Introduction to PL/pgSQL

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Procedural Language Overview

- PostgreSQL allows user-defined functions to be written in a variety of procedural languages. The database server has no built-in knowledge about how to interpret the function's source text. Instead, the task is passed to a handler that knows the details of that particular language.
- PostgreSQL currently supports several standard procedural languages
  - PL/pgSQL
  - PL/Tcl
  - PL/Perl
  - PL/Python
  - PL/Java
  - And many more

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What is PL/pgSQL

- PL/pgSQL is the procedural extension to SQL with features of programming languages
- Data Manipulation and Query statements of SQL are included within procedural units of code
- Allows using general programming tools with SQL, for example: loops, conditions, functions, etc.
- This allows a lot more freedom than general SQL, and is lighter-weight than calling from a client program

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How PL/pgSQL works

- PL/pgSQL is like every other “loadable, procedural language.”
- When a PL function is executed, the fmgr loads the language handler and calls it.
- The language handler then interprets the contents of the pg_proc entry for the function (proargtypes, prorettype, prosrc).

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How PL/pgSQL works

- On the first call of a function in a session, the call handler will “compile” a function statement tree.
- SQL queries in the function are just kept as a string at this point.
- What might look to you like an expression is actually a SELECT query:

```
my_variable := some_parameter * 100;
```

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How PL/pgSQL works

- The PL/pgSQL statement tree is very similar to a PostgreSQL execution tree.
- The call handler then executes that statement tree.
- On the first execution of a statement node, that has an SQL query in it, that query is prepared via SPI.
- The prepared plan is then executed for every invocation of that statement in the current session.

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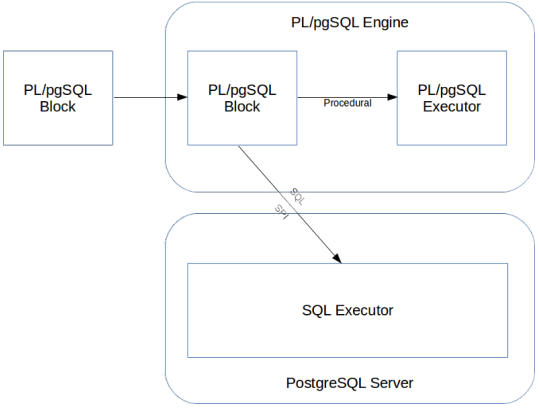
PL/pgSQL Environment



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Kinds of PL/pgSQL Blocks

The basic unit in any PL/pgSQL code is a BLOCK. All PL/pgSQL code is composed of a single block or blocks that occur either sequentially or nested within another block. There are two kinds of blocks:

- Anonymous blocks (DO)
  - Generally constructed dynamically and executed only once by the user. It is sort of a complex SQL statement
- Named blocks (Functions and Stored Procedures)
  - Have a name associated with them, are stored in the database, and can be executed repeatably, and can take in parameters

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Structure of Anonymous Block

```
DO $$
[ <<label>> ]
DECLARE
/* Declare section (optional).  */

BEGIN
/* Executable section (required).  */

EXCEPTION
/* Exception handling section (optional).  */

END [ label ]
$$;
```

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Comments

- There are two types of comments in PL/pgSQL
  - -- starts a comment that extends to the end of the line
  - /* multi-line comments */
- Commenting is necessary to tell people what is intended and why it was done a specific way
- Err on the side of too much commenting

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Variables

- Use variables for
  - Temporary storage of data
  - Manipulation of stored values
  - Re-usability
  - Ease of maintenance
- Declared in the declarative section within a block

```
v_last_name      VARCHAR(15);
```

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Handling Variables

- Variables declared in the declarations section preceding a block are initialized to their default values every time the block is entered, not only once per function call
- Variables in a declaration section can shadow variables of the same name in an outer block. If the outer block is named with a label, its variables are still available by specifying them as <label>.<varname>

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Declarations

Syntax

```
identifier [CONSTANT] datatype [NOT NULL] [:= | = | DEFAULT expr];
```

Examples

```
DECLARE
  v_birthday     DATE;
  v_age          INT NOT NULL = 21;
  v_name         VARCHAR(15) := 'Homer';
  v_magic        CONSTANT NUMERIC := 42;
  v_valid        BOOLEAN DEFAULT TRUE;
```

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%TYPE

- Declare variable according to :
  - A database column definition
  - Another previously declared variable

```
identifier table.column_name%TYPE;
```

Example

```
DECLARE
  v_email       users.email%TYPE;
  v_my_email    v_email%TYPE := 'rds-postgres-extensions-request@amazon.com';
```

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%ROWTYPE

- Declare a variable with the type of a ROW of a table

```
identifier table%ROWTYPE;
```

Example

```
DECLARE
  v_user       users%ROWTYPE;
```

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Records

- A record is a type of variable similar to ROWTYPE, but with no predefined structure
- The actual structure of the record is created when the variable is first assigned
- A record is not a true data type, only a place holder

```
DECLARE
  r record;
```

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Variable Scope

```
DO $$
DECLARE
    quantity integer := 30;
BEGIN
    RAISE NOTICE 'Quantity here is %', quantity;  -- 30
    quantity := 50;
    -- Create a subblock
    DECLARE
        quantity integer := 80;
    BEGIN
        RAISE NOTICE 'Quantity here is %', quantity;  -- 80
    END;
    RAISE NOTICE 'Quantity here is %', quantity;  -- 50
END
$$;
```

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Qualify an Identifier

```
DO $$
<< mainblock >>
DECLARE
    quantity integer := 30;
BEGIN
    RAISE NOTICE 'Quantity here is %', quantity; --30
    quantity := 50;
    -- Create a subblock
    DECLARE
        quantity integer := 80;
    BEGIN
        RAISE NOTICE 'Quantity here is %', mainblock.quantity; --50
        RAISE NOTICE 'Quantity here is %', quantity; --80
    END;
    RAISE NOTICE 'Quantity here is %', quantity; --50
END
$$;
```

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RAISE

- Reports messages
  - Can be seen by the client if the appropriate level is used

```
RAISE NOTICE 'Calling cs_create_job(%)', v_job_id;
```

