# Advanced SQL

## 07 — Procedural SQL

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## 1 ┆ Scripting Language + SQL = Procedural SQL

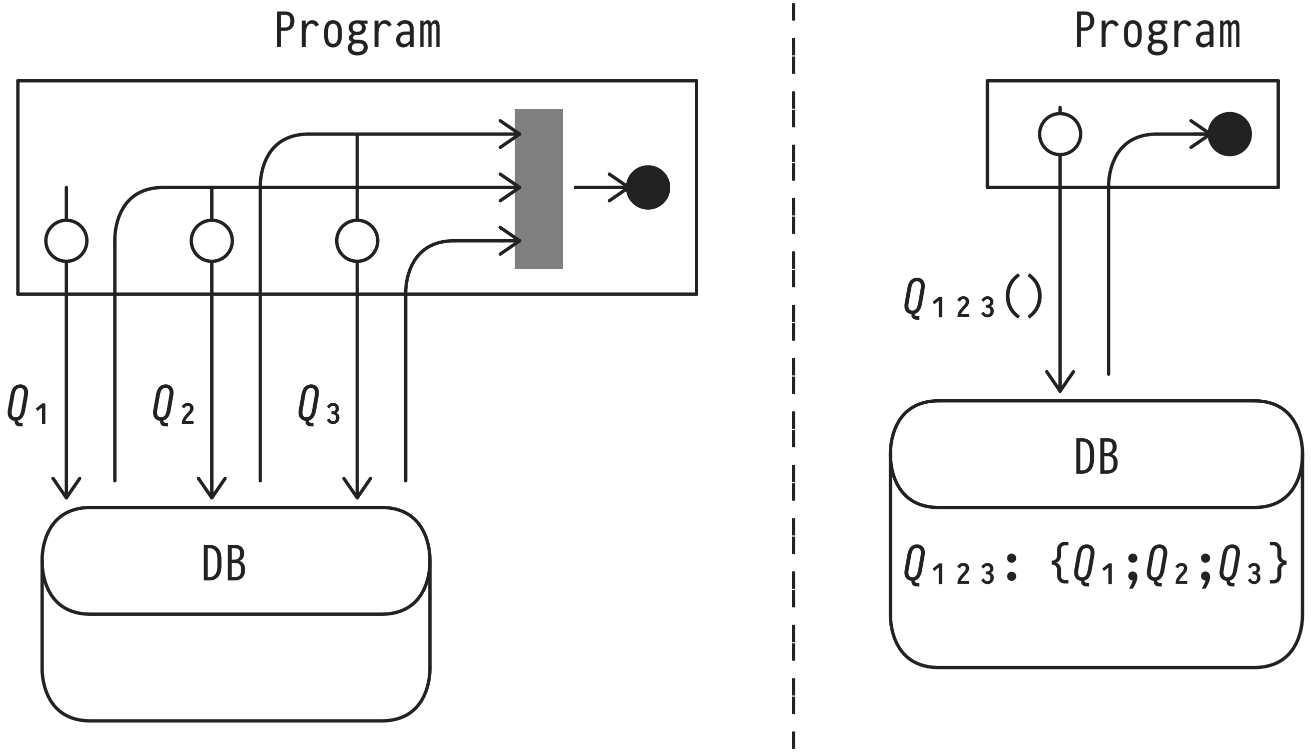
We started out in this course with the aim to **move more computation close to the data.** Admitting recursion in SQL is one way to declaratively express complex computation.

**Procedural SQL** follows an entirely different path towards this goal:

- Implement application logic *inside* the RDBMS, even if this **computation is inherently procedural** (≡ sequential, imperative).

- Use **SQL as a sub-language of a scripting language** whose types match those of the tabular data model.

# Procedural SQL: Less Round-Trips, Less Stitching



$Q_i$ SQL query

○ query invocation

▨ *stitching*

● result processing

{;;} SQL procedure

- *Stitching*: On the PL heap, piece together the tabular results delivered by the individual SQL queries $Q_i$.

## Procedural SQL aka *Stored Procedures*

Code in Procedural SQL is organized in **functions/procedures that are stored persistently** by the DBMS.[1]

These functions/procedures…

- may be used anywhere that SQL's built-ins could be used,
- inherit all user-defined types, functions, and operators,
- can define new operators, aggregate/window functions, and triggers.

[1] This implies that we need to manage these procedures using familiar constructs like `CREATE PROCEDURE …`, `CREATE FUNCTION …`, `DROP PROCEDURE [IF EXISTS] …`, etc.

