Computing

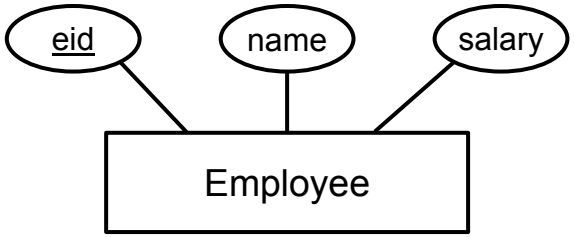
CS2102: Database Systems

Lecture 9 — Triggers

Overview

- **Triggers — Overview**
  - **Motivation**
  - Basic Example
  - Basic Concepts
- Triggers — Options
  - Events
  - Timing
  - Granularity
- Triggers — Refinements
  - Conditions
  - Deferrable Triggers
- Summary

Constraints Regarding Changes of Data



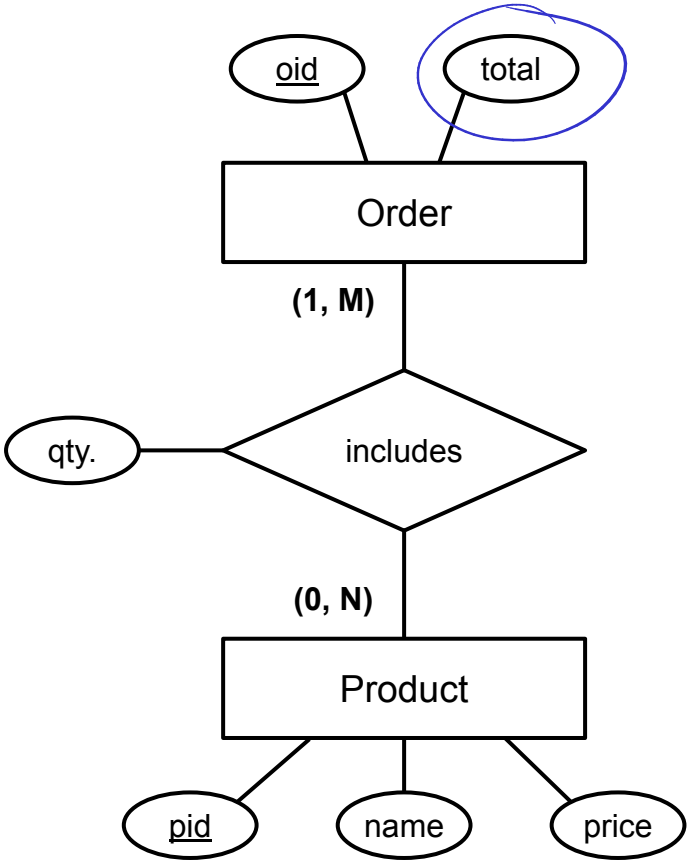

```
CREATE TABLE employees (
 eid INT PRIMARY KEY,
 name TEXT NOT NULL,
 salary DECIMAL(12,2) NOT NULL DEFAULT 0,
 CONSTRAINT check_pos_salary CHECK (salary >= 0)
);
```

Additional constraint: The salary of an employee is only allowed to increase.

Question: How can we check and ensure integrity transparent to the user?

- The user/app should not be forced to call a stored procedure or function

Recall: ER Model — Stored Attributes but with Derived Values



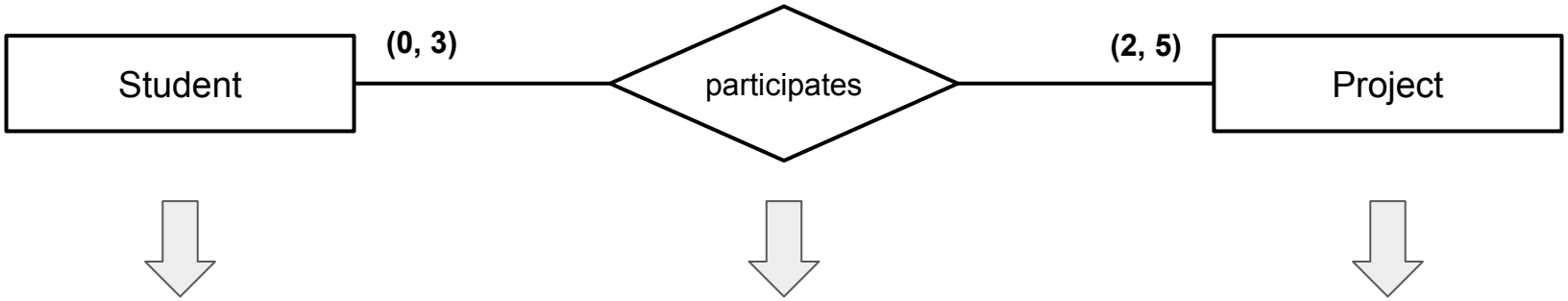

```
CREATE TABLE orders (
 oid INT PRIMARY KEY,
 total DECIMAL(12,2) NOT NULL DEFAULT 0
);
```

Integrity Constraint: `orders.total` must reflect the total price of the order!

Question: How can we check and ensure integrity transparent to the user?

