TRANSACTION MANAGEMENT

RELATIONAL DATABASES

TRANSACTIONS

- TRANSACTIONS ARE A FUNDAMENTAL CONCEPT OF ALL DATABASE SYSTEMS
- TRANSACTIONS ALLOW USERS TO MAKE CHANGES TO DATA AND THEN DECIDE WHETHER TO SAVE OR DISCARD THE WORK
- DATABASE TRANSACTIONS BUNDLE MULTIPLE STEPS INTO ONE LOGICAL UNIT OF WORK

TRANSACTIONS

- A TRANSACTION CONSISTS OF ONE OF THE FOLLOWING:
  - DML STATEMENT WHICH CONSTITUTE ONE CONSISTENT CHANGE TO THE DATA
  - INSERT, UPDATE, DELETE AND MERGE
  - ONE DDL STATEMENT SUCH AS CREATE, ALTER, DROP, RENAME, OR TRUNCATE
  - ONE DCL STATEMENT SUCH AS GRANT OR REVOKE

TRANSACTIONS

- A BANK DATABASE CONTAINS BALANCES FOR VARIOUS CUSTOMER ACCOUNTS, AS WELL AS DEPOSIT BALANCES FOR OTHER BRANCHES
- A CUSTOMER WANTS TO WITHDRAW AND TRANSFER MONEY FROM HIS ACCOUNT AND DEPOSIT IT INTO ANOTHER CUSTOMER'S ACCOUNT AT A DIFFERENT BRANCH
- SEVERAL STEPS INVOLVED, BOTH BRANCHES WANT TO ENSURE ALL STEPS HAPPEN, OR NONE OF THEM HAPPEN AND IF THE SYSTEM CRASHES THE TRANSACTION IS NOT PARTIALLY COMPLETE.
- GROUPING THE WITHDRAWAL AND DEPOSIT STEPS INTO ONE TRANSACTION PROVIDES THIS GUARANTEE

TRANSACTIONS

- TRANSACTIONS ARE CONTROLLED USING THE FOLLOWING STATEMENTS:
  - COMMIT: REPRESENTS THE POINT IN TIME WHERE THE USER HAS MADE ALL THE CHANGES HE/SHE WANTS TO HAVE LOGICALLY GROUPED TOGETHER, AND BECAUSE NO MISTAKES HAVE BEEN MADE, THE USER IS READY TO SAVE THE WORK. WHEN A COMMIT STATEMENT IS ISSUED THE CURRENT TRANSACTION ENDS, MAKING ALL PENDING CHANGES PERMANENT.
  - ROLLBACK: ENABLES THE USER TO DISCARD ALL PENDING CHANGES MADE TO THE DATABASE
  - SAVEPOINT: CREATES A MARKER IN A TRANSACTION, WHICH DIVIDES IT INTO SMALLER PIECES.
  - ROLLBACK TO SAVEPOINT: ALLOWS THE USER TO ROLLBACK TO A SPECIFIED SAVEPOINT, THUS DISCARDING ONLY THOSE CHANGES MADE AFTER THE SAVEPOINT

TRANSACTIONS

- A TRANSACTION BEGINS WITH THE FIRST DML STATEMENT
  - IT ENDS WHEN ONE OF THE FOLLOWING OCCURS:
    - A COMMIT OR ROLLBACK STATEMENT IS ISSUED
    - A DDL STATEMENT IS ISSUED
    - A DCL STATEMENT IS ISSUED
    - A USER EXITS NORMALLY FROM THE DATABASE UTILITY, CAUSING THE CURRENT TRANSACTION TO BE IMPLICITLY COMMITTED.
- A DDL STATEMENT OR DCL STATEMENT IS AUTOMATICALLY COMMITTED THEREFORE IMPLICITLY ENDS A TRANSACTION
- EVERY DATA CHANGE MADE DURING A TRANSACTION IS TEMPORARY UNTIL THE TRANSACTION IS COMMITTED.

