# PL/pgSQL internals

**Pavel Stěhule**

GoodData

# Content

- Function management
- Language handlers
- PL/pgSQL function life cycle
- PL/pgSQL architecture
  - expression parsing
  - expression evaluating

# Function management

- described in *pg_proc*
- indirect call by *FunctionCallInvoke(fcinfo)*

```
typedef struct FmgrInfo
{
	PGFunction	fn_addr;		/* pointer to function or handler to be called */
	Oid			fn_oid;		/* OID of function (NOT of handler, if any) */
	short		fn_nargs;		/* 0..FUNC_MAX_ARGS, or -1 if variable arg
								 * count */
	bool		fn_strict;		/* function is "strict" (NULL in => NULL out) */
	bool		fn_retset;		/* function returns a set */
	unsigned char fn_stats;		/* collect stats if track_functions > this */
	void	   *fn_extra;		/* extra space for use by handler */
	MemoryContext fn_mcxt;		/* memory context to store fn_extra in */
	fmNodePtr	fn_expr;		/* expression parse tree for call, or NULL */
} FmgrInfo;

#define FunctionCallInvoke(fcinfo)	((* (fcinfo)->flinfo->fn_addr) (fcinfo))
```

# Language handlers

- **Call function**
  - execute code, translate arguments and result (from/to) PG types
- Validator function
  - validate record in pg_proc
- Inline function
  - execute string

```
postgres=# \h CREATE LANGUAGE
Command:     CREATE LANGUAGE
Description: define a new procedural language
Syntax:
CREATE [ OR REPLACE ] [ PROCEDURAL ] LANGUAGE name
CREATE [ OR REPLACE ] [ TRUSTED ] [ PROCEDURAL ] LANGUAGE name
    HANDLER call_handler [ INLINE inline_handler ] [ VALIDATOR valfunction ]
```

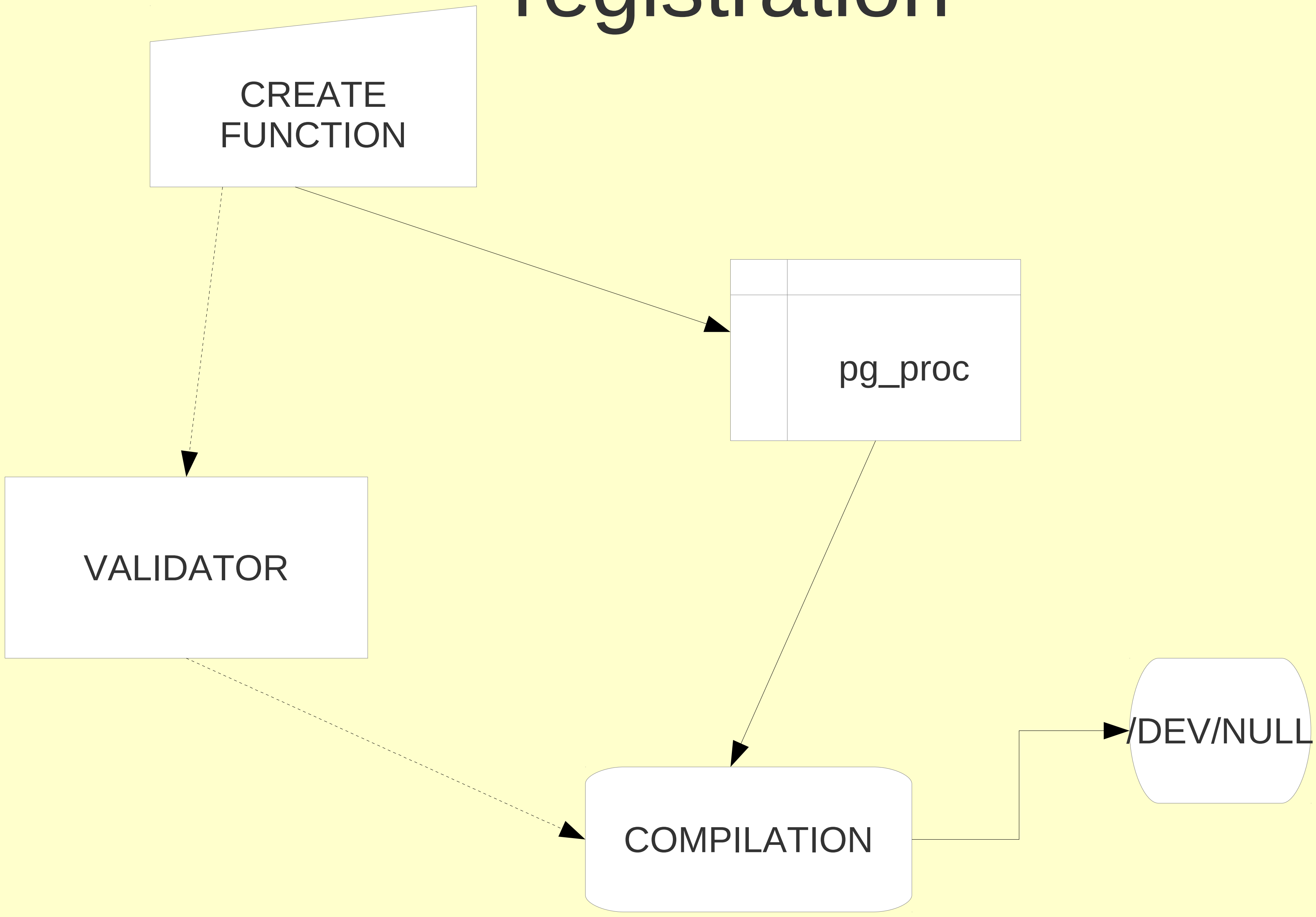
# Predefined language handlers

```
postgres=# select * from pg_language ;
 lanname  | lanowner | lanispl | lanpltrusted | lanplcallfoid | laninline | lanvalidator | lanacl
----------+----------+---------+--------------+---------------+-----------+--------------+--------
 internal |       10 | f       | f            |             0 |         0 |         2246 |
 c        |       10 | f       | f            |             0 |         0 |         2247 |
 sql      |       10 | f       | t            |             0 |         0 |         2248 |
 plpgsql  |       10 | t       | t            |         12654 |     12655 |        12656 |
(4 rows)
```

