Introduction to transaction management

Data Management for Big Data

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These slides are a modified version of the slides provided with the book

Özsu and Valduriez, *Principles of Distributed Database Systems* (3rd Ed.), 2011

The original version of the slides is available at: extras.springer.com

Outline (distributed DB)

- Introduction (Ch. 1) *
- Distributed Database Design (Ch. 3) *
- Distributed Query Processing (Ch. 6-8) *
- Distributed Transaction Management (Ch. 10-12) *
  - ➡ **Introduction to transaction management (Ch. 10)** *
  - ➡ Distributed Concurrency Control (Ch. 11) *
  - ➡ Distributed DBMS Reliability (Ch. 12) *

* Özsu and Valduriez, *Principles of Distributed Database Systems* (3rd Ed.), 2011

Outline (today)

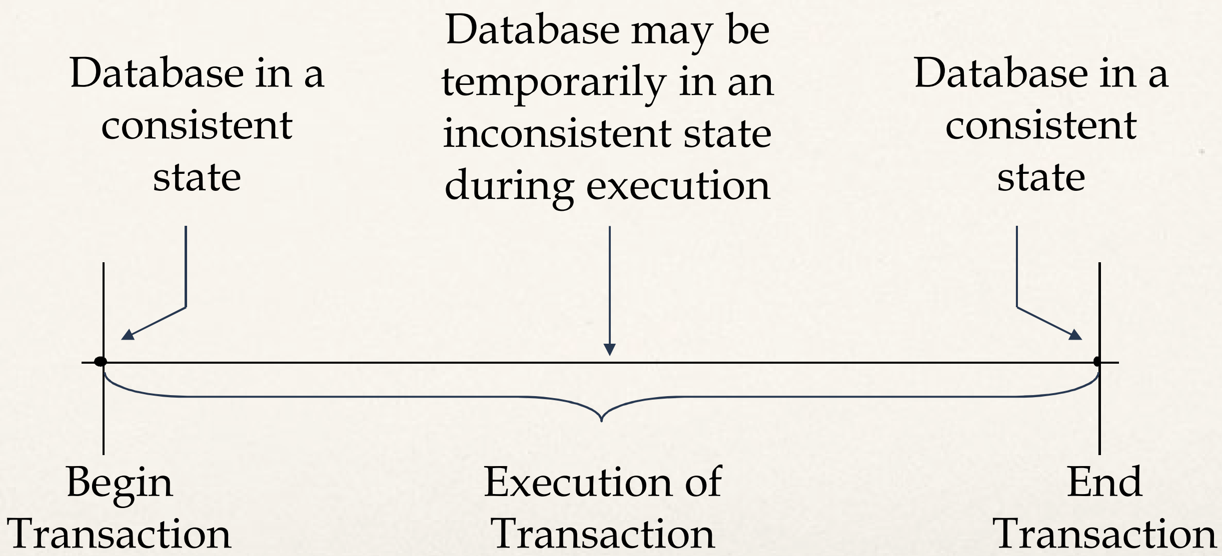
- Introduction to transaction management (Ch. 10) *
  - ➡ Definitions of transaction
  - ➡ Properties of Transactions (ACID)
    - ✦ Atomicity
    - ✦ Consistency
    - ✦ Isolation
    - ✦ Durability
  - ➡ Architecture

* Özsu and Valduriez, *Principles of Distributed Database Systems* (3rd Ed.), 2011

Transactions

A transaction is a collection of actions that make transformations of system states while preserving system consistency (from consistent state to another consistent state)

- ➡ concurrency: expected behavior when 2 queries modify the DB simultaneously
- ➡ Integrity: integrity constraints (e.g., primary/foreign keys), replicated copies have same values
- ➡ failure: restart or abort on failure while updating