READ CONSISTENCY

- READ CONSISTENCY GUARANTEES A CONSISTENT VIEW OF THE DATA BY ALL USERS AT ALL TIMES
- READERS DO NOT VIEW DATA THAT IS IN THE PROCESS OF BEING CHANGED
- WRITERS ARE ENSURED THAT THE CHANGES TO THE DATABASE ARE DONE IN A CONSISTENT WAY
- CHANGES MADE BY ONE WRITER DO NOT DESTROY OR CONFLICT WITH CHANGES ANOTHER WRITER IS MAKING

CONCURRENCY

- READ CONSISTENCY IS AN AUTOMATIC IMPLEMENTATION
- THIS IS TO ENSURE THAT IN A MULTI USER ENVIRONMENT SUCH AS RELATIONAL DATABASE THAT TRANSACTIONS THAT ARE RUNNING AT THE SAME TIME WORKING ON THE SAME PIECES OF DATA DO NOT INTERFERE WITH EACHOTHER.

CONCURRENCY CONTROL TECHNIQUES

- TWO BASIC CONCURRENCY CONTROL TECHNIQUES ARE:
  - LOCKING
  - TIMESTAMPING
- BOTH ARE CONSERVATIVE (PESSIMISTIC) APPROACHES: DELAY TRANSACTIONS IN CASE THEY CONFLICT WITH OTHER TRANSACTIONS.
- OPTIMISTIC METHODS ASSUME CONFLICT IS RARE AND ONLY CHECK FOR CONFLICTS AT COMMIT.
  - VERSIONING

LOCKING

- TRANSACTION USES LOCKS TO DENY ACCESS TO OTHER TRANSACTIONS AND SO PREVENT INCORRECT UPDATES.
- MOST WIDELY USED APPROACH TO ENSURE READ CONSISTENCY.
- GENERALLY, A TRANSACTION MUST CLAIM A SHARED (READ) OR EXCLUSIVE (WRITE) LOCK ON A DATA ITEM BEFORE READ OR WRITE.
- LOCK PREVENTS ANOTHER TRANSACTION FROM MODIFYING ITEM OR EVEN READING IT, IN THE CASE OF A WRITE LOCK.

LOCKING - BASIC RULES

- IF TRANSACTION HAS **SHARED** LOCK ON ITEM, IT CAN READ BUT NOT UPDATE ITEM.
- IF TRANSACTION HAS **EXCLUSIVE** LOCK ON ITEM, IT CAN BOTH READ AND UPDATE ITEM.
- READS CANNOT CONFLICT, SO MORE THAN ONE TRANSACTION CAN HOLD SHARED LOCKS SIMULTANEOUSLY ON SAME ITEM.
- EXCLUSIVE LOCK GIVES TRANSACTION EXCLUSIVE ACCESS TO THAT ITEM (I.E. THE ITEM CANNOT EVEN BE READ BY OTHER TRANSACTIONS).

LOCKING - BASIC RULES

- SOME SYSTEMS ALLOW TRANSACTION TO UPGRADE READ LOCK TO AN EXCLUSIVE LOCK, OR DOWNGRADE EXCLUSIVE LOCK TO A SHARED LOCK.

LOCKING

- LOCKING DOES NOT GUARANTEE READ CONSISTENCY
- IN THE EXAMPLE ON THE NEXT SLIDE, IF THE LOCK ON BAL_X IS RELEASED BY T9 AS SOON AS THE UPDATE IS COMPLETED, T10 CAN PROCEED TO READ THE VALUE OF BAL_X
- HOWEVER, THIS COULD CAUSE INCONSISTENCIES IF T9 WAS LATER ROLLED BACK INSTEAD OF COMMITTED