- The user/app should not worry about that
- The user/app should not be forced to call a stored procedure or function

Recall: ER Model — Many-to-Many with Cardinality Constraints




```
CREATE TABLE student (
 id INT PRIMARY KEY,
 name TEXT NOT NULL,
 email TEXT NOT NULL,
 dob DATE,
 …
);
```

```
CREATE TABLE participates (
 sid INT FOREIGN KEY REFERENCES students (id),
 pid INT FOREIGN KEY REFERENCES projects (id),
 PRIMARY KEY (sid, pid)
);
```

```
CREATE TABLE projects (
 id INT PRIMARY KEY,
 title TEXT NOT NULL,
 budget INT NOT NULL,
 dob DATE,
 …
);
```

Problem: Relational Schema can **not** capture cardinality constraints!

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Running Example Database

- Toy database: Just 1 table
  - Over-simplified table `students`

```
CREATE TABLE students (
 id SERIAL PRIMARY KEY,
 name TEXT NOT NULL,
 points INTEGER DEFAULT 0,
 graduated BOOLEAN DEFAULT FALSE
);
```

id	name	points	graduated
1	Bob	94	TRUE
2	Eve	82	FALSE
3	Sam	65	FALSE
4	Liz	86	TRUE
5	Tom	90	TRUE
6	Sue	94	FALSE
7	Zac	75	FALSE
8	Ida	84	TRUE
9	Leo	91	FALSE
10	Pam	70	FALSE

Motivation — Simple Use Case

Question: How could we solve this with the things we have learned so far?

- Application requirement
  - Every time a new students gets entered, we need log this event
  - Logging is done using a separate table: `basic_logs(student:INT, created_at:TIMESTAMP)`

Table **`students`**

id	name	points	graduated
1	Bob	94	TRUE
2	Eve	82	FALSE
3	Sam	65	FALSE
4	Liz	86	TRUE
5	Tom	90	TRUE
…	…	…	…

Desired design goals

- Insert into **`basic_logs`** automatically
- Do not force user to write too much SQL
- Log not matter how students are added

Table **`basic_logs`**

id	created_at
1	2023-08-24 09:02:50
2	2023-08-24 13:25:41
3	2023-08-24 15:40:23
4	2023-08-24 20:11:08
5	2023-08-25 08:55:10
…	…

Motivation — Simple Use Case

Quick Quiz: How could we fix the 3rd design goal as well here?

- Possible solution: stored procedure (not a bad solution for this simple case!)
  - Stored procedure that combines inserting students and inserting log entries

```
CREATE OR REPLACE PROCEDURE enter_student(sname TEXT, spoints INTEGER)
AS
$$
DECLARE
    new_id INTEGER;
BEGIN
    INSERT INTO students (name, points) VALUES (sname, spoints)
      RETURNING id INTO new_id;
    INSERT INTO points_log_basic (student) VALUES (new_id);
END;
$$ LANGUAGE plpgsql;
```

SECURITY DEFINER

```
CALL enter_student('Adi', 80);
```

Desired design goals

- Insert into **`basic_logs`** automatically ✔
- Do not force user to write too much SQL ✔
- Log no matter how students are added ✗

What if a user runs **`INSERT INTO`** `students` … instead of calling `enter_student()`?

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Triggers — Basic Concepts

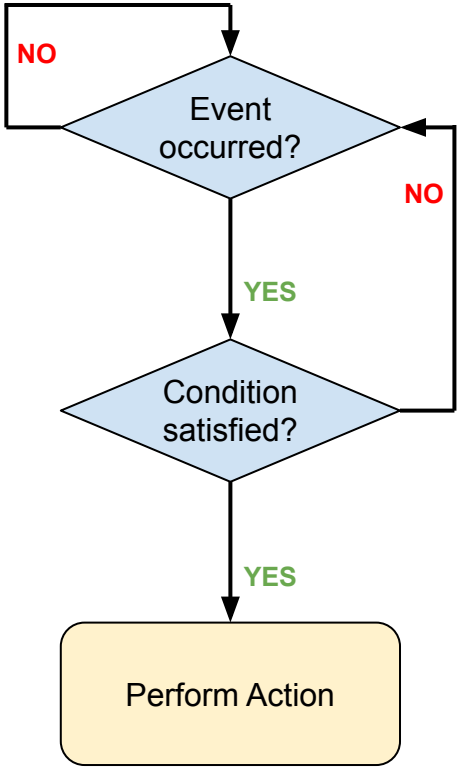
- Trigger = event-condition-action (**ECA**) rule
  - When an **event** occurs…
  - …test **condition** and…
  - …if satisfied, perform **action**.

- Example (for our simple use case)

Event: New tuple inserted into `students`

Condition: (nothing)

Action: Insert into `basic_logs`



Triggers — Basic Concepts

Quick Quiz: Why do we split the code into two distinct definitions?

- **ECA** rule split into 2 parts

Event: New tuple inserted into **`students`**

Condition: (nothing)

} **Trigger**

Action: Insert into **`basic_logs`**

} **Trigger Function**

Trigger

```
CREATE TRIGGER on_student_entered
AFTER INSERT ON students
FOR EACH ROW
EXECUTE FUNCTION log_student_basic();
```

Trigger Function

```
CREATE FUNCTION log_student_basic()
RETURNS TRIGGER AS
$$
BEGIN
    INSERT INTO basic_logs (student) VALUES (NEW.id);
    RETURN NEW;
END;
$$ LANGUAGE plpgsql;
```

Trigger Function vs "Normal" Function

Quick Quiz: What is an intuitive case where, say, `NEW` is not available?