Alternative definitions

- One way to see transactions: we often treat a transaction as a program, that is, a sequence of DB operations, Write (W) and Read (R), interleaved with computation steps (e.g., $x := x+1$) and delimited by Begin (B) and Commit (C)/Abort (A)
- Another way to see then: a transaction is just a single execution the program

Transaction Example – A Simple SQL Query

```
Transaction   BUDGET_UPDATE
begin
    EXEC SQL      UPDATE    PROJ
                  SET       BUDGET = BUDGET∗1.1
                  WHERE     PNAME = “CAD/CAM”
end.
```

Example Database

Consider an airline reservation example with the relations:

FLIGHT(FNO, DATE, SRC, DEST, STSOLD, CAP)

CUST(CNAME, ADDR)

FC(FNO, DATE, CNAME,SPECIAL)

Example Transaction – A Simple Program

```
Begin_transaction Reservation
begin
    input(flight_no, date, customer_name);
    EXEC SQL   UPDATE      FLIGHT
                  SET      STSOLD = STSOLD + 1
                  WHERE    FNO = flight_no AND DATE = date;
    EXEC SQL   INSERT
                  INTO     FC(FNO, DATE, CNAME, SPECIAL);
                  VALUES   (flight_no, date, customer_name, null);
    output("reservation completed")
end . {Reservation}
```

Termination condition

- Commit (C) vs. Abort (A)
- Commit (C) denotes success
  - ➡ DB goes into a new state, visible to everybody
  - ➡ Cannot be undone
- Abort (A) happens on failure
  - ➡ Application logic reach a failure state (Abort keyword in the program)
    - ✦ Bad input, unfulfilled condition
    - ✦ Controlled through the program flow control (e.g., if-then-else)
    - ✦ E.g., a seat is reserved but payment does not go through
  - ➡ Deadlock (Abort command is sent by DBMS or OS)
  - ➡ Node/hardware failure
  - ➡ Abort causes **rollback** (restore the state before transaction started)

Termination of Transactions

```
Begin_transaction Reservation
begin
    input(flight_no, date, customer_name);
    EXEC SQL    SELECT      STSOLD,CAP
                INTO        temp1,temp2
                FROM        FLIGHT
                WHERE       FNO = flight_no AND DATE =  date;
    if temp1 = temp2 then
        output("no free seats");
        Abort
    else
        EXEC SQL  UPDATE    FLIGHT
                  SET       STSOLD = STSOLD + 1
                  WHERE     FNO = flight_no AND DATE = date;
        EXEC SQL  INSERT
                  INTO      FC(FNO, DATE, CNAME, SPECIAL);
                  VALUES    (flight_no, date, customer_name, null);
       Commit
       output("reservation completed")
   endif
end . {Reservation}
```

Properties of Transactions

ATOMICITY (Ch. 12) *

- ➡ unit of operation, all or nothing/ Abort or Commit

CONSISTENCY (Ch. 11) *

- ➡ ensures correctness (if DB is in a consistent state, so is after transaction execution, independently from failures or other issues)
  - ✦ no violation of integrity constraints
  - ✦ expected behavior in presence of concurrency

ISOLATION (Ch. 11) *

- ➡ changes visible only after commit
- ➡ Intermediate changes invisible to other transactions $\Rightarrow$ serializability

DURABILITY (Ch. 12) *

- ➡ committed updates persist (permanent, cannot be undone)

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Atomicity

- Either all or none of the transaction's operations are performed
- Atomicity requires that if a transaction is interrupted by a failure, its partial results must be undone
- The activity of preserving the transaction's atomicity in presence of transaction aborts due to input errors, system overloads, or deadlocks is called transaction recovery
- The activity of ensuring atomicity in the presence of system crashes is called crash recovery

Consistency

- Internal consistency
  - ➡ A transaction which executes alone against a consistent database leaves it in a consistent state.
  - ➡ Transactions do not violate database integrity constraints
- Transactions are correct programs