EXAMPLE

Time	T_9	T_{10}
t_1	begin_transaction	
t_2	read(**bal**$_x$)	
t_3	**bal**$_x$ = **bal**$_x$ + 100	
t_4	write(**bal**$_x$)	begin_transaction
t_5		read(**bal**$_x$)
t_6		**bal**$_x$ = **bal**$_x$ *1.1
t_7		write(**bal**$_x$)
t_8		read(**bal**$_y$)
t_9		**bal**$_y$ = **bal**$_y$ *1.1
t_{10}		write(**bal**$_y$)
t_{11}	read(**bal**$_y$)	commit
t_{12}	**bal**$_y$ = **bal**$_y$ − 100	
t_{13}	write(**bal**$_y$)	
t_{14}	commit	

TWO-PHASE LOCKING (2PL)

- TRANSACTION FOLLOWS 2PL PROTOCOL IF ALL LOCKING OPERATIONS PRECEDE FIRST UNLOCK OPERATION IN THE TRANSACTION.
  - IN OTHER WORDS, ALL LOCKS ARE HELD UNTIL THE TRANSACTION ENDS (EITHER COMMITTED OR ROLLED BACK)

- TWO PHASES FOR TRANSACTION:
  - GROWING PHASE - ACQUIRES ALL LOCKS BUT CANNOT RELEASE ANY LOCKS.
  - SHRINKING PHASE - RELEASES LOCKS BUT CANNOT ACQUIRE ANY NEW LOCKS.

PREVENTING LOST UPDATE PROBLEM USING 2PL

Time	T_1	T_2	$\mathbf{bal_x}$
t_1		begin_transaction	100
t_2	begin_transaction	write_lock($\mathbf{bal_x}$)	100
t_3	write_lock($\mathbf{bal_x}$)	read($\mathbf{bal_x}$)	100
t_4	WAIT	$\mathbf{bal_x} = \mathbf{bal_x} + 100$	100
t_5	WAIT	write($\mathbf{bal_x}$)	200
t_6	WAIT	commit/unlock($\mathbf{bal_x}$)	200
t_7	read($\mathbf{bal_x}$)		200
t_8	$\mathbf{bal_x} = \mathbf{bal_x} - 10$		200
t_9	write($\mathbf{bal_x}$)		190
t_{10}	commit/unlock($\mathbf{bal_x}$)		190

PREVENTING UNCOMMITTED DEPENDENCY PROBLEM USING 2PL

Time	T_3	T_4	$\mathbf{bal_x}$
t_1		begin_transaction	100
t_2		write_lock($\mathbf{bal_x}$)	100
t_3		read($\mathbf{bal_x}$)	100
t_4	begin_transaction	$\mathbf{bal_x} = \mathbf{bal_x} + 100$	100
t_5	write_lock($\mathbf{bal_x}$)	write($\mathbf{bal_x}$)	200
t_6	WAIT	rollback/unlock($\mathbf{bal_x}$)	100
t_7	read($\mathbf{bal_x}$)		100
t_8	$\mathbf{bal_x} = \mathbf{bal_x} - 10$		100
t_9	write($\mathbf{bal_x}$)		90
t_{10}	commit/unlock($\mathbf{bal_x}$)		90

PREVENTING INCONSISTENT ANALYSIS

Time	T_5	T_6	bal_x	bal_y	bal_z	sum
t_1		begin_transaction	100	50	25	
t_2	begin_transaction	sum = 0	100	50	25	0
t_3	write_lock(bal_x)		100	50	25	0
t_4	read(bal_x)	read_lock(bal_x)	100	50	25	0
t_5	$bal_x = bal_x - 10$	WAIT	100	50	25	0
t_6	write(bal_x)	WAIT	90	50	25	0
t_7	write_lock(bal_z)	WAIT	90	50	25	0
t_8	read(bal_z)	WAIT	90	50	25	0
t_9	$bal_z = bal_z + 10$	WAIT	90	50	25	0
t_{10}	write(bal_z)	WAIT	90	50	35	0
t_{11}	commit/unlock(bal_x, bal_z)	WAIT	90	50	35	0
t_{12}		read(bal_x)	90	50	35	0
t_{13}		sum = sum + bal_x	90	50	35	90
t_{14}		read_lock(bal_y)	90	50	35	90
t_{15}		read(bal_y)	90	50	35	90
t_{16}		sum = sum + bal_y	90	50	35	140
t_{17}		read_lock(bal_z)	90	50	35	140
t_{18}		read(bal_z)	90	50	35	140
t_{19}		sum = sum + bal_z	90	50	35	175
t_{20}		commit/unlock(bal_x, bal_y, bal_z)	90	50	35	175

