Figure 12.1 Operations of the *Account* interface

deposit(amount)
deposit *amount* in the account

withdraw(amount)
withdraw *amount* from the account

getBalance() → *amount*
return the balance of the account

setBalance(amount)
set the balance of the account to *amount*

Operations of the *Branch* interface

create(name) → *account*
create a new account with a given name

lookUp(name) → *account*
return a reference to the account with the given name

branchTotal() → *amount*
return the total of all the balances at the branch

Figure 12.2 A client's banking transaction

```
Transaction T:
a.withdraw(100);
b.deposit(100);
c.withdraw(200);
b.deposit(200);
```

Figure 12.3 Operations in *Coordinator* interface

openTransaction() $\rightarrow$ *trans;*

starts a new transaction and delivers a unique TID *trans*. This identifier will be used in the other operations in the transaction.

closeTransaction(trans) $\rightarrow$ *(commit, abort);*

ends a transaction: a *commit* return value indicates that the transaction has committed; an *abort* return value indicates that it has aborted.

abortTransaction(trans);

aborts the transaction.

Figure 12.4 Transaction life histories

Successful	*Aborted by client*		*Aborted by server*
openTransaction	*openTransaction*		*openTransaction*
operation	*operation*		*operation*
operation	*operation*		*operation*
•	•	server aborts	•
•	•	transaction →	•
operation	*operation*		*operation ERROR*
			reported to client
closeTransaction	*abortTransaction*		

Figure 12.5 The lost update problem

Transaction *T*:		**Transaction *U*:**	
balance = b.getBalance(); *b.setBalance(balance*1.1);* *a.withdraw(balance/10)*		*balance = b.getBalance();* *b.setBalance(balance*1.1);* *c.withdraw(balance/10)*	
balance = b.getBalance();	$200		
		balance = b.getBalance();	$200
		*b.setBalance(balance*1.1);*	$220
*b.setBalance(balance*1.1);*	$220		
a.withdraw(balance/10)	$80		
		c.withdraw(balance/10)	$280

Figure 12.6 The inconsistent retrievals problem

Transaction *V*:		**Transaction *W*:**	
a.withdraw(100)		*aBranch.branchTotal()*	
b.deposit(100)			
a.withdraw(100);	$100		
		total = a.getBalance( )	$100
		total = total + b.getBalance()	$300
		total = total + c.getBalance()	
b.deposit(100)	$300	•	
		•	

Figure 12.7 A serially equivalent interleaving of *T* and *U*

Transaction *T*:		**Transaction *U*:**	
balance = b.getBalance()		*balance = b.getBalance()*	
*b.setBalance(balance*1.1)*		*b.setBalance(balance*1.1)*	
a.withdraw(balance/10)		*c.withdraw(balance/10)*	
balance = b.getBalance()	$200		
*b.setBalance(balance*1.1)*	$220		
		balance = b.getBalance()	$220
		*b.setBalance(balance*1.1)*	$242
a.withdraw(balance/10)	$80		
		c.withdraw(balance/10)	$278

Figure 12.8 A serially equivalent interleaving of *V* and *W*

Transaction *V*:		**Transaction *W*:**	
a.withdraw(100); *b.deposit(100)*		*aBranch.branchTotal( )*	
a.withdraw(100);	$100		
b.deposit(100)	$300		
		total = a.getBalance( )	$100
		total = total + b.getBalance()	$400
		total = total + c.getBalance()	
		...	

Figure 12.9 *Read* and *write* operation conflict rules

Operations of different transactions		*Conflict*	*Reason*
read	*read*	No	Because the effect of a pair of *read* operations does not depend on the order in which they are executed
read	*write*	Yes	Because the effect of a *read* and a *write* operation depends on the order of their execution
write	*write*	Yes	Because the effect of a pair of *write* operations depends on the order of their execution

Figure 12.10 A non-serially equivalent interleaving of operations of transactions *T* and *U*

Transaction *T*:	**Transaction *U*:**
x = read(i)	
write(i, 10)	
	y = read(j)
	write(j, 30)
write(j, 20)	
	z = read (i)

