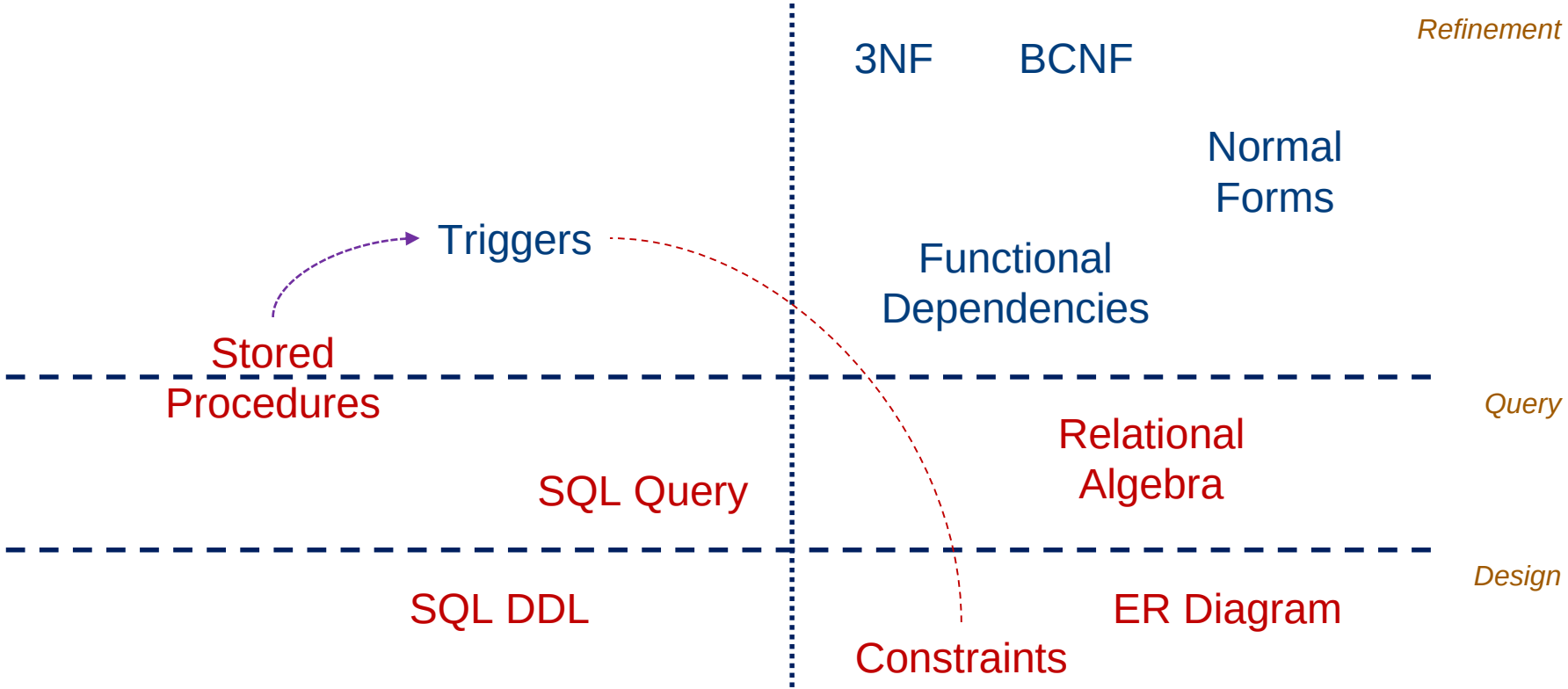
CS2102 Database Systems

Lecture 9 – Triggers

Roadmap


Refinement
3NF
BCNF
Normal Forms
Triggers
Functional Dependencies
Stored Procedures
Query
Relational Algebra
SQL Query
Design
SQL DDL
ER Diagram
Constraints