DEADLOCK

- AN IMPASSE THAT MAY RESULT WHEN TWO (OR MORE) TRANSACTIONS ARE EACH WAITING FOR LOCKS HELD BY THE OTHER TO BE RELEASED.

Time	T_{17}	T_{18}
t_1	begin_transaction	
t_2	write_lock(**bal_x**)	begin_transaction
t_3	read(**bal_x**)	write_lock(**bal_y**)
t_4	$bal_x = bal_x - 10$	read(**bal_y**)
t_5	write(**bal_x**)	$bal_y = bal_y + 100$
t_6	write_lock(**bal_y**)	write(**bal_y**)
t_7	WAIT	write_lock(**bal_x**)
t_8	WAIT	WAIT
t_9	WAIT	WAIT
t_{10}	⋮	WAIT
t_{11}	⋮	⋮

DEADLOCK

- ONLY ONE WAY TO BREAK DEADLOCK: ABORT ONE OR MORE OF THE TRANSACTIONS.
- DEADLOCK SHOULD BE TRANSPARENT TO USER, SO DBMS SHOULD RESTART TRANSACTION(S).
- THREE GENERAL TECHNIQUES FOR HANDLING DEADLOCK:
  - TIMEOUTS.
  - DEADLOCK PREVENTION.
  - DEADLOCK DETECTION AND RECOVERY.

TIMEOUTS

- TRANSACTION THAT REQUESTS LOCK WILL ONLY WAIT FOR A SYSTEM-DEFINED PERIOD OF TIME.
- IF LOCK HAS NOT BEEN GRANTED WITHIN THIS PERIOD, LOCK REQUEST TIMES OUT.
- IN THIS CASE, DBMS ASSUMES TRANSACTION MAY BE DEADLOCKED, EVEN THOUGH IT MAY NOT BE, AND IT ABORTS AND AUTOMATICALLY RESTARTS THE TRANSACTION.

DEADLOCK PREVENTION

- DBMS LOOKS AHEAD TO SEE IF TRANSACTION WOULD CAUSE DEADLOCK AND NEVER ALLOWS DEADLOCK TO OCCUR.
- COULD ORDER TRANSACTIONS USING TRANSACTION TIMESTAMPS:
  - WAIT-DIE: ONLY AN OLDER TRANSACTION CAN WAIT FOR YOUNGER ONE, OTHERWISE TRANSACTION IS ABORTED (DIES) AND RESTARTED WITH SAME TIMESTAMP.
  - WOUND-WAIT: ONLY A YOUNGER TRANSACTION CAN WAIT FOR AN OLDER ONE. IF OLDER TRANSACTION REQUESTS LOCK HELD BY YOUNGER ONE, YOUNGER ONE IS ABORTED (WOUNDED).