- Trigger function — requirements
  - Must take no (ordinary) arguments
  - Must have a return type `TRIGGER`
  - Must be defined before trigger itself
- Trigger function — "input"
  - Special internal data structure received from the trigger
  - Useful data within the trigger function
    (which data is available depends on trigger definition!)

`TG_NAME`	Name of the trigger that fired
`TG_OP`	Operation that fired the trigger (`INSERT`, `UPDATE`, `DELETE`)
`TG_WHEN`	Time when the trigger was fired (`BEFORE`, `AFTER`, or `INSTEAD OF`)
`NEW`	Record holding the new row for `INSERT`/`UPDATE` operations
`OLD`	Record holding the old row for `UPDATE`/`DELETE` operations
…	…
`TG_ARGV[]`	Array of arguments from the `CREATE TRIGGER` statement.

Relevant PostgreSQL Docs

Extended Use Case

Quick Quiz: Where in the code could be arbitrarily `NEW` or `OLD`?

- Additional requirements
  - Log all events that might modify students' points (`INSERT`, `UPDATE`, `DELETE`)

➜ `advanced_logs(student: INT, operation: TEXT, points_old: INT, points_new: INT, created_at: TIMESTAMP)`

```
CREATE OR REPLACE FUNCTION log_student_advanced()
RETURNS TRIGGER AS
$$
BEGIN
    IF TG_OP = 'INSERT' THEN
        INSERT INTO points_log_advanced VALUES (NEW.id, TG_OP, NULL, NEW.points, DEFAULT);
        RETURN NEW;
    ELSIF (TG_OP = 'DELETE') THEN
        INSERT INTO points_log_advanced VALUES (OLD.id, TG_OP, OLD.points, NULL, DEFAULT);
        RETURN OLD;
    ELSIF (TG_OP = 'UPDATE') THEN
        INSERT INTO points_log_advanced VALUES (OLD.id, TG_OP, OLD.points, NEW.points, DEFAULT);
        RETURN NEW;
    END IF;
END;
$$ LANGUAGE plpgsql;
```

Extended Use Case

- Define trigger
  - Can listen to multiple event types

- Example execution
  - 4 SQL statements of different types affecting table **`students`**
  - All statements reflected in log table

```
CREATE TRIGGER on_student_modified_advanced
AFTER INSERT OR DELETE OR UPDATE ON students
FOR EACH ROW
EXECUTE FUNCTION log_student_advanced();
```

```
INSERT INTO students (name, points) VALUES ('Adi', 80);

UPDATE students SET points = 92 WHERE id = 1;

UPDATE students SET points = 75 WHERE id = 7;

DELETE FROM students WHERE id = 4;
```

id	operation	points_old	points_new	created_at
11	INSERT	*null*	80	2023-09-25 09:02:50
1	UPDATE	94	92	2023-09-27 13:25:41
7	UPDATE	75	75	2023-09-28 13:25:41
4	DELETE	86	*null*	2023-09-28 15:40:23

Triggers — Trigger Options

Event

- Occurrence or situation that fires the trigger
- Alternatives: **`INSERT`**, **`UPDATE`**, **`DELETE`**

Timing

- Specifies *when* trigger is fired
- For tables: **`BEFORE`** or **`AFTER`**
- For views: **`INSTEAD OF`**

```
CREATE TRIGGER on_student_entered
AFTER INSERT ON students
FOR EACH ROW
EXECUTE FUNCTION log_student_basic();
```

Granularity

- Specifies if triggered for each affect row or only once
- Alternatives: **`FOR EACH ROW`** or **`FOR EACH STATEMENT`**

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Triggers — Events

```
CREATE TRIGGER on_student_entered
AFTER INSERT ON students
FOR EACH ROW
EXECUTE FUNCTION log_student_basic();
```

- Trigger event — the **Why?**
  - Operation that causes the trigger to fire
  - 3 event types reflect the 3 basic DB operations

```
INSERT ON table
DELETE ON table
UPDATE [OF column] ON table
```

➜ `TG_OP =` { *'INSERT'* | *'DELETE'* | *'UPDATE'* }

  - Multiple events can fire the same trigger

```
CREATE TRIGGER on_student_modified_advanced
AFTER INSERT OR DELETE OR UPDATE ON students
…
```

Triggers — Events

- Trigger event specifies access to **transition variables**
  - **NEW**: modified row *after* the triggering event
    (can only exist for **INSERT** and **UPDATE** operations)
  - **OLD**: modified row *before* the triggering event
    (can only exist for **DELETE** and **UPDATE** operations)

	NEW	OLD
INSERT	✔	✘
UPDATE	✔	✔
DELETE	✘	✔

```
CREATE TRIGGER on_student_entered
AFTER INSERT ON students
FOR EACH ROW
EXECUTE FUNCTION log_student_basic();
```

```
CREATE FUNCTION log_student_basic()
RETURNS TRIGGER AS
$$
BEGIN
    INSERT INTO basic_logs (student) VALUES (OLD.id);
    RETURN NEW;
END;
$$ LANGUAGE plpgsql;
```

This will cause problems since **OLD.id** is **NULL**!