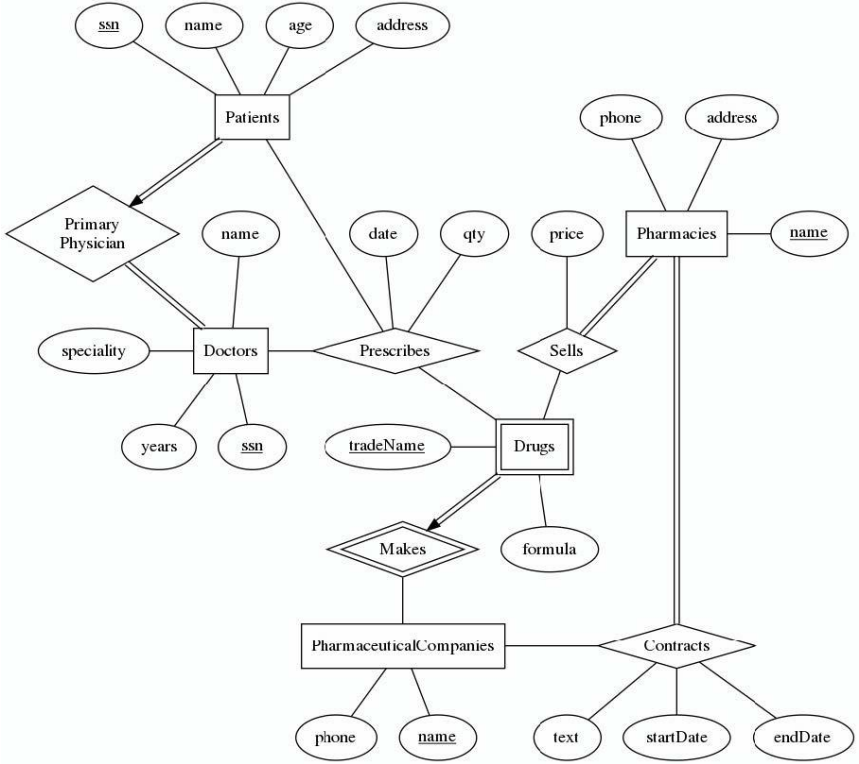
Previous Lectures

- **SQL Functions and Procedures**
  - Named operations
  - Expressive control structures (*Turing complete*)
- **Constraints**
  - Key constraints
  - Referential constraints
  - Uniqueness
  - Check
- What if there are constraints that cannot be handled by the constructs above?

Difficult Constraints

- **Tutorial 03**
  - There is exactly one contract between a pharmacy and a pharmaceutical company if and only if that pharmacy sells some drug that is made by that pharmaceutical company.

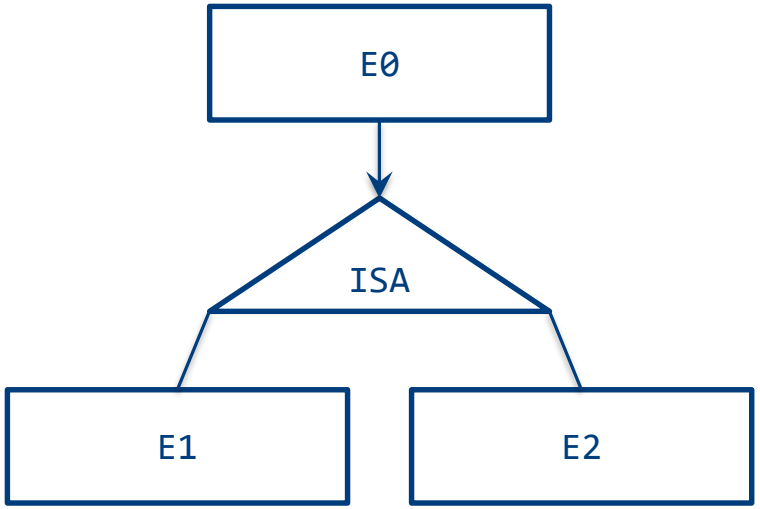
This is quite complex, instead, we will use a simpler motivating example but Trigger is powerful enough to handle this



Difficult Constraints

- **ISA Hierarchy**
  - A different difficult constraint that cannot be enforced via relational schema only is the ISA hierarchy with non-overlapping constraint (i.e., does not satisfy overlapping constraint).

The solution is:
- For each insertion to E1
- Check if the row is already present in E2
- Same for insert to E2, check on E1
- Checking can be done via trigger



Triggers

Triggers

- **Other Motivating Example**

Table "Scores"

Name	Mark
Alice	92
Bob	63
Cathy	58
David	47

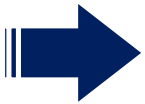


Table "Scores_Log"

Name	Date
Alice	2021-10-01
Bob	2021-10-09
Cathy	2021-10-12
David	2021-10-15

- Suppose we want to log when the marks are entered
  - This should be done automatically
    - The user of the database should not be bothered to write SQL statement to insert
  - This should be done *each time* an insertion occurs regardless of how it is done
  - We want to record the following data
    - The name of the student
    - The date of entry

Triggers

- **Other Motivating Example**

  What we want?
  1. Automatic insertion
  2. Regardless of how

Table "Scores"

Name	Mark
Alice	92
Bob	63
Cathy	58
David	47

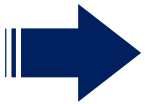


Table "Scores_Log"

Name	Date
Alice	2021-10-01
Bob	2021-10-09
Cathy	2021-10-12
David	2021-10-15

- Suppose we want to log when the marks are entered
  - **Idea?**
    - A procedure that enters both data
    - What if the user forgot to use the procedure?

```
CREATE OR REPLACE PROCEDURE enter_data
  (Name TEXT, Mark INT)
AS $$

    INSERT INTO Scores VALUES (Name, Mark);
    INSERT INTO Scores_Log
           VALUES (Name, CURRENT_DATE);

$$ LANGUAGE sql;
```

Triggers

- **Other Motivating Example**

  Issues?
  1. How to check insertion?
  2. How to get the name?

