PL/pgSQL
Procedural programming language in PostgreSQL

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Announcement

- PL/pgSQL won’t be in the Exam but it will be used for the project.
- A non-graded quiz will be released by 1 October, tentatively.
- Refer to the recording from CS1010E for Examplify.
- Prof. Adi will announce mid-term rules.

Outline

1. Quick Recap on SQL
2. Motivation
3. Host language + SQL
4. PL/pgSQL Part I
5. PL/pgSQL Part II
6. SQL Injection

01 Quick Recap on SQL

01 Quick Recap on SQL

- So far, we have learnt …

SQL 1

DDL
ALTER
CREATE
DROP
CONSTRAINT
DQL SELECT
DML INSERT
UPDATE DELETE

SQL 2

LIMIT ORDER BY
NATURAL JOIN
LEFT/RIGHT JOIN
UNION FULL JOIN
EXCEPT INTERSECT
EXISTS IN ANY
SCALAR SUBQUERY

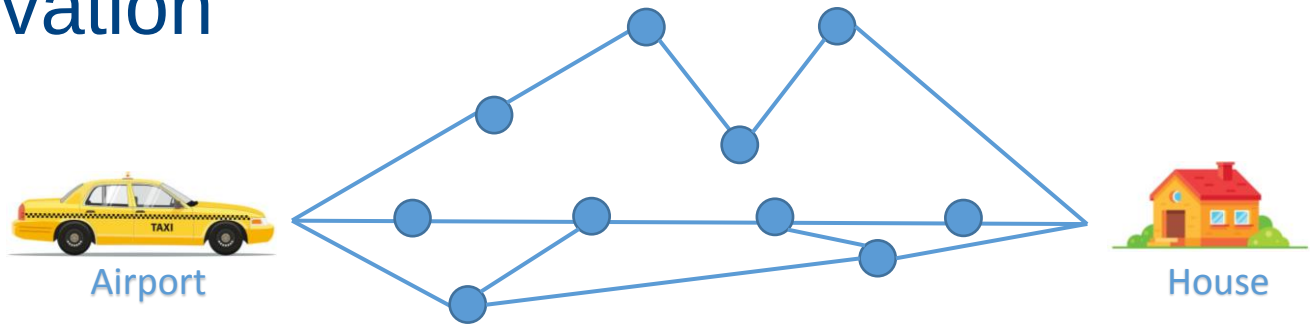
SQL 3

GROUP BY HAVING
MAX AVG
MIN CASE
COALESCE
CTE
VIEWS

Takeaway: you guys have learnt a lot of SQL constructs, keywords, and statements. But there is still a need to use a procedural language for solving some problems such that PostgreSQL provides PL/pgSQL.

02 Motivation

02 Motivation



Tells the taxi driver the *address of the house*, then he/she can figure out the way to the house.

Tells the taxi driver the *step-by-step directions* to the house.

Declarative vs. Procedural

- Declarative specifies the "what", whereas Procedural specifies the "how".
- Declarative was traditionally slower than Procedural, but this is changing.
- Declarative tends to require less lines of codes for solving a generic query as compared to Procedural.
- Declarative may require a complex solution for solving a very specific query as compared to Procedural.

In the context of SQL, it was slower when the query is complex, i.e., has many joins and/or subqueries.

02 Motivation

Based on this ranking system of cryptocurrencies,
I want to have daily record of *first three coins* from the TOP 10 cryptocurrencies that are *down by more than 5% in the past 7 days* and are *within 2 ranks apart* from each other.

We will do it!

Highlighted rows are those with < -5% changes.

Since the manager asks for the *first* three coins, then 8, 9, 10 is ***NOT*** the answer.

Rank	Symbol	Changes
1	BTC	-6%
2	ETH	+3%
3	DOGE	-6%
4	ZIL	+10%
5	XMR	-1%
6	SHIB	-8%
7	ADA	+1%
8	LTC	-7%
9	XRP	-7%
10	BNB	-6%

Expected output

Rank	Symbol	Changes
6	SHIB	-8%
8	LTC	-7%
9	XRP	-7%

Possible to use SQL?

Possible, but can be very complex.

Any easier way?

Yes, traverse the top 10 coins to find the first three desired coins.

02 Motivation

Based on this ranking system of cryptocurrencies,
I want to have daily record of *first three coins* from the TOP 10 cryptocurrencies that are *down by more than 5% in the past 7 days* and are *within 2 ranks apart* from each other.

We will do it!

Generally, it is *easier* to use a *procedural language* for problems that require *very specific* traversal of the data.

Two possible solutions:

Host language + SQL
(Java, C, Python, etc.)

Just briefly covered.

PL/pgSQL

Main topic of this lecture

03 Host language + SQL

03 Host language + SQL

- Let's use C language as an example for host language.
- There are two types of mixing:

Statement-level Interface

C
+ SQL

Call-level Interface

C
only

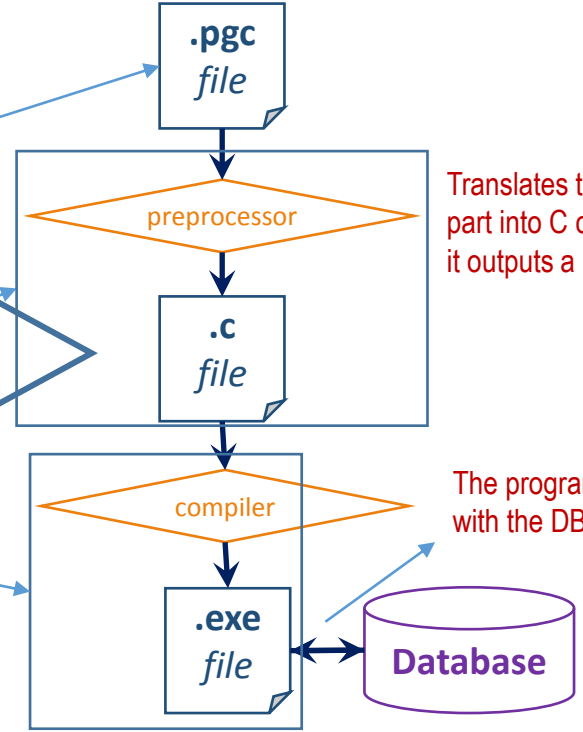
03 Statement-level Interface

Click here to read more about ECPG.

C + SQL ▶

Basic idea

1. **Write** a program that mixes host language with SQL, i.e., ECPG.
2. **Preprocess** the program using a preprocessor.
3. **Compile** the program into an executable code.



Translates the SQL part into C codes, thus it outputs a .c file.