Consistency Degrees

- Degree 0
  - ➡ Transaction *T* does not overwrite dirty data of other transactions
  - ➡ Dirty data refers to data values that have been updated by a transaction prior to its commitment
- Degree 1
  - ➡ *T* does not overwrite dirty data of other transactions
  - ➡ *T* does not commit any writes before EOT

Consistency Degrees (cont'd)

- Degree 2
  - ➡ *T* does not overwrite dirty data of other transactions
  - ➡ *T* does not commit any writes before EOT
  - ➡ *T* does not read dirty data from other transactions
- Degree 3
  - ➡ *T* does not overwrite dirty data of other transactions
  - ➡ *T* does not commit any writes before EOT
  - ➡ *T* does not read dirty data from other transactions
  - ➡ Other transactions do not dirty any data read by *T* before *T* completes.

Isolation

- Serializability
  - ➡ If several transactions are executed concurrently, the results must be the same as if they were executed serially in some order
- Incomplete results
  - ➡ An incomplete transaction cannot reveal its results to other transactions before its commitment
  - ➡ Necessary to avoid cascading aborts

Isolation Example

- Consider the following two transactions:

T_1:	Read(x)	T_2:	Read(x)
	$x \leftarrow x+1$		$x \leftarrow x+1$
	Write(x)		Write(x)
	Commit		Commit

- Possible execution sequences:

T_1:	Read(x)	T_1:	Read(x)
T_1:	$x \leftarrow x+1$	T_1:	$x \leftarrow x+1$
T_1:	Write(x)	T_2:	Read(x)
T_1:	Commit	T_1:	Write(x)
T_2:	Read(x)	T_2:	$x \leftarrow x+1$
T_2:	$x \leftarrow x+1$	T_2:	Write(x)
T_2:	Write(x)	T_1:	Commit
T_2:	Commit	T_2:	Commit

SQL-92 Isolation Levels

Phenomena:

- Dirty read
  - ➡ T_1 modifies x which is then read by T_2 before T_1 terminates; T_1 aborts
    - ✦ T_2 has read value which never exists in the database
- Non-repeatable (fuzzy) read
  - ➡ T_1 reads x; T_2 then modifies or deletes x and commits. T_1 tries to read x again but reads a different value or can't find it
- Phantom
  - ➡ T_1 searches the database according to a predicate while T_2 inserts new tuples that satisfy the predicate