Figure 12.11 A dirty read when transaction *T* aborts

Transaction *T*:		**Transaction *U*:**	
a.getBalance()		*a.getBalance()*	
a.setBalance(balance + 10)		*a.setBalance(balance + 20)*	
balance = a.getBalance()	$100		
a.setBalance(balance + 10)	$110		
		balance = a.getBalance()	$110
		a.setBalance(balance + 20)	$130
		commit transaction	
abort transaction			

Figure 12.12 Overwriting uncommitted values

Transaction *T*:		**Transaction *U*:**	
a.setBalance(105)		*a.setBalance(110)*	
	$100		
a.setBalance(105)	$105		
		a.setBalance(110)	$110

Figure 12.13 Nested transactions

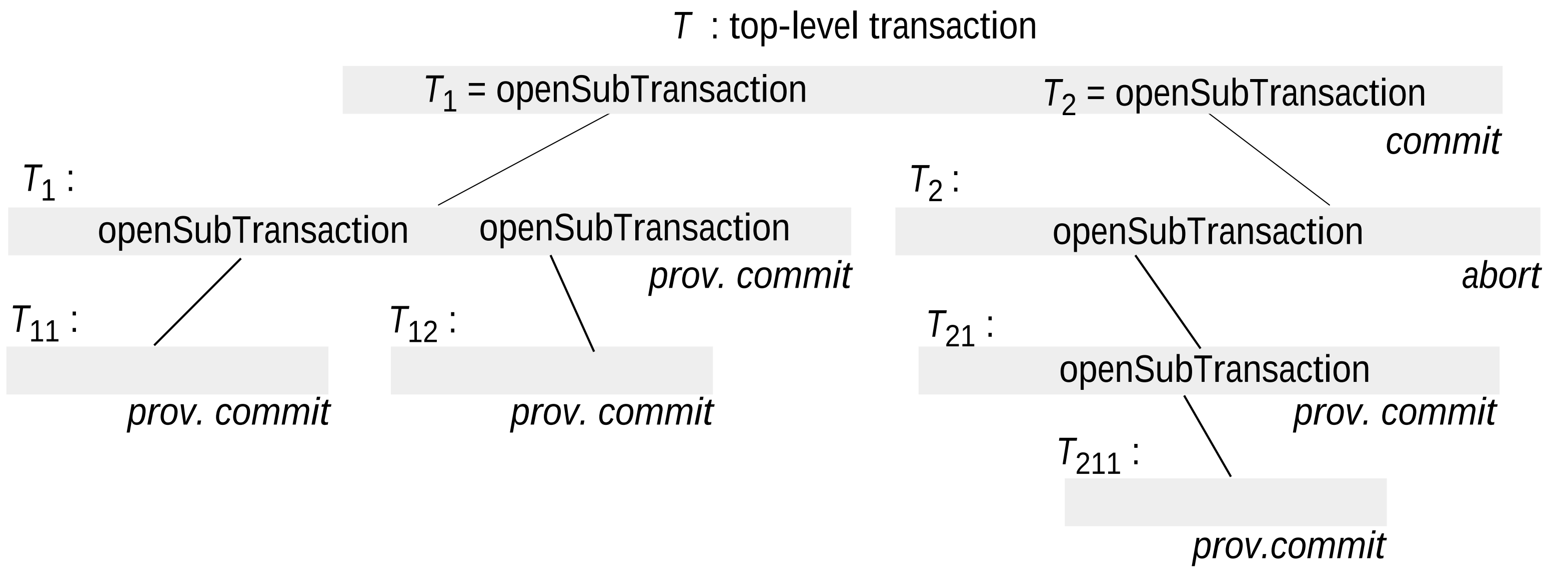


Figure 12.14 Transactions *T* and *U* with exclusive locks

Transaction *T*:		**Transaction *U*:**	
balance = b.getBalance()		*balance = b.getBalance()*	
*b.setBalance(bal*1.1)*		*b.setBalance(bal*1.1)*	
a.withdraw(bal/10)		*c.withdraw(bal/10)*	
Operations	Locks	Operations	Locks
openTransaction			
bal = b.getBalance()	lock *B*		
*b.setBalance(bal*1.1)*		*openTransaction*	
a.withdraw(bal/10)	lock *A*	*bal = b.getBalance()*	waits for *T*'s lock on *B*
closeTransaction	unlock *A*, *B*	• • •	
			lock *B*
		*b.setBalance(bal*1.1)*	
		c.withdraw(bal/10)	lock *C*
		closeTransaction	unlock *B*, *C*

