Writing fast trusted stored functions in PL/Rust

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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 or execute the function’s source text

PostgreSQL has many procedural languages

- PL/pgSQL
- PL/Tcl
- PL/Perl
- PL/Python
- plv8
- PL/Rust
- And more…

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What is a trusted procedural language?

“Trusted” is no indication of quality, it is just an indicator of the potential access a function may have

Trusted languages do not allow access to database server internals, the file system and other resources like the network

Only superusers can create functions with untrusted languages

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What is Rust?

Developed by Mozilla as a language to give the performance of a low level language like C with things like memory management of higher level languages

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What is PL/Rust?

Allows writing PostgreSQL functions in Rust

Uses the pgrx extension to bridge Rust code to PostgreSQL internals

Can be configured as a trusted language so non-superusers can write functions with it

```
CREATE FUNCTION one()
  RETURNS int
AS
$$
    Ok(Some(1))
$$ LANGUAGE plrust;
```

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Creating a PL/Rust function

```
CREATE FUNCTION one()
  RETURNS int
AS
$$
    Ok(Some(1))
$$ LANGUAGE plrust;
```

- Write to pg_proc
- PL/Rust Validator
  - Write lib.rs and crate.toml
  - Check lints
  - Compile
  - Update pg_proc

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Storing a compiled function

```
--
-- Name: one(); Type: FUNCTION; Schema: public; Owner: postgres
--

CREATE FUNCTION public.one() RETURNS integer    LANGUAGE plrust    AS
$${"src":"\n    Ok(Some(1))\n","trusted_pgrx_version":"=1.2.7","lib":{"aarch64-
postgres-linux-
gnu":{"encoding":"GzBase64","symbol":"plrust_fn_oid_16695_16702","encoded":"H4sI
AAAAAAAC_-
39C3xU1dU3jp8zMyGTScgFAoRrJtwMAcLcL4oy4SIBEWKIotZ2MplLEsmNZKLgpQRFBaGVKK0-
aBXUtiRKSytWbW0N2guttvVWS_v4tAHt0yBYCUUlCuT_XXvvM3PmMMOl9Xl-7_v5v4GZffY6a6-
99tprrb323ufsWbtgyeU6WZaUP730nES56lE87xNw33_EcXySR0rH9xRpMsNNk1L_7X82MZUkOfY9BJ8
Tz3HoiefkhLTAyOHVxsRyOlHO8iKHWl6UE1KzTkpIleLp-
BjOUp_ylycllqv4WzRE5dY_wvNnpIbEVCTSVSg3RDr_v1yRVor6UvFpFIwpqcL9fHyKxXUmPjkqXsYmq
Y_kMQWfSSrYVHxG4ENdn5-kTJYmPwafcfgUqWCF-IyP6RL6AZ-
LktAaic9klcyz8TEl0SVjkrITRTpMpKNV9yaorodK__5fxgXgFqiuhyfp2wvRBy4_o-
QZkQyee4be7pXj8lD_bUsB_6uKL_Xf31PAh-iS0-lIgb8oRb2_S4F_uapf1X_3p6BjkJPT-
SAF_tVMX0zS0bGJujw5BZ2lKej0p-D_pyngd6ag87UU-F8RfJ4UfL4v4LYUfO5IQT-cAn5bCnh5Cvo
```

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Why store the binary in pg_proc?

Performance - Compiling a PL/Rust function may take minutes so storing the binary avoids the first start penalty

Replication - Replicas need the binaries in a transactionally consistent way and cannot impose a first start penalty

Backups - pg_restore cannot take an extended period of time restoring many PL/Rust functions

Consistency - There are race conditions on REPLACE when considering a separate table in the plrust schema

