Part VIII

Transactions, Integrity and Triggers

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Learning goals for today . . .

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- Understanding of fundamentals of integrity control in databases
- Knowledge to formalize and implement integrity constraints
- Knowledge of the transaction concept in databases

Basic Terms

Integrity

- Integrity constraint *(also: assertion)*: Condition for the "permissibility" or "correctness"
- with respect to databases:
  - (single) database states,
  - state transitions from an old to a new database state,
  - long term database evolution

Classification of Integrity

Constraint Class		**Temporal Context**
static		database state
dynamic	transitional	state transition
	temporal	state sequence

Inherent Integrity Constraints in the RM

1. *Type Integrity*:
   - SQL allows domain definitions for a range of values for attributes
   - Permission or forbidding of null values
2. *Key Integrity*:
   - Specification of a key for a relation
3. *Referential Integrity*:
   - Specification of foreign keys

Term Transaction

Example Scenarios

- Seat reservation for flights simultaneously from multiple travel agencies
  $\rightarrow$ Seat could be sold multiple times when multiple travel agencies identify the seat as available
- Overlapping account operations of a bank
- Statistics database operations
  $\rightarrow$ results are corrupted when data is changed during the calculation

Transaction

A transaction is a sequence of operations (actions) that transforms the database from a consistent state into a consistent, possibly changed, state, while the ACID-principle must be hold.

- Aspects:
  - Semantic Integrity: Correct (consistent) DB-state after a transaction has finished
  - Operational Integrity: Prevent fault caused by "simultaneous" access of multiple users on the same data

ACID-Properties

- **A**tomicity:
  Transaction is executed completely or not at all
- **C**onsistency:
  Database is before the start and after the end of a transaction in a consistent state
- **I**solation:
  User, who is working on a database, should have the impression that she works alone on the database
- **D**urability (Persistence):
  The result of transaction has to be saved "permanently" in a database after the transaction competed successfully

Commands of a Transaction Language

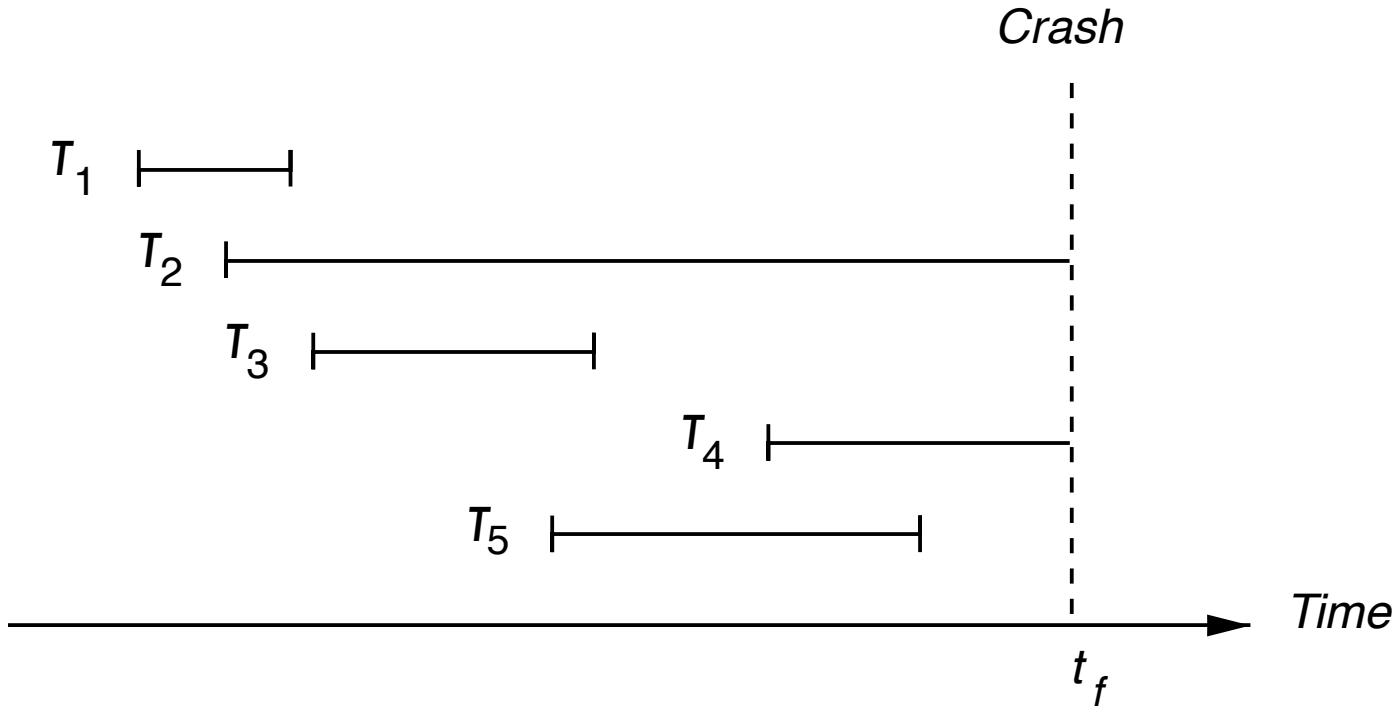
- Begin of a transaction: Begin-of-Transaction-Command **`BOT`** (implicit in SQL!)
- **`commit`**: the transaction should try to finish successfully
  - success is not guaranteed!
- **`abort`**: the transaction has to be aborted
  - abort is guaranteed!