The program interacts with the DB engine.

Standard compilation of C codes

03 Statement-level Interface

C + SQL

"Scores"

Name	Mark
Alice	92
…	…

.pgc file

Array of characters of size 30.

```
void main() {
  EXEC SQL BEGIN DECLARE SECTION;
    char name[30]; int mark;
  EXEC SQL END DECLARE SECTION;
  EXEC SQL CONNECT @localhost USER john;
  // some code that assigns values to
  // name and mark.
  EXEC SQL INSERT INTO
    Scores (Name, Mark) VALUES (:name, :mark);
  EXEC SQL SELECT … INTO :name FROM …;
  EXEC SQL DISCONNECT;
}
```

Defines a section that involves SQL.

Defines a line that involves SQL.

SELECT … INTO …
Assigns the selected value into the shared variable.
Note that the number of values/variables should be the same.

Use shared variables in SQL by adding a colon : as prefix

Declaration
declares variables that are shared between host & SQL.

Connection
setup DB connection with localhost and username John

Host language
perform operations using host language

Query execution
perform SQL queries/statements.

Disconnect
Disconnect from DB to release resources

The SQL query above is fixed, i.e., **static SQL**.
Can we generate the SQL query during runtime?
Yes, it is called **Dynamic SQL**.

Referring to the INSERT and SELECT statements.
What if we want the user to generate the query? Not possible using static SQL.

03 Statement-level Interface

C
+ SQL

"Scores"

Name	Mark
Alice	92
...	...

.pgc
file

Use a variable with type "string" instead to store the SQL statements.

this is an example of dynamic sql - so that the user can call the SQL query on runtime

```
void main() {
```

Declaration

```
EXEC SQL BEGIN DECLARE SECTION;
  char *query; char name[30]; int mark;
EXEC SQL END DECLARE SECTION;
```

Connection

```
EXEC SQL CONNECT @localhost USER john;
```

Host language

```
// some code that assigns values to
// name and mark

// assign any SQL statement to the query,
// the query may include name and/or mark.
```

Run the SQL statement in the query variable.

Query execution

```
EXEC SQL EXECUTE IMMEDIATE :query;
```

Disconnect

```
EXEC SQL DISCONNECT;
}
```

Quick Quiz

Can this be used to retrieve query results?

No, this approach is usually used for DML and DDL, e.g., CREATE, INSERT, UPDATE, DELETE.

03 Statement-level Interface

C
+ SQL

"Scores"

Name	Mark
Alice	92
…	…

.pgc
file

Another example of a dynamic SQL that can retrieve query results.

```
void main() {
EXEC SQL BEGIN DECLARE SECTION;
  const char *query = "INSERT INTO Scores
                       VALUES(?, ?);";
  char name[30]; int mark;
EXEC SQL END DECLARE SECTION;

EXEC SQL CONNECT @localhost USER john;

// some code that assigns values to
// name and mark, or modify query. Then,

EXEC SQL PREPARE stmt FROM :query;
EXEC SQL EXECUTE stmt [INTO …] USING :name, :mark;

EXEC SQL DEALLOCATE PREPARE stmt;
EXEC SQL DISCONNECT;
}
```

"partially" compile the SQL statements in variable query, and "save" it in stmt.

Execute the query in *stmt* using some parameters, if any.
One prepared *stmt* can be executed multiple times with different parameters.

Use INTO … to assign retrieved values to variables, if needed.

Variables that are passed as parameters, i.e., "replacing" the ? signs in query variable.

Release resources on stmt.

What if we want to use C only?

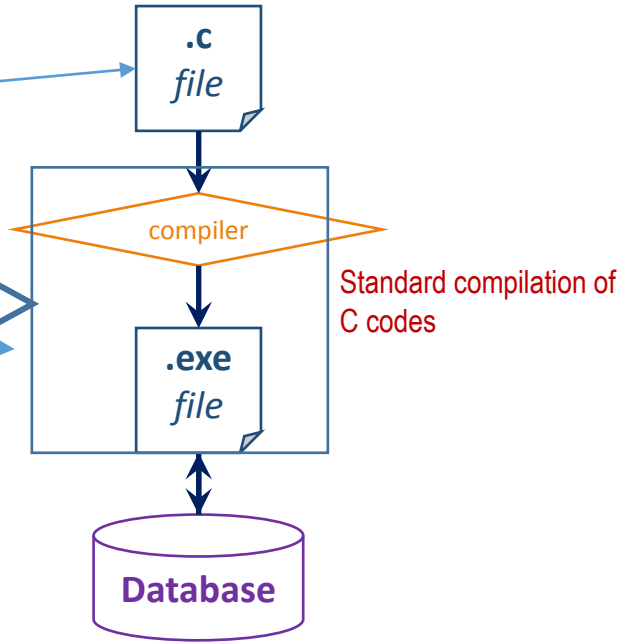
03 Call-level Interface

C *only*

Basic idea

1. **Write** in host language only*.
2. **Compile** the program into an executable code.

*Need to load a library that provides APIs to access the DB.
The libraries are libpq, psqlODBC, JDBC, ODBC, etc.



03 Call-level Interface

C *only*

"Scores"

Name	Mark
Alice	92
...	...

.c *file*

Everything is in host language. With some objects, C and W, that belongs to the class defined by the library.

```
void main() {
  char *query; char name[30]; int mark;

  connection C("dbname = testdb user = postgres \
    password = test hostaddr = 127.0.0.1 \
    port = 5432");

  // assign any SQL statement to the query,
  // the query may include name and/or mark.

  work W(C);
  W.exec(query);
  W.commit();

  C.disconnect();
}
```

Declaration

Connection

Query execution

Disconnect

Quick Quiz
Is this more like a static or dynamic SQL? **Dynamic**, due to usage of string variable to store the SQL statements.

Quick Quiz
What's the pros of using this instead of statement-level interface?
Some libraries provide functions, i.e., insert, that is compatible for many DB engines.

03 Summary

- Statement-level Interface

C
+ SQL

  - Code is written in a mix of host language and SQL.
    - Static SQL has fixed queries.
    - Dynamic SQL generates queries at runtime.
  - Code is pre-processed before compiled into an executable program.

- Call-level Interface

C
only

  - Code is written only in host language.
    - Need a library that provides APIs to run the SQL queries.
  - Code is directly compiled into an executable program.

What if we want to use SQL only?