WAIT-DIE VS. WOUND-WAIT

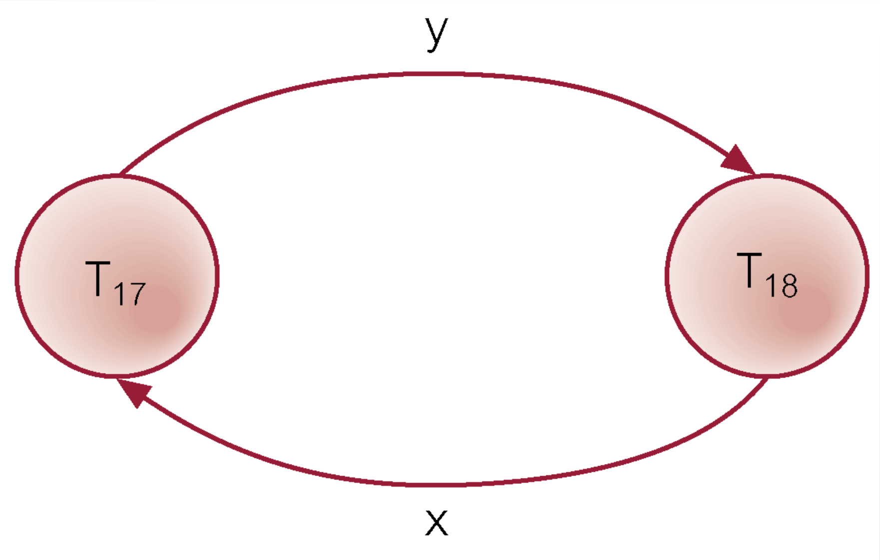
	Wait-Die	Wound-Wait
O needs resource held by Y	O waits	Y dies
Y needs resource held by O	Y dies	Y waits

O = Older transaction
Y = Younger transaction

DEADLOCK DETECTION AND RECOVERY

- DBMS ALLOWS DEADLOCK TO OCCUR BUT RECOGNIZES IT AND BREAKS IT.
- USUALLY HANDLED BY CONSTRUCTION OF WAIT-FOR GRAPH (WFG) SHOWING TRANSACTION DEPENDENCIES:
  - CREATE A NODE FOR EACH TRANSACTION.
  - CREATE EDGE TI -> TJ, IF TI WAITING TO LOCK ITEM LOCKED BY TJ.
- DEADLOCK EXISTS IF AND ONLY IF WFG CONTAINS CYCLE.
- WFG IS CREATED AT REGULAR INTERVALS.

EXAMPLE - WAIT-FOR-GRAPH (WFG)



RECOVERY FROM DEADLOCK DETECTION

- SEVERAL ISSUES:
  - CHOICE OF DEADLOCK VICTIM;
  - HOW FAR TO ROLL A TRANSACTION BACK;
  - AVOIDING STARVATION.

TIMESTAMPING

- TRANSACTIONS ORDERED GLOBALLY SO THAT OLDER TRANSACTIONS, TRANSACTIONS WITH SMALLER TIMESTAMPS, GET PRIORITY IN THE EVENT OF CONFLICT.
- CONFLICT IS RESOLVED BY ROLLING BACK AND RESTARTING TRANSACTION.
- NO LOCKS SO NO DEADLOCK.

TIMESTAMPING

- TIMESTAMP
  - A UNIQUE IDENTIFIER CREATED BY DBMS THAT INDICATES RELATIVE STARTING TIME OF A TRANSACTION.
- CAN BE GENERATED BY USING SYSTEM CLOCK AT TIME TRANSACTION STARTED, OR BY INCREMENTING A LOGICAL COUNTER EVERY TIME A NEW TRANSACTION STARTS.

TIMESTAMPING

- READ/WRITE PROCEEDS ONLY IF LAST READ/WRITE ON THAT DATA ITEM WAS CARRIED OUT BY AN OLDER TRANSACTION.
- OTHERWISE, TRANSACTION REQUESTING READ/WRITE IS RESTARTED AND GIVEN A NEW TIMESTAMP.
- ALSO TIMESTAMPS FOR DATA ITEMS:
  - READ-TIMESTAMP - TIMESTAMP OF LAST TRANSACTION TO READ ITEM;
  - WRITE-TIMESTAMP - TIMESTAMP OF LAST TRANSACTION TO WRITE ITEM.