Transaction: Integrity Violation

- Example:
  - Transfer of an amount `A` from a household post `K1` to another post `K2`
  - Condition: Sum of the account balances stays constant
- Simplified notation

  $Transfer = < K1:=K1-A;\ K2:=K2+A >;$
- Realization in SQL: as sequence of two elementary changes $\rightsquigarrow$ Condition is not necessarily fulfilled between single changing steps!

Transaction: Behavior at System Crash



Transaction: Behavior at System Crash /2

- **Consequences:**
  - Contents of the volatile memory at the time t_f is unusable $\rightarrow$ transactions in different ways affected by this
- **Transaction states:**
  - Still active transactions at the time of the failure (T_2 and T_4)
  - Already finished transactions before the time of the failure (T_1, T_3 and T_5)

Simplified Model for Transactions

- Representation of database changes of a transaction
  - **read**(A,x): assign the value of the DB-object A to the variable x
  - **write**(x, A): save the value of the variable x in the DB-object A
- Example of a transaction T:

read(A, x); $x := x - 200$; **write**(x, A);
read(B, y); $y := y + 100$; **write**(y, B);

- Execution variants for two transactions T_1, T_2:
  - serially, e.g. T_1 before T_2
  - "mixed", e.g. alternating steps of T_1 and T_2

Possible Problems with Parallel Transactions

Problems with Multi-User Operation

- Nonrepeatable Read
- Dependencies on not released data: Dirty Read
- The Phantom-Problem
- Lost Update

Nonrepeatable Read

Example:

- Assurance $x = A + B + C$ at the end of transaction T_1
- x, y, z are local variables
- T_i is the transaction i
- Integrity constraint $A + B + C = 0$

Example for Nonrepeatable Read

T_1	T_2
read(A, x);	
	read(A, y);
	$y := y/2$;
	write(y, A);
	read(C, z);
	$z := z + y$;
	write(z, C);
	commit;
read(B, y);	
$x := x + y$;	
read(C, z);	
$x := x + z$;	
commit;	

Dirty Read

T_1	T_2
read(A, x);	
$x := x + 100$;	
write(x, A);	
	read(A, x);
	read(B, y);
	$y := y + x$;
	write(y, B);
	commit;
abort;	

The Phantom-Problem

T_1	T_2
select count $(*)$ **into** X **from** Customer;	
	insert **into** Customer **values** ('Meier', 0, ...); **commit**;
update Customer **set** Bonus $=$ Bonus $+10000/X$; **commit**;	

Lost Update

T_1	T_2	A
read(A, x);		10
	read(A, x);	10
$x := x + 1$;		10
	$x := x + 1$;	10
write(x, A);		11
	write(x, A);	11

Serializability

An interleaved execution of multiple transactions is called serializable, if its effect is identical to the effect of a (arbitrarily chosen) serial execution of these transactions.

- Problem for checking serializability:
  - there are $n!$ different serial execution orders for n transactions...
- **Schedule:** Plan of execution for transactions (ordered list of transaction operations)

Transactions in SQL

Transactions in SQL-DBS

Weakening of ACID in SQL: Isolation levels

```
set transaction
   [ { read only | read write }, ]
   [isolation level
      {  read uncommitted |
         read committed |
         repeatable read |
         serializable }, ]
   [ diagnostics size ...]
```

Default settings:

```
set transaction read write,
   isolation level serializable
```

Meaning of Isolation Levels

- **`read uncommitted`**
  - weakest level: access to not committed data, only for **`read only`** transactions
  - statistic and similar transactions (approximate overview, incorrect values possible)
  - no locks $\rightarrow$ efficient executable, other transactions are not hindered
- **`read committed`**
  - only read finally written values, but *nonrepeatable read* possible
- **`repeatable read`**
  - no *nonrepeatable read*, but phantom-problem can occur
- **`serializable`**
  - guarantees serializability