Figure 12.15 Lock compatibility

For one object		*Lock requested*	
		read	*write*
Lock already set	*none*	OK	OK
	read	OK	wait
	write	wait	wait

Figure 12.16 Use of locks in strict two-phase locking

1. When an operation accesses an object within a transaction:
   (a) If the object is not already locked, it is locked and the operation proceeds.
   (b) If the object has a conflicting lock set by another transaction, the transaction must wait until it is unlocked.
   (c) If the object has a non-conflicting lock set by another transaction, the lock is shared and the operation proceeds.
   (d) If the object has already been locked in the same transaction, the lock will be promoted if necessary and the operation proceeds. (Where promotion is prevented by a conflicting lock, rule (b) is used.)
2. When a transaction is committed or aborted, the server unlocks all objects it locked for the transaction.

Figure 12.17 Lock class

```
public class Lock {
    private Object object;        // the object being protected by the lock
    private Vector holders;       // the TIDs of current holders
    private LockType lockType;  // the current type

    public synchronized void acquire(TransID trans,   LockType aLockType ){
        while(/*another transaction holds the lock in conflicing mode*/) {
            try {
                wait();
            }catch ( InterruptedException e){/*...*/ }
        }
        if(holders.isEmpty()) { // no TIDs  hold lock
            holders.addElement(trans);
            lockType  = aLockType;
        } else if(/*another transaction holds the lock, share it*/ ) ){
            if(/* this transaction not a holder*/) holders.addElement(trans);
        } else if (/* this transaction is a holder but needs a more exclusive lock*/)
                lockType.promote();
        }
    }
```

// this figure continues on the next slide

Figure 12.17 continued

```
public synchronized void release(TransID trans ){
        holders.removeElement(trans);    // remove this holder
        // set locktype to none
        notifyAll();
    }
}
```

igure 12.18 *LockManager* class

```
public class LockManager {
    private Hashtable theLocks;

    public  void setLock(Object object, TransID trans,  LockType lockType){
        Lock foundLock;
        synchronized(this){
                // find the lock associated with object
                // if there isn't one, create it and add to the hashtable
            }
         foundLock.acquire(trans, lockType);
    }

   // synchronize this one because we want to remove all entries
    public synchronized void unLock(TransID trans) {
        Enumeration e = theLocks.elements();
        while(e.hasMoreElements()){
            Lock aLock = (Lock)(e.nextElement());
            if(/* trans is a holder of this lock*/ ) aLock.release(trans);
         }
    }
}
```

Figure 12.19 Deadlock with write locks

Transaction *T*		**Transaction *U***	
Operations	Locks	Operations	Locks
a.deposit(100);	write lock *A*		
		b.deposit(200)	write lock *B*
b.withdraw(100)			
•••	waits for *U*'s	*a.withdraw(200);*	waits for *T*'s
	lock on *B*	•••	lock on *A*
•••		•••	
•••		•••	