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Assigning Values

- Use the assignment operator (:= or =)

```
DECLARE
    v_last_name     VARCHAR := 'Smith';
    v_date          DATE;
BEGIN
    v_last_name := lower(v_last_name);
    v_date := to_date('2000-01-01', 'YYYY-MM-DD');
```

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SELECT in PL/pgSQL

- Retrieve data from the database with a SELECT statement
- Queries must return only one row
- INTO clause is required

```
DECLARE
    v_first_name   users.first_name%TYPE;
    v_last_name    users.last_name%TYPE;
BEGIN
    SELECT first_name, last_name
      INTO v_first_name, v_last_name
     FROM users
    WHERE user_id = 1;
END
```

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INSERT / UPDATE / DELETE

```
DECLARE
    v_forum_name    forums.name%TYPE := 'Hackers';
BEGIN
    INSERT INTO forums (name)
    VALUES (v_forum_name);

    UPDATE forums
       SET moderated = true
     WHERE name = v_forum_name;
END
```

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PERFORM

- Evaluate an expression or query but discard the result
- Frequently used when executing maintenance commands

```
BEGIN
    PERFORM create_partition('moderation_log', '2016-06');
END
```

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Structure of Named Blocks

```
CREATE FUNCTION [ function_name ] ()
RETURNS [return_type] $$
[ <<label>> ]
DECLARE
/* Declare section (optional).  */

BEGIN
/* Executable section (required).  */

EXCEPTION
/* Exception handling section (optional).  */

END [ label ]
$$ LANGUAGE plpgsql;
```

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Function Example

```
CREATE FUNCTION get_user_count()
  RETURNS integer
AS $$
DECLARE
    v_count    integer;
BEGIN
    SELECT count(*)
      INTO v_count
     FROM users;

    RETURN v_count;
END
$$ LANGUAGE plpgsql;
```

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Dollar Quoting

- The tag $$ denotes the start and end of a string
- Optionally can have a non-empty tag as part of the quote
  - $_$
  - abc
- Can be used to prevent unnecessary escape characters throughout the string

```
$function$
BEGIN
    RETURN ($1 ~ $q$[\t\r\n\v\\]$q$);
END;
$function$
```

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Function Parameters

- One or more parameters can be used
- Parameter names are optional, but highly recommended

```
CREATE FUNCTION get_user_name(varchar, p_last_name varchar)
  RETURNS varchar AS $$
DECLARE
    v_first_name    varchar;
    v_name          varchar;
BEGIN
    v_first_name := $1;
    SELECT name INTO v_name FROM users
     WHERE first_name = v_first_name AND last_name = p_last_name
     LIMIT 1;

    RETURN v_name;
END
$$ LANGUAGE plpgsql;
```

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Default Parameters

- Paramters can have a default value
- This essentially makes them optional parameters

```
CREATE FUNCTION get_user_count(p_active boolean DEFAULT true)
  RETURNS integer AS $$
DECLARE
    v_count    integer;
BEGIN
    SELECT count(*) INTO v_count
     FROM users
    WHERE active = p_active;

    RETURN v_count;
END
$$ LANGUAGE plpgsql;
```

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Assertions

- A convenient shorthand for inserting debugging checks
- Can be controlled by plpgsql.check_asserts variable

```
CREATE FUNCTION get_user_count(p_active boolean DEFAULT true)
  RETURNS integer AS $$
DECLARE
    v_count    integer;
BEGIN
    ASSERT p_active IS NOT NULL;

    SELECT count(*) INTO v_count
     FROM users
    WHERE active = p_active;

    RETURN v_count;
END
$$ LANGUAGE plpgsql;
```

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PL/pgSQL Control Structures

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Control the Flow

- The logical flow of statements can be changed using conditional IF statements and loop control structures
  - Conditional Strucutres
  - Loop Structures

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IF Statements

IF-THEN

```
IF boolean-expression THEN
    statements
END IF;
```

IF-THEN-ELSE

```
IF boolean-expression THEN
    statements
ELSE
    statements
END IF;
```

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Nested IF Statements

```
IF boolean-expression THEN
    IF boolean-expression THEN
        statements
    END IF;
ELSE
    statements
END IF;
```

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ELSIF Statements

- A sequence of statements based on multiple conditions

```
IF number = 0 THEN
    result := 'zero';
ELSIF number > 0 THEN
    result := 'positive';
ELSIF number < 0 THEN
    result := 'negative';
ELSE
    -- the only other possibility is that number is null
    result := 'NULL';
END IF;
```

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CASE Statements

- Used for complex conditionals
- Allows a variable to be tested for equality against a list of values

```
BEGIN
    CASE status
         WHEN 'Pending' THEN RAISE NOTICE 'PENDING';
         WHEN 'Accepted' THEN RAISE NOTICE 'ACCEPTED';
         WHEN 'Declined' THEN RAISE NOTICE 'DECLINED';
         WHEN 'Blocked' THEN RAISE NOTICE 'BLOCKED';
         ELSE RAISE NOTICE 'UNKNOWN';
    END CASE;
END
```

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Searched CASE Statements

- Each WHEN clause sequentially evaluated until a TRUE is evaluated
- Subsequent WHEN expressions are not evaluated

```
BEGIN
    CASE
        WHEN x BETWEEN 0 AND 10 THEN
            RAISE NOTICE 'Value is between zero and ten';
        WHEN x BETWEEN 11 AND 20 THEN
            RAISE NOTICE 'Value is between eleven and twenty';
    END CASE;
$$;
```

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FOUND

- FOUND, which is of type boolean, starts out false within each PL/pgSQL function call
- It is set by each of the following types of statements:
  - A SELECT INTO statement sets FOUND true if it returns a row, false if no row is returned
  - A PERFORM statement sets FOUND true if it produces (and discards) a row, false if no row is produced
  - UPDATE, INSERT, and DELETE statements set FOUND true if at least one row is affected, false if no row is affected
  - A FETCH statement sets FOUND true if it returns a row, false if no row is returned.
  - A FOR statement sets FOUND true if it iterates one or more times, else false.

