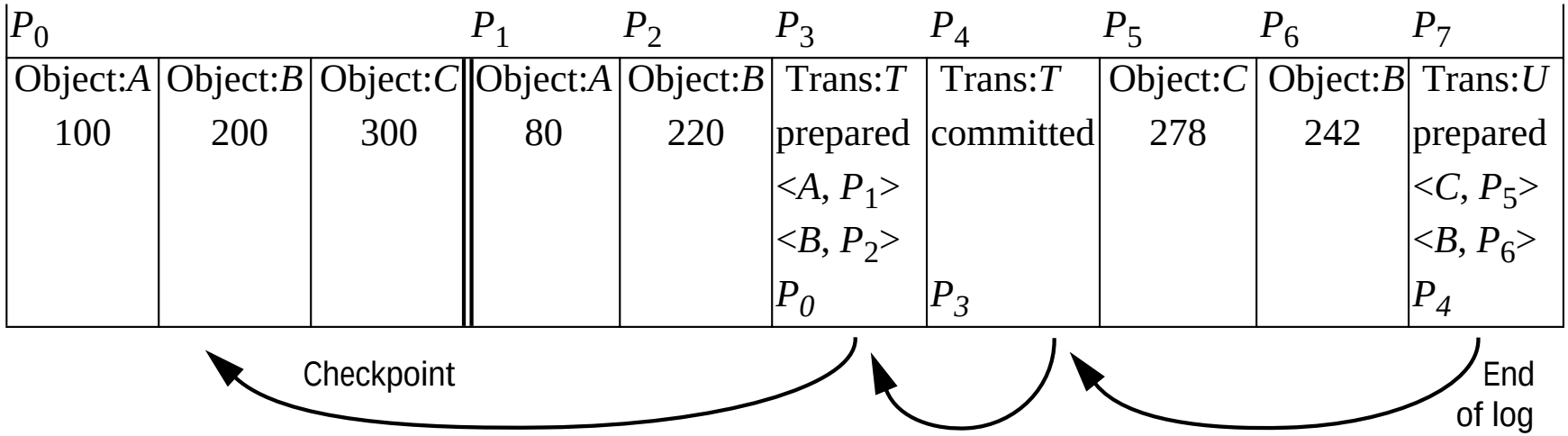


Figure 13.20 Shadow versions

| *Map at start* | *Map when T commits* |
|---|---|
| $A \rightarrow P_0$ | $A \rightarrow P_1$ |
| $B \rightarrow P_0'$ | $B \rightarrow P_2$ |
| $C \rightarrow P_0''$ | $C \rightarrow P_0''$ |

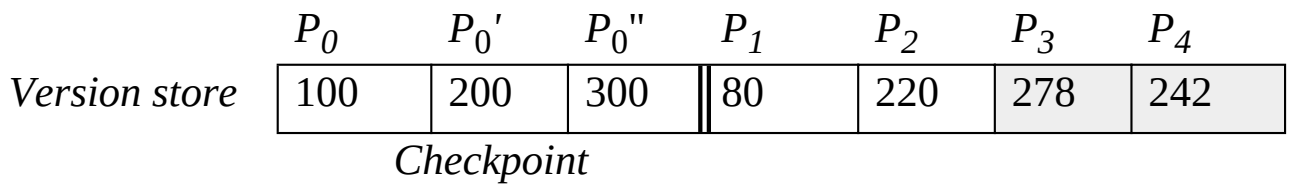


Figure 13.21 Log with entries relating to two-phase commit protocol

| | Trans:*T* | Coord'r:*T* | • |
|---|---|---|---|
| | prepared | part'pant list: . . . | |
| | intentions list | | |

| • | Trans:*T* | Trans:*U* | • |
|---|---|---|---|
| | committed | prepared | |
| | | intentions list | |

| • | Part'pant:*U* | Trans:*U* | Trans:*U* | |
|---|---|---|---|---|
| | Coord'r: . . . | uncertain | committed | |

Figure 13.22 Recovery of the two-phase commit protocol

| *Role* | *Status* | *Action of recovery manager* |
|---|---|---|
| Coordinator | *prepared* | No decision had been reached before the server failed. It sends *abortTransaction* to all the servers in the participant list and adds the transaction status *aborted* in its recovery file. Same action for state *aborted*. If there is no participant list, the participants will eventually timeout and abort the transaction. |
| Coordinator | *committed* | A decision to commit had been reached before the server failed. It sends a *doCommit* to all the participants in its participant list (in case it had not done so before) and resumes the two-phase protocol at step 4 (Fig 13.5). |
| Participant | *committed* | The participant sends a *haveCommitted* message to the coordinator (in case this was not done before it failed). This will allow the coordinator to discard information about this transaction at the next checkpoint. |
| Participant | *uncertain* | The participant failed before it knew the outcome of the transaction. It cannot determine the status of the transaction until the coordinator informs it of the decision. It will send a *getDecision* to the coordinator to determine the status of the transaction. When it receives the reply it will commit or abort accordingly. |
| Participant | *prepared* | The participant has not yet voted and can abort the transaction. |
| Coordinator | *done* | No action is required. |

Figure 13.23 Nested transactions