04 PL/pgSQL Part I

Functions and Procedures

04 PL/pgSQL

- SQL-based Procedural Language
  - Server-side Programming.
  - ISO standard: SQL/PSM (Persistent Stored Modules).
  - It standardizes syntax and semantics of SQL Procedural Language.
  - Unfortunately, different vendors have different implementations:
    - Oracle `PL/SQL`
    - PostgreSQL `PL/pgSQL`
    - SQL Server `TransactSQL`

Let's learn a new programming language!

04 PL/pgSQL

SQL *only*

- Why do we want to use this?
  - Code reuse.
  - Ease of maintenance.
  - Performance.
  - Security (will be discussed near the end).

04 Functions

Click this whenever there is a play button → SQL *only* ▶

Converts number marks to letter grades.

Grading scheme:
[70, 100] → A
[60, 70) → B
[50, 60) → C
[0, 50) → F

"Scores"

Name	Mark
Alice	92
Bob	63
Cathy	58
David	47

"Scores"

Name	Grade
Alice	A
Bob	B
Cathy	C
David	F

Quick Quiz

Can we do this with a SQL query? Yes, using CASE

04 Functions

Click this → SQL *only* ▶

"Scores"

Name	Mark
Alice	92
Bob	63
Cathy	58
David	47

[70, 100] → A
[60, 70) → B
[50, 60) → C
[0, 50) → F

Name	Grade
Alice	A
Bob	B
Cathy	C
David	F

Example of using SQL only, i.e., without using SQL function.

```
SELECT Name, CASE
    WHEN Mark >= 70 THEN 'A'
    WHEN Mark >= 60 THEN 'B'
    WHEN Mark >= 50 THEN 'C'
    ELSE 'F'
  END AS Grade
FROM Scores;
```

Can we abstract away the conversion with a function? Yes.

04 Functions

SQL *only*

General Syntax

Function name

Function parameters and type, if any

Strictly speaking, this is called SQL function due to "LANGUAGE sql".

```
CREATE OR REPLACE FUNCTION <name>
  (<param> <type>, <param> <type>, ...)
RETURNS <type> AS $$

<Code>

$$ LANGUAGE sql;
```

Return type

Main body of the function

Enclosed within dollar-quote or '

These are used to enclosed the main body of the function. If you use ', then to define a string need two single quotes "A",
Check the link on the next slide.

The language used by the code

`<type>`: all data types in SQL, a tuple, a set of tuples, custom tuples, triggers.

Will be covered in the next lecture

04 Functions

SQL *only* ▶

How do we abstract away the conversion with a function?

```
CREATE OR REPLACE FUNCTION convert(Mark INT)
RETURNS CHAR(1) AS $$
  SELECT CASE
      WHEN Mark >= 70 THEN 'A'
      WHEN Mark >= 60 THEN 'B'
      WHEN Mark >= 50 THEN 'C'
      ELSE 'F'
  END;
$$ LANGUAGE sql;
```

The difference is more obvious when the function returns a tuple. Try it out.

```
-- Call the function
SELECT convert(66);
SELECT * FROM convert(66);
```

This returns value of composite type

This returns value in "table" format

Quick Quiz
What is the output of this SQL query? Click the link above to reveal the answer.

04 Functions

SQL *only*

"Scores"

Name	Mark
Alice	92
Bob	63
Cathy	58
David	47

[70, 100] → A
[60, 70) → B
[50, 60) → C
[0, 50) → F

"Scores"

Name	Grade
Alice	A
Bob	B
Cathy	C
David	F

```
CREATE OR REPLACE FUNCTION convert(Mark INT)
RETURNS CHAR(1) AS $$
  SELECT CASE
      WHEN Mark >= 70 THEN 'A'
      WHEN Mark >= 60 THEN 'B'
      WHEN Mark >= 50 THEN 'C'
      ELSE 'F'
  END;
$$ LANGUAGE sql;
```

```
SELECT Name, convert(Mark) AS Grade
From Scores
;
```

```
SELECT Name, … AS Grade FROM Scores;
```

Quick Quiz

Fill in the blank... The blank is convert(mark).
Thus, the select query gives the output table.

04 Functions

SQL *only*

"Scores"

Name	Mark
Alice	92
Bob	63
Cathy	58
David	47

[75, 100] → A
[65, 75) → B
[50, 65) → C
[0, 50) → F

Name	Grade
Alice	A
Bob	B
Cathy	C
David	F

```
CREATE OR REPLACE FUNCTION convert
  (Mark INT)
RETURNS CHAR(1) AS $$
  SELECT CASE
      WHEN Mark >= 70 THEN 'A'
      WHEN Mark >= 60 THEN 'B'
      WHEN Mark >= 50 THEN 'C'
      ELSE 'F'
    END;
$$ LANGUAGE sql;
```

- Code reuse. → Convert(mark) can be re-used for different queries as shown below.
- Ease of maintenance.
- Performance.

```
SELECT Name, convert(Mark) FROM Scores;
SELECT Name FROM Scores
WHERE convert(Mark) = 'B';
```

Quick Quiz

What is the output of this SQL query?

The second select query returns the name of the student where the letter grade is B, i.e., Bob.

04 Functions

SQL *only*

"Scores"

Name	Mark
Alice	92
Bob	63
Cathy	58
David	47

[**75**, 100] → A
[**65**, **75**) → B
[50, **65**) → C
[0, 50) → F

Name	Grade
Alice	A
Bob	B
Cathy	C
David	F

```
CREATE OR REPLACE FUNCTION convert
  (Mark INT)
RETURNS CHAR(1) AS $$
  SELECT CASE
      WHEN Mark >= 75 THEN 'A'
      WHEN Mark >= 65 THEN 'B'
      WHEN Mark >= 50 THEN 'C'
      ELSE 'F'
    END;
$$ LANGUAGE sql;
```

- Code reuse.
- Ease of maintenance.
- Performance.

If I need to change the grading scheme, then just need to change the range in the function.

```
SELECT Name, convert(Mark) FROM Scores;
SELECT Name FROM Scores
WHERE convert(Mark) = 'B';
```

04 Functions

SQL *only*

"Scores"

Name	Mark
Alice	92
Bob	63
Cathy	58
David	47

[75, 100] → A
[65, 75) → B
[50, 65) → C
[0, 50) → F

Name	Grade
Alice	A
Bob	B
Cathy	C
David	F

```
CREATE OR REPLACE FUNCTION convert
  (Mark INT)
RETURNS CHAR(1) AS $$
  SELECT CASE
      WHEN Mark >= 75 THEN 'A'
      WHEN Mark >= 65 THEN 'B'
      WHEN Mark >= 50 THEN 'C'
      ELSE 'F'
    END;
$$ LANGUAGE sql;
```

compiled

- Code reuse.
- Ease of maintenance.
- Performance.