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FOUND

```
DECLARE
    v_first_name   users.first_name%TYPE;
    v_last_name    users.last_name%TYPE;
BEGIN
    SELECT first_name, last_name
      INTO v_first_name, v_last_name
     FROM users
    WHERE user_id = 1;

    IF FOUND THEN
        RAISE NOTICE 'User Found';
    ELSE
        RAISE NOTICE 'User Not Found';
    END IF;
END
```

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Loop Structures

- Unconstrained Loop
- WHILE Loop
- FOR Loop
- FOREACH Loop

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Unconstrained Loops

- Allows execution of its statements at least once, even if the condition already met upon entering the loop

```
LOOP
    -- some computations
    IF count > 0 THEN
        EXIT;  -- exit loop
    END IF;
END LOOP;
```

```
LOOP
    -- some computations
    EXIT WHEN count > 0;  -- same result as previous example
END LOOP;
```

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CONTINUE

```
CONTINUE [ label ] [ WHEN expression ];
```

- If no label is given, the next iteration of the innermost loop is begun
- If WHEN is specified, the next iteration of the loop is begun only if expression is true. Otherwise, control passes to the statement after CONTINUE
- CONTINUE can be used with all types of loops; it is not limited to use with unconstrained loops.

```
LOOP
    -- some computations
    EXIT WHEN count > 100;
    CONTINUE WHEN count < 50;
    -- some computations for count IN [50 .. 100]
END LOOP;
```

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WHILE Loops

```
WHILE condition LOOP
  statement1..;
END LOOP;
```

- Repeats a sequence of statements until the controlling condition is no longer TRUE
- Condition is evaluated at the beginning of each iteration

```
WHILE NOT done LOOP
    -- some computations here
END LOOP;
```

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FOR Loops

```
FOR <loop_counter> IN [REVERSE] <low bound>..<high bound> LOOP
  -- some computations here
END LOOP;
```

- Use a FOR loop to shortcut the test for the number of iterations.
- Do not declare the counter; it is declared implicitly

```
DO $$
BEGIN
    FOR i IN 1..10 LOOP
        RAISE NOTICE 'value: %', i;
    END LOOP;
END
$$;
```

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Looping Over Results

- For loops can directly use a query result

```
DECLARE
    r record;
BEGIN
    FOR r IN SELECT email FROM users LOOP
        RAISE NOTICE 'Email: %', r.email;
    END LOOP;
END
```

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Looping Over Results

- The last row is still accessible after exiting the loop

```
DECLARE
    r record;
BEGIN
    FOR r IN SELECT email FROM users LOOP
        RAISE NOTICE 'Email: %', r.email;
    END LOOP;
    RAISE NOTICE 'Email: %', r.email;
END
```

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Looping Over Results

- Looping over dynamic SQL
- Re-planned each time it is executed

```
DECLARE
    rec RECORD;
    sql text;
BEGIN
    sql := 'SELECT email FROM users';
    FOR rec IN EXECUTE sql LOOP
        RAISE NOTICE 'Email: %', rec.email;
    END LOOP;
END
```

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Looping Over Arrays

- Uses the FOREACH statement

```
DECLARE
    users    varchar[] := ARRAY['Mickey', 'Donald', 'Minnie'];
    v_user   varchar;
BEGIN
    FOREACH v_user IN ARRAY users LOOP
        RAISE NOTICE 'User: %', v_user;
    END LOOP;
END
```

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Looping Over Arrays

- Use the SLICE syntax to iterate over multiple dimensions

```
DECLARE
    users     varchar[];
    v_dim     varchar[];
BEGIN
    users := ARRAY[ARRAY['Mickey', 'Donald'], ARRAY['Mouse', 'Duck']];
    FOREACH v_dim SLICE 1 IN ARRAY users LOOP
        RAISE NOTICE 'Dimension: %', v_dim;
    END LOOP;
END
```

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Nested Loops

- Nest loops to multiple levels
- Use labels to distinguish between blocks
- Exit the outer loop with the EXIT statement that references the label

```
BEGIN
   <<Outer_loop>>
  LOOP
    v_counter := v_counter + 1;
  EXIT WHEN v_counter > 10; -- leaves both loops
    <<Inner_loop>>
      LOOP
         EXIT Outer_loop WHEN total_done = 'YES';
        -- leaves both loops
         EXIT WHEN inner_done = 'YES';
        -- leaves inner loop only
      END LOOP Inner_loop;
  END LOOP Outer_loop;
END
```

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Dynamic SQL

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Dynamic SQL

- A programming methodology for generating and running SQL statements at run time
- Useful for:
  - Ad-hoc query systems
  - DDL and database maitenance

```
EXECUTE command-string [ INTO target ] [ USING expression [, ... ] ];
```

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Dynamic SQL - CAUTION

- There is no plan caching for commands executed via EXECUTE
  - The command is planned each time it is run
- Open to SQL injection attacks
  - All incoming parameters need to be validated
  - Bind the parameters to the command instead of generating the string

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Execute

```
CREATE FUNCTION grant_select(p_table varchar, p_role varchar)
  RETURNS void AS
$$
DECLARE
    sql         varchar;
BEGIN
  sql := 'GRANT SELECT ON TABLE ' || p_table || ' TO ' || p_role;
  EXECUTE sql;
END
$$ LANGUAGE plpgsql;
```

Note: Do not do this. Validate the parameters first.

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Execute Into

```
CREATE FUNCTION get_connection_count(p_role varchar)
  RETURNS integer
AS $$
DECLARE
    v_count     integer;
    sql         varchar;
BEGIN
  sql := 'SELECT count(*) FROM pg_stat_activity
          WHERE usename = ''' || p_role || '''';
  EXECUTE sql INTO v_count;

  RETURN v_count;
END
$$ LANGUAGE plpgsql;
```

Note: Do not do this. Validate the parameters first.