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Triggers — Timing

```
CREATE TRIGGER on_student_entered
AFTER INSERT ON students
FOR EACH ROW
EXECUTE FUNCTION log_student_basic();
```

- Trigger timing — the **When?**
  - The moment the trigger is fired
  - 3 possible timings

`AFTER`	Triggers fires after the operation has completed (this includes that any relevant constraints have been checked)
`BEFORE`	Trigger fires before the operation is attempted
`INSTEAD OF`	Trigger fires if an operation on a view is attempted

- Importance of timing
  - **`BEFORE`** and **`INSTEAD OF`** triggers can skip or modify the operation
  - For **`BEFORE`** and **`INSTEAD OF`** triggers the return value of the trigger function matters

Triggers — BEFORE vs AFTER

- Effects of return values
  - **BEFORE** triggers can intercept and modify / change the operation
  - **AFTER** triggers cannot affect operations that fired them

	RETURN value	
	NULL tuple	non-NULL tuple t
BEFORE INSERT	No tuple inserted	Tuple t inserted
BEFORE UPDATE	No tuple updated	Tuple t updated
BEFORE DELETE	No tuple deleted	Tuple t deleted
AFTER INSERT	No effects!	
AFTER UPDATE		
AFTER DELETE		

```
CREATE TRIGGER on_student_entered
AFTER INSERT ON students
FOR EACH ROW
EXECUTE FUNCTION log_student_basic();
```

```
CREATE FUNCTION log_student_basic()
RETURNS TRIGGER AS
$$
BEGIN
    INSERT INTO basic_logs (student) VALUES (NEW.id);
    RETURN NULL;  -- or RETURN NEW;
END;
$$ LANGUAGE plpgsql;
```

Quick Quiz

DO NOT INSERT student

DO logging

Given this trigger and trigger function…

```
CREATE TRIGGER on_student_entered
BEFORE INSERT ON students
FOR EACH ROW
EXECUTE FUNCTION log_student_basic();
```

```
CREATE FUNCTION log_student_basic()
RETURNS TRIGGER AS
$$
BEGIN
    INSERT INTO basic_logs (student) VALUES (NEW.id);
    RETURN NULL;
END;
$$ LANGUAGE plpgsql;
```

…what is the effect of the following SQL statement?

```
INSERT INTO students (name, points) VALUES ('Adi', 80)
```

Triggers — Intercepting Operations with BEFORE Triggers

- Example use case
  - If we insert or update a student named "Adi", we give him full points
  - Use **BEFORE** trigger to intercept initial **INSERT** or **UPDATE** operation

```
CREATE TRIGGER on_student_entered
BEFORE INSERT OR UPDATE ON students
FOR EACH ROW
EXECUTE FUNCTION help_adi_cheat();
```

```
CREATE FUNCTION help_adi_cheat()
RETURNS TRIGGER AS
$$
BEGIN
    IF NEW.name = 'Adi' THEN
        NEW.points := 100;
    RETURN NEW;
END;
$$ LANGUAGE plpgsql;
```

Triggers — Intercepting Operations with BEFORE Triggers

- Alternative implementations of trigger function
  - Any valid non-**NULL** tuple will be inserted into students
  - We can even set and return **OLD** transition variable despite **INSERT** operation

```
CREATE FUNCTION help_adi_cheat()
RETURNS TRIGGER AS
$$
BEGIN
    IF NEW.name = 'Adi' THEN
        OLD := NEW;
        OLD.points := 100
    RETURN OLD;
END;
$$ LANGUAGE plpgsql;
```

```
CREATE FUNCTION help_adi_cheat()
RETURNS TRIGGER AS
$$
DECLARE
    s RECORD;
BEGIN
    IF NEW.name = 'Adi' THEN
        s := NEW;
        s.points := 100
    RETURN s;
END;
$$ LANGUAGE plpgsql;
```

Triggers — Timing

- INSTEAD OF trigger
  - Can only be defined on views
  - Why do we want / need those?

```
CREATE VIEW <name> AS
    SELECT …
    FROM …
    …
;
```

- Views — quick recap
  - Virtual table (permanently named query)
  - Result of a query is not permanently stored! (query is executed each time the view is used)
  - Looks and can be used like any other table (well, kind of…)
  - Hide data or complexity from users (recall: logical data independence)
  - Heavily used in real-world database applications

Triggers — Working with Views

- Views vs "normal" tables
  - No restriction when used in SQL queries (**`SELECT`** statements)
  - But what about **`INSERT`**, **`UPDATE`**, **`DELETE`** statements?

➜ **Updatable View —** requirements

- Only one entry in **`FROM`** clause (table or updatable view)
- No **`WITH`**, **`DISTINCT`**, **`GROUP BY`**, **`HAVING`**, **`LIMIT`**, or **`OFFSET`**
- No **`UNION`**, **`INTERSECT`** or **`EXCEPT`**
- No aggregate functions
- etc. (incl. no constraint violations)

Direct modification of view not possible in most cases.