# PL/SQL:[2] Scripting with SQL Types

```
CREATE FUNCTION f(x_1 τ_1, …, x_n τ_n) RETURNS τ AS
$$ … ‹block› …$$
LANGUAGE PLPGSQL;
```

- The $\tau_i$, $\tau$ may be any scalar, array, or (named) row type.
- Limited polymorphism: functions may accept/return types anyelement, anyarray (recall our discussion of SQL UDFs).
  - Functions may return type record (then the caller must provide column names/types through explicit aliasing).
- Functions may return—but *not* accept ☹—sets of (row) values with $\tau \equiv$ SETOF $\bar{\tau}$.

[2] *PL/SQL* is the widely adopted abbreviation for *Procedural Language for SQL*, originating in the Oracle® RDBMS. Variants include *Transact-SQL* (Microsoft® SQL Server) and *PL/pgSQL* (PostgreSQL).

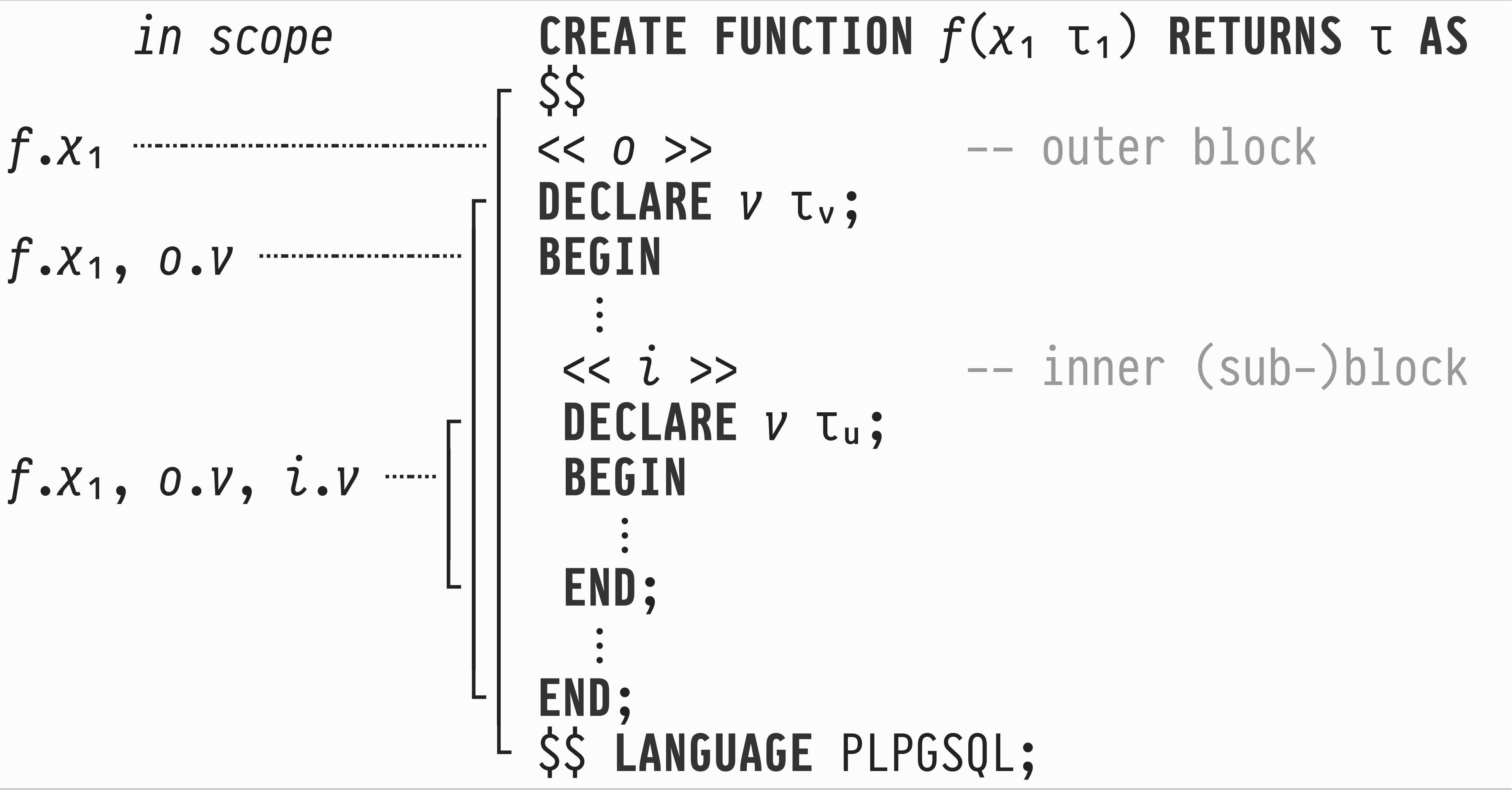
# 2 ¦ Block Structure

PL/SQL code is organized in (nested) **blocks** that group statements and define **variable scopes:**

```
      ⎧ [ DECLARE ‹declarations› ]
block ⎨ BEGIN
      ⎪   ‹statement›               -- ◀ any statement may be
      ⎩ END;                        --    a (sub-)block again
```

