# Transaction Processing
# Concurrency

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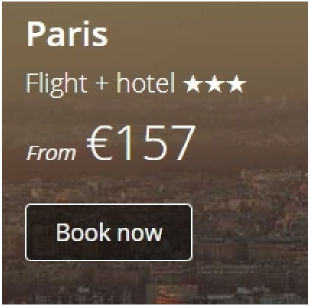
# Transactions

Transactions are about a group of database operations (inserts, deletes, updates) that should be regarded as one logical unit and one atomic action:



# Transactions

Applications often require the possibility to execute transactions in a concurrent mode:

> The Seattle-based company said customers ordered 34.4 million items during Prime Day, or to put it another way, 398 items per second. In the U.S. alone it sold 47,000 TVs, marking a 1300 percent increase on last year; 41,000 Bose headphones, compared to eight the previous Wednesday; and 14,000 iRobot Roomba 595 Pet Vacuum Cleaning Robots, compared to one the

# Transaction concept

*Definition:*

Atomic database action

$R(x)$: read data element $x$

$W(x)$: write data element $x$

data element: attribute, tuple, block, table

*Definition:*

A transaction is a collection of atomic database actions considered to be one logical unit, with respect to:

- concurrency
- recovery

# Transaction concept

Termination of a transaction

- *commit*: positive, complete, irreversible, persistent; effects to real world will become visible
- *abort* or *rollback*: negative, nihil; no effects to real world; no partial results visible

ACID-properties:

**A** tomicity

**C** onsistency preservation

**I** solation

**D** urability

# Schedules

The (concurrent) execution order of a sequence of database operations generated by a set of transactions is represented by a *schedule* or *history*

*Example:*
an interleaved schedule $S1$ and a serial schedule $S2$

*S1*

| T1 | T2 | T3 |
|---|---|---|
| | W(y) | |
| | | R(x) |
| W(x) | | |
| | W(z) | |
| | | R(y) |

↓ time

*S2*

| T1 | T2 | T3 |
|---|---|---|
| | W(y) | |
| | W(z) | |
| | | R(x) |
| | | R(y) |
| W(x) | | |

# Lost update

*Problem 1:* lost update

*S3*

| T1 | T2 |
|---|---|
| R(x) | |
| | R(x) |
| W(x) | |
| | W(x) |

# Inconsistent retrieval

*Problem 2:* inconsistent retrieval

*S4*

| T1 | T2 |
|---|---|
| | $R(x_1)$ |
| | $R(x_2)$ |
| | $\vdots$ |
| | $R(x_m)$ |
| $R(x_m)$ | |
| $W(x_m)$ | |
| $R(x_{m+1})$ | |
| $W(x_{m+1})$ | |
| | $R(x_{m+1})$ |
| | $\vdots$ |
| | $R(x_n)$ |

# Correctness criterion

Formalizing correctness

- serial schedules (schedules without concurrency) are correct
- two schedules are equivalent iff
  their effects visible to the outside world
  are exactly the same
- an interleaved schedule is correct iff
  it is equivalent to a serial schedule;
  such a schedule is called serializable

# Correctness criterion

- *Intuition:* two atomic database actions are conflicting if the effects of reversing the relative order of their execution are visible to the outside world
- *Definition:* two atomic database actions are <u>conflicting</u> iff they affect the same data element and at least one of the operations is a write
- *Definition:* two schedules are <u>equivalent</u> iff they order all the conflicts the same way

# Correctness criterion

*S5*

| T1 | T2 | T3 |
|---|---|---|
| | | W(x) |
| R(x) | | |
| | | R(z) |
| | W(x) | |
| W(y) | | |
| | W(y) | |

*S6*

| T1 | T2 | T3 |
|---|---|---|
| | | W(x) |
| | | R(z) |
| R(x) | | |
| W(y) | | |
| | W(x) | |
| | W(y) | |

# Correctness criterion

*S5*

| T1 | T2 | T3 |
|---|---|---|
| | | W(x) |
| R(x) | | |
| | | R(z) |
| | W(x) | |
| W(y) | | |
| | W(y) | |