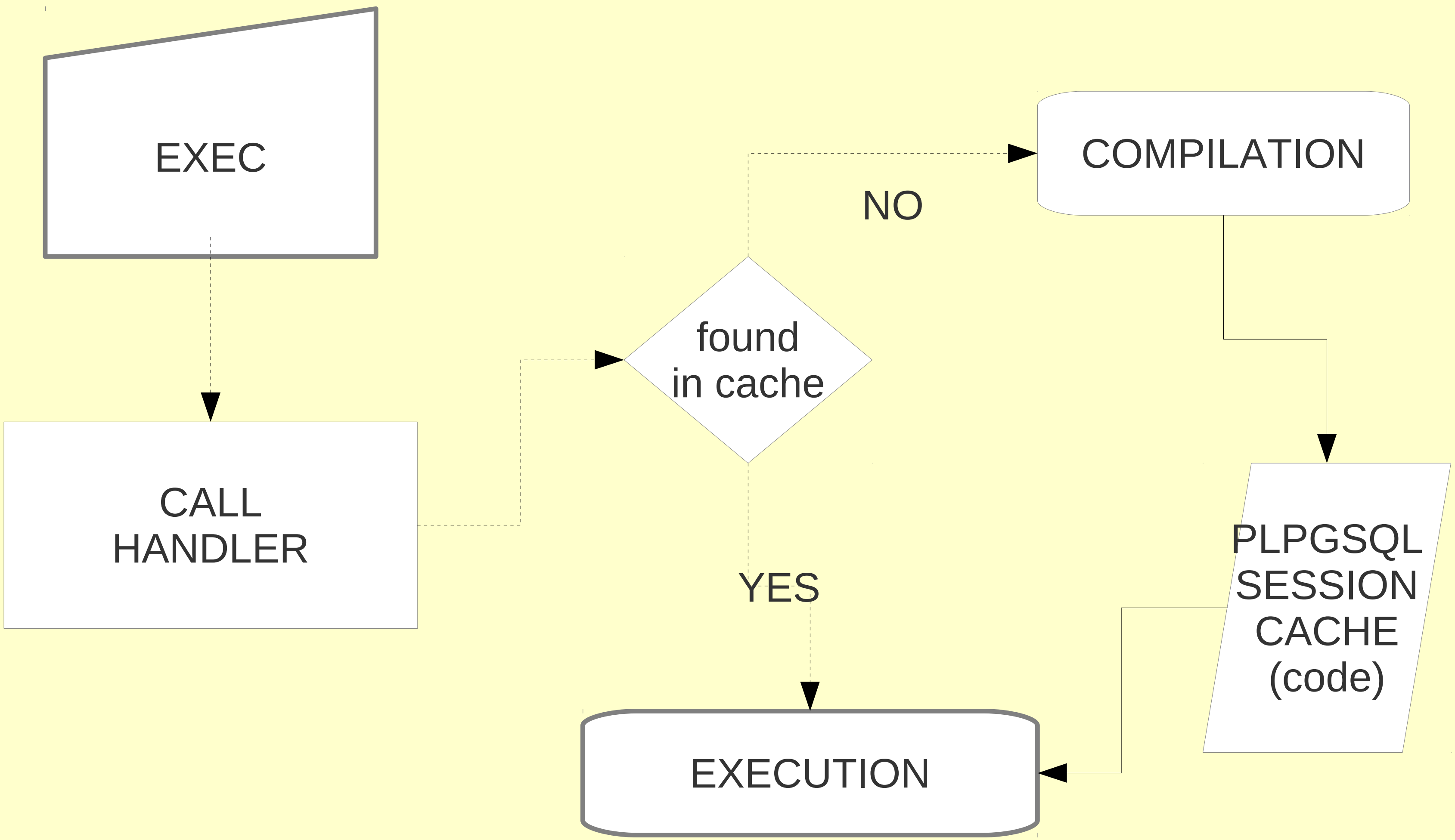
```
postgres=# \sf plpgsql_call_handler
CREATE OR REPLACE FUNCTION pg_catalog.plpgsql_call_handler()
 RETURNS language_handler
 LANGUAGE c
AS '$libdir/plpgsql', $function$plpgsql_call_handler$function$
```

```
postgres=# \sf plpgsql_validator
CREATE OR REPLACE FUNCTION pg_catalog.plpgsql_validator(oid)
 RETURNS void
 LANGUAGE c
 STRICT
AS '$libdir/plpgsql', $function$plpgsql_validator$function$
```