Table "Scores"

Name	Mark
Alice	92
Bob	63
Cathy	58
David	47

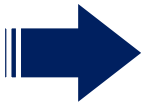


Table "Scores_Log"

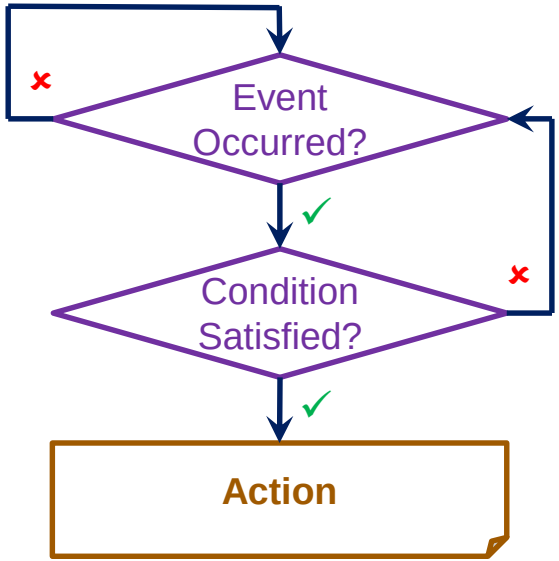
Name	Date
Alice	2021-10-01
Bob	2021-10-09
Cathy	2021-10-12
David	2021-10-15

- Suppose we want to log when the marks are entered
  - **What we want?**
    - A procedure to insert into `Scores_Log`
    - But called *automatically*

```
CREATE OR REPLACE PROCEDURE log_score()
AS $$
BEGIN                          (1) How to check insertion?
  IF (there is an insertion into Scores) THEN
    INSERT INTO Scores_Log
           VALUES (Name, CURRENT_DATE);
  END IF;                      (2) How to get the name?
END;
$$ LANGUAGE plpgsql;
```

Triggers

- **Basic of Triggers**
  - Trigger is an event-condition-action (ECA) rule
    - When event occurs
    - Test condition
    - If satisfied, execute action



- **Example**
  - Event — New tuple inserted into `Scores`
  - Condition — Nothing *(always execute action)*
  - Action — Insert into `Scores_Log`

Trigger

Trigger Function

Triggers

- **Other Motivating Example**

Trigger

```
CREATE TRIGGER score_log
AFTER INSERT ON Scores
FOR EACH ROW EXECUTE FUNCTION
    log_score();
```

Table "Scores"

Name	Mark
Alice	92
Bob	63
Cathy	58
David	47

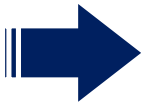


Table "Scores_Log"

Name	Date
Alice	2021-10-01
Bob	2021-10-09
Cathy	2021-10-12
David	2021-10-15

- Suppose we want to log when the marks are entered
  - **Trigger Function**
    - Actions to run when event occurred and conditions satisfied

Trigger Function

```
CREATE OR REPLACE FUNCTION log_score()
RETURNS TRIGGER AS $$
BEGIN

    INSERT INTO Scores_Log
           VALUES (NEW.Name, CURRENT_DATE);
    RETURN NULL;
END;
$$ LANGUAGE plpgsql;
```

Triggers

Table "Scores"

Name	Mark
Alice	92
Bob	63
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David	47

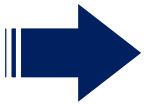


Table "Scores_Log"

Name	Date
Alice	2021-10-01
Bob	2021-10-09
Cathy	2021-10-12
David	2021-10-15

- The Trigger

Trigger

```
CREATE TRIGGER score_log
AFTER INSERT ON Scores
FOR EACH ROW EXECUTE FUNCTION
    log_score();
```

- This tells the database to
  - Watch out for insertion on `Score`
  - ~~Check for certain condition~~ *(we'll come back to this later)*
  - Call the function `log_score()` after each insertion of a tuple
  - There are other options, but that will be discussed later on

Triggers

- The Trigger Function
  - `RETURNS TRIGGER` indicates that this is a trigger function
    - Can only `RETURNS TRIGGER`
  - `NEW` refers to the new row inserted into `Scores`
    - Only accessible by trigger functions
  - Other accessible data?
    - `TG_OP`
    - `TG_TABLE_NAME`
    - `OLD`
    - `...`

Table "Scores"

Name	Mark
Alice	92
Bob	63
Cathy	58
David	47

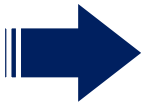


Table "Scores_Log"

Name	Date
Alice	2021-10-01
Bob	2021-10-09
Cathy	2021-10-12
David	2021-10-15

```
CREATE OR REPLACE FUNCTION log_score()
RETURNS TRIGGER AS $$
BEGIN

    INSERT INTO Scores_Log
           VALUES (NEW.Name, CURRENT_DATE);
    RETURN NULL;
END;
$$ LANGUAGE plpgsql;
```

Trigger Function

Triggers

- Syntax

Trigger

```
CREATE TRIGGER <trigger_name>
<timing> <event> ON <table>
FOR EACH <granularity>
EXECUTE FUNCTION <function_name>();
```

only applicable to this table

when triggered, this trigger calls this function

NOTE

`<timing>`, `<event>` and `<granularity>` are called trigger options.