Isolation Levels: `read committed`

	T_1	T_2
	set transaction **isolation level** **read committed**	
1	**select** Name **from** WINES **where** WineID = 1014 $\longrightarrow$ *Riesling*	
2		**update** WINES **set** Name = 'Riesling Superiore' **where** WineID = 1014
3	**select** Name **from** WINES **where** WineID = 1014 $\longrightarrow$ *Riesling*	
4		**commit**
5	**select** Name **from** WINES **where** WineID = 1014 $\longrightarrow$ *Riesling Superiore*	

Isolation Levels: `read committed` /2

	T_1	T_2
	set transaction **isolation level** **read committed**	
1	**select** Name **from** WINES **where** WineID = 1014	
2		**update** WINES **set** Name = 'Riesling Superiore' **where** WineID = 1014
3	**update** WINES **set** Name = 'Superiore Riesling' **where** WineID = 1014 $\longrightarrow$ *blocked*	
4		**commit**
5	**commit**	

Isolation Levels: `serializable`

	T_1	T_2
	set transaction **isolation level** **serializable**	
1	**select** Name **into** N **from** WINES **where** WineID = 1014 $\longrightarrow$ N := *Riesling*	
2		**update** WINES **set** Name = 'Riesling Superiore' **where** WineID = 1014
4		**commit**
5	**update** WINES **set** Name = 'Superior' || N **where** WineID = 1014 $\longrightarrow$ *Abort*	

Integrity Constraints in SQL

Integrity Constraints in SQL-DDL

- **`not null`**: Null values prohibited
- **`default`**: Specification of default values
- **`check`** (*search-condition*): Attribute specific constraint (usually *One-Tuple-Integrity-Condition*)
- **`primary key`**: Specification of a primary key
- **`foreign key`** (*Attribute(e)*)
  `references` *Table*(*Attribute(e)*):
  Specification of the referential integrity

Integrity Constraints: Range of Values

- **`create domain`**: Establishing of a user defined range of values
- Example

```
create domain WineColor varchar(5)
   default 'Red'
   check (value in ('Red', 'White', 'Rose'))
```

- Application

```
create table WINES (
   WineID int primary key,
   Name varchar(20) not null,
   Color WineColor,
   ...)
```

Integrity Constraints: `check`-Clause

- **`check`**: Establishing of further local integrity constraints within the defined range of values, attributes and relational scheme
- Example: Restriction of permitted values
- Example

```
create table WINES (
   WineID int primary key,
   Name varchar(20) not null,
   Year int check(Year between 1980 and 2010),
   ...
)
```

Preservation of Referential Integrity

- Checking of foreign keys after database changes
- for $\pi_A(r_1) \subseteq \pi_K(r_2)$,
  e.g. $\pi_{\text{Vineyard}}(\texttt{WINES}) \subseteq \pi_{\text{Vineyard}}(\texttt{PRODUCER})$
  - Tuple t is inserted into $r_1 \Rightarrow$ check, whether $t' \in r_2$ exists with: $t'(K) = t(A)$, d.h. $t(A) \in \pi_K(r_2)$
    if not $\Rightarrow$ reject
  - Tuple t' is removed from $r_2 \Rightarrow$ check, whether $\sigma_{A=t'(K)}(r_1) = \{\}$, i.e. no tuple from r_1 references t'
    if not empty $\Rightarrow$ reject or remove tuple from r_1, that reference t' (at cascading deletion)

Checking Modes of Constraints

- **`on update | delete`**
  Specification of a triggering event that starts the checking of the condition
- **`cascade`** | **`set null`** | **`set default`** | **`no action`**
  Cascading: Handling of some integrity violations propagates over multiple levels, e.g. deletion as reaction on a violation of the referential integrity
- **`deferred`** | **`immediate`** sets the checking time for a condition
  - **`deferred`**: put back to the end of the transaction
  - **`immediate`**: immediate verification at any relevant database change

Checking Modes: Example

- Cascading deletion

```
create table WINES (
   WineID int primary key,
   Name varchar(50) not null,
   Price float not null,
   Jahr int not null,
   Vineyard varchar(30),
   foreign key (Vineyard) references PRODUCER (Vineyard)
      on delete cascade)
```

The `assertion`-Clause

- Assertion: Predicate expressed by a condition that always has to be fulfilled by a database
- Syntax (SQL:2003)

```
create assertion name check ( predicate )
```

- Example:

```
create assertion Prices check
   ( ( select sum (Price)
       from WINES) < 10000 )
```

```
create assertion Prices2 check
   ( not exists (
       select * from WINES where Price > 200) )
```

Trigger

Trigger

- Trigger: Statement/Procedure that is executed automatically by the DBMS at the occurrence of a specific event
- Application:
  - Enforcement of integrity conditions ("implementation" of integrity rules)
  - Auditing of DB-actions
  - Propagation of DB-changes
- Definition:

```
create trigger ...
after <Operation>
<Procedure>
```