# Lifecycle registration



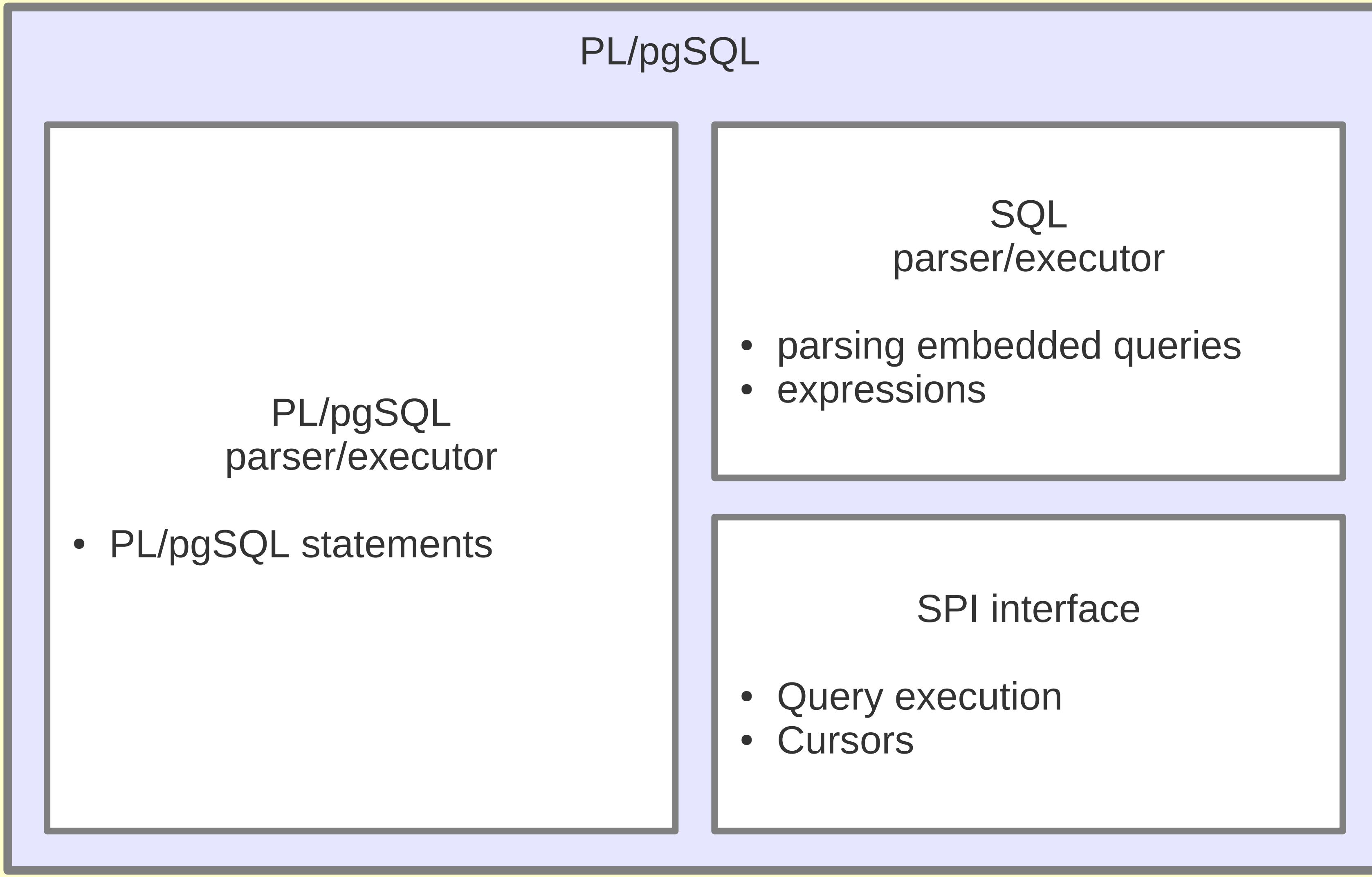
# Lifecycle invocation



# Notes about PL/pgSQL

- has no own expression unit
  - expressions are not cheap
- shares data types with PostgreSQL
- run in PostgreSQL session process
  - processing query result is not expensive
    - no interprocess communication
    - no data types conversions
- uses late I/O casting
  - expensive - when result is not of same type as target, then CAST based on IOfunc is invoked

# PL/pgSQL architecture



# #option dump

```
CREATE OR REPLACE FUNCTION Hello(msg text)
RETURNS text AS $$
#option dump
BEGIN
  RETURN 'Hello, ' || msg;
END;
$$ LANGUAGE plpgsql IMMUTABLE;



/* from postgresql log */
Execution tree of successfully compiled PL/pgSQL function hello(text):

Function's data area:
    entry 0: VAR $1               type text (typoid 25) atttypmod -1
    entry 1: VAR found            type bool (typoid 16) atttypmod -1

Function's statements:
  3:BLOCK <<*unnamed*>>
  4:  RETURN 'SELECT 'Hello, ' || msg'
    END -- *unnamed*

End of execution tree of function hello(text)
```

# "WHILE LOOP" example

```
CREATE OR REPLACE FUNCTION foo(a int)
RETURNS int AS $$
#option dump
DECLARE
  s int := 0;
  i int := 1;
BEGIN
  WHILE i <= a
  LOOP
    s := s + i;
    i := i + 1;
  END LOOP;
  RETURN i;
END;
$$ LANGUAGE plpgsql IMMUTABLE;
```

# "WHILE LOOP" dump

```