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Execute Using

```
CREATE FUNCTION get_connection_count(p_role varchar)
  RETURNS integer
AS $$
DECLARE
    v_count    integer;
    sql        varchar;
BEGIN
  sql := 'SELECT count(*) FROM pg_stat_activity
          WHERE usename = $1';
  EXECUTE sql INTO v_count USING p_role;

  RETURN v_count;
END
$$ LANGUAGE plpgsql;
```

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PL/pgSQL Cursors

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Cursors

- Every SQL statement executed by PostgreSQL has an individual cursor associated with it
  - Implicit cursors: Declared for all DML and PL/pgSQL SELECT statements
  - Explicit cursors: Declared and named by the programmer
- Use CURSOR to individually process each row returned by a multiple-row SELECT Statement

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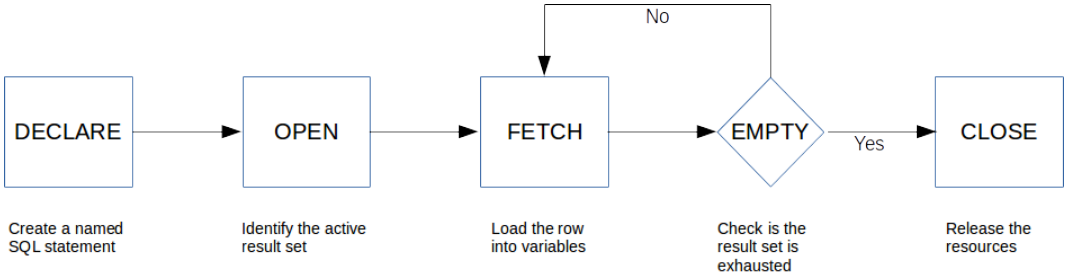
Cursor Flow



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Declaring Cursors

- A cursor must be declared as a variable
  - Use the SCROLL keyword to move backwards through a cursor

```
name [ [ NO ] SCROLL ] CURSOR [ ( arguments ) ] FOR query;
```

```
DECLARE
    curs1 refcursor;
    curs2 CURSOR FOR SELECT * FROM tenk1;
    curs3 CURSOR (key integer) FOR SELECT *
                                     FROM tenk1
                                    WHERE unique1 = key;
```

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Opening Cursors

- The OPEN method to use is dependant on the way it was declared

```
OPEN curs1 FOR SELECT * FROM foo WHERE key = mykey;
OPEN cur2;

OPEN curs3(42);
OPEN curs3 (key := 42);
```

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Fetching Data

- FETCH returns the next row

```
FETCH curs2 INTO foo, bar, baz;
```

- FETCH can also move around the cursor

```
FETCH LAST FROM curs3 INTO x, y;
```

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Fetching Data

```
CREATE FUNCTION grant_select(p_role varchar)
  RETURNS void AS $$
DECLARE
    sql         varchar;
    r           record;
    tbl_cursor CURSOR FOR SELECT schemaname, relname
                          FROM pg_stat_user_tables;
BEGIN
    OPEN tbl_cursor;
    LOOP
        FETCH tbl_cursor INTO r;
        EXIT WHEN NOT FOUND;
        sql := 'GRANT SELECT ON TABLE ' || r.schemaname ||
               '.' || r.relname || ' TO ' || p_role;
        EXECUTE sql;
    END LOOP;
    CLOSE tbl_cursor;
END
$$ LANGUAGE plpgsql;
```

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PL/pgSQL Returning Data

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Returning Scalars

- Simplest return type

```
CREATE FUNCTION get_connection_count()
  RETURNS integer AS $$
DECLARE
    v_count     integer;
BEGIN
    SELECT count(*) INTO v_count
      FROM pg_stat_activity;

    RETURN v_count;
END
$$ LANGUAGE plpgsql;
```

```
SELECT get_connection_count();
 get_connection_count
----------------------
                   11
(1 row)
```

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Returning Nothing

- Some functions do not need a return value
  - This is usually a maintenance function of some sort such as creating partitions or data purging
  - Starting in PostgreSQL 11, Stored Procedures can be used in these cases

- Return VOID

```
CREATE FUNCTION purge_log()
  RETURNS void AS
$$
BEGIN
    DELETE FROM moderation_log
     WHERE log_date < now() - '90 days'::interval;
END
$$ LANGUAGE plpgsql;
```

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Returning Sets

- Functions can return a result set
- Use SETOF
- Use RETURN NEXT
  - RETURN NEXT does not actually return from the function
  - Successive RETURN NEXT commands build a result set
- A final RETURN exits the function

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Returning Sets

```
CREATE FUNCTION fibonacci(num integer)
  RETURNS SETOF integer AS $$
DECLARE
    a int := 0;
    b int := 1;
BEGIN
    IF (num <= 0)
        THEN RETURN;
    END IF;

    RETURN NEXT a;
    LOOP
        EXIT WHEN num <= 1;
        RETURN NEXT b;
        num = num - 1;
        SELECT b, a + b INTO a, b;
    END LOOP;
END;
$$ language plpgsql;
```

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Returning Records

- More complex structures can be returned

```
CREATE FUNCTION get_oldest_session()
  RETURNS record AS
$$
DECLARE
    r    record;
BEGIN
    SELECT *
      INTO r
      FROM pg_stat_activity
     WHERE usename = SESSION_USER
     ORDER BY backend_start DESC
     LIMIT 1;

    RETURN r;
END
$$ LANGUAGE plpgsql;
```

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Returning Records

- Using a generic record type requires the structure to be defined at run time

```
# SELECT * FROM get_oldest_session();
ERROR:  a column definition list is required for functions ...
LINE 1: SELECT * FROM get_oldest_session();
```

```
SELECT * FROM get_oldest_session()
AS (a oid, b name, c integer, d oid, e name, f text, g inet,
    h text, i integer, j timestamptz, k timestamptz,
    l timestamptz, m timestamptz, n boolean, o text, p xid,
    q xid, r text);
```

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Returning Records

- All tables and views automatically have corresponding type definitions so they can be used as return types

```
CREATE FUNCTION get_oldest_session()
  RETURNS pg_stat_activity AS $$
DECLARE
    r    record;
BEGIN
    SELECT *
      INTO r
      FROM pg_stat_activity
     WHERE usename = SESSION_USER
     ORDER BY backend_start DESC
     LIMIT 1;

    RETURN r;
END
$$ LANGUAGE plpgsql;
```