Example for Triggers

- Realization of a calculated attribute with two triggers:
  - Introduction of new tasks

```
create trigger TaskCounter+
   on insertion of Task A:
   update Customer
   set NrTasks = NrTasks + 1
   where CName = new A.CName
```

  - Analogously for deletion of tasks:

```
create trigger TaskCounter-
   on deletion ...:
   update ...- 1 ...
```

Trigger: Design and Implementation

- Specification of
  - *Event* and *condition* for activation of the trigger
  - *Action(s)* for the execution
- Syntax in SQL:2003 defined
- Available in most commercial systems (but with different syntax)

SQL:2003-Trigger

- Syntax:

```
create trigger <Name:>
after | before <Event>
on <Relation>
[ when <Condition> ]
begin atomic < SQL-statements > end
```

- Event:
  - **insert**
  - **update** [**of** <list of attributes>]
  - **delete**

Further Specifications for Triggers

- **`for each row`** resp. **`for each statement`**: Activation of the trigger for *each* single change of a set-valued change or just once for the whole change
- **`before`** resp. **`after`**: Activation *before* or *after* the change
- **`referencing new as`** resp. **`referencing old as`**: Binding of a tuple variable on the new introduced resp. just removed ("old") tuple of a relation
  $\rightsquigarrow$ tuple of the *difference relation*

Example for Triggers

- *No customer account can fall below 0:*

```
create trigger bad_account
after update of Acc on CUSTOMER
referencing new as INSERTED
when (exists
   (select * from INSERTED where Acc < 0)
)
begin atomic
   rollback;
end
```

$\rightsquigarrow$ similar trigger for **insert**

Example for triggers /2

- *Producers **must** be removed, if they do not offer any wine:*

```
create trigger useless_Vineyard
after delete on WINES
referencing old as o
for each row
when (not exists
    (select * from WINES W
     where W.Vineyard = o.Vineyard))
begin atomic
   delete from PRODUCER where Vineyard = o.Vineyard;
end
```

Integrity Enforcement with Triggers

Integrity Enforcement with Triggers

1. Specify object o_i, for which the condition ϕ should be monitored
   - Usually monitor multiple o_i when condition is across relations
   - Candidates for o_i are tuples of the relation names that occur in ϕ
2. Specify the elemental database changes u_{ij} on objects o_i that can violate ϕ
   - Rules: e.g., check existence requirements on deletion and updates, but not on insertion etc.

Integrity Enforcement with Triggers /2

3. Specify, depending on the application, the reaction r_i on the integrity violation
   - Reset the transaction (**`rollback`**)
   - Correcting database changes
4. Formulate following triggers:

`create trigger` `t-phi-ij` **`after`** u_{ij} **`on`** o_i
`when` $\neg\phi$
`begin` r_i **`end`**

5. If possible, simplify the created trigger

Trigger in Oracle

Trigger in Oracle

- Implementation in PL/SQL
- Notation

```
create [ or replace ] trigger trigger-name
   before | after
   insert or update [ of columns ]
      or delete on table
   [ for each row
   [ when ( predicate ) ] ]
   PL/SQL-Block
```

Trigger in Oracle: Types

- Statement level trigger: Trigger is triggered before resp. after the DML-statement
- Row level trigger: Trigger is triggered before resp. after each single modification (*one tuple at a time*)

Trigger on row level:

- Predicate for restriction (**`when`**)
- Access on old (**`:old.`***col*) resp. new (**`:new.`***col*) tuple
  - for **`delete`**: only (**`:old.`***col*)
  - for **`insert`**: only (**`:new.`***col*)
  - in **`when`**-clause only (**`new.`***col*) resp. (**`old.`***col*)

Trigger in Oracle /2

- Transaction abortion with **raise_application_error**(*code*, *message*)
- Distinction of the type of the DML-statement

```
if deleting then ...  end if;
if updating then ...  end if;
if inserting then ...  end if;
```

Trigger in Oracle: Example

- *No customer account can fall below 0:*

```
create or replace trigger bad_account
after insert or update of Acc on Customer
for each row
when (:new.Acc < 0)
begin
   raise_application_error(-20221,
      'Not below 0');
end;
```

Summary

Summary

- Enforcement of correctness resp. integrity of the data
- Inherent integrity constraints of the relational model
- Additional SQL-integrity constraints: **`check`**-clause, **`assertion`**-statement
- Trigger for "implementation" of integrity constraints resp. rules

Control Questions

- What is the purpose of integrity enforcement? Which types of integrity constraints are there?

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- What is the purpose of integrity enforcement? Which types of integrity constraints are there?
- How can integrity constraints and rules be formulated in SQL systems?
- What requirements result from the ACID-principle? How are these achieved in database systems?