- Declared variables are in scope in the block and its sub-blocks. Local names shadow outer names.
- Optionally introduce block with << *‹label›* >>: variable *v* may then also be referred to as *‹label›*.*v*.
- Outermost block of body for *f* has implicit << *‹f›* >>.

# Block Structure and Variable Scope[3]



*in scope*

$f.x_1$

$f.x_1,\ o.v$

$f.x_1,\ o.v,\ i.v$

```
CREATE FUNCTION $f(x_1\ \tau_1)$ RETURNS $\tau$ AS
$$
<< $o$ >>                        -- outer block
DECLARE $v\ \tau_v$;
BEGIN
  ⋮
 << $i$ >>                       -- inner (sub-)block
 DECLARE $v\ \tau_u$;
 BEGIN
   ⋮
 END;
  ⋮
END;
$$ LANGUAGE PLPGSQL;
```

[3] Additional special variables (like FOUND) are bound in the outermost $f$ scope (see below).

## 3 ¦ Variable Declarations

The optional DECLARE *‹declarations›* brings **typed variable(s)** *v* into scope. An initial binding expression *e* may be given:

```
DECLARE v [ CONSTANT ] τ [ NOT NULL ] [ := e ];
        ⋮
```

- If := *e* is omitted, *v* has initial value NULL.
- NOT NULL: any assignment of NULL yields a runtime error.
- CONSTANT: the initial binding may not be overwritten.

- Use *c*%TYPE for τ to declare *v* with the same type as variable or table column named *v*.

## Variables With Row Types Have Row Values

Let *T* be a table with **row type** $(c_1\ \tau_1, …, c_n\ \tau_n)$. Recall: this row type is also known as *T*. Thus:

```
--                        ▼ row type name
CREATE FUNCTION accessᵢ(t T) RETURNS T.cᵢ%TYPE AS
$$
--        ▼+▼ table + column name
DECLARE x T.cᵢ%TYPE;  -- x has type τᵢ
BEGIN
  x := t.cᵢ;          -- field access uses dot notation
  RETURN x;
END;
$$
LANGUAGE PLPGSQL;
```

## 4 ¦ PL/SQL Expressions

In PL/SQL, any expression *e* that could also occur in a SELECT clause, is a valid expression.

In fact, the execution of PL/pgSQL statements like

```
v := e
IF e THEN … ELSE … END IF
```

lead to the evaluation of SELECT *e* by the SQL interpreter.

- Interoperability between PL/pgSQL and SQL. 👍
- Performance impact: context switches PL/SQL↔SQL. 👎
- If $e \equiv e(x,y)$, compile SQL once with parameters $x$,$y$.

# 5 ¦ PL/SQL Statements — Assignment

```
v := e
```

1. Evaluate $e$, yields a single value (scalar, row, array, user-defined, including NULL). $e$ may **not be table-valued.**

2. Cast value to type $\tau$ of $v$.
   - SQL casting rules apply (may fail at runtime).
   - $e$ may use textual literal syntax (e.g., for user-defined enumerations, JSON, or geometric objects).

3. Bind variable $v$ to value.

## Assignment of Single-Row Query Results

A single-row[4] SQL query augmented with INTO is a valid PL/SQL assignment statement:

```
❶  SELECT $e_1$, $e_2$, …, $e_n$
   INTO   $v$
   FROM   …
```

```
❷  SELECT $e_1$, $e_2$, …, $e_n$
   INTO   $v_1$, $v_2$, …, $v_n$
   FROM   …
```

1. Evaluate SQL query, obtain a single row of $n$ values.
   ❶ Assign row value to row-typed variable $v$, or
   ❷ assign value of $e_i$ to $v_i$ ($i \in \{1,\dots,n\}$).