For more details: https://www.postgresql.org/docs/current/sql-createview.html

Triggers — Updatable Views

```
CREATE VIEW students_view AS
    SELECT name, points
    FROM students
;
```

Example of an **Updatable View**

```
DELETE FROM students_view WHERE name = 'Bob';
```
⇒
```
DELETE FROM students WHERE name = 'Bob';
```
✔

```
UPDATE students_view SET points = points + 3;
```
⇒
```
UPDATE students SET points = points + 3;
```
✔

```
INSERT INTO students_view VALUES ('Adi', 80);
```
⇒
```
INSERT INTO students VALUES (DEFAULT, 'Adi', 80, DEFAULT);
```
✔

works since we have default values ➜ no constraint violations

Triggers — Non-Updatable Views

```
CREATE VIEW point_groups AS
    SELECT points, COUNT(*) AS num_students
    FROM students
    GROUP BY points
;
```

Example of a **Non-Updatable View**

```
SELECT * FROM point_groups;
```

points	num_students
65	1
70	1
82	3
86	1
90	1
91	1
94	2

"Give the best students a bonus!"

```
UPDATE point_groups
SET points = points + 3
WHERE points = 94;
```

➜ **This will throw an error!** (`GROUP BY` in view)

Triggers — INSTEAD OF

```
CREATE TRIGGER on_point_groups_updated
INSTEAD OF UPDATE ON point_groups
FOR EACH ROW
EXECUTE FUNCTION update_student_points();
```

```
CREATE FUNCTION update_student_points()
RETURNS TRIGGER AS
$$
BEGIN
    UPDATE students SET points = NEW.points
    WHERE points = OLD.points;
    RETURN NEW;
END;
$$ LANGUAGE plpgsql;
```

Table students

id	name	points	graduated
1	Bob	97	TRUE
2	Eve	82	FALSE
3	Sam	65	FALSE
4	Liz	86	TRUE
5	Tom	90	TRUE
6	Sue	97	FALSE
7	Zac	75	FALSE
8	Ida	84	TRUE
9	Leo	91	FALSE
10	Pam	70	FALSE

"Give the best students a bonus!"

```
UPDATE point_groups
SET points = points + 3
WHERE points = 94;
```

➜ **This works now**

Quick Quiz

```
CREATE TRIGGER on_point_groups_updated
INSTEAD OF UPDATE ON point_groups
FOR EACH ROW
EXECUTE FUNCTION update_student_points();
```

```
CREATE FUNCTION update_student_points()
RETURNS TRIGGER AS
$$
BEGIN
      UPDATE students SET points = NEW.points
      WHERE points = OLD.points;
      RETURN NEW;
END;
$$ LANGUAGE plpgsql;
```

What *"bad thing"* can happen here?

*"Give **all** students a bonus!"*

```
UPDATE point_groups
SET points = points + 3
WHERE points = 94;
```

➜ **This will throw no error but…???**

Quick Quiz — Solution

```
UPDATE point_groups
SET points = points + 3
```

SQL statements executed by trigger functions

```
UPDATE students SET points=68 WHERE points=65;
UPDATE students SET points=73 WHERE points=70;
UPDATE students SET points=85 WHERE points=82;
UPDATE students SET points=89 WHERE points=86;
UPDATE students SET points=93 WHERE points=90;
UPDATE students SET points=94 WHERE points=91;
UPDATE students SET points=97 WHERE points=94;
```

id	name	points	graduated
1	Bob	94	TRUE
2	Eve	82	FALSE
3	Sam	65	FALSE
4	Liz	86	TRUE
5	Tom	90	TRUE
6	Sue	94	FALSE
7	Zac	75	FALSE
8	Ida	84	TRUE
9	Leo	91	FALSE
10	Pam	70	FALSE

id	name	points	graduated
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3	Sam	68	FALSE
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6	Sue	97	FALSE
7	Zac	78	FALSE
8	Ida	87	TRUE
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Triggers — Granularity

- Row-level triggers
  - Trigger function is executed for each affected row
  - Keyword: **`FOR EACH ROW`**

- Statement-level triggers
  - Trigger function is executed once for each transaction (no matter how many rows are affected)
  - Keyword: **`FOR EACH STATEMENT`**
  - Ignored return value of trigger function
    (Enforcing a rollback requires **`RAISE EXCEPTION`**!)

Example for a statement-level trigger

- Prohibit the deletion of rows from the logs
- Show warning to user only once no matter how many rows the user attempted to delete

```
CREATE TRIGGER on_delete_from_log
BEFORE DELETE ON advanced_log
FOR EACH STATEMENT
EXECUTE FUNCTION show_warning();
```

```
CREATE FUNCTION show_warning()
RETURNS TRIGGER AS
$$
BEGIN
    RAISE EXCEPTION 'Do not DELETE the logs!!!';
    RETURN NULL;
END;
$$ LANGUAGE plpgsql;
```

Triggers — Granularity

- Granularity and timing
  - **`AFTER`** and **`BEFORE`** allowed for *both* row-level and statement-level triggers
  - **INSTEAD OF** *only* allowed for row-level triggers

- Possible combinations

Timing	Row-Level	Statement-Level
`AFTER`	Tables	Tables & Views
`BEFORE`	Tables	Tables & Views
`INSTEAD OF`	Views	–

Relevant PostgreSQL Docs

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Triggers — Conditions

- Throwback to previous example
  - Log any update of points in the students table
  - Example on the right shows initial solution
- Now: additional refinement
  - Let's not log updates that do not really change points

```
CREATE TRIGGER on_student_modified_advanced
AFTER INSERT OR DELETE OR UPDATE ON students
FOR EACH ROW
EXECUTE FUNCTION log_student_advanced();
```

```
INSERT INTO students (name, points) VALUES ('Adi', 80);

UPDATE students SET points = 92 WHERE id = 1;

UPDATE students SET points = 75 WHERE id = 7;

DELETE FROM students WHERE id = 4;
```

id	operation	points_old	points_new	created_at
11	INSERT	*null*	80	2023-09-25 09:02:50
1	UPDATE	94	92	2023-09-27 13:25:41
7	UPDATE	75	75	2023-09-28 13:25:41
4	DELETE	86	*null*	2023-09-28 15:40:23

No need to log this row, just wastes disk space?