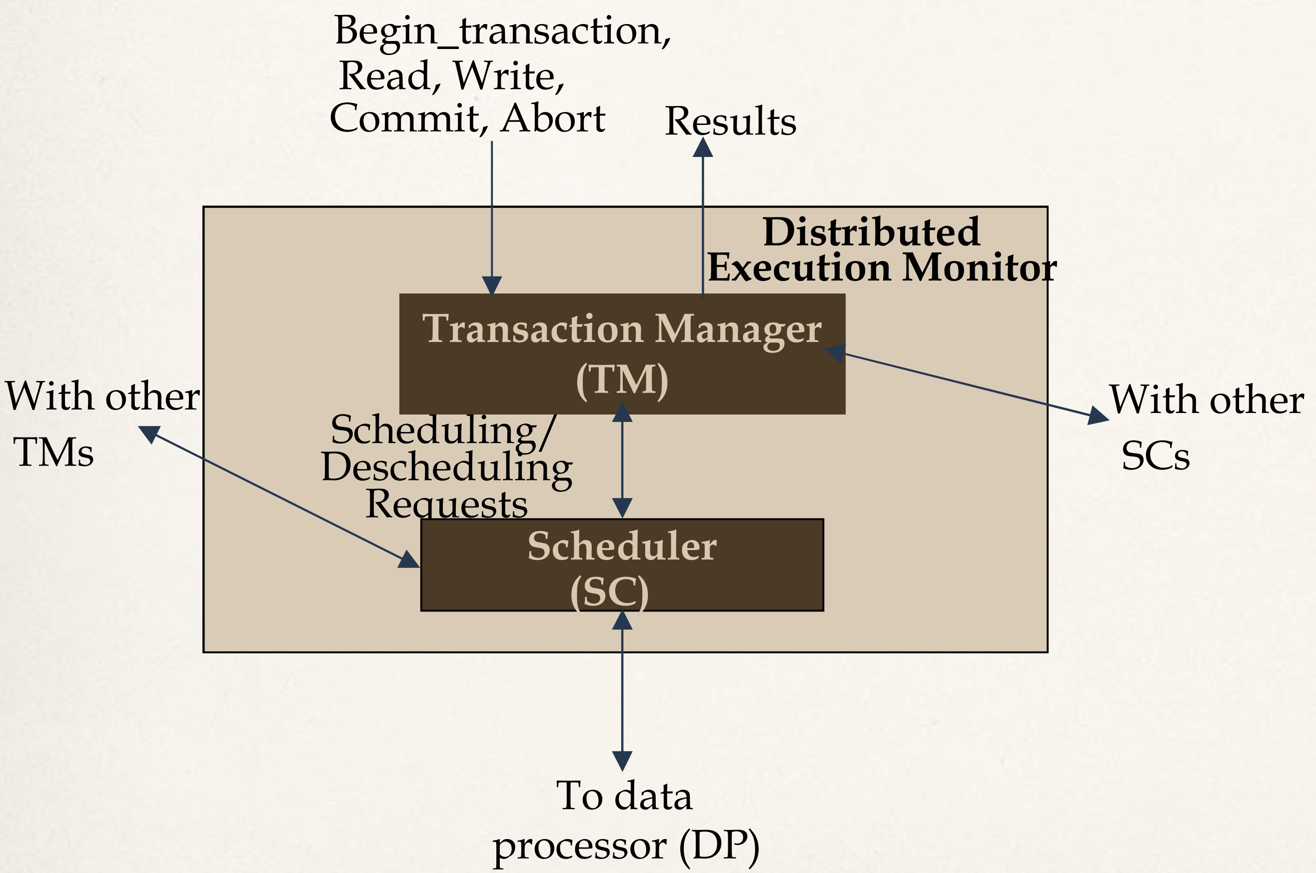
SQL-92 Isolation Levels (cont'd)

- Read Uncommitted
  - ➡ For transactions operating at this level, all three phenomena are possible
- Read Committed
  - ➡ Fuzzy reads and phantoms are possible, but dirty reads are not
- Repeatable Read
  - ➡ Only phantoms possible
- Anomaly Serializable
  - ➡ None of the phenomena are possible

Durability

- Once a transaction commits, the system must guarantee that the results of its operations will never be lost, in spite of subsequent failures
- Database recovery

Architecture



TM: coordinates requests (OP) of transaction operations by applications, sends requests to SC's at same and different sites

SC: manages concurrent accesses to resources (DB entities)

DP: local DBMS module for query processing

Transaction management protocol

- Transactions originate at one site
- TM of that site will be the coordinator for that transaction
- Transaction operations (interface between TM and user/application)
  - { B, R, W, C, A }
  - B (Begin): TM and DP do some bookkeeping (record transaction name, originating site, originating application, …)
  - R (Read)/W (Write) – these have to do with concurrent access control (Consistency and Isolation) – Ch. 11*:
    - data item stored locally: TM sends request to DP to perform the read/update
    - otherwise: TM locates site where data item is stored and request to remote DP to read/update after concurrent access controls is granted by remote SC
  - C (Commit) – this has to do with reliability (Atomicity and Durability) – Ch. 12*:
    - TM coordinates all sites involved to make data permanently available
  - A (Abort) – this has to do with reliability (Atomicity and Durability) – Ch. 12*:
    - TM coordinates rollback; no effect of transaction is visible to other transactions
- We ignore data replication. To extend our discussion see Ch. 13 (we do not cover that chapter)