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Returning Sets of Records

- Many times, a subset of the table data is needed
- A view can be used to define the necessary structure

```
CREATE VIEW running_queries AS
SELECT CURRENT_TIMESTAMP - query_start as runtime, pid,
       usename, waiting, query
  FROM pg_stat_activity
 ORDER BY 1 DESC
 LIMIT 10;
```

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Returning Sets of Records

- RETURN QUERY can be used to simplify the function

```
CREATE FUNCTION running_queries(p_rows int, p_len int DEFAULT 50)
  RETURNS SETOF running_queries AS
$$
BEGIN
   RETURN QUERY SELECT runtime, pid, usename,  waiting,
                       substring(query,1,p_len) as query
                  FROM running_queries
                 ORDER BY 1 DESC
                 LIMIT p_rows;
END
$$ LANGUAGE plpgsql;
```

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OUT Parameters

- Used to return structured information
- RETURNS is optional, but must be record if included

```
CREATE FUNCTION active_locks(OUT p_exclusive int, OUT p_share int)
```

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OUT Parameters

```
CREATE FUNCTION active_locks(OUT p_exclusive int, OUT p_share int) AS $$
DECLARE
    r    record;
BEGIN
    p_exclusive := 0;
    p_share := 0;
    FOR r IN SELECT l.mode
               FROM pg_locks l, pg_stat_activity a
              WHERE a.pid = l.pid
                AND a.usename = SESSION_USER
    LOOP
        IF r.mode = 'ExclusiveLock' THEN
            p_exclusive := p_exclusive + 1;
        ELSIF r.mode = 'ShareLock' THEN
            p_share := p_share + 1;
        END IF;
    END LOOP;
END
$$ LANGUAGE plpgsql;
```

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OUT Parameters

- TIP: Think in sets not loops when writing functions for better performance
- NOTE: Use “OR REPLACE” when updating functions

```
CREATE OR REPLACE FUNCTION active_locks(OUT p_exclusive int,
                                        OUT p_share int)
  AS $$
BEGIN
    SELECT sum(CASE l.mode WHEN 'ExclusiveLock' THEN 1 ELSE 0 END),
           sum(CASE l.mode WHEN 'ShareLock' THEN 1 ELSE 0 END)
      INTO p_exclusive, p_share
      FROM pg_locks l, pg_stat_activity a
     WHERE a.pid = l.pid
       AND a.usename = SESSION_USER;

END
$$ LANGUAGE plpgsql;
```

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Structured Record Sets

- Use OUT parameters and SETOF record

```
CREATE FUNCTION all_active_locks(OUT p_lock_mode varchar,
                                 OUT p_count int)
  RETURNS SETOF record AS $$
DECLARE
    r    record;
BEGIN
    FOR r IN SELECT l.mode, count(*) as k
               FROM pg_locks l, pg_stat_activity a
              WHERE a.pid = l.pid
                AND a.usename = SESSION_USER
              GROUP BY 1
    LOOP
        p_lock_mode := r.mode;
        p_count := r.k;
        RETURN NEXT;
    END LOOP;
    RETURN;
...
```

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Structured Record Sets

- Can return a TABLE

```
CREATE FUNCTION all_active_locks()
  RETURNS TABLE (p_lock_mode varchar, p_count int) AS $$
DECLARE
    r    record;
BEGIN
    FOR r IN SELECT l.mode, count(*) as k
               FROM pg_locks l, pg_stat_activity a
              WHERE a.pid = l.pid
                AND a.usename = SESSION_USER
              GROUP BY 1
    LOOP
        p_lock_mode := r.mode;
        p_count := r.k;
        RETURN NEXT;
    END LOOP;
    RETURN;
END
$$ LANGUAGE plpgsql;
```

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Refcursors

- A cursor can be returned for large result sets
- The only way to return multiple result sets from a function

```
CREATE FUNCTION active_info(OUT p_queries refcursor,
                            OUT p_locks refcursor)
```

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Refcursors

```
CREATE FUNCTION active_info(OUT p_queries refcursor,
                            OUT p_locks refcursor)
  AS $$
BEGIN
   OPEN p_queries FOR SELECT runtime, pid, usename,  waiting,
                             substring(query,1,50) as query
                        FROM running_queries
                       ORDER BY 1 DESC;

   OPEN p_locks FOR SELECT l.mode, count(*) as k
                      FROM pg_locks l, pg_stat_activity a
                     WHERE a.pid = l.pid
                       AND a.usename = SESSION_USER
                     GROUP BY 1;
END
$$ LANGUAGE plpgsql;
```

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Handling Meta Information and Exceptions

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Meta Information

- Information about the last command run inside of a function
- Several available values
  - ROW_COUNT
  - RESULT_OID
  - PG_CONTEXT

```
GET DIAGNOSTICS variable { = | := } item [ , ... ];
```

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Meta Information

```
CREATE OR REPLACE FUNCTION purge_log()
  RETURNS void AS
$$
DECLARE
  l_rows    int;
BEGIN
    DELETE FROM moderation_log
     WHERE log_date < now() - '90 days'::interval;

    GET DIAGNOSTICS l_rows = ROW_COUNT;
    RAISE NOTICE 'Deleted % rows from the log', l_rows;
END
$$ LANGUAGE plpgsql;
```

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Exceptions

- An exception is an identifier in PL/pgSQL that is raised during execution
- It is raised when an error occurs or explicitly by the function
- It is either handled in the EXCEPTION block or propagated to the calling environment

```
[DECLARE]
BEGIN
    Exception/Error is Raised
EXCEPTION
    Error is Trapped
END
```

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Exceptions

- Use the WHEN block inside of the EXCEPTION block to catch specific cases
- Can use the error name or error code in the EXCEPTION block

```
WHEN division_by_zero THEN ...
WHEN SQLSTATE '22012' THEN …
```