The function is compiled, thus when the function is called multiple times the DB engine won't keep checking the validity of the query/function. This is more efficient than say CTE and Views.

```
SELECT Name, convert(Mark) FROM Scores;
SELECT Name
FROM Scores WHERE convert(Mark) = 'B';
```

How do we return a tuple from a function?

04 Functions

"Scores"

Name	Mark
Alice	92
Bob	63
Cathy	58
David	47

```
CREATE OR REPLACE FUNCTION convert
  (Mark INT)
RETURNS CHAR(1) AS $$
  SELECT CASE
      WHEN Mark >= 75 THEN 'A'
      WHEN Mark >= 65 THEN 'B'
      WHEN Mark >= 50 THEN 'C'
      ELSE 'F'
    END;
$$ LANGUAGE sql;
```

SQL *only* ▶

```
CREATE OR REPLACE FUNCTION GradeStudent
  (Grade CHAR(1))
RETURNS Scores AS $$

  SELECT    *
  FROM      Scores
  WHERE     convert(Mark) = Grade
  LIMIT 1;

$$ LANGUAGE sql;
```

When the tuple consists of attributes of a particular table, i.e., Scores table

If there are multiple SELECT statements, then only the result of last SELECT statement will be returned. In other words, the result of the statements are not cached.

```
SELECT GradeStudent('C');
```

Quick Quiz

What is the output of this SQL query? Click the link above to reveal the answer.

What if I remove the LIMIT? It's okay, only the first tuple is shown.

Try running SELECT * FROM GradeStudent('C'), and notice the different output format.

How do we return a set of tuples from a function?

04 Functions

"Scores"

Name	Mark
Alice	92
Bob	63
Cathy	58
David	47

```
CREATE OR REPLACE FUNCTION convert
  (Mark INT)
RETURNS CHAR(1) AS $$
  SELECT CASE
      WHEN Mark >= 75 THEN 'A'
      WHEN Mark >= 65 THEN 'B'
      WHEN Mark >= 50 THEN 'C'
      ELSE 'F'
    END;
$$ LANGUAGE sql;
```

SQL *only* ▶

```
CREATE OR REPLACE FUNCTION GradeStudents
  (Grade CHAR(1))
RETURNS SETOF Scores AS $$

  SELECT  *
  FROM    Scores
  WHERE   convert(Mark) = Grade;

$$ LANGUAGE sql;
```

Add SETOF to return more than one tuples.

```
SELECT GradeStudents('C');
```

Quick Quiz

What is the output of this SQL query? Click the link above to reveal the answer.

How do we return a custom tuple from a function?

04 Functions

"Scores"

Name	Mark
Alice	92
Bob	63
Cathy	58
David	47

```
CREATE OR REPLACE FUNCTION convert
  (Mark INT)
RETURNS CHAR(1) AS $$
  SELECT CASE
      WHEN Mark >= 75 THEN 'A'
      WHEN Mark >= 65 THEN 'B'
      WHEN Mark >= 50 THEN 'C'
      ELSE 'F'
    END;
$$ LANGUAGE sql;
```

SQL *only* ▶

OUT indicates output parameter.

IN indicates input parameter, which is the default.

Return one custom tuple according to the OUT parameters

```
CREATE OR REPLACE FUNCTION CountGradeStudents
  (IN Grade CHAR(1), OUT Mark CHAR(1), OUT Count INT)
RETURNS RECORD AS $$

  SELECT      Mark, COUNT(*)
  FROM        Scores
  WHERE       convert(Mark) = Grade
  GROUP BY    convert(Mark);

$$ LANGUAGE sql;
```

Parameter and attribute name can differ, but not the order and type.

```
SELECT CountGradeStudents('C');
```

Quick Quiz

What is the output of this SQL query? Click the link above to reveal the answer.

It will throw an error because Mark appears in select statement but not in GROUP BY.

To fix it, replace Mark with either convert(Mark) or Grade.

How do we return a set of custom tuples from a function?

04 Functions

"Scores"

Name	Mark
Alice	92
Bob	63
Cathy	58
David	47

```
CREATE OR REPLACE FUNCTION convert
  (Mark INT)
RETURNS CHAR(1) AS $$
  SELECT CASE
      WHEN Mark >= 75 THEN 'A'
      WHEN Mark >= 65 THEN 'B'
      WHEN Mark >= 50 THEN 'C'
      ELSE 'F'
    END;
$$ LANGUAGE sql;
```

SQL *only* ▶

```
CREATE OR REPLACE FUNCTION CountGradeStudents
  (OUT Mark CHAR(1), OUT Count INT)
RETURNS SETOF RECORD AS $$

  SELECT      convert(Mark), COUNT(*)
  FROM        Scores
  GROUP BY    convert(Mark);

$$ LANGUAGE sql;
```

Add SETOF to return more than one custom tuples.

```
SELECT CountGradeStudents();
```

Can we simplify the params for custom tuples? Yes!

04 Functions

"Scores"

Name	Mark
Alice	92
Bob	63
Cathy	58
David	47

```
CREATE OR REPLACE FUNCTION convert
  (Mark INT)
RETURNS CHAR(1) AS $$
  SELECT CASE
      WHEN Mark >= 75 THEN 'A'
      WHEN Mark >= 65 THEN 'B'
      WHEN Mark >= 50 THEN 'C'
      ELSE 'F'
    END;
$$ LANGUAGE sql;
```

SQL *only*

Another way to return more than one custom tuples.

```
CREATE OR REPLACE FUNCTION CountGradeStudents()
RETURNS TABLE(MARK CHAR(1), COUNT INT) AS $$

  SELECT      convert(Mark), COUNT(*)
  FROM        Scores
  GROUP BY    convert(Mark);

$$ LANGUAGE sql;
```

```
SELECT CountGradeStudents();
```

Can the function return "nothing"?

04 Functions

"Scores"

Name	Mark
Alice	92
Bob	63
Cathy	58
David	47

```
CREATE OR REPLACE FUNCTION convert
  (Mark INT)
RETURNS CHAR(1) AS $$
  SELECT CASE
      WHEN Mark >= 75 THEN 'A'
      WHEN Mark >= 65 THEN 'B'
      WHEN Mark >= 50 THEN 'C'
      ELSE 'F'
    END;
$$ LANGUAGE sql;
```

SQL *only* ▶

```
CREATE OR REPLACE FUNCTION UpdateMark
  (IN amount INT)
RETURNS VOID AS $$

  UPDATE Scores SET Mark = Mark + amount;
  ALTER TABLE Scores ADD COLUMN IF NOT EXISTS
    Grade CHAR(1) DEFAULT NULL;
  UPDATE Scores SET Grade = convert(Mark);
  SELECT * FROM Scores;

$$ LANGUAGE sql;
```

To make a function returns "nothing".