2. Variable FOUND :: boolean indicates if a row was found.

[4] Use INTO STRICT to enforce a single-row query result. Otherwise, the “first” row is picked…

# Assignment of Scalar Query Results

RHS of assignment $v$ := $e$ is evaluated like a regular SQL query. In particular, $e$ may be a *scalar subquery* in (…):

```
v := (Q)   --
           -- Q yields single row, single column:  c
           --
```

- Evaluates SELECT ($Q$) behind the scenes. Thus:
    - assigns cell value $c$ cast to type τ of v, or
    - assigns NULL :: τ to $v$ if $Q$ returns no row, or
    - yields runtime error if $Q$ returns more than one row or column (or if the cast fails). ⚠

# 6 ¦ If All You Want Are the Side Effects…

1. Statement NULL does nothing (no side effects).

2. SQL **DML statements** (INSERT/DELETE/UPDATE) without RETURNING clauses are valid PL/SQL statements: no value is returned, the effect on the database is performed.

3. A SQL **query** SELECT …*‹query›*… may be performed solely for its side effects (e.g., invocation of a side-effecting UDF) as well:

```
PERFORM …‹query›… -- ⚠️ PERFORM replaces the SELECT keyword
```

Resulting rows are discarded (but variable FOUND is set).

# 7 ¦ Returning From a Non-Table Function (RETURNS τ)

```
RETURN e
```

1. Evaluate $e$, cast value to return type $\tau$ of the function.
    - ○ If $\tau \equiv$ void, omit $e$. A void function whose control flow reaches the end of the top-level block, returns automatically.
2. Execution resumes in the calling function or query which receives the returned value.

To return multiple values, declare the function to return a row type.

# “Returning” From a Table Function (RETURNS SETOF τ)

```
❶  RETURN NEXT e;
   s
```

```
❷  RETURN QUERY Q;
   s
```

- **Add (bag semantics: ⊎) to the result table** computed by the function. Execution resumes with following statement *s* — **no** return to the caller yet.
  ❶ Evaluate expression *e*, add scalar/row to result.
  ❷ Evaluate SQL query *Q*, append all rows to result.

- Use plain `RETURN;` to return the result table accumulated so far and resume execution in the caller.

# 8 ¦ Conditional Statements

$$\texttt{IF}\ p_0\ \texttt{THEN}\ s_0\ \underbrace{[\ \texttt{ELSIF}\ p_i\ \texttt{THEN}\ s_i\ ]^*}_{\text{optional, repeatable}}\ \underbrace{[\ \texttt{ELSE}\ s_e\ ]}_{\text{optional}}\ \texttt{END IF}$$

- Semantics as expected; $p_i$ :: bool, $s_i$ statements.

$$\texttt{CASE}\ e\ \underbrace{[\ \texttt{WHEN}\ e_{i1}\ [,\ e_{ij}]^*\ \texttt{THEN}\ s_i\ ]^+}_{\text{mandatory, repeatable}}\ [\ \texttt{ELSE}\ s_e\ ]\ \texttt{END CASE}$$

- Execute first branch $s_i$ with $\exists_j\!: e = e_{ij}$.
- Raise CASE_NOT_FOUND exception (see below) if no branch was found and ELSE $s_e$ is missing.

# 9 ¦ Iterated Statements

❶ LOOP $s^{\circlearrowleft}$ END LOOP

❷ WHILE $p$ LOOP $s^{\circlearrowleft}$ END LOOP

❸ FOR $v_i$ IN [ REVERSE ] $e_0$..$e_1$ [ BY $e_2$ ] LOOP $s^{\circlearrowleft}$ END LOOP

❹ FOR $v_r$ IN $q$ LOOP $s^{\circlearrowleft}$ END LOOP

❺ FOREACH $v_a$ IN [ SLICE $n$ ] ARRAY $e_a$ LOOP $s^{\circlearrowleft}$ END LOOP

❶ Endless loop (see EXIT below).

❷ $p$ :: bool.

❸ $e_{0,1,2}$ :: int. No BY: $e_2 \equiv 1$. $v_i$ :: int (auto-declared) bound to $e_0$, $e_0 \pm 1\times e_2$, $e_0 \pm 2\times e_2$, … (REVERSE: $\pm \equiv -$).

❹ $q$ SQL query. $v_r$ successively bound to resulting rows.

❺ $e_a$ :: $\tau$[]. No SLICE: $v_a$ :: $\tau$ bound to array elements. SLICE $n$: $v_a$ :: $\tau$[] bound to sub-arrays in $n$th dimension.