Figure 12.20 The wait-for graph for Figure 12.19

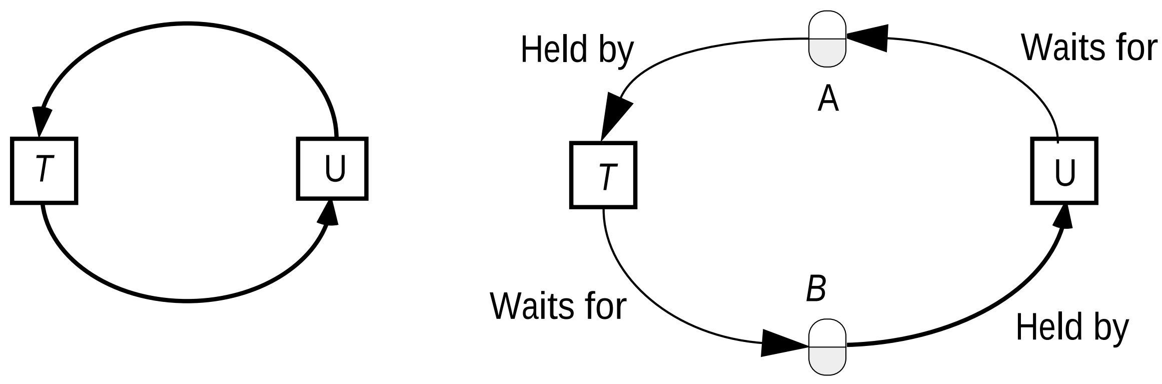


Figure 12.21 A cycle in a wait-for graph

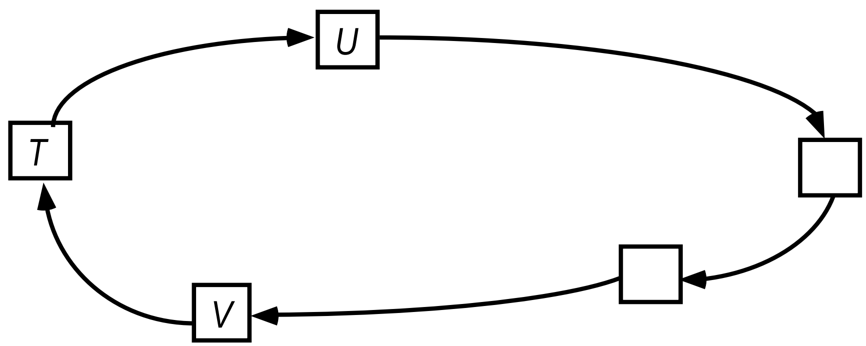


Figure 12.22 Another wait-for graph

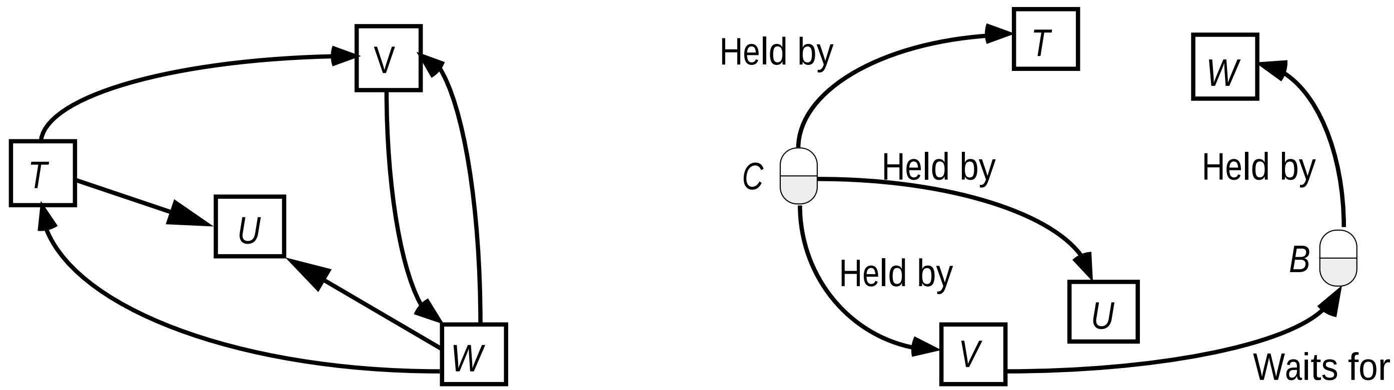


Figure 12.23 Resolution of the deadlock in Figure 12.19

Transaction T		**Transaction U**	
Operations	Locks	Operations	Locks
a.deposit(100);	write lock *A*		
		b.deposit(200)	write lock *B*
b.withdraw(100)			
•••	waits for *U*'s	*a.withdraw(200);*	waits for T's
	lock on *B*	•••	lock on *A*
	(timeout elapses)	•••	
T's lock on *A* becomes vulnerable, unlock *A*, abort T			
		a.withdraw(200);	write locks *A*
			unlock *A*, *B*

Figure 12.24 Lock compatibility (*read*, *write* and *commit* locks)

For one object		*Lock to be set*		
		read	*write*	*commit*
Lock already set	*none*	OK	OK	OK
	read	OK	OK	wait
	write	OK	wait	–
	commit	wait	wait	–