Having a SELECT statement in a "void" function will not throw any error.

Throws an error because Grade is unidentified at this step. Thus, need to remove this part.

```
SELECT UpdateMark(1);
```

Can't we use procedure for this? Yes!

04 Functions

"Scores"

Name	Mark
Alice	92
Bob	63
Cathy	58
David	47

```
CREATE OR REPLACE FUNCTION convert
  (Mark INT)
RETURNS CHAR(1) AS $$
  SELECT CASE
      WHEN Mark >= 75 THEN 'A'
      WHEN Mark >= 65 THEN 'B'
      WHEN Mark >= 50 THEN 'C'
      ELSE 'F'
    END;
$$ LANGUAGE sql;
```

SQL *only*

```
CREATE OR REPLACE FUNCTION UpdateMark
  (IN amount INT)
RETURNS VOID AS $$

  UPDATE Scores SET Mark = Mark + amount;
  ALTER TABLE Scores ADD COLUMN IF NOT EXISTS
    Grade CHAR(1) DEFAULT NULL;
  SELECT * FROM Scores;

$$ LANGUAGE sql;
```

```
SELECT UpdateMark(1);
```

Can't we use procedure for this? Yes!

04 Procedures

SQL *only*

General Syntax

Procedure name

Procedure parameters and type, if any

The only differences as compared to a function

No RETURN

Main body of the function

Enclosed within dollar-quote or '

The language used by the code

```
CREATE OR REPLACE PROCEDURE <name>
  (<param> <type>, <param> <type>, ...)
AS $$

  <Code>

$$ LANGUAGE sql;
```

`<type>`: all data types in SQL, a tuple, a set of tuples, custom tuples, triggers.

04 Procedures

"Scores"

Name	Mark
Alice	92
Bob	63
Cathy	58
David	47

```
CREATE OR REPLACE FUNCTION convert
  (Mark INT)
RETURNS CHAR(1) AS $$
  SELECT CASE
      WHEN Mark >= 75 THEN 'A'
      WHEN Mark >= 65 THEN 'B'
      WHEN Mark >= 50 THEN 'C'
      ELSE 'F'
    END;
$$ LANGUAGE sql;
```

SQL *only* ▶

```
CREATE OR REPLACE PROCEDURE UpdateMark
  (IN amount INT)
AS $$

  UPDATE Scores SET Mark = Mark + amount;
  ALTER TABLE Scores ADD COLUMN IF NOT EXISTS
    Grade CHAR(1) DEFAULT NULL;
  SELECT * FROM Scores;

$$ LANGUAGE sql;
```

Use CALL to execute a procedure, instead of SELECT.

```
CALL UpdateMark(1);
```

Any question?

04

Summary

SQL *only*

- SQL Functions
  - Returns a value
    - SQL data types, Set of existing tuples, Set of custom tuples, Etc..
  - `CREATE OR REPLACE FUNCTION <function_name>(...)`
  - `SELECT <func_name>(...) or SELECT … FROM <func_name>(…)`
- SQL Procedures
  - No return value
  - `CREATE OR REPLACE PROCEDURE <procedure_name>(...)`
  - `CALL <procedure_name>(...)`

05 PL/pgSQL Part II

Variables and Control Structure

05

PL/pgSQL Part II

SQL *only*

- Previous SQL functions or procedures are limited to executing one or more SQL queries sequentially.
- PL/pgSQL is more powerful than that as it has variables and control structure.
- List of control structure:
  - `IF ... END IF`
  - `IF ... ELSIF ... THEN ... ELSE ... END IF`
  - `LOOP ... END LOOP`
  - `EXIT WHEN ...`
  - `WHILE ... LOOP ... END LOOP`
  - `FOR ... IN ... LOOP ... END LOOP`

05 Functions

SQL *only*

General Syntax

Strictly speaking, this is called PL/pgSQL function due to "LANGUAGE `plpgsql`".

DECLARE is needed to declare one or more variables.

BEGIN … END; is mandatory

```
CREATE OR REPLACE FUNCTION <name>
  (<param> <type>, <param> <type>, ...)
RETURNS <type> AS $$
DECLARE
    … variables …
BEGIN

  <Code>

END;
$$ LANGUAGE plpgsql;
```

The language used by the code

Quick Quiz

How about a procedure?

Change FUNCTION to PROCEDURE, and remove RETURNS <type>.

05 Variables

"Scores"

Name	Mark
Alice	92
Bob	63
Cathy	58
David	47

SQL *only* ▶

```
CREATE OR REPLACE FUNCTION splitMarks
  (IN name1 VARCHAR(20), IN name2 VARCHAR(20),
  OUT mark1 INT, OUT mark2 INT)
RETURNS RECORD AS $$
DECLARE
  temp INT := 0;
BEGIN
  SELECT mark INTO mark1 FROM Scores WHERE name = name1;
  SELECT mark INTO mark2 FROM Scores WHERE name = name2;

  temp := (mark1 + mark2) / 2;

  UPDATE Scores SET mark = temp WHERE name = name1 OR name = name2;
  RETURN; --optional
END;
$$ LANGUAGE plpgsql;
```

Use := to assign value to a variable. Variables can be initialized when declared.

Assign selected marks into output parameters.

Input parameters.

This is optional. When executed, it will return the output params, namely mark1 and mark2, then **exit** the function. Otherwise, the function will end naturally and return the output params.

```
SELECT splitMarks('Alice', 'Bob');
```

Quick Quiz

What is the output of this SQL query? Click the link above to reveal the answer.

Why the result is not (77, 77)? Because the returned values are mark1 and mark2, which is (92, 63).

How to return multiple tuples?

05 Variables

"Scores"

Name	Mark
Alice	92
Bob	63
Cathy	58
David	47

SQL *only* ▶

One way to return a multiple tuples.

```
CREATE OR REPLACE FUNCTION splitMarks
  (IN name1 VARCHAR(20), IN name2 VARCHAR(20))
RETURNS TABLE(Mark1 INT, Mark2 INT) AS $$
DECLARE
  temp INT := 0;
BEGIN
  SELECT mark INTO mark1 FROM Scores WHERE name = name1;
  SELECT mark INTO mark2 FROM Scores WHERE name = name2;

  temp := (mark1 + mark2) / 2;

  UPDATE Scores SET mark = temp WHERE name = name1 OR name = name2;
  RETURN QUERY SELECT mark1, mark2;
  RETURN NEXT;
END;
$$ LANGUAGE plpgsql;
```

Must be followed by a SELECT statement, as it expects a query.