Execution tree of successfully compiled PL/pgSQL function foo(integer):

Function's data area:
    entry 0: VAR $1               type int4 (typoid 23) atttypmod -1
    entry 1: VAR found            type bool (typoid 16) atttypmod -1
    entry 2: VAR s                type int4 (typoid 23) atttypmod -1
                                  DEFAULT 'SELECT 0'
    entry 3: VAR i                type int4 (typoid 23) atttypmod -1
                                  DEFAULT 'SELECT 1'

Function's statements:
  6:BLOCK <<*unnamed*>>
  7:  WHILE 'SELECT i <= a'
  9:    ASSIGN var 2 := 'SELECT s + i'
 10:    ASSIGN var 3 := 'SELECT i + 1'
      ENDWHILE
 12:  RETURN 'SELECT i'
    END -- *unnamed*

End of execution tree of function foo(integer)
```

# PLpgSQL architecture

- it is glue for SQL statements
  - basic control structures
    - IF, WHILE, FOR, BEGIN
  - nested variables stack
    - assign statement, references to variables
- it is very simple interpret of abstract syntax tree
  - PL/pgSQL parser skips expressions
  - every node type has exec handler

# PLpgSQL architecture

- it is glue for SQL statements
  - basic control structures
    - IF, WHILE, FOR, BEGIN
  - nested variables stack
    - assign statement, references to variables
- it is very simple interpret of abstract syntax tree
  - every node type has exec handler
  - Execution ~ iteration over nodes (via handler invocations)