Triggers — Conditions

Quick Quiz: Why might we not be that happy with this solution?

- Approach 1: Modify trigger function

```
CREATE OR REPLACE FUNCTION log_student_advanced()
RETURNS TRIGGER AS
$$
BEGIN
    IF TG_OP = 'INSERT' THEN
        INSERT INTO points_log_advanced VALUES (NEW.id, TG_OP, NULL, NEW.points, DEFAULT);
        RETURN NEW;
    ELSIF (TG_OP = 'DELETE') THEN
        INSERT INTO points_log_advanced VALUES (OLD.id, TG_OP, OLD.points, NULL, DEFAULT);
        RETURN OLD;
    ELSIF (TG_OP = 'UPDATE') THEN
        IF NEW.points <> OLD.points THEN
            INSERT INTO points_log_advanced VALUES (OLD.id, TG_OP, OLD.points, NEW.points, DEFAULT);
        END IF;
        RETURN NEW;
    END IF;
END;
$$ LANGUAGE plpgsql;
```

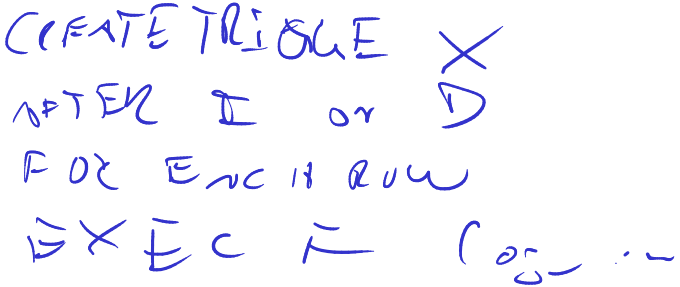
Triggers — Conditions

Quick Quiz: What happened to [...] `INSERT OR DELETE OR` [...]?

- Approach 2: Modify trigger
  - Move condition from trigger function to trigger
  - Only execute trigger function of condition is true

```
CREATE TRIGGER on_student_updated_advanced
AFTER UPDATE ON students
FOR EACH ROW WHEN (NEW.points <> OLD.points)
EXECUTE FUNCTION log_student_advanced();
```

Fires for every **`UPDATE`** but executes trigger function only if the points are indeed different.



Triggers — Conditions

- What conditions can we formulate
  - In general, any Boolean expression
  - In principle, can be arbitrarily complex

- Restrictions
  - **NO** `SELECT` in `WHEN()`
  - **NO** `OLD` in `WHEN()` for `INSERT`
  - **NO** `NEW` in `WHEN()` for `DELETE`
  - **NO** `WHEN()` for `INSTEAD OF`

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Triggers — Deferrable Triggers

- Triggers — default behavior
  - Triggers run immediately for **every** statement that fire them
  - Problem: operations of **multiple statements** yielding intermediate inconsistent states

- Example
  - Table with customer accounts
    (Customers can have multiple accounts)
  - Constraint: all balances of the same costumer's account must be at least 150
    (we already know how to write a trigger for that)

id	name	balance
…	…	…
10	Bob	100
11	Bob	80
…	…	…

Triggers — Deferrable Triggers

```
CREATE TRIGGER on_customers_modified
AFTER INSERT OR DELETE OR UPDATE ON customers
FOR EACH ROW
EXECUTE FUNCTION check_balance();
```

```
CREATE OR REPLACE FUNCTION check_balance()
RETURNS TRIGGER AS
$$
…
    SELECT SUM(balance)  INTO total_balance
    FROM customers  WHERE id = NEW.id;
    IF total_balance < 150 THEN
        RETURN NULL;
…
$$ LANGUAGE plpgsql;
```

Question: How to transfer 50 dollar between Bob's accounts? — naive approach:

```
BEGIN TRANSACTION;
UPDATE customers SET balance = balance - 50 WHERE id = 10;
UPDATE customers SET balance = balance + 50 WHERE id = 11;
END TRANSACTION;
```

Trigger will fire and complain here!

Triggers — Deferrable Triggers

- **Deferred triggers** — behavior
  - Run trigger only at the end of transactions
  - Ignore potential inconsistent states within transaction

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

```
BEGIN TRANSACTION;
UPDATE customers SET balance = balance - 50 WHERE id = 10;
UPDATE customers SET balance = balance + 50 WHERE id = 11;
END TRANSACTION;
```

This works now!