Returns the output parameters.

! RETURN NEXT or RETURN QUERY does **not** exit the function.

These returns will be cached in the output "table". Thus, this function will output two tuples.

Quick Quiz

What is the output of this SQL query? Click the link above to reveal the answer.

```
SELECT splitMarks('Alice', 'Bob');
```

this one will return
(92, 63)
(92, 63)

05 Selection

"Scores"

Name	Mark
Alice	92
Bob	63
Cathy	58
David	47

SQL *only*

```
CREATE OR REPLACE FUNCTION splitMarks
  (IN name1 VARCHAR(20), IN name2 VARCHAR(20))
RETURNS TABLE(Mark1 INT, Mark2 INT) AS $$
DECLARE
  temp INT := 0;
BEGIN
  -- SELECT statements are omitted.
  temp := (mark1 + mark2) / 2;
  IF temp > 60 THEN      temp := temp / 2;
  ELSIF temp > 50 THEN   temp := temp - 20;
  ELSE                   temp := temp - 10;
  END IF;
  -- UPDATE statement is omitted.
  RETURN QUERY SELECT mark1, mark2;
END;
$$ LANGUAGE plpgsql;
```

Just to show the syntax.

Quick Quiz

What is the output of this SQL query? Modify the function in the previous link.

```
SELECT splitMarks('Alice', 'Bob');
```

05 Repetition

"Scores"

Name	Mark
Alice	92
Bob	63
Cathy	58
David	47

SQL *only*

```
CREATE OR REPLACE FUNCTION splitMarks
  (IN name1 VARCHAR(20), IN name2 VARCHAR(20))
RETURNS TABLE(Mark1 INT, Mark2 INT) AS $$
DECLARE
  temp INT := 0;
BEGIN
  -- SELECT statements are omitted.
  temp := (mark1 + mark2) / 2;
  WHILE temp > 30 LOOP
    temp := temp / 2;
  END LOOP;
  -- UPDATE statement is omitted.
  RETURN QUERY SELECT mark1, mark2;
END;
$$ LANGUAGE plpgsql;
```

It works the same way as the typical "while loop" in procedural language.

Quick Quiz

What is the output of this SQL query? Modify the function in the previous link.

```
SELECT splitMarks('Alice', 'Bob');
```

05 Repetition

"Scores"

Name	Mark
Alice	92
Bob	63
Cathy	58
David	47

SQL *only*

```
CREATE OR REPLACE FUNCTION splitMarks
  (IN name1 VARCHAR(20), IN name2 VARCHAR(20))
RETURNS TABLE(Mark1 INT, Mark2 INT) AS $$
DECLARE
  temp INT := 0;
BEGIN
  -- SELECT statements are omitted.
  temp := (mark1 + mark2) / 2;
  LOOP
    EXIT WHEN temp < 30;
    temp := temp / 2;
  END LOOP;
  -- UPDATE statement is omitted.
  RETURN QUERY SELECT mark1, mark2;
END;
$$ LANGUAGE plpgsql;
```

in Procedural Language ...

```
while (true) {
  if (temp < 30)
    break;
}
```

Quick Quiz

What is the output of this SQL query? Modify the function in the previous link.

```
SELECT splitMarks('Alice', 'Bob');
```

LOOP will just create a loop that will never end

05 Repetition

"Scores"

Name	Mark
Alice	92
Bob	63
Cathy	58
David	47

SQL *only*

```
CREATE OR REPLACE FUNCTION splitMarks
  (IN name1 VARCHAR(20), IN name2 VARCHAR(20))
RETURNS TABLE(Mark1 INT, Mark2 INT) AS $$
DECLARE
  temp INT := 0; d INT; denoms INT[] := ARRAY[1, 2, 3];
BEGIN
  -- SELECT statements are omitted.
  temp := (mark1 + mark2) / 2;
  FOREACH d IN ARRAY denoms LOOP
    temp := temp / d;
  END LOOP;
  -- UPDATE statement is omitted.
  RETURN QUERY SELECT mark1, mark2;
END;
$$ LANGUAGE plpgsql;
```

Looping through each element in an array

```
SELECT splitMarks('Alice', 'Bob');
```

05 Is that all?

SQL *only*

Based on this ranking system of cryptocurrencies,
I want to have daily record of *first three coins* from the TOP 10 cryptocurrencies that are *down by more than 5% in the past 7 days* and are *within 2 ranks apart* from each other.

We will do it!

Rank	Symbol	Changes
1	BTC	-6%
...	...	...
...	...	...
8	LTC	-7%
9	XRP	-7%
10	BNB	-6%

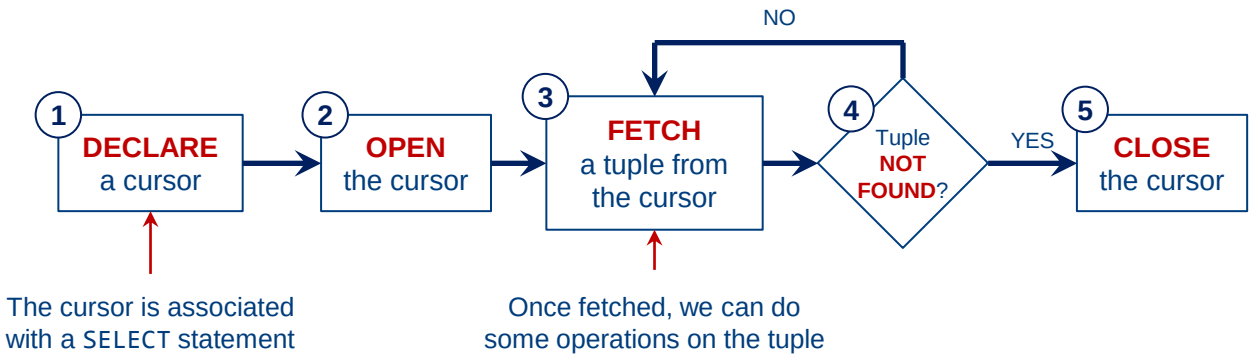
Rank	Symbol	Changes
6	SHIB	-8%
8	LTC	-7%
9	XRP	-7%

How do we traverse a query's result?

Cursor

SQL *only*

- A cursor enables us to access each individual row returned by a SELECT statement.
- Workflow:



- Can use other statements at step 3 such as `MOVE`, `UPDATE`, `DELETE`, `etc`.