TIMESTAMPING EXAMPLE

John	Time	Marsha	Bal_x	Data Item Timestamp
read (bal_x)	t1		100	Last read by John at t1
	t2	read (bal_x)	100	Last read by Marsha at t2
$bal_x = bal_x - 50$	t3		50	
write (bal_x) *	t4		50	
roll back	t5	$bal_x = bal_x – 10$	90	
	t6	write (bal_x)	90	Last updated by Marsha at t6
read (bal_x)	t7		90	Last read by John at t7
	t8		90	
$bal_x = bal_x - 50$	t9		40	
write (bal_x) **	t10		40	Last update by John at t10
	t11			
	t12			

TIMESTAMPING EXAMPLE

* PROBLEM OCCURS HERE – JOHN HAS TRIED TO UPDATE A DATA ITEM WHICH WAS LAST READ BY ANOTHER TRANSACTION (MARSHA). THEREFORE HIS TRANSACTION MUST BE ROLLED BACK - ABORTED AND RESTARTED, AND GIVEN A NEW TIMESTAMP. **FROM TIME T6 AND ONWARDS MARSHA IS NOW THE OLDER TRANSACTION, WHEREAS JOHN'S TRANSACTION IS THE NEWER OF THE TWO (HAVING BEEN GIVEN A NEW TIMESTAMP).**

** THIS TIME JOHN'S UPDATE TO THE BALANCE IS ALLOWED TO PROCEED, AS THE DATA ITEM HAS NOT BEEN READ/UPDATED BY ANYONE ELSE SINCE HIS TRANSACTION WAS RESTARTED.

OPTIMISTIC TECHNIQUES

- BASED ON ASSUMPTION THAT CONFLICT IS RARE AND MORE EFFICIENT TO LET TRANSACTIONS PROCEED WITHOUT DELAYS TO ENSURE SERIALIZABILITY.
- AT COMMIT, CHECK IS MADE TO DETERMINE WHETHER CONFLICT HAS OCCURRED.
- IF THERE IS A CONFLICT, TRANSACTION MUST BE ROLLED BACK AND RESTARTED.
- POTENTIALLY ALLOWS GREATER CONCURRENCY THAN TRADITIONAL PROTOCOLS.

VERSIONING

- VERSIONING OF DATA CAN BE USED TO INCREASE CONCURRENCY.
- BASIC TIMESTAMP ORDERING PROTOCOL ASSUMES ONLY ONE VERSION OF DATA ITEM EXISTS, AND SO ONLY ONE TRANSACTION CAN ACCESS DATA ITEM AT A TIME.
- CAN ALLOW MULTIPLE TRANSACTIONS TO READ AND WRITE DIFFERENT VERSIONS OF SAME DATA ITEM.
- IN MULTIVERSION CONCURRENCY CONTROL, EACH WRITE OPERATION CREATES NEW VERSION OF DATA ITEM WHILE RETAINING OLD VERSION.
- NEW VERSIONS ARE LATER MERGED INTO THE DATABASE; CONFLICTS ARE DEALT WITH IF THEY ARISE

GRANULARITY OF DATA ITEMS

- SIZE OF DATA ITEMS CHOSEN AS UNIT OF PROTECTION BY CONCURRENCY CONTROL PROTOCOL.
- RANGING FROM COARSE TO FINE:
  - THE ENTIRE DATABASE.
  - A FILE.
  - A PAGE (OR AREA OR DATABASE SPACED).
  - A RECORD.
  - A FIELD VALUE OF A RECORD.

GRANULARITY OF DATA ITEMS

- TRADEOFF:
  - COARSER, THE LOWER THE DEGREE OF CONCURRENCY;
  - FINER, MORE LOCKING INFORMATION THAT IS NEEDED TO BE STORED.
- BEST ITEM SIZE DEPENDS ON THE TYPES OF TRANSACTIONS.