Triggers — Deferrable Triggers

- **Deferred triggers** — requirements
  - Only work for **`AFTER`** and **`FOR EACH ROW`** triggers
  - Both **`CONSTRAINT`** and **`DEFERRABLE`** must be specified
  - Two different default behaviors

    `INITIALLY DEFERRED`: triggered is deferred by default

    `INITIALLY IMMEDIATE`: triggered is not deferred by default (but can be deferred on demand)

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

Triggers — Deferrable Triggers

- **Deferred triggers** — deferred on demand

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

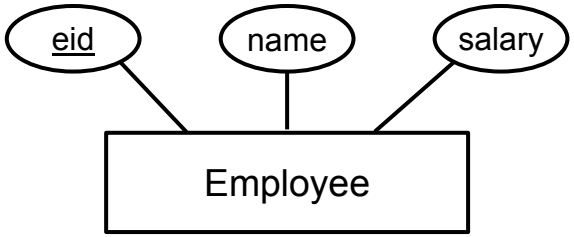
```
BEGIN TRANSACTION;
SET CONSTRAINT on_customer_modifed DEFERRED;
UPDATE customers SET balance = balance - 50 WHERE id = 10;
UPDATE customers SET balance = balance + 50 WHERE id = 11;
END TRANSACTION;
```

Without that line, the transaction would fail!

Overview

- Triggers — Overview
  - Motivation
  - Basic Example
  - Basic Concepts
- Triggers — Options
  - Events
  - Timing
  - Granularity
- Triggers — Refinements
  - Conditions
  - Deferrable Triggers
- **Summary**

Constraints Regarding Changes of Data

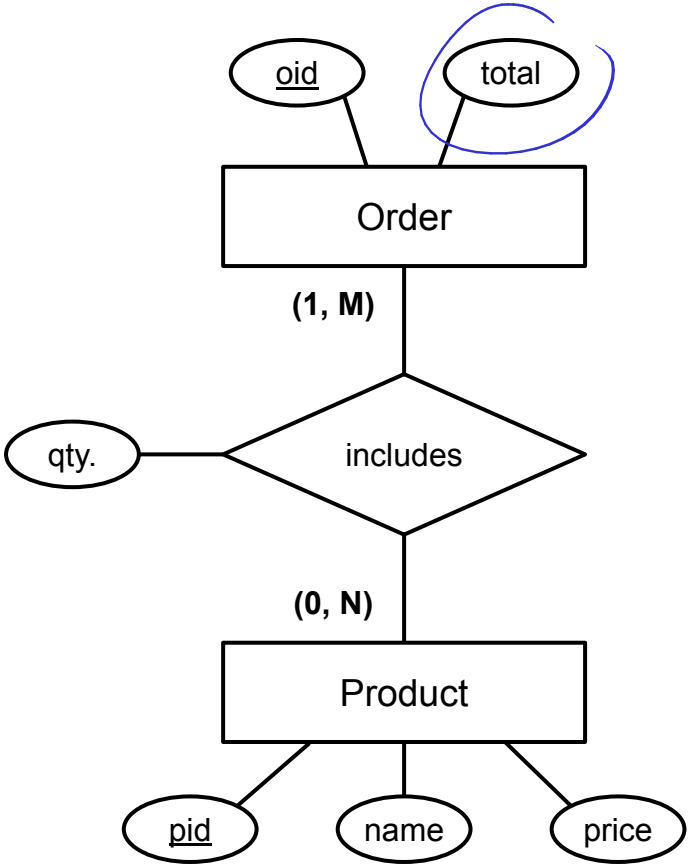



```
CREATE TABLE employees (
 eid INT PRIMARY KEY,
 name TEXT NOT NULL,
 salary DECIMAL(12,2) NOT NULL DEFAULT 0,
 CONSTRAINT check_pos_salary CHECK (salary >= 0)
);
```

```
CREATE TRIGGER on_employee_updated
BEFORE UPDATE ON employees
FOR EACH ROW
EXECUTE FUNCTION check_valid_salary();
```

```
CREATE OR REPLACE FUNCTION check_valid_salary()
RETURNS TRIGGER AS
$$
BEGIN
    IF OLD.salary < NEW.salary THEN
        RAISE EXCEPTION 'Salary may not decrease!';
    END IF;
    RETURN NEW;
END;
$$ LANGUAGE plpgsql;
```

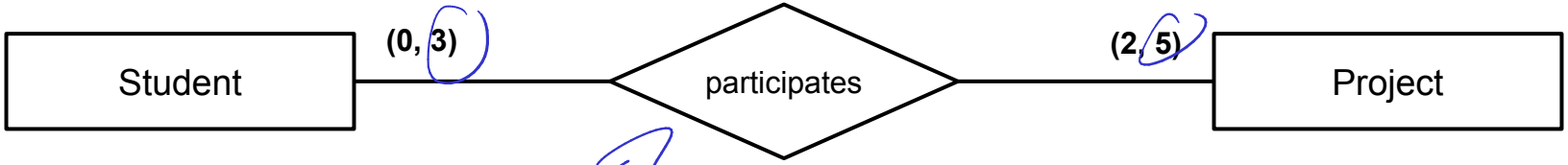
Recall: ER Model — Stored Attributes but with Derived Values




```
CREATE TRIGGER on_order_change
AFTER INSERT OR DELETE OR UPDATE ON includes
FOR EACH STATEMENT
EXECUTE FUNCTION calculate_total();
```

```
CREATE FUNCTION calculate_total()
RETURNS TRIGGER AS
$$
BEGIN
    UPDATE orders
    SET total = (SELECT SUM(p.price*i.qty)
                 FROM products p, includes i
                 WHERE p.pid = i.pid
                 AND i.oid = NEW.oid)
    WHERE o.oid = NEW.oid;
    RETURN NEW;
END;
$$ LANGUAGE plpgsql;
```