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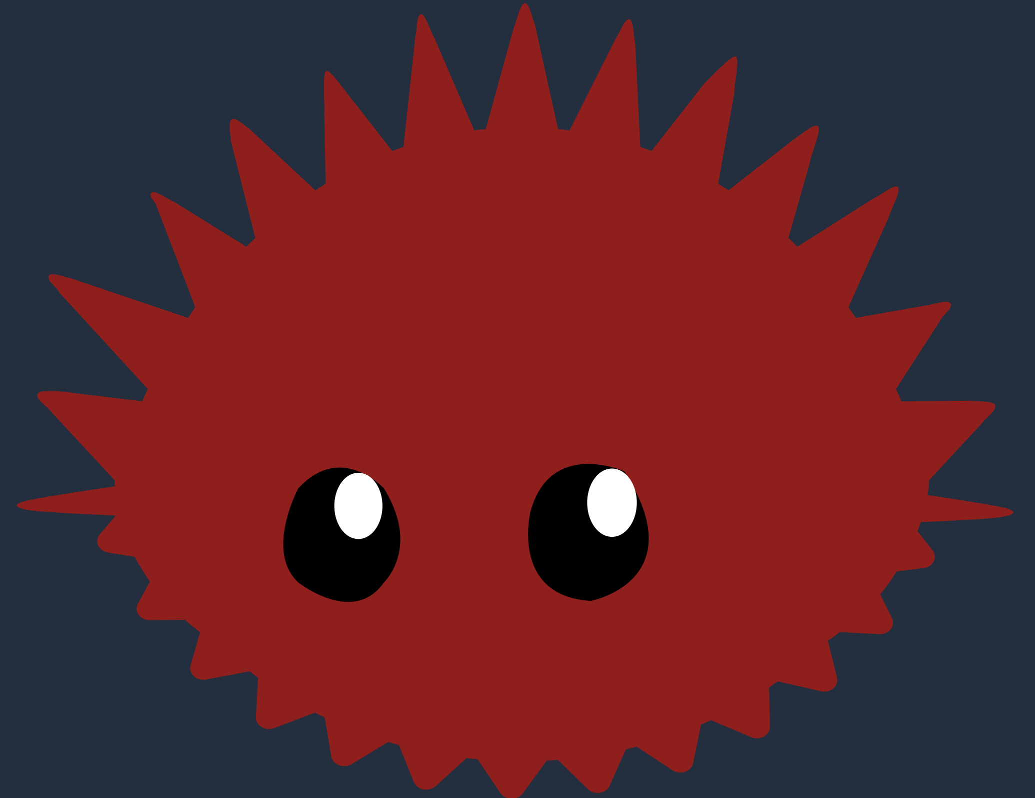
Making PL/Rust trusted

Rust has some strong safety properties over C/C++ around memory

Prevents the use of “unsafe” Rust and other known safety issues

Uses a specialized standard library to control OS access



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Lints

Statically analyzes the user code to look for patterns that an known to violate safety

Throws errors at compile time

Uses a combination of standard Rust lints and custom PL/Rust lints

```
CREATE FUNCTION read_file()
  RETURNS text AS
$$
  let s = include_str!("/etc/passwd");
  Ok(Some(s.into()))
$$ LANGUAGE plrust;


ERROR:
   0: `cargo build` failed
...
   error: the `include_str`, `include_bytes`,
and `include` macros are forbidden in PL/Rust
     --> src/lib.rs:44:17
      |
   44 |         let s =
include_str!("/etc/passwd");
      |
^^^^^^^^^^^^^^^^^^^^^^^^^^^
      |
   note: the lint level is defined here
     --> src/lib.rs:25:15
```