# Good to know

- There is no compilation to byte code
- There is no JIT
- There is no any optimization
- Function is compiled to AST when it is first called in session – source code is in readable form in pg_proc (compilation is very simple and then relative fast)
- It is just relative simple, relative fast glue of SQL statements binary compatible with PostgreSQL (speed is comparable with other simple interprets)
  - Reduce network, protocol, ... overheads
  - Possible use faster interprets for different task (Perl)

# WHILE statement

Syntax

```
<<label>> WHILE expression
LOOP
  {statements}
END LOOP
```

Basic structure

```
typedef struct
{                                                               /* WHILE cond LOOP statement            */
        int                     cmd_type;
        int                     lineno;
        char        *label;
        PLpgSQL_expr *cond;
        List        *body;                      /* List of statements */
} PLpgSQL_stmt_while;
```

# WHILE statemement parser

```
proc_stmt               : pl_block ';'
                                        { $$ = $1; }
                        | stmt_assign   { $$ = $1; }
                        | stmt_while    { $$ = $1; }
                                ....


stmt_while              : opt_block_label K_WHILE expr_until_loop loop_body
                                {
                                        PLpgSQL_stmt_while *new;

                                        new = palloc0(sizeof(PLpgSQL_stmt_while));
                                        new->cmd_type = PLPGSQL_STMT_WHILE;
                                        new->lineno   = plpgsql_location_to_lineno(@2);
                                        new->label        = $1;
                                        new->cond         = $3;
                                        new->body         = $4.stmts;

                                        check_labels($1, $4.end_label, $4.end_label_location);
                                        plpgsql_ns_pop();

                                        $$ = (PLpgSQL_stmt *)new;
                                }
                        ;

loop_body               : proc_sect K_END K_LOOP opt_label ';'
                                {
                                        $$.stmts = $1;
                                        $$.end_label = $4;
                                        $$.end_label_location = @4;
                                }
                        ;
```

# WHILE statemement parser

```
proc_stmt               : pl_block ';'
                                        { $$ = $1; }
                        | stmt_assign   { $$ = $1; }
                        | stmt_while    { $$ = $1; }
                                ....


stmt_while              : opt_block_label K_WHILE expr_until_loop loop_body
                                {
                                        PLpgSQL_stmt_while *new;

                                        new = palloc0(sizeof(PLpgSQL_stmt_while));
                                        new->cmd_type = PLPGSQL_STMT_WHILE;
                                        new->lineno   = plpgsql_location_to_lineno(@2);
                                        new->label        = $1;
                                        new->cond         = $3;
                                        new->body         = $4.stmts;

                                        check_labels($1, $4.end_label, $4.end_label_location);
                                        plpgsql_ns_pop();

                                        $$ = (PLpgSQL_stmt *)new;
                                }
                        ;

loop_body               : proc_sect K_END K_LOOP opt_label ';'
                                {
                                        $$.stmts = $1;
                                        $$.end_label = $4;
                                        $$.end_label_location = @4;
                                }
                        ;
```

# WHILE statement executor/main switch

```
static int
exec_stmt(PLpgSQL_execstate *estate, PLpgSQL_stmt *stmt)
{
        PLpgSQL_stmt *save_estmt;
        int                     rc = -1;

        save_estmt = estate->err_stmt;
        estate->err_stmt = stmt;

        /* Let the plugin know that we are about to execute this statement */
        if (*plugin_ptr && (*plugin_ptr)->stmt_beg)
                ((*plugin_ptr)->stmt_beg) (estate, stmt);

        CHECK_FOR_INTERRUPTS();

        switch ((enum PLpgSQL_stmt_types) stmt->cmd_type)
        {
                case PLPGSQL_STMT_BLOCK:
                        rc = exec_stmt_block(estate, (PLpgSQL_stmt_block *) stmt);
                        break;

                case PLPGSQL_STMT_ASSIGN:
                        rc = exec_stmt_assign(estate, (PLpgSQL_stmt_assign *) stmt);
                        break;

                case PLPGSQL_STMT_PERFORM:
                        rc = exec_stmt_perform(estate, (PLpgSQL_stmt_perform *) stmt);
                        break;

                case PLPGSQL_STMT_GETDIAG:
                        rc = exec_stmt_getdiag(estate, (PLpgSQL_stmt_getdiag *) stmt);
                        break;
```