This is what we will discuss next.

Trigger Function

```
CREATE OR REPLACE FUNCTION <function_name>()
RETURNS TRIGGER AS $$
BEGIN

    <code>

END;
$$ LANGUAGE plpgsql;
```

can only return `TRIGGER`

this code is then executed

Triggers Options

- Trigger Options
  - Events:
    - `INSERT ON table`
    - `DELETE ON table`
    - `UPDATE [OF column] ON table`

    TG_OP → *'INSERT'*, *'DELETE'*, *'UPDATE'*
  - Timing:
    - `AFTER` or `BEFORE` *(the triggering event)*
    - `INSTEAD OF` *(the triggering event on views)*
  - Granularity:
    - `FOR EACH ROW` *(modified)*
    - `FOR EACH STATEMENT` *(that performs the modification)*

Triggers Events

INSERT

DELETE

UPDATE

Triggers Event

- **Another Motivating Example**

Table "Scores"

Name	Mark
Alice	92
Bob	63
Cathy	58
David	47

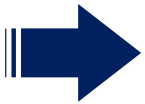


Table "Scores_Log2"

Name	Op	Date
Alice	Insert	2021-10-01
Bob	Delete	2021-10-09
Cathy	Update	2021-10-12
David	Insert	2021-10-15

- Suppose we want to log when the marks are entered
  - This should be done automatically
    - The user of the database should not be bothered to write SQL statement to insert
  - This should be done *each time* an insertion occurs regardless of how it is done
  - We want to record the following data
    - The name of the student
    - The date of entry
    - The operation performed

Triggers Event

- The Trigger Function

```
CREATE OR REPLACE FUNCTION log_score2() RETURNS TRIGGER AS $$
BEGIN
  IF    (TG_OP = 'INSERT') THEN
    INSERT INTO Scores_Log2 VALUES (NEW.Name, 'Insert', CURRENT_DATE);
    RETURN NEW;
  ELSIF (TG_OP = 'DELETE') THEN
    INSERT INTO Scores_Log2 VALUES (OLD.Name, 'Delete', CURRENT_DATE);
    RETURN OLD;
  ELSIF (TG_OP = 'UPDATE') THEN
    INSERT INTO Scores_Log2 VALUES (NEW.Name, 'Update', CURRENT_DATE);
    RETURN NEW;
  END IF;
END;
$$ LANGUAGE plpgsql;
```

Trigger Function

Question

Can we `RETURN NULL` like before?

Return value has effect, we will discuss later.

Triggers Event

- The Trigger Function

```
CREATE OR REPLACE FUNCTION log_score2() RETURNS TRIGGER AS $$
BEGIN
  IF    (TG_OP = 'INSERT') THEN ...
  ELSIF (TG_OP = 'DELETE') THEN ...
  ELSIF (TG_OP = 'UPDATE') THEN ...
  END IF;
END;
$$ LANGUAGE plpgsql;
```

Trigger Function

- The Trigger

```
CREATE TRIGGER score_log2
AFTER INSERT OR DELETE OR UPDATE ON Scores
FOR EACH ROW EXECUTE FUNCTION log_score2();
```

Trigger

Triggers Timing

AFTER

BEFORE

INSTEAD OF

Triggers Timing

Table "Scores"

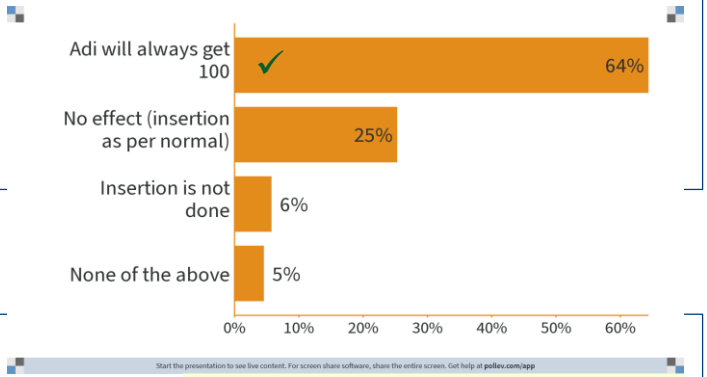
Name	Mark
...	...

- The Trigger Function

Trigger Function

```
CREATE OR REPLACE FUNCTION give_adi_full_mark() RETURNS TRIGGER AS $$
BEGIN
  IF (NEW.Name = 'Adi') THEN
    NEW.Mark := 100;
  END IF;   RETURN NEW;
END;
$$ LANGUAGE plpgsql;
```

Effect?