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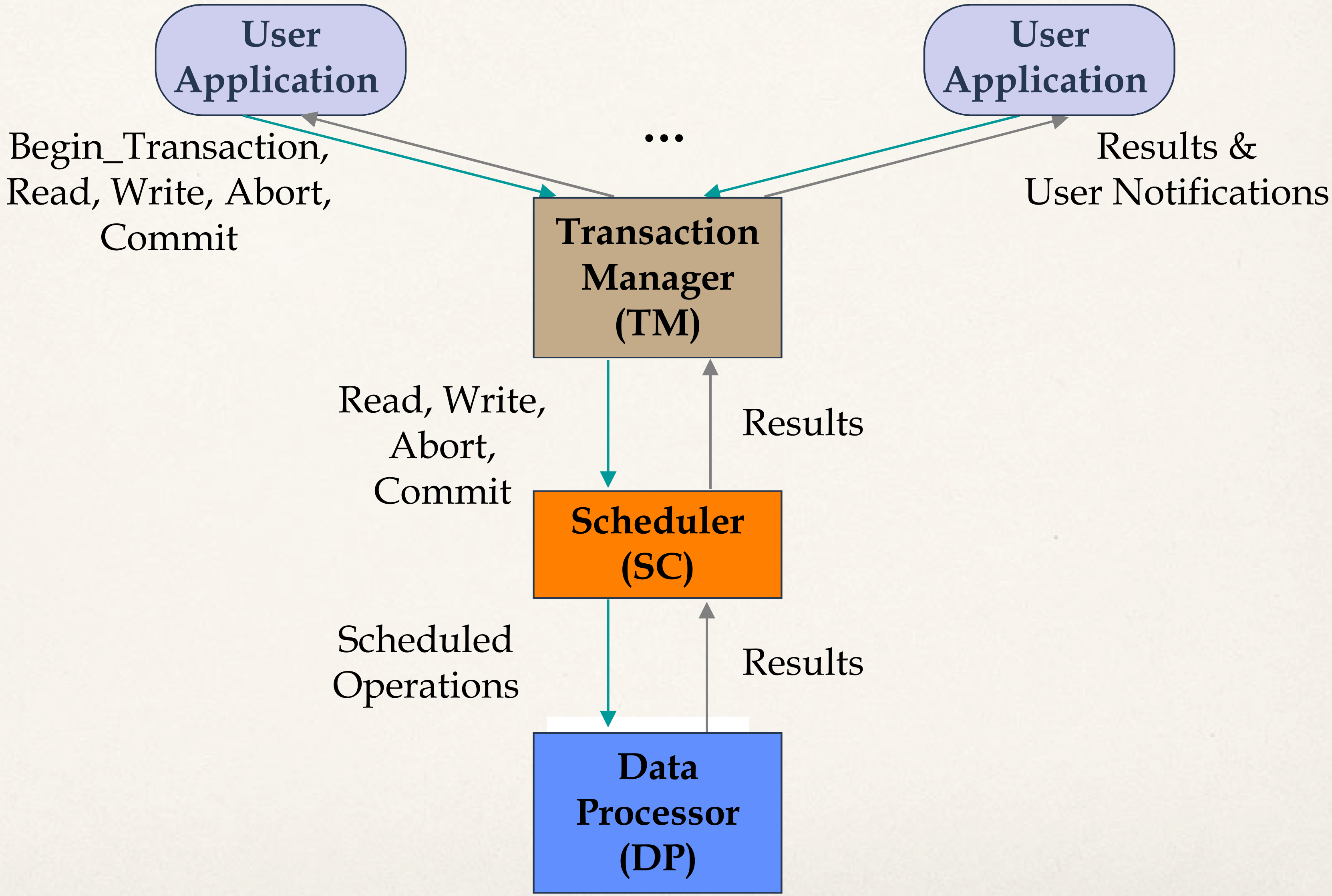
Centralized Transaction Execution



Distributed Transaction Execution