05 Cursor

SQL *only*

Based on this ranking system of cryptocurrencies, I want to have daily record of first three consecutive coins from the TOP 10 cryptocurrencies that are *down by more than 5% in the past 7 days.*

Let's simplify the original problem.

Rank	Symbol	Changes
1	BTC	-6%
2	ETH	+3%
3	DOGE	-6%
4	ZIL	+10%
5	XMR	-1%
6	SHIB	-8%
7	ADA	+1%
8	LTC	-7%
9	XRP	-7%
10	BNB	-6%

One possible solution:

1. Query the cryptos that are *down by more than 5% in the past 7 days* from the top 10 of the given ranking system.
2. Find the three consecutive coins by traversing (1) using a cursor.

Note that (1) is declarative and (2) is procedural.

05 Cursor

SQL *only* ▶

Cursor declaration

```
CREATE OR REPLACE FUNCTION consCryptosDown
  (IN num INT)
RETURNS TABLE(rank INT, sym CHAR(4)) AS $$
DECLARE
  curs  CURSOR FOR (SELECT * FROM cryptosRank
                    WHERE changes < -5);
  r1      RECORD;
  r2      RECORD;
BEGIN
  OPEN curs;

  LOOP

    …

  END LOOP;

  CLOSE curs;
END;
$$ LANGUAGE plpgsql;
```

Main idea:
For each tuple in the "table", check if the rank of tuple after its next tuple is two ranks higher than itself.

true

false

```
SELECT consCryptosDown(3);
```

curs →

Rank	Symbol	Changes
1	BTC	-6%
3	DOGE	-6%
6	SHIB	-8%
8	LTC	-7%
9	XRP	-7%
10	BNB	-6%

```
FETCH curs INTO r1;
EXIT WHEN NOT FOUND;
FETCH RELATIVE (num-1)
  FROM curs INTO r2;
EXIT WHEN NOT FOUND;
```

Fetch BTC at first iteration.

i.e., cursor reaches the end of the "table".

Fetch SHIB at first iteration.

```
IF r2.rank - r1.rank = 2 THEN
  MOVE RELATIVE -(num) FROM curs;
  FOR c IN 1..num LOOP
    FETCH curs INTO r1;
    rank := r1.rank;
    sym := r1.symbol;
    RETURN NEXT;
  END LOOP;
  CLOSE curs;
  RETURN;
END IF;
```

Fetch and return the three consecutive coins.

Close cursor to release resources, then exit the function.

```
MOVE RELATIVE -(num - 1) FROM curs;
```

Relative to the current position of the cursor.
Move cursor to the bottom border of BTC at first iteration, thus the next FETCH curs INTO r1 will return DOGE.

Cursor

SQL *only* ▶

- Cursor movement
  - `FETCH curs INTO r;`
  - `FETCH NEXT FROM curs INTO r;`
- Other variants
  - `FETCH PRIOR FROM curs INTO r;`
    - Fetch from previous row
  - `FETCH FIRST FROM curs INTO r;` → Fetch BTC
  - `FETCH LAST FROM curs INTO r;` → Fetch BNB
  - `FETCH ABSOLUTE 3 FROM curs INTO r;`
    - Fetch the 3rd tuple, i.e., SHIB.
  - `FETCH RELATIVE -2 FROM curs INTO r;`
  - `MOVE … FROM curs;`
  - `UPDATE/DELETE … WHERE CURRENT OF curs;` → Perform update or delete statement on the tuple at the current position of the cursor.

curs →

Rank	Symbol	Changes
1	BTC	-6%
3	DOGE	-6%
6	SHIB	-8%
8	LTC	-7%
9	XRP	-7%
10	BNB	-6%

05

Summary

SQL *only*

- `plpgsql` Control Structures
  - Declare `DECLARE <var> <type> BEGIN`
  - Assignment `<var> := ...`
  - Selection `IF ... THEN ... ELSIF ... THEN ... ELSE ... END IF`
  - Repetition `LOOP ... END LOOP`
    `WHILE ... LOOP ... END LOOP`
    - Break `EXIT WHEN ...`
- Cursor
  - Declare → Open → Fetch → Check *(repeat)* → Close
  - `FETCH [PRIOR | FIRST | LAST | ABSOLUTE n | RELATIVE n] [FROM] <cursor> INTO <var>`
  - `MOVE [PRIOR | FIRST | LAST | ABSOLUTE n | RELATIVE n] [FROM] <cursor>`
  - `[UPDATE | DELETE] … WHERE CURRENT OF <cursor>`

05 PL/pgSQL - Practice

SQL *only* ▶

Based on this ranking system of cryptocurrencies,
I want to have daily record of *first three coins* from the TOP 10 cryptocurrencies that are *down by more than 5% in the past 7 days* and are *within 2 ranks apart* from each other.

We will do it!

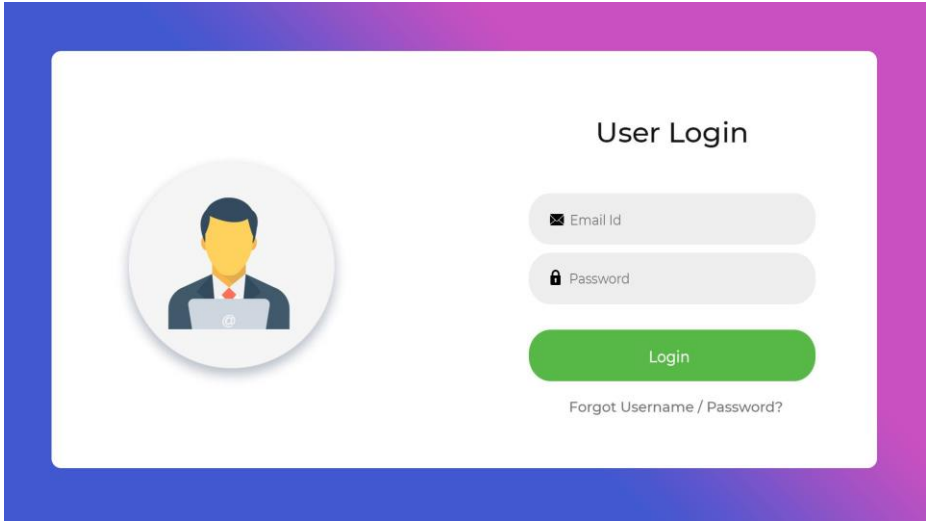
Homework. Any question?

06 SQL Injection

- Code reuse.
- Ease of maintenance.
- Performance.
- Security.

06 SQL Injection

- **What is it?**
  - A class of attacks on dynamic SQL.