Trigger

```
CREATE TRIGGER adi_should_get_full_mark
BEFORE INSERT ON Scores
FOR EACH ROW EXECUTE FUNCTION give_adi_full_mark();
```

NOTE

`NEW` is a tuple `(Adi, 100)`.
Hence, the result.

Triggers Return Value

Table "Scores"

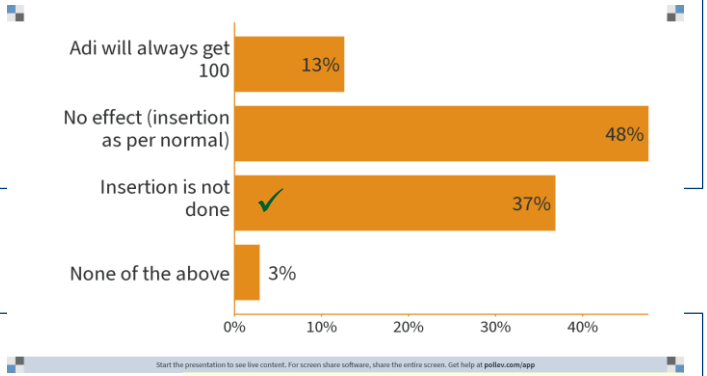
Name	Mark
...	...

- The Trigger Function

Trigger Function

```
CREATE OR REPLACE FUNCTION give_adi_full_mark() RETURNS TRIGGER AS $$
BEGIN
  IF (NEW.Name = 'Adi') THEN
    NEW.Mark := 100;
  END IF;   RETURN NULL;
END;
$$ LANGUAGE plpgsql;
```

Effect?



- The Trigger

Trigger

```
CREATE TRIGGER adi_should_get_full_mark
BEFORE INSERT ON Scores
FOR EACH ROW EXECUTE FUNCTION give_adi_full_mark();
```

NOTE

`NULL` stops `BEFORE` trigger.

Hence, the result.

Triggers Return Value

ERRATA
Here, OLD is initially NULL. So it is the same as return NULL.

Table "Scores"

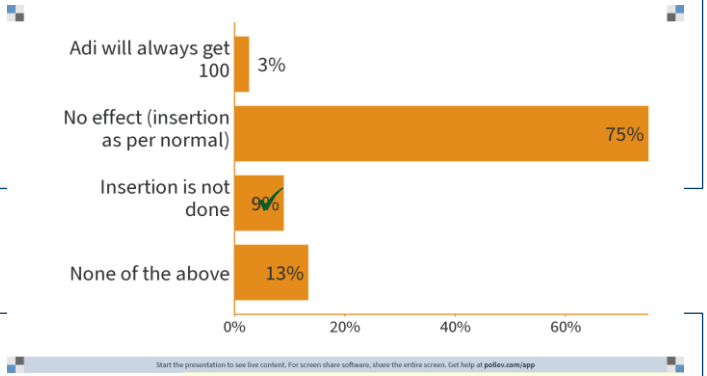
Name	Mark
...	...

- The Trigger Function

```
CREATE OR REPLACE FUNCTION give_adi_full_mark() RETURNS TRIGGER AS $$
BEGIN
  IF (NEW.Name = 'Adi') THEN
    NEW.Mark := 100;
  END IF;   RETURN OLD;
END;
$$ LANGUAGE plpgsql;
```

Trigger Function

Effect?



- The Trigger

```
CREATE TRIGGER adi_should_get_full_mark
BEFORE INSERT ON Scores
FOR EACH ROW EXECUTE FUNCTION give_adi_full_mark();
```

Trigger

NOTE
OLD is NULL for BEFORE trigger.
Hence, the result.

Triggers Return Value

Table "Scores"

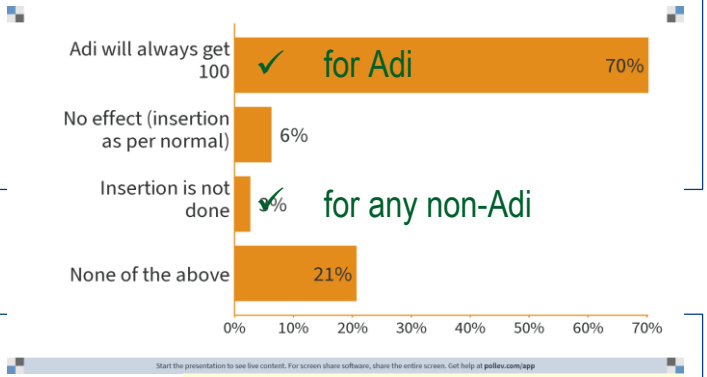
Name	Mark
...	...

- The Trigger Function

```
CREATE OR REPLACE FUNCTION give_adi_full_mark() RETURNS TRIGGER AS $$
BEGIN
  IF (NEW.Name = 'Adi') THEN
    OLD.Name := 'Adi';   OLD.Mark := 100;
  END IF;   RETURN OLD;
END;
$$ LANGUAGE plpgsql;
```

Trigger Function

Effect?