- Use the special conditions OTHERS as a catch all

```
WHEN OTHERS THEN ...
```

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Sample Error Codes

Code	Name
22000	data_exception
22012	division_by_zero
2200B	escape_character_conflict
22007	invalid_datetime_format
22023	invalid_parameter_value
2200M	invalid_xml_document
2200S	invalid_xml_comment
23P01	exclusion_violation

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Exceptions

```
CREATE OR REPLACE FUNCTION get_connection_count()
  RETURNS integer AS $$
DECLARE
    v_count    integer;
BEGIN
    SELECT count(*)
      INTO STRICT v_count
     FROM pg_stat_activity;

    RETURN v_count;
EXCEPTION
    WHEN TOO_MANY_ROWS THEN
        RAISE NOTICE 'More than 1 row returned';
        RETURN -1;
    WHEN OTHERS THEN
        RAISE NOTICE 'Unknown Error';
        RETURN -1;
END
$$ LANGUAGE plpgsql;
```

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Exception Information

- SQLSTATE Returns the numeric value for the error code.
- SQLERRM Returns the message associated with the error number.

```
DECLARE
    v_count    integer;
    err_num    integer;
    err_msg    varchar;
BEGIN
...
EXCEPTION
    WHEN OTHERS THEN
        err_num  := SQLSTATE;
        err_msg  := SUBSTR(SQLERRM,1,100);
        RAISE NOTICE 'Trapped Error: %', err_msg;
        RETURN -1;
END
```

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Exception Information

- The details of an error are usually required when handling
- Use GET STACKED DIAGNOSTICS to return the details

```
GET STACKED DIAGNOSTICS variable { = | := } item [ , ... ];
```

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Exception Information

Diagnostic Item
RETURNED_SQLSTATE
COLUMN_NAME
CONSTRAINT_NAME
PG_DATATYPE_NAME
MESSAGE_TEXT
TABLE_NAME
SCHEMA_NAME
PG_EXCEPTION_DETAIL
PG_EXCEPTION_HINT
PG_EXCEPTION_CONTEXT

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Propagating Exceptions

- Exceptions can be raised explicitly by the function

```
CREATE OR REPLACE FUNCTION grant_select(p_role varchar)
  RETURNS void AS
$$
DECLARE
    sql         varchar;
    r           record;
    tbl_cursor CURSOR FOR SELECT schemaname, relname
                          FROM pg_stat_user_tables;
BEGIN
    IF NOT EXISTS (SELECT 1 FROM pg_roles
                   WHERE rolname = p_role) THEN
        RAISE EXCEPTION 'Invalid Role: %', p_role;
    END IF;
...
```

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Exceptions

- TIP: Use exceptions only when necessary, there is a large performance impact
  - Sub transactions are created to handle the exceptions

```
CREATE FUNCTION t1()
  RETURNS void AS $$
DECLARE
  i  integer;
BEGIN
  i := 1;
END
$$ LANGUAGE plpgsql;



Avg Time: 0.0017ms
```

```
CREATE FUNCTION t2()
  RETURNS void AS $$
DECLARE
  i  integer;
BEGIN
  i := 1;
EXCEPTION
    WHEN OTHERS THEN
      RETURN;
END
$$ LANGUAGE plpgsql;

Avg Time: 0.0032ms
```

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PL/pgSQL Triggers

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Triggers

- Code that gets executed when an event happens in the database
  - INSERT, UPDATE, DELETE
- Event Triggers fire on DDL
  - CREATE, DROP, ALTER

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Use Cases

- Table Partitioning before PostgreSQL 10
- Automatically generate derived column values
- Enforce complex constraints
- Enforce referential integrity across nodes in a distributed database
- Provide transparent event logging
- Provide auditing
  - Invalidate cache entries

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Structure

- Unlike other databases, a trigger is broken into two pieces
  - Trigger
  - Trigger Function

```
CREATE TRIGGER name
    { BEFORE | AFTER | INSTEAD OF }
    { event [ OR ... ] }
    ON table_name
    [ FOR [ EACH ] { ROW | STATEMENT } ]
    [ WHEN ( condition ) ]
    EXECUTE PROCEDURE function_name ( arguments )
```

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Trigger Function

- A function with no parameters that returns TRIGGER

```
CREATE FUNCTION trg() RETURNS trigger AS $$
BEGIN
    RETURN NEW;
END;
$$ LANGUAGE plpgsql;
```

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Trigger Events

- Insert
- Update
- Delete
- Truncate

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Timing

- Before
  - The trigger is fired before the change is made to the table
  - Trigger can modify NEW values
  - Trigger can suppress the change altogether
- After
  - The trigger is fired after the change is made to the table
  - Trigger sees final result of row

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Frequency

- For Each Row
  - The trigger is fired once each time a row is affected
- For Each Statement
  - The trigger is fired once each time a statement is executed

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Trigger Overhead

- A firing trigger adds overhead to the calling transaction
- The percentage overhead can be found with a simple pgbench test:

```
INSERT INTO trigger_test (value) VALUES ('hello');

\set keys :scale
\setrandom key 1 :keys
UPDATE trigger_test SET value = 'HELLO' WHERE key = :key;
```

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Trigger Overhead

```
pgbench -n -t 100000
        -f INSERTS.pgbench postgres

pgbench -n -s 100000 -t 10000
        -f UPDATES.pgbench postgres

Inserts: 4510 tps
Updates: 4349 tps
```

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Trigger Overhead

```
CREATE FUNCTION empty_trigger()
  RETURNS trigger AS $$
BEGIN
 RETURN NEW;
END;
$$ LANGUAGE plpgsql;

CREATE TRIGGER empty_trigger
 BEFORE INSERT OR UPDATE ON trigger_test
 FOR EACH ROW EXECUTE PROCEDURE empty_trigger();
```

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Trigger Overhead

```
pgbench -n -t 100000
        -f INSERTS.pgbench postgres

pgbench -n -s 100000 -t 10000
        -f UPDATES.pgbench postgres

Inserts: 4296 tps (4.8% overhead)
Updates: 3988 tps (8.3% overhead)
```