# WHILE statement node handler

```
static int
exec_stmt_while(PLpgSQL_execstate *estate, PLpgSQL_stmt_while *stmt)
{
        for (;;)
        {
                int                     rc;
                bool            value;
                bool            isnull;

                value = exec_eval_boolean(estate, stmt->cond, &isnull);
                exec_eval_cleanup(estate);

                if (isnull || !value)
                        break;

                rc = exec_stmts(estate, stmt->body);

                switch (rc)
                {
                        case PLPGSQL_RC_OK:
                                break;
                        case PLPGSQL_RC_EXIT:
                                return PLPGSQL_RC_OK;
                        case PLPGSQL_RC_CONTINUE:
                                break;
                        case PLPGSQL_RC_RETURN:
                                return rc;
                        default:
                                elog(ERROR, "unrecognized rc: %d", rc);
                }
        }
        return PLPGSQL_RC_OK;
}
```

# Known issues

- Collisions of PL/pgSQL and SQL identifiers
  - solved in 9.0 (smart parameter placeholder positioning)
- Suboptimal plan for some queries
  - solved in 9.2 (prepared statements optimization)
  - in older version - using DYNAMIC SQL
- Late complete check of expressions
  - it is feature
    - + don't need to solve dependencies
    - - some errors are detected only in run-time
      - missing columns, wrong identifiers

# Identifiers collisions

- dumb algorithm (8.4 and older)
  - use placeholder $n everywhere, where is varname in query string
    - collisions cannot be detected (strange errors)
    - positioning placeholder on wrong position (strange run-time errors)

```
CREATE OR REPLACE FUNCTION foo(a integer)
RETURNS int AS $$
DECLARE x int;
BEGIN
  SELECT a FROM mytab WHERE mytab.a = a INTO x;
```

# Identifiers collisions

- smart algorithm (9.0 and higher)
  - callback functions from PostgreSQL parser
    - p_pre_columnref_hook
    - **p_post_columnref_hook**
      - called when PostgreSQL parser process column references - raise error or return placeholder node
    - p_paramref_hook

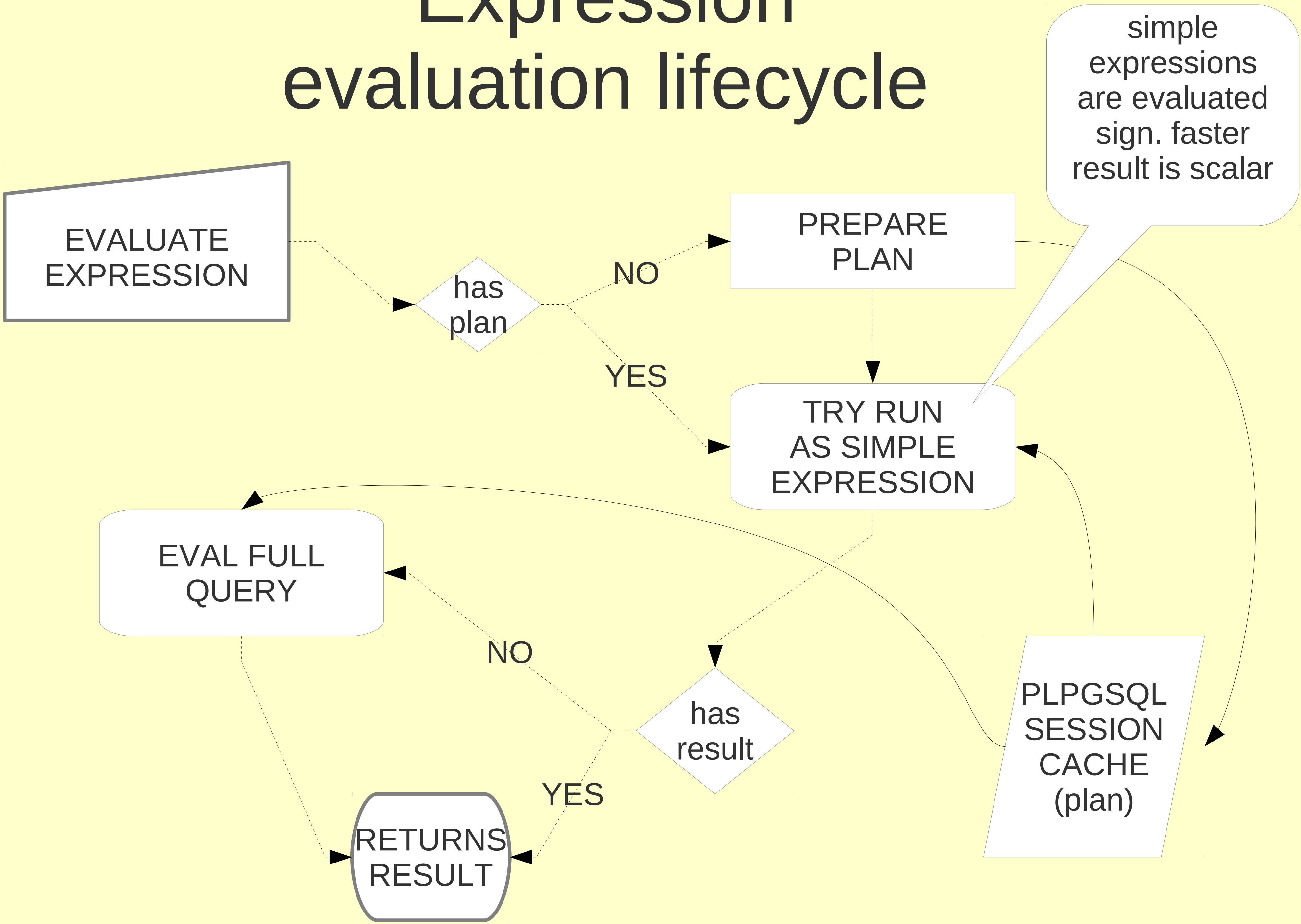
```
/*
 * plpgsql_parser_setup         set up parser hooks for dynamic parameters
 *
 * Note: this routine, and the hook functions it prepares for, are logically
 * part of plpgsql parsing.  But they actually run during function execution,
 * when we are ready to evaluate a SQL query or expression that has not
 * previously been parsed and planned.
 */
void
plpgsql_parser_setup(struct ParseState *pstate, PLpgSQL_expr *expr)
{
        pstate->p_pre_columnref_hook = plpgsql_pre_column_ref;
        pstate->p_post_columnref_hook = plpgsql_post_column_ref;
        pstate->p_paramref_hook = plpgsql_param_ref;
        /* no need to use p_coerce_param_hook */
        pstate->p_ref_hook_state = (void *) expr;
}
```