06 SQL Injection

- **What is it?**
  - A class of attacks on dynamic SQL.
  - **Expected case**
    - `email = aa@bb.com`
    - `password = abcd`
    - `if (count > 0) { … }`

IF user with those email and password exists, then count(*) will be > 0. Note that there can be multiple way to check if log in successful, this is just one example.

Take user inputs

```
void main() {
EXEC SQL BEGIN DECLARE SECTION;
  char *query;
EXEC SQL END DECLARE SECTION;

EXEC SQL CONNECT TO @localhost USER john;

char email[100];
scanf("%s", email);
char password[100];
scanf("%s", password);

//query = "SELECT COUNT(*) FROM Users" +
//      "WHERE email = '" + name + "'" +
//      "AND password = '" + password + "';";

EXEC SQL EXECUTE IMMEDIATE :query;

EXEC SQL DISCONNECT;
}
```

Generated Query

```
SELECT COUNT(*)
FROM Users
WHERE email  = 'aa@bb.com'
AND password = 'abcd';
```

06 SQL Injection

- **What is it?**
  - A class of attacks on dynamic SQL.
- **Malicious case**
  - email = aa@bb.com
  - password = 'OR 1 = 1 --
  - if (count > 0) { … }

IF user with those email and password exists, then count(*) will be > 0. Note that there can be multiple way to check if log in successful, this is just one example.

Take user inputs

```
void main() {
EXEC SQL BEGIN DECLARE SECTION;
  char *query;
EXEC SQL END DECLARE SECTION;

EXEC SQL CONNECT TO @localhost USER john;

char email[100];
scanf("%s", email);
char password[100];
scanf("%s", password);

//query = "SELECT COUNT(*) FROM Users" +
//      "WHERE email = '" + name + "'" +
//      "AND password = '" + password + "';";

EXEC SQL EXECUTE IMMEDIATE :query;

EXEC SQL DISCONNECT;
}
```

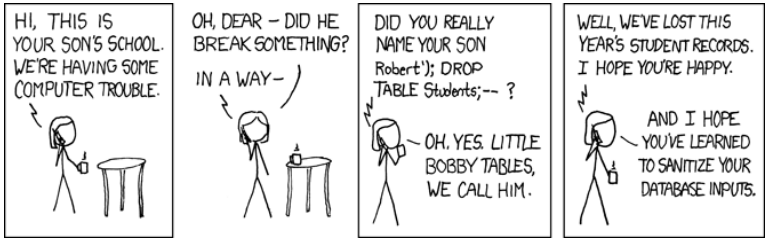
Generated Query

```
SELECT COUNT(*)
FROM Users
WHERE email  = 'aa@bb.com'
AND password = ''
OR 1 = 1 --;
```

Because of this, the count(*) == number of tuples in the Users table, no matter what the email or password are.

06 SQL Injection

- **What is it?**
  - A class of attacks on dynamic SQL.
  - **Malicious case**
    - `email = aa@bb.com`
    - `password = '; DROP TABLE … --`




```
void main() {
EXEC SQL BEGIN DECLARE SECTION;
  char *query;
EXEC SQL END DECLARE SECTION;

EXEC SQL CONNECT TO @localhost USER john;

char email[100];
scanf("%s", email);
char password[100];
scanf("%s", password);

//query = "SELECT COUNT(*) FROM Users" +
//      "WHERE email = '" + name + "'" +
//      "AND password = '" + password + "';";

EXEC SQL EXECUTE IMMEDIATE :query;

EXEC SQL DISCONNECT;
}
```

Generated Query

```
SELECT COUNT(*)
FROM Users
WHERE email  = 'aa@bb.com'
AND password = '';
DROP TABLE … --;
```

Even worse, malicious user can drop a table, say User table.

SQL Injection

- **How to Protect?**
  - Use a function or procedure
  - **Why?**
    - SQL function or procedure is compiled and stored in DB
    - At runtime, anything in `email and password` are treated as strings.

```
void main() {
  EXEC SQL BEGIN DECLARE SECTION;
    char *query;
  EXEC SQL END DECLARE SECTION;

  EXEC SQL CONNECT TO @localhost USER john;

  char email[100];
  scanf("%s", email);
  char password[100];
  scanf("%s", password);

  //query = "SELECT * FROM verifyUser" +
  //      "(" + name + "," + password + ");";

  EXEC SQL EXECUTE IMMEDIATE :query;

  EXEC SQL DISCONNECT;
}
```

```
CREATE OR REPLACE FUNCTION verifyUser
  (IN email_param TEXT, IN password_param TEXT)
RETURNS INT AS $$
  SELECT COUNT(*) FROM Users
  WHERE email  = email_param
  AND password = password_param;
$$ LANGUAGE sql;
```

Generated Query

```
SELECT COUNT(*)
FROM Users
WHERE email  = 'aa@bb.com'
AND password = '\' OR 1 = 1 --';
```

The count(*) is no longer always equal to the number of tuples in the Users table.

06 SQL Injection

- **How to Protect?**
  - Use prepares statements
  - **Why?**
    - SQL query is compiled when it is prepared.
    - At runtime, anything in `email and password` are treated as strings.

```
void main() {
    EXEC SQL BEGIN DECLARE SECTION;
      const char *query = "SELECT COUNT(*)
                           FROM Users
                           WHERE email = ?
                           AND password = ?;";
       char email[100], password[100];
    EXEC SQL END DECLARE SECTION;

    EXEC SQL CONNECT TO @localhost USER john;

    scanf("%s", email);
    scanf("%s", password);

    EXEC SQL PREPARE stmt FROM :query;
    EXEC SQL EXECUTE stmt USING :email, :password;
    EXEC SQL DEALLOCATE PREPARE stmt;
    EXEC SQL DISCONNECT;
}
```

Generated Query

```
SELECT COUNT(*)
FROM Users
WHERE email  = 'aa@bb.com'
AND password = '\' OR 1 = 1 --';
```

The count(*) is no longer always equal to the number of tuples in the Users table

Summary

1. Quick Recap on SQL
   - "Generic" queries may be easier to be solved using SQL.
2. Motivation
   - "Specific" queries may be easier to be solved using a procedural language.
3. Host language + SQL
   - Use host procedural language to interact with the database.
4. PL/pgSQL Part I
   - Use SQL procedural language, e.g., function and procedure.
5. PL/pgSQL Part II
   - Use SQL procedural language, e.g., variables, cursor, and control structure.
6. SQL Injection
   - Sanitize user inputs to avoid injection of malicious query.

THANK YOU

anonymous feedback:
https://forms.gle/FesPvnAPiABKxx5U6