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Arguments

- NEW
  - Variable holding the new row for INSERT/UPDATE operations in row-level triggers
- OLD
  - Variable holding the old row for UPDATE/DELETE operations in row-level triggers

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NEW vs OLD

```
CREATE TABLE audit (
    event_time timestamp NOT NULL,
    user_name  varchar   NOT NULL,
    old_row    json,
    new_row    json
);
```

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NEW vs OLD

```
CREATE OR REPLACE FUNCTION audit_trigger()
    RETURNS TRIGGER AS $$
BEGIN
    INSERT INTO audit
        VALUES (CURRENT_TIMESTAMP,
                CURRENT_USER,
                row_to_json(OLD),
                row_to_json(NEW));

    RETURN NEW;
END;
$$
LANGUAGE plpgsql;
```

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Arguments

- TG_OP
  - A string of INSERT, UPDATE, DELETE, or TRUNCATE telling for which operation the trigger was fired
- TG_NAME
  - Variable that contains the name of the trigger actually fired
- TG_WHEN
  - A string of BEFORE, AFTER, or INSTEAD OF, depending on the trigger's definition
- TG_LEVEL
  - A string of either ROW or STATEMENT depending on the trigger's definition

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TG_OP

```
CREATE TABLE audit (
    event_time timestamp NOT NULL,
    user_name  varchar   NOT NULL,
    operation  varchar   NOT NULL,
    old_row    json,
    new_row    json
);
```

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TG_OP

```
CREATE OR REPLACE FUNCTION audit_trigger() RETURNS TRIGGER AS $$
BEGIN
  IF (TG_OP = 'DELETE') THEN
    INSERT INTO audit VALUES
    (CURRENT_TIMESTAMP, CURRENT_USER,TG_OP, row_to_json(OLD), null);
    RETURN OLD;
  ELSIF (TG_OP = 'UPDATE') THEN
    INSERT INTO audit VALUES
    (CURRENT_TIMESTAMP, CURRENT_USER,TG_OP,
     row_to_json(OLD), row_to_json(NEW));
    RETURN NEW;
  ELSIF (TG_OP = 'INSERT') THEN
   INSERT INTO audit VALUES
   (CURRENT_TIMESTAMP, CURRENT_USER,TG_OP, null, row_to_json(NEW));
   RETURN NEW;
 END IF;
 RETURN NULL;
END;
$$ LANGUAGE plpgsql;
```

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Arguments

- TG_TABLE_NAME
  - The name of the table that caused the trigger invocation.
- TG_RELNAME
  - The name of the table that caused the trigger invocation
- TG_RELID
  - The object ID of the table that caused the trigger invocation
- TG_TABLE_SCHEMA
  - The name of the schema of the table that caused the trigger invocation

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TG_TABLE_NAME

```
CREATE TABLE audit (
    event_time timestamp NOT NULL,
    user_name  varchar   NOT NULL,
    operation  varchar   NOT NULL,
    table_name varchar   NOT NULL,
    old_row    json,
    new_row    json
);
```

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TG_TABLE_NAME

```
CREATE OR REPLACE FUNCTION audit_trigger() RETURNS TRIGGER AS $$
BEGIN
    IF (TG_OP = 'DELETE') THEN
        INSERT INTO audit
            VALUES (CURRENT_TIMESTAMP, CURRENT_USER,TG_OP,
                    TG_TABLE_NAME, row_to_json(OLD), null);
        RETURN OLD;
    ELSIF (TG_OP = 'UPDATE') THEN
        INSERT INTO audit
            VALUES (CURRENT_TIMESTAMP, CURRENT_USER,TG_OP,
                    TG_TABLE_NAME, row_to_json(OLD), row_to_json(NEW));
        RETURN NEW;
...
```

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Arguments

- TG_NARGS
  - The number of arguments given to the trigger procedure in the CREATE TRIGGER statement
- TG_ARGV[]
  - The arguments from the CREATE TRIGGER statement

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Trigger Use Cases

- Table Partitioning
  - Splitting what is logically one large table into smaller physical pieces
- Used to:
  - Increase performance
  - Archive data
  - Storage tiering

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Table Partitioning before PostgreSQL 10

- Create child tables for each partition

```
CREATE TABLE audit_2014 (
 CHECK ( event_time >= DATE '2014-01-01'
      AND event_time < DATE '2015-01-01')
) INHERITS (audit);

CREATE TABLE audit_2015 (
 CHECK ( event_time >= DATE '2015-01-01'
     AND event_time <  DATE '2016-01-01')
) INHERITS (audit);
```

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Table Partitioning before PostgreSQL 10

- The trigger function will move the row to the correct child table

```
CREATE OR REPLACE FUNCTION partition_audit_trigger()
    RETURNS TRIGGER AS $$
BEGIN
    EXECUTE 'INSERT INTO audit_' ||
            to_char(NEW.event_time, 'YYYY') ||
            '    VALUES ($1, $2, $3, $4, $5, $6)'
    USING NEW.event_time, NEW.user_name, NEW.operation,
          NEW.table_name, NEW.old_row, NEW.new_row;

    RETURN NULL;
END;
$$
LANGUAGE plpgsql;
```

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Table Partitioning before PostgreSQL 10

- A trigger needs to be added to the parent table

```
CREATE TRIGGER partition_audit_trigger
    BEFORE INSERT ON audit
    FOR EACH ROW
    EXECUTE PROCEDURE
       partition_audit_trigger();
```

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Execution Performance

- Performance is much better if dynamic SQL is not used

```
CREATE OR REPLACE FUNCTION partition_audit_trigger()
  RETURNS TRIGGER AS $$
BEGIN
    IF ( NEW.event_time >= DATE '2015-01-01' AND
         NEW.event_time < DATE '2016-01-01' ) THEN
        INSERT INTO audit_2015 VALUES (NEW.*);
    ELSIF ( NEW.event_time >= DATE '2014-01-01' AND
            NEW.event_time < DATE '2015-01-01' ) THEN
        INSERT INTO audit_2014 VALUES (NEW.*);
    ELSE
        RAISE EXCEPTION 'Date out of range.  Fix
             partition_audit_trigger() function!';
    END IF;
    RETURN NULL;
END;
$$ LANGUAGE plpgsql;
```