# Dumb positioning

```
DECLARE
  a int;
  r record;
BEGIN
  SELECT x AS a, y AS b FROM tab INTO rec;


/* RESULT */
  SELECT x AS $1, y AS b FROM tab INTO rec; --- SYNTAX ERROR
```

# Expression evaluation lifecycle



# Late IO casting

```
static bool
exec_eval_boolean(PLpgSQL_execstate *estate, PLpgSQL_expr *expr, bool *isNull)
{
        Datum           exprdatum; Oid exprtypeid;

        exprdatum = exec_eval_expr(estate, expr, isNull, &exprtypeid);
        exprdatum = exec_simple_cast_value(estate, exprdatum, exprtypeid, BOOLOID, -1, *isNull);
        return DatumGetBool(exprdatum);
}

static Datum
exec_cast_value(PLpgSQL_execstate *estate, Datum value, Oid valtype, Oid reqtype,
                                FmgrInfo *reqinput, Oid reqtypioparam, int32 reqtypmod, bool isnull)
{
        /* If the type of the given value isn't what's requested, convert it.  */
        if (valtype != reqtype || reqtypmod != -1)
        {
                MemoryContext oldcontext;

                oldcontext = MemoryContextSwitchTo(estate->eval_econtext->ecxt_per_tuple_memory);
                if (!isnull)
                {
                        char       *extval;

                        extval = convert_value_to_string(estate, value, valtype);
                        value = InputFunctionCall(reqinput, extval, reqtypioparam, reqtypmod);
                }
                else
                {
                        value = InputFunctionCall(reqinput, NULL, reqtypioparam, reqtypmod);
                }
                MemoryContextSwitchTo(oldcontext);
        }
        return value;
}
```

# PL/pgSQL expressions

- Reuse PostgreSQL parser/executor
- No redundant code
- Absolutely compatible with PostgreSQL
- Some operations are slow – array update
- Usually fast enough – bottle neck is in query processing – it is little bit slower than Python (1M iterations ~ 370 ms, Python ~ 256ms)

# Late (IO) casting issue

- IO cast can be slow
- Possible lost of precission
- Different behave than SQL Casting
- It is not solved yet

```
postgres=# \sf test_assign
CREATE OR REPLACE FUNCTION public.test_assign()
 RETURNS void
 LANGUAGE plpgsql
AS $function$ declare x int;
BEGIN
x := 9E3/2;
END
$function$

postgres=# select test_assign();
ERROR:  invalid input syntax for integer: "4500.0000000000000000"
CONTEXT:  PL/pgSQL function test_assign() line 3 at assignment
```