*S6*

| T1 | T2 | T3 |
|---|---|---|
| | | W(x) |
| | | R(z) |
| R(x) | | |
| W(y) | | |
| | W(x) | |
| | W(y) | |

S5 orders all the conflicts the same way S6 does
... so S5 is equivalent to S6 ...
... and S6 is serial ...
... so S5 is correct: *serializable*

# INTERMEZZO

*S7*

| T1 | T2 | T3 | T4 |
|---|---|---|---|
| | | W(x) | |
| | R(x) | | |
| W(z) | | | |
| | | | R(z) |
| | | | W(y) |
| | | W(y) | |
| | R(y) | | |
| W(y) | | | |
| | W(x) | | |

*S8*

| T1 | T2 | T3 | T4 |
|---|---|---|---|
| | | W(x) | |
| | R(x) | | |
| | | | R(z) |
| | | | W(y) |
| W(z) | | | |
| | | W(y) | |
| | R(y) | | |
| W(y) | | | |
| | W(x) | | |

is *S7* serializable ?

is *S8* serializable ?

# Testing serializability

So, testing serializability means

comparing with ... serial schedules of $n$ transactions?

# Testing serializability

*Definition:* a precedence graph $G(S)$ is a directed graph connected to a schedule $S$ such that:

- the set of nodes is the set of transactions in $S$
- there exists an edge $T_i \rightarrow T_j$ in $G$ iff
  there is a conflicting pair of operations $o_i, o_j$ in $S$
  such that $o_i$ occurs before $o_j$

# Testing serializability

*Theorem:*
a schedule $S$ is serializable $\Leftrightarrow$ $G(S)$ is acyclic

# Enforcing serializability: 2PL

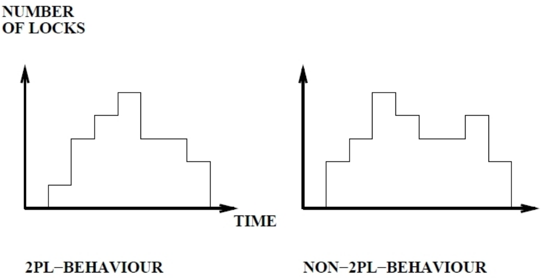
*Two phase locking (2PL)*

Scheduling technique based on locking principle

- before executing an atomic operation, the requesting transaction has to acquire an exclusive lock on the data element; if the data element is locked by another transaction, the requesting transaction has to wait until release of the lock by the other transaction
- after executing the operation, the scheduler has to release the lock

# Enforcing serializability: 2PL

- the transaction is not allowed to acquire new locks after the release of a lock; so locking is executed in two consecutive phases: the growing phase and the shrinking phase (with respect to the number of locks held by the transaction)



# Enforcing serializability: 2PL

*Theorem:*
$S$ is a 2PL-schedule $\Rightarrow$ $S$ is serializable

# Enforcing serializability: 2PL

Refinement

- concurrent execution of read-operations should be allowed
- exclusiveness of locks is only required in case of conflicting operations
- we distinguish read-locks and write-locks (or exclusive locks)

Lock compatibility matrix

| | read | write |
|---|---|---|
| read | yes | no |
| write | no | no |

Note that 2PL behaviour is enforced on *every* transaction separately!

# Enforcing serializability: 2PL

*Problem:* deadlock

*Solution:*

- prevention
- detection by time out
- detection by wait-for-graphs

# Enforcing serializability: timestamping

Alternative to 2PL

- Every transaction receives a timestamp at birth
- Timestamps are emitted in some order (typically a counter or system time)
- Conflicting operations are executed in timestamp order
- Application: ad hoc concurrency control in loosely coupled databases

# Enforcing serializability: timestamp ordering principle

Timestamp rule:

For each conflicting pair of operations $o_i, o_j$ in $S$,
if $o_i < o_j$ then $ts(T_i) < ts(T_j)$

where $o_i < o_j$ denotes time order

Implementation:
timestamp manager maintains a table of recently used data entries

# Enforcing serializability: timestamping

*Theorem:*

If schedule $S$ obeys the timestamp rule
then $S$ is serializable

# Enforcing serializability: other methods

Optimistic concurrency control by a posteriori validation

no further details