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Moving Partitions

- If the column used for the partition key changes, the row may need to be moved to a different partition

```
CREATE TRIGGER move_partition_audit_trigger
    BEFORE UPDATE
      ON audit_2014
    FOR EACH ROW EXECUTE PROCEDURE
    move_partition_audit_trigger('2014-01-01', '2015-01-01');

CREATE TRIGGER move_partition_audit_trigger
    BEFORE UPDATE
      ON audit_2015
    FOR EACH ROW EXECUTE PROCEDURE
    move_partition_audit_trigger('2015-01-01', '2016-01-01');
```

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Moving Partitions

```
CREATE FUNCTION move_partition_audit_trigger() RETURNS TRIGGER AS $$
DECLARE
  start_date DATE;
  end_date DATE;
BEGIN
  start_date := TG_ARGV[0];
  end_date := TG_ARGV[1];

  IF ( NEW.event_time IS DISTINCT FROM OLD.event_time ) THEN
    IF (NEW.event_time < start_date OR NEW.event_time >= end_date) THEN
     EXECUTE 'DELETE FROM ' || TG_TABLE_SCHEMA || '.' || TG_TABLE_NAME ||
             ' WHERE ctid = $1' USING OLD.ctid;
     INSERT INTO audit VALUES (NEW.*);
     RETURN null;
    END IF;
  END IF;
  RETURN NEW;
END;
$$ LANGUAGE plpgsql;
```

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Moving Partitions

- Only fire the trigger if the partition key changes

```
CREATE TRIGGER move_partition_audit_trigger
    BEFORE UPDATE
      ON audit_2014
    FOR EACH ROW
    WHEN (NEW.event_time IS DISTINCT FROM OLD.event_time)
    EXECUTE PROCEDURE
move_partition_audit_trigger('2014-01-01', '2015-01-01');

CREATE TRIGGER move_partition_audit_trigger
    BEFORE UPDATE
      ON audit_2015
    FOR EACH ROW
    WHEN (NEW.event_time IS DISTINCT FROM OLD.event_time)
    EXECUTE PROCEDURE
move_partition_audit_trigger('2015-01-01', '2016-01-01');
```

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Trigger Use Cases

- Calculate columns
  - Calculate complex values
  - Extract values from complex structures
  - Enforce derived values when using denormalization
  - Used to:
    - Increase performance
    - Simplify queries

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Extract JSON

```
$ head -n 5 zips.json
{ "_id" : "01001", "city" : "AGAWAM",
  "loc" : [ -72.622739, 42.070206 ], "pop" : 15338, "state" : "MA" }
{ "_id" : "01002", "city" : "CUSHMAN",
  "loc" : [ -72.51564999999999, 42.377017 ], "pop" : 36963, "state" : "MA" }
{ "_id" : "01005", "city" : "BARRE",
  "loc" : [ -72.10835400000001, 42.409698 ], "pop" : 4546, "state" : "MA" }
{ "_id" : "01007", "city" : "BELCHERTOWN",
  "loc" : [ -72.41095300000001, 42.275103 ], "pop" : 10579, "state" : "MA" }
{ "_id" : "01008", "city" : "BLANDFORD",
  "loc" : [ -72.936114, 42.182949 ], "pop" : 1240, "state" : "MA" }
```

```
CREATE TABLE zips (
    zip_code varchar PRIMARY KEY,
    state    varchar,
    data     json
);
```

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Extract JSON

```
CREATE OR REPLACE FUNCTION extract_data_trigger()
  RETURNS TRIGGER AS $$
BEGIN
    NEW.zip_code := NEW.data->>'_id';
    NEW.state := NEW.data->>'state';

    RETURN NEW;
END;
$$ LANGUAGE plpgsql;

CREATE TRIGGER extract_data_trigger
    BEFORE UPDATE OR INSERT ON zips
    FOR EACH ROW EXECUTE PROCEDURE extract_data_trigger();
```

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Trigger Use Cases

- Cache invalidation
  - Remove stale entries from a cache
  - The database tracks all data so is the single source of truth
  - Used to:
    - Simplify cache management
    - Remove application complexity

Note: Foreign Data Wrappers simplify this process significantly

Note: ON (action) CASCADE contraints can simplify this too.

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Cache Invalidation

```
CREATE FUNCTION remove_cache_trigger()
  RETURNS TRIGGER AS $$
BEGIN
    DELETE from myredis_cache
     WHERE key = OLD.id::varchar;

    RETURN NEW;
END;
$$ LANGUAGE plpgsql;

CREATE TRIGGER remove_cache_trigger
    AFTER UPDATE OR DELETE ON users
    FOR EACH ROW EXECUTE PROCEDURE remove_cache_trigger();
```

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Cache Invalidation - Async

- The latency of updating the cache may not be an acceptable as part of the main transaction

```
CREATE FUNCTION remove_cache_trigger()
  RETURNS TRIGGER AS $$
BEGIN
    PERFORM pg_notify(TG_TABLE_NAME, OLD.id::varchar);

    RETURN NEW;
END;
$$ LANGUAGE plpgsql;
```

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Things to Remember

- Triggers are part of the parent transaction
  - The trigger fails, the main transaction fails
  - The main transaction rolls back, the trigger call never happened
  - If the trigger takes a long time, the whole transaction timing is affected
- Triggers can be difficult to debug
  - Especially cascaded triggers

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PL/pgSQL Best Practices

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Programming Practices

- Follow good programming practices
  - Indent code consistantly
  - Comment code liberly
  - Code reuse/modularity practices are different than other programming languages
    - Deep call stacks in PL/pgSQL can be performance intensive

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Naming Conventions

- Create and follow a consistent naming convention for objects
  - PostgreSQL is case insensitive so init cap does not work, use ”_” to seperate words in names
  - Prefix all parameter names with something like “p_”
  - Prefix all variable names with something like “v_”

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Performance

- Avoid expensive constructs unless necessary
  - Dynamic SQL
  - EXCEPTION blocks

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