# Late (IO) casting issue

- IO cast can be slow
- Possible lost of precission
- Different behave than SQL Casting

```
postgres=# \sf test_assign
CREATE OR REPLACE FUNCTION public.test_assign()
 RETURNS void
 LANGUAGE plpgsql
AS $function$ declare x int;
BEGIN
x := 9E3/2;
END
$function$

postgres=# select test_assign();
ERROR:  invalid input syntax for integer: "4500.0000000000000000"
CONTEXT:  PL/pgSQL function test_assign() line 3 at assignment
```

# Cached query plans

- Every query, every expression has a execution plan
- Plans are stored in session cache, created when query is evaluated first time
- Plans are dropped when related relations are dropped

# Cached query plans

- Every query, every expression has a execution plan
- Plans are stored in session cache, created when query is evaluated first time
- Plans are dropped when related relations are dropped
- Plans are dropped when cost is significantly different for current parameters (9.2)

# Cached plan issue (solved in 9.2)

- Index are used when should not be used
- Index are not used, but should be used

```
postgres=# \d omega
     Table "public.omega"
 Column |  Type   | Modifiers
--------+---------+-----------
 a      | integer |
Indexes:
    "omega_a_idx" btree (a)


postgres=# insert into omega select 1 from generate_series(1,1000000);
INSERT 0 10000
postgres=# insert into omega select 2 from generate_series(1,1000);
INSERT 0 10
```

# Optimization based on heuristic (blind optimization)

```
postgres=# prepare x(int) as select count(*) from omega where a = $1;
PREPARE
postgres=# explain execute x(1);
                                       QUERY PLAN
-------------------------------------------------------------------------------------
 Aggregate  (cost=17808.36..17808.37 rows=1 width=0)
   ->  Index Scan using omega_a_idx on omega  (cost=0.00..16545.86 rows=505000 width=0)
         Index Cond: (a = $1)
(3 rows)

postgres=# explain execute x(2);
                                       QUERY PLAN
-------------------------------------------------------------------------------------
 Aggregate  (cost=17808.36..17808.37 rows=1 width=0)
   ->  Index Scan using omega_a_idx on omega  (cost=0.00..16545.86 rows=505000 width=0)
         Index Cond: (a = $1)
(3 rows)
```

# Optimization for real value (wait for first and recheck)

```
postgres=# prepare x(int) as select count(*) from omega where a = $1;
PREPARE

postgres=# explain execute x(1);
                             QUERY PLAN
--------------------------------------------------------------------------
 Aggregate  (cost=19085.83..19085.84 rows=1 width=0)
   ->  Seq Scan on omega  (cost=0.00..16586.00 rows=999934 width=0)
         Filter: (a = 1)
(3 rows)

postgres=# explain execute x(2);
                                        QUERY PLAN
----------------------------------------------------------------------------------------
 Aggregate  (cost=318.73..318.74 rows=1 width=0)
   ->  Index Only Scan using omega_a_idx on omega  (cost=0.00..293.57 rows=10066 width=0)
         Index Cond: (a = 2)
(3 rows)
```

# Performance tips

- In 99% SQL and built-in function and functionality will be faster than your code
- FOR statement will be faster than WHILE
  - FOR IN int
  - FOR IN SELECT
- Minimalist code is usually faster
- PL/pgSQL is perfect language for data operations (based on SQL), and worst language for intensive mathematic op

# Performance tips - examples

```
--bad
DECLARE v varchar;
BEGIN
  v := 'a';
  v := v || 'b';
  v := v || 'c';
  RETURN v;
END;

--good
BEGIN
  RETURN 'a' || 'b' || 'c';
END;
```

```
-- bad
DECLARE s varchar := '';
BEGIN
  IF x1 IS NULL THEN
    s := s || 'NULL,'
  ELSE
    s := s || x1;
  END IF;

  IF x2 IS NULL THEN
    s := s || 'NULL, '
  ELSE
    s := s || x2;
  END IF;
  ...

-- good
DECLARE s varchar;
BEGIN
  s := COALESCE(x1 || ',', 'NULL,')
       || COALESCE(x2 || ',', 'NULL,')
```

# Pavel Stěhule

- PostgreSQL lector, consultant
- Now in GoodData performance team
- Some patches to PostgreSQL (PL/pgSQL)
  - CONTINUE statement
  - EXECUTE **USING**
  - RETURN QUERY
  - CASE statement in PL/pgSQL
  - RAISE **USING** ..
  - VARIADIC FUNCTIONS, DEFAULT parameters
  - FOREACH IN ARRAY
  - GET STACKED DIAGNOSTICS