Figure 12.25 Lock hierarchy for the banking example

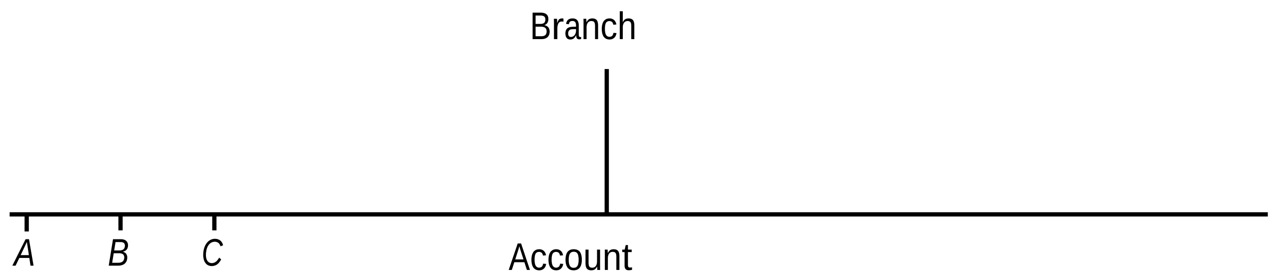


Figure 12.26 Lock hierarchy for a diary

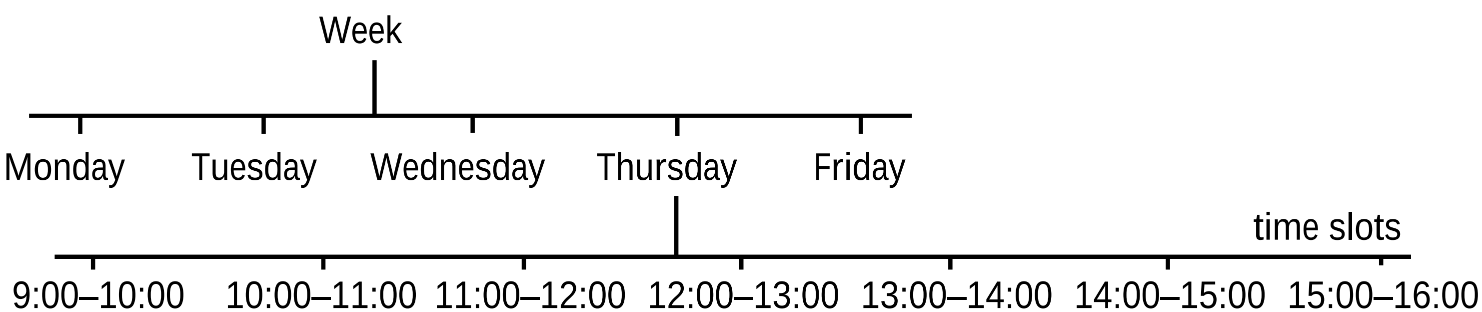


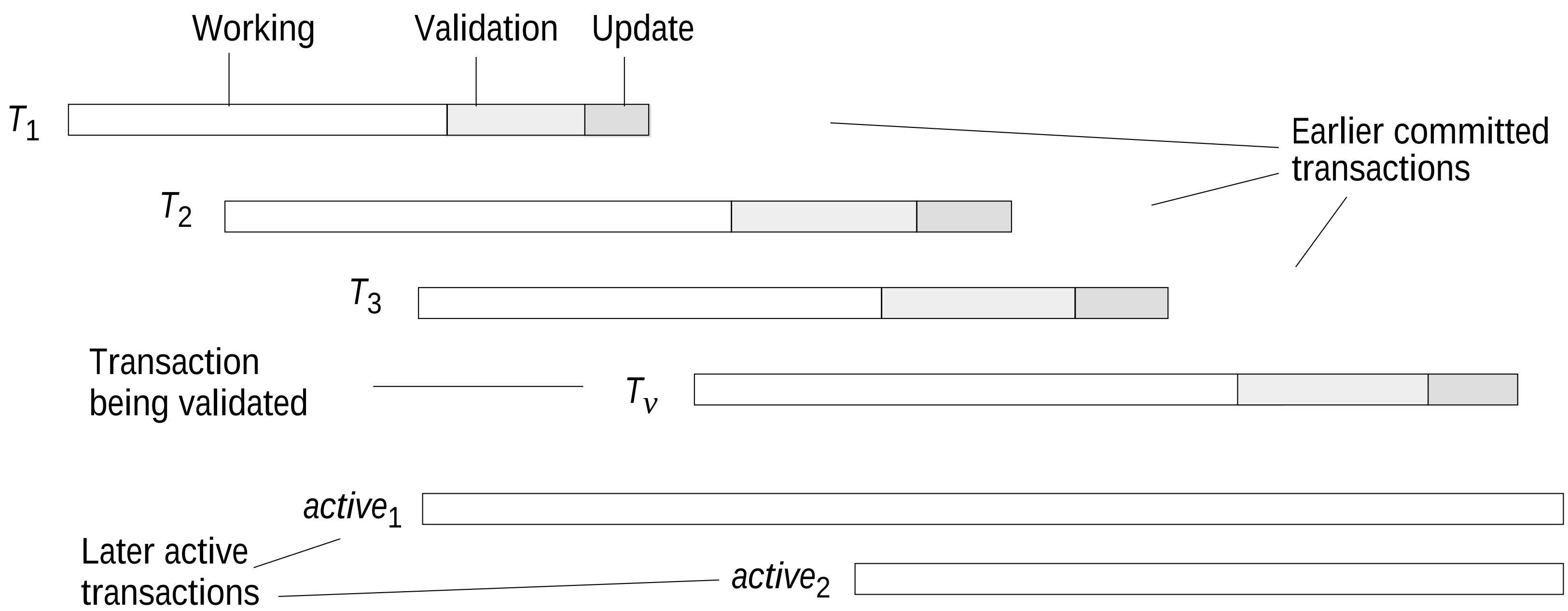
Figure 12.27 Lock compatibility table for hierarchic locks

For one object		*Lock to be set*			
		read	*write*	*I-read*	*I-write*
Lock already set	*none*	OK	OK	OK	OK
	read	OK	wait	OK	wait
	write	wait	wait	wait	wait
	I-read	OK	wait	OK	OK
	I-write	wait	wait	OK	OK

Serializability of transaction T with respect to transaction T_i

T_v	T_i	Rule	
write	*read*	1.	T_i must not read objects written by T_v.
read	*write*	2.	T_v must not read objects written by T_i.
write	*write*	3.	T_i must not write objects written by T_v and T_v must not write objects written by T_i.

Figure 12.28 Validation of transactions



Backward validation of transaction T_v

```
boolean valid = true;
for (int Ti = startTn+1; Ti <= finishTn; Ti++){
    if (read set of Tv intersects write set of Ti) valid = false;
}
```