- The Trigger

```
CREATE TRIGGER adi_should_get_full_mark
BEFORE INSERT ON Scores
FOR EACH ROW EXECUTE FUNCTION give_adi_full_mark();
```

Trigger

NOTE

`OLD` is `NULL` for non-Adi.
`Old` is `(Adi, 100)` for Adi.
Hence, the result.

Triggers Return Value

- **Transition Variables**
  - `NEW` The modified row *after* the triggering event
  - `OLD` The modified row *before* the triggering event
  - ❖ Not all make sense all the time
- **Effect of Return Value**

NOTE
× is NULL

	NEW	OLD
INSERT	✓	×
UPDATE	✓	✓
DELETE	×	✓

	NULL tuple	non-NULL tuple t
BEFORE INSERT	No tuple inserted	Tuple `t` will be inserted
BEFORE UPDATE	No tuple updated	Tuple `t` will be the updated tuple
BEFORE DELETE	No deletion performed	Deletion proceeds as normal
AFTER INSERT	*Does not matter* *It's done already, cannot be changed now*	
AFTER UPDATE		
AFTER DELETE		

Triggers Timing

- `INSTEAD OF` Trigger
  - This kind of trigger can only be defined on `VIEWS`

- First Off...
  - What is a `VIEW`?
    - A *“virtual”* table defined by a query to compute the view
    - Can be used in queries just like a regular table
  - Why use a `VIEW`?
    - Hide data and/or complexity from users
    - Logical data independence
    - Captures common query to be reused
  - ❖ Real database applications use ***tons*** of `VIEW`

Triggers Timing

- `INSTEAD OF` Trigger
  - This kind of trigger can only be defined on `VIEWS`

- Secondly ...
  - Why do we want to modify a `VIEW`?
    - User sees it as a table and they can modify table
  - Does it even make sense?
    - In most cases, we cannot modify `VIEW` directly
    - But we can modify the underlying table

Triggers Timing

- `INSTEAD OF` Trigger
  - This kind of trigger can only be defined on `VIEWS`

- Modifying a VIEW
  - Simple case
    - ```
      CREATE VIEW Students AS
      SELECT Name FROM Scores;
      ```

    - ```
      DELETE FROM Students WHERE Name = 'Alice';
      ```
      translates to
      ```
      DELETE FROM Scores WHERE Name = 'Alice';
      ```

Triggers Timing

- `INSTEAD OF` Trigger
  - This kind of trigger can only be defined on `VIEWS`

- Modifying a VIEW
  - Impossible case
    - ```
      CREATE VIEW A_Students AS
      SELECT Name, Mark FROM Scores WHERE Mark >= 70;
      ```
    - ```
      INSERT INTO A_Students VALUES ('Bryan', 69);
      ```
      insertion does not affect the `VIEW`, only the underlying table

Triggers Timing

- `INSTEAD OF` Trigger
  - This kind of trigger can only be defined on `VIEWS`

- Modifying a VIEW
  - Too many possible case
    - ```
      CREATE VIEW Top_Marks(Mark) AS
      SELECT MAX(Mark) FROM Scores;
      ```
    - ```
      UPDATE Top_Marks SET Mark = 80;
      ```
      what if more than one people have top marks?

Triggers Timing

- `INSTEAD OF` Trigger
  - This kind of trigger can only be defined on `VIEWS`

- OK, so what to do here?
  - Let's say we want to modify all people with the maximum mark
  - We modify the underlying table instead
    - Use `INSTEAD OF` trigger

```
CREATE TRIGGER modify_top_mark
INSTEAD OF UPDATE ON Top_Marks
FOR EACH ROW EXECUTE FUNCTION update_top_mark();
```

Trigger

Triggers Timing

Table "Scores"

Name	Mark
...	...

- The Trigger Function

```
CREATE OR REPLACE FUNCTION update_top_mark() RETURNS TRIGGER AS $$
BEGIN
  UPDATE Scores SET Mark = NEW.Mark WHERE Mark = OLD.Mark;
  RETURN NEW;
END;
$$ LANGUAGE plpgsql;
```

Trigger Function

Return Value

- **NULL**
  - Ignore all operations on current row
- **Non-NULL**
  - Signals the database to proceed as normal

- The Trigger

```
CREATE TRIGGER modify_top_mark
INSTEAD OF UPDATE ON Top_Marks
FOR EACH ROW EXECUTE FUNCTION update_top_mark();
```

Trigger

Triggers Granularity

FOR EACH ROW

FOR EACH STATEMENT

Triggers Granularity

- **Row-Level Trigger** *(FOR EACH ROW)*
  - Executes the trigger function for every tuple encountered
- **Statement-Level Trigger** *(FOR EACH STATEMENT)*
  - Executes the trigger function only once
  - Why would we want to do this?
    - If we already prevent an operation, then just once is enough
    - There are other contextual data available, but we will not discuss this

```
CREATE TRIGGER modify_top_mark
INSTEAD OF UPDATE ON Top_Marks
FOR EACH ROW EXECUTE FUNCTION update_top_mark();
```

Triggers Granularity

Table "Scores_Log"

Name	Date
...	...