Recall: ER Model — Many-to-Many with Cardinality Constraints

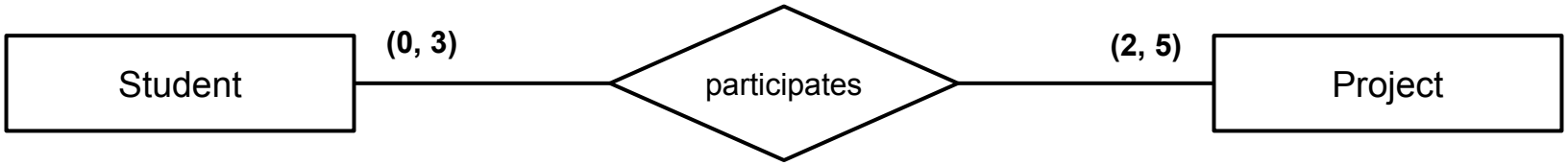



```
CREATE TRIGGER on_new_allocation
BEFORE INSERT ON participates
FOR EACH ROW
EXECUTE FUNCTION on_insert_participates();
```

Comment: **BEFORE UPDATE** and **BEFORE DELETE** triggers needed

```
CREATE OR REPLACE FUNCTION on_insert_participates()
RETURNS TRIGGER AS
$$
DECLARE
    team_size, num_projects INT;
BEGIN
    SELECT COUNT(*) INTO team_size
    FROM participates WHERE pid = NEW.pid;
    SELECT COUNT(*) INTO num_projects
    FROM participates WHERE sid = NEW.sid;
    IF team_size > 5 OR num_projects > 3 THEN
        RETURN NULL;
    END IF;
    RETURN NEW;
END;
$$ LANGUAGE plpgsql;
```

Recall: ER Model — Many-to-Many with Cardinality Constraints



Things to consider

- **`BEFORE UPDATE`** trigger requires to set of checks
  (e.g., moving a student to different team affects both teams' sizes!)
- What if we want to remove a student?
  (this might yield an under-staffed project)
- How can we add a new project?
  (just an INSERT into "Project" would violate participation constraint)

Triggers — Final Notes

- Multiple triggers for the same event on the same table ➜ What to do?
  - Basic order of activation:

`BEFORE` statement-level triggers

`BEFORE` row-level triggers

`AFTER` row-level triggers

`AFTER` statement-level triggers

  - With each category, triggers are fired in **alphabetic order**
  - If **`BEFORE`** row-level trigger returns **`NULL`**, subsequent triggers on the same row are omitted

- Universality of triggers
  - Focus on PostgreSQL; syntax and exact behavior might vary between DBMS

Triggers — Final Notes

- Triggers give you the freedom to do **odd** things
  - Example: delete any student we just added
  - Question: Is there requirement where this would be meaningful?
  - Even if, a **`BEFORE`** trigger with **`RETURN NULL`** more suitable

```
CREATE TRIGGER on_student_added
AFTER INSERT ON students
FOR EACH ROW
EXECUTE FUNCTION remove_student();
```

```
CREATE OR REPLACE FUNCTION remove_student()
RETURNS TRIGGER AS
$$
BEGIN
    DELETE FROM students WHERE id = NEW.id;
    RETURN NULL;
END;
$$ LANGUAGE plpgsql;
```

Triggers — Final Notes

- Triggers give you the freedom to do **dangerous** things
  - Recursive or circular triggers are perfectly valid
  - Difficult to spot when many tables are involved ➜ chain reaction
  - Example: An **`INSERT`** into Table **`A`**, triggers an **`INSERT`** into **`A`**, which triggers in **`INSERT`** into **`A`**, …

```
CREATE TRIGGER on_insert_A
AFTER INSERT ON table_A
FOR EACH ROW
EXECUTE FUNCTION insert_into_A();
```

```
CREATE OR REPLACE FUNCTION insert_into_A()
RETURNS TRIGGER AS
$$
BEGIN
    INSERT INTO table_A (0);
    RETURN NULL;
END;
$$ LANGUAGE plpgsql;
```

Summary

- Triggers — event-condition-action (ECA) rule for databases
  - Powerful tool to automate actions for certain events (i.e., database operations)
  - Built on top of stored function (trigger function = "special" stored function)
  - Common use case: check constraint not captured by relational schema
  - Well-defined arguments: events, timing, granularity

- Powerful ➜ (potentially) dangerous
  - Typically require take care
  - Behavior not always intuitive
  - Possibility of "bad cases"
    (e.g., chain reactions, circular firings)

"With great power comes great responsibility!"

Spiderman's Uncle Ben

Solutions to Quick Quizzes

- Slide 08: Write a stored procedure to perform the **`INSERT`**
- Slide 09: Permission management
  - Revoke **`INSERT`** rights on table
  - Grant **`EXECUTE`** rights on procedure (with **`SECURITY DEFINER`**!)
- Slide 13: We don't have **`NEW`** in case of deletion
- Slide 14: We can use **`OLD`**`.id` or **`NEW`**`.id` in case of update operation
- Slide 23:
  - New student "Adi" gets NOT inserted into students table
  - But we still make the log entry!

Solutions to Quick Quizzes

- Slide 31: The same row in the students table might be update multiple times
  - See also example on Slide 32
- Slide 38: Simply calling the trigger function requires overhead
- Slide 39: We only have **`NEW`** and **`OLD`** together for update operations
  - We can define the trigger for **`INSERT`** and **`DELETE`** but it will throw an error when fired