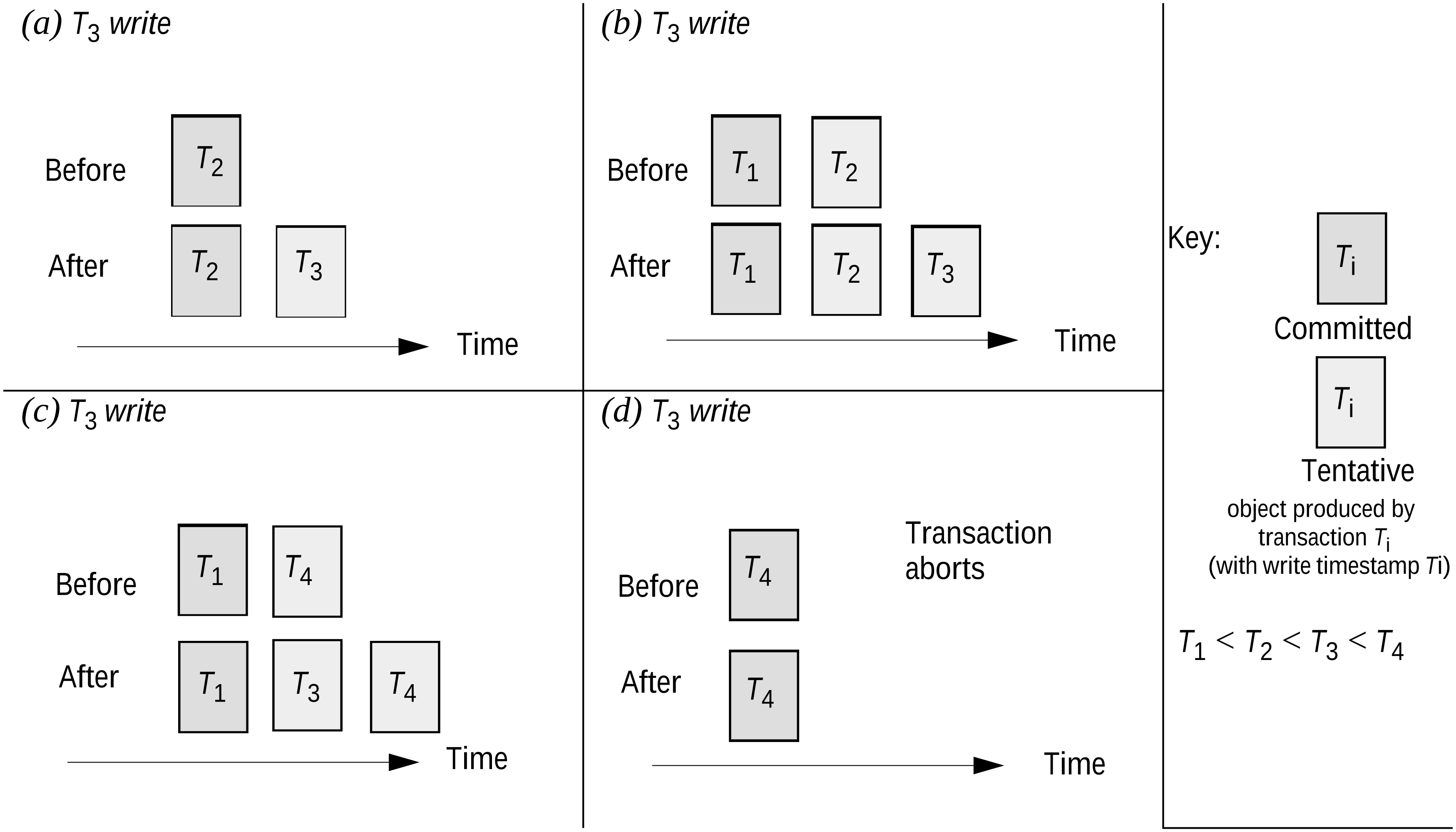
Forward validation of transaction T_v

```
boolean valid = true;
for (int Tid = active1; Tid <= activeN; Tid++){
    if (write set of Tv intersects read set of Tid) valid = false;
}
```

Figure 12.29 Operation conflicts for timestamp ordering

Rule	T_c	T_i	
1.	*write*	*read*	T_c must not *write* an object that has been *read* by any T_i where $T_i > T_c$ this requires that $T_c \geq$ the maximum read timestamp of the object.
2.	*write*	*write*	T_c must not *write* an object that has been *written* by any T_i where $T_i > T_c$ this requires that $T_c >$ write timestamp of the committed object.
3.	*read*	*write*	T_c must not *read* an object that has been *written* by any T_i where $T_i > T_c$ this requires that $T_c >$ write timestamp of the committed object.