- The Trigger Function

```
CREATE OR REPLACE FUNCTION show_warning() RETURNS TRIGGER AS $$
BEGIN
  RAISE NOTICE 'You are not supposed to delete from log...';
  RETURN NULL;
END;
$$ LANGUAGE plpgsql;
```

Trigger Function

Effect?

- **RAISE NOTICE**
  - Database will give you prompt whenever a deletion is attempted
- **RETURN NULL**
  - Unfortunately, still perform deletion

- The Trigger

```
CREATE TRIGGER warn_delete
BEFORE DELETE ON Scores_Log
FOR EACH STATEMENT EXECUTE FUNCTION show_warning();
```

Trigger

Triggers Granularity

Table "Scores_Log"

Name	Date
...	...

- The Trigger Function

Trigger Function

```
CREATE OR REPLACE FUNCTION show_warning() RETURNS TRIGGER AS $$
BEGIN
  RAISE EXCEPTION 'You are not supposed to delete from log...';
  RETURN NULL;
END;
$$ LANGUAGE plpgsql;
```

- **Statement-Level Trigger** *(FOR EACH STATEMENT)*
  - Ignores the values returned by the trigger functions
  - `RETURN NULL` would not make the database omit the subsequent operation
  - What to do?
    - `RAISE EXCEPTION`

Triggers Granularity

- **Granularity and Timing**
  - `INSTEAD OF` is only allowed on row-level granularity
  - `AFTER` or `BEFORE` are allowed on both row-level as well as statement-level granularity

Granularity

Timing	Row-Level	Statement-Level
`AFTER`	Tables	Tables and View
`BEFORE`	Tables	Tables and View
`INSTEAD OF`	Views	-

Triggers Condition

Event

Trigger

Condition

... we are here ...

Action

Trigger Function

Triggers Condition

Table "Scores"

Name	Mark
Adi	100

- The Trigger Function

```
CREATE OR REPLACE FUNCTION give_adi_full_mark() RETURNS TRIGGER AS $$
BEGIN
  IF (NEW.Name = 'Adi') THEN
    NEW.Mark := 100;
  END IF;
  RETURN NEW;
END;
$$ LANGUAGE plpgsql;
```

Trigger Function

Observation

Trigger function only cares about the case when name is *Adi*

We can move this condition to the trigger definition

- The Trigger

```
CREATE TRIGGER adi_should_get_full_mark
BEFORE INSERT ON Scores
FOR EACH ROW WHEN (NEW.Name = 'Adi')
EXECUTE FUNCTION give_adi_full_mark();
```

Trigger

Triggers Condition

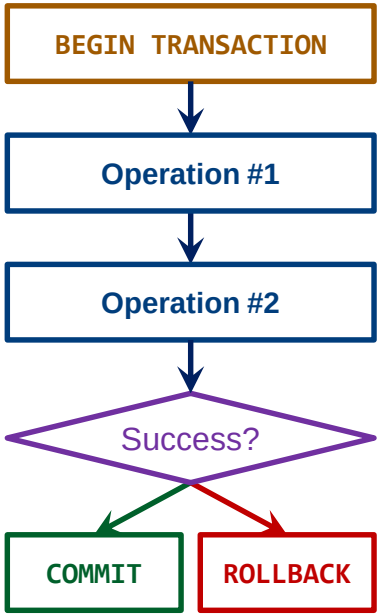
- **What Can We Use?**
  - In general, the condition in `WHEN()` could be more complicated
  - Subject to the following requirements:
    - **NO** `SELECT` in `WHEN()`
    - **NO** `OLD` in `WHEN()` for `INSERT`
    - **NO** `NEW` in `WHEN()` for `DELETE`
    - **NO** `WHEN()` for `INSTEAD OF`

```
CREATE TRIGGER adi_should_get_full_mark
BEFORE INSERT ON Scores
FOR EACH ROW WHEN (NEW.Name = 'Adi')
EXECUTE FUNCTION give_adi_full_mark();
```

Triggers Condition

- **Deferred Trigger**
  - Triggers happen at the end of either statement or at the end of transaction
  - **Operation** consisting of multiple statements may leave the database in an intermediate *inconsistent* state
  - In such cases, we want the trigger to check consistency constraint only at the end of a transaction