# Leaving/Short-Cutting Loops

All five LOOP forms support optional << ‹*label*› >> prefixes:

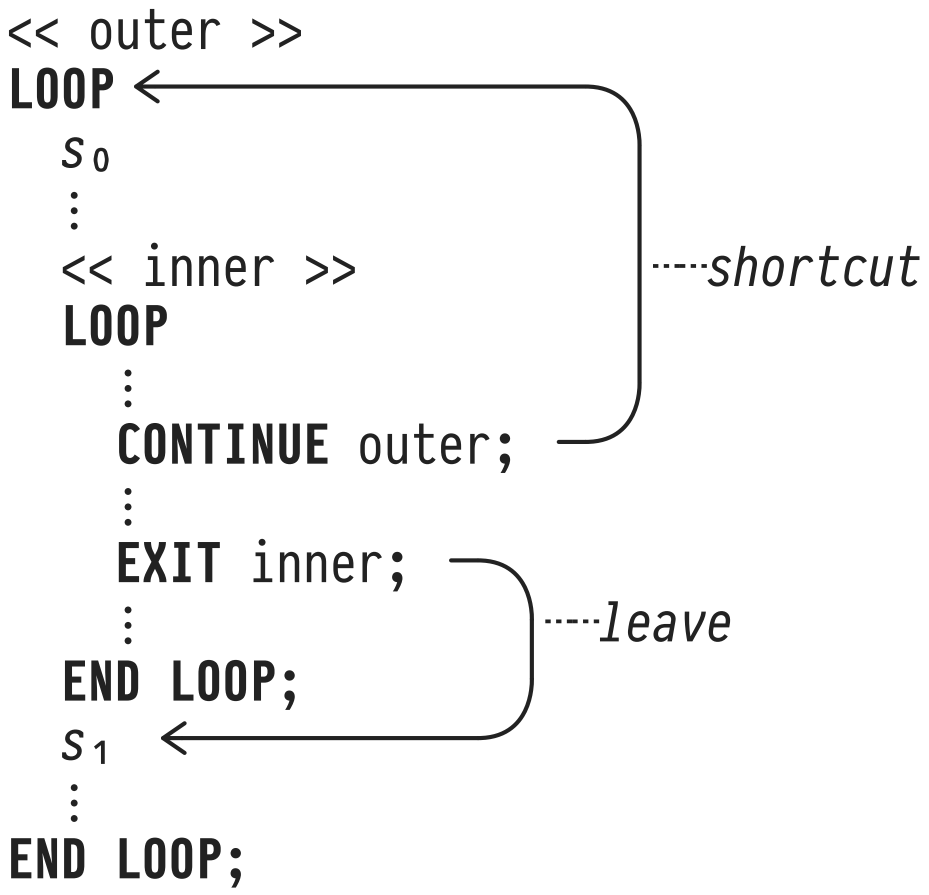
```
<< ‹label› >> … LOOP s↻ END LOOP
```

We may alter the control flow inside a loop via:

```
❶      EXIT [‹label›] [ WHEN p ]
❷  CONTINUE [‹label›] [ WHEN p ]
```

- No ‹*label*›: refer to innermost enclosing loop.
- WHEN *p*: leave/shortcut loop only if *p* ≡ true.
- EXIT ‹*label*› may also be used to leave a statement block.

# Leaving/Shortcutting Loops



```
<< outer >>
LOOP
  s_0
  ⋮
  << inner >>
  LOOP
    ⋮
    CONTINUE outer;
    ⋮
    EXIT inner;
    ⋮
  END LOOP;
  s_1
  ⋮
END LOOP;
```

- Shortcutting a WHILE $p$ loop leads to re-evaluation of $p$.

## 10 ⁝ Trapping Exceptions in Blocks

```
BEGIN
  ⋮     -- ⎫  errors or RAISE ex statements transfer control
  $s_x$ -- ⎬  to the EXCEPTION clause – if $s_x$ changed the
  ⋮     -- ⎭  database, also performs a rollback
EXCEPTION
  [ WHEN $ex_{i1}$ [, $ex_{ij}$]* THEN $s_i$ ]+
END;
$s_1$   -- next statement if no exception occurred
```

- On error or RAISE, search for first matching exception category/name $ex_{ij}$, execute $s_i$, then $s_1$.
- If no match is found (or $s_i$ fails), propagate exception to enclosing block. Abort function if in outermost block.

## Raising Exceptions

```
                 one expression per '%' in message
                                  ⏞
❶  RAISE [ ‹level› ] '… % … % …' [, e]*
❷  RAISE [ ‹level› ] ex
❸  ASSERT p [, e]
```

- *level* ∈ {DEBUG,LOG,INFO,NOTICE,WARNING}. Only the default *level* ≡ EXCEPTION raises an exception of name RAISE_EXCEPTION (or *ex*[5], if provided).

- ASSERT *p* (*p* :: bool) raises exception ASSERT_FAILURE—with optional message *e* :: text—if *p* ≡ false.

[5] See https://www.postgresql.org/docs/current/errcodes-appendix.html for a catalog of exception categories/names.