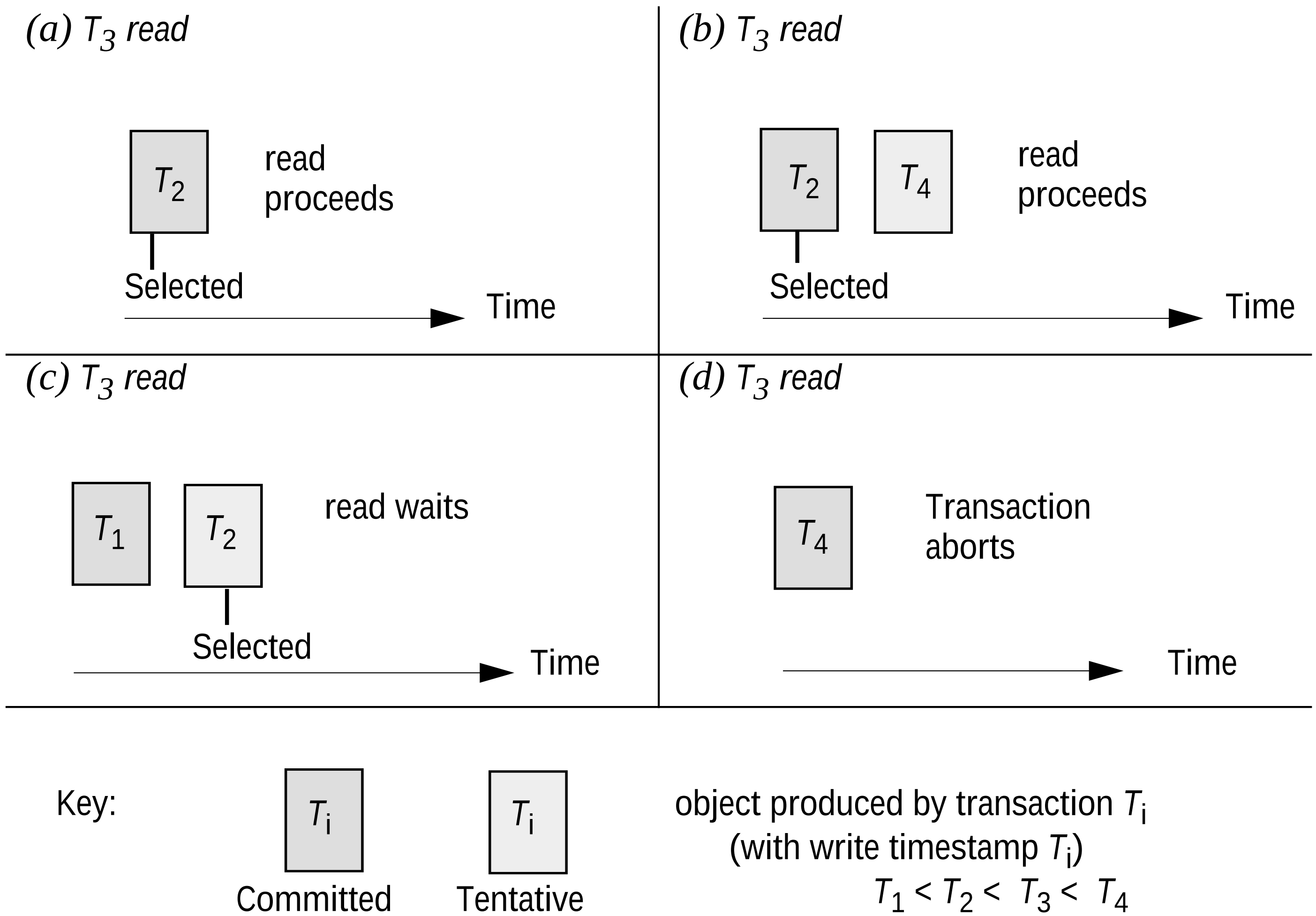
Figure 12.30 Write operations and timestamps



Timestamp ordering write rule

if ($T_c \geq$ maximum read timestamp on *D* &&
$T_c >$ write timestamp on committed version of *D*)
perform *write* operation on tentative version of *D* with write timestamp T_c
else /* write is too late */
Abort transaction T_c

Figure 12.31 *Read* operations and timestamps



Timestamp ordering read rule

if (T_c > write timestamp on committed version of D) {
  let $D_{selected}$ be the version of D with the maximum write timestamp $\leq T_c$
  if ($D_{selected}$ is committed)
    perform *read* operation on the version $D_{selected}$
  else
    Wait until the transaction that made version $D_{selected}$ commits or aborts
    then reapply the *read* rule
} else
  Abort transaction T_c

Figure 12.32 Timestamps in transactions *T* and *U*

		Timestamps and versions of objects					
T	*U*	*A*		*B*		*C*	
		RTS	*WTS*	*RTS*	*WTS*	*RTS*	*WTS*
		{}	***S***	{}	***S***	{}	***S***
openTransaction							
bal = b.getBalance()				{*T*}			
	openTransaction						
*b.setBalance(bal*1.1)*					***S***, *T*		
	bal = b.getBalance()						
	wait for T						
a.withdraw(bal/10)	•••		***S***, *T*				
commit	•••		***T***		***T***		
	bal = b.getBalance()			{*U*}			
	*b.setBalance(bal*1.1)*				***T***, *U*		
	c.withdraw(bal/10)						***S***, *U*

Figure 12.33 Late *write* operation would invalidate a *read*