  ❖ This is called a ***deferred*** trigger



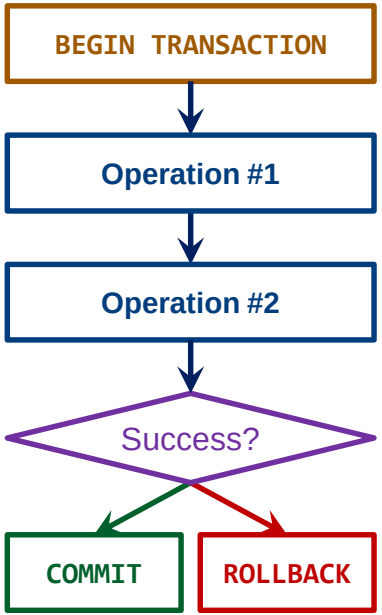
Triggers Condition

- **Deferred Trigger**
  - Example:
    - Customer may have multiple account
    - Total balance for all accounts must be at least 150

Table "Account"

AID	Name	Balance
1	Alice	100
2	Alice	100

    - Task: Transfer money from one account to another



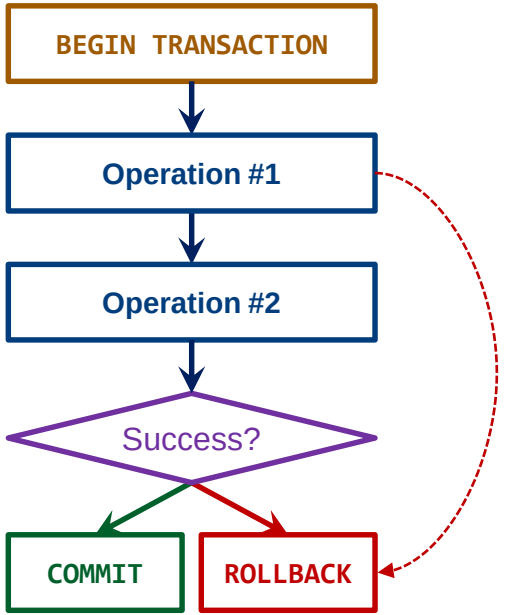
Triggers Condition

- **Deferred Trigger**
  - Naïve approach:
    1. Deduct amount from account 1
    2. Add amount to account 2

May violate constraint!

Table "Account"

AID	Name	Balance
1	Alice	100
2	Alice	100



  - Solution:
    1. Put the two update into one transaction
    2. Defer trigger to check only at the end of transaction

Triggers Condition

Table "Account"

AID	Name	Balance
1	Alice	100
2	Alice	100

- **Deferred Trigger**

```
CREATE CONSTRAINT TRIGGER balance_check
AFTER INSERT OR UPDATE OR DELETE ON Account
DEFERRABLE INITIALLY DEFERRED
FOR EACH ROW EXECUTE FUNCTION check_balance();
```

  - `CONSTRAINT` and `DEFERRABLE` ***together*** indicate that the trigger can be deferred
  - `INITIALLY DEFERRED` indicates that by default, the trigger is deferred
    - In other words, only check at the end of transaction
    - Other option is `INITIALLY IMMEDIATE`
      - *i.e.,* the trigger is not deferred by default
  - Deferred triggers only work with `AFTER` and `FOR EACH ROW`

Triggers Condition

Table "Account"

AID	Name	Balance
1	Alice	100
2	Alice	100

- **Deferred Trigger**

```
CREATE CONSTRAINT TRIGGER balance_check
AFTER INSERT OR UPDATE OR DELETE ON Account
DEFERRABLE INITIALLY DEFERRED
FOR EACH ROW EXECUTE FUNCTION check_balance();
```

- Now we can do the following

```
BEGIN TRANSACTION;

UPDATE Account SET Balance = Balance – Amount WHERE AID = Account1;
UPDATE Account SET Balance = Balance + Amount WHERE AID = Account2;

COMMIT;
```

Triggers Condition

Table "Account"

AID	Name	Balance
1	Alice	100
2	Alice	100

- **Deferred Trigger**

```
CREATE CONSTRAINT TRIGGER balance_check
AFTER INSERT OR UPDATE OR DELETE ON Account
DEFERRABLE INITIALLY IMMEDIATE
FOR EACH ROW EXECUTE FUNCTION check_balance();
```

- What if the trigger is `INITIALLY IMMEDIATE`?
  - Change it on the fly

```
BEGIN TRANSACTION;
SET CONSTRAINTS balance_check DEFERRED;
UPDATE Account SET Balance = Balance – Amount WHERE AID = Account1;
UPDATE Account SET Balance = Balance + Amount WHERE AID = Account2;

COMMIT;
```

Final Note on Triggers

- **Multiple Triggers**
  - There can be multiple triggers defined for the same event on the same table
    - There need to be an *order of activation*
      - `BEFORE` statement-level triggers
      - `BEFORE` row-level triggers
      - `AFTER` row-level triggers
      - `AFTER` statement-level triggers
    - Within each category, triggers are activated in ***alphabetic*** order
    - If `BEFORE` row-level trigger returns `NULL`, then subsequent triggers on the same row are omitted
- Universality of Triggers?
  - Our discussions are based on PostgreSQL syntax and implementation only

Questions?