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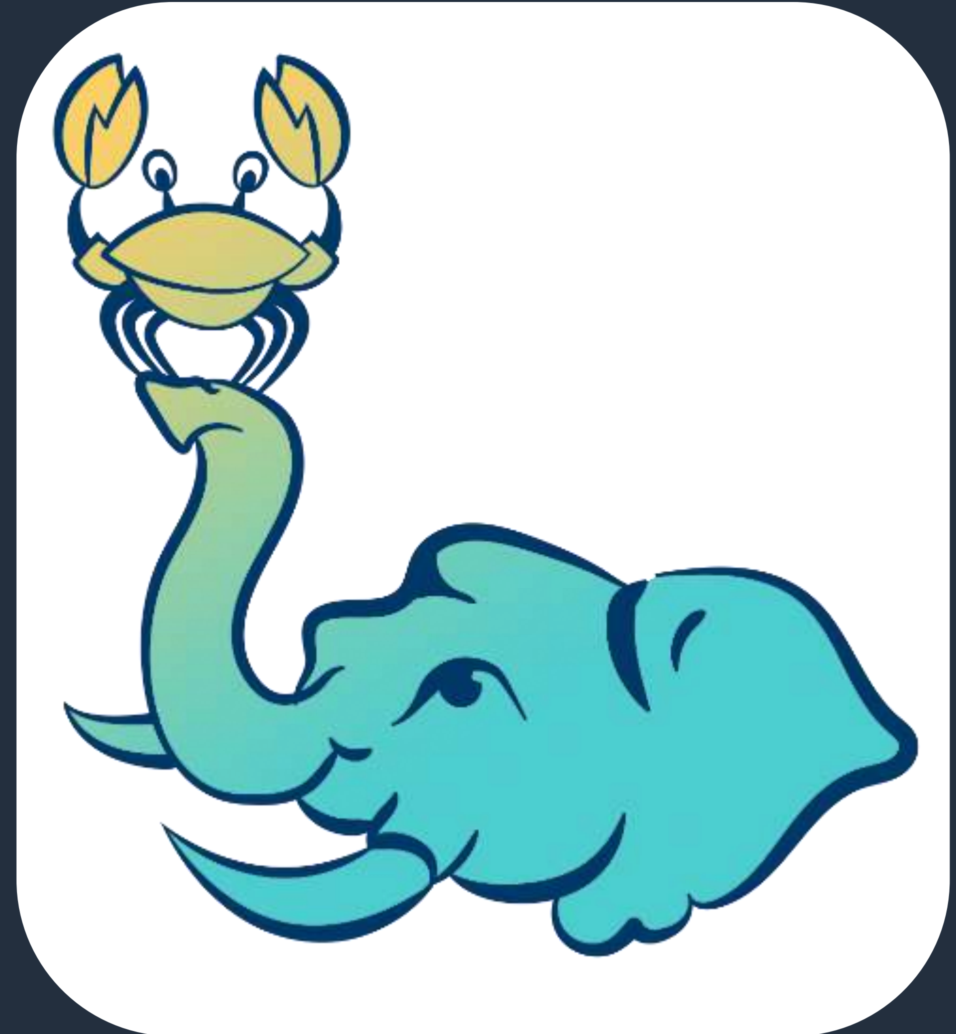
postgrestd

Fork of the Rust standard library and implements a variant of std::sys for system bindings

Some functions are stubbed out preventing them from being used

Others are implemented using PostgreSQL features such as the global allocator using palloc



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Configuring PL/Rust

PL/Rust has parameters to configure how functions are built

Allows PL/Rust to use an existing Rust environment if necessary

The level of “trustness” can be adjusted based on specific needs

plrust.work_dir

plrust.path_override

plrust.allowed_dependencies

plrust.compilation_targets

plrust.compile_lints

plrust.tracing_level

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PL/Rust structure

```
CREATE FUNCTION {fn_name} ({args})
RETURNS {ret}
-- function attributes can go here
AS $$
    // PL/Rust function body goes here
    // All PL/Rust functions return Result<Option<{ret}>>
$$ LANGUAGE plrust;
```

The return of a PL/Rust function needs to be of the format Result<Option<T>>

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Parameter strictness

The STRICT keyword determines if a function will execute on NULL input

PL/Rust uses STRICT to determine how a parameter is passed to the function

```
CREATE FUNCTION echo(input int)
  RETURNS int
AS
$$
  Ok(Some(input))
$$ STRICT
LANGUAGE plrust;

CREATE FUNCTION echo(input int)
  RETURNS int
AS
$$
  Ok(Some(input.unwrap_or_default()))
$$ LANGUAGE plrust;
```

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Data types

Some map to native Rust types

PostgreSQL Type	Rust Type
bytea	Vec<u8> or &[u8]
text	String or &str
varchar	String or &str
smallint	i16
integer	i32
bigint	i64
oid	u32
real	f32
double precision	f64
bool	bool

Others map to PGRX types

PostgreSQL Type	Rust Type
json	Json(serde_json::Value)
jsonb	JsonB(serde_json::Value)
date	Date
time	Time
timestamp	Timestamp
time with time zone	TimeWithTimeZone
timestamp with time zone	TimestampWithTimeZone
numeric	AnyNumeric
uuid	Uuid([u8; 16])
int4range	Range<i32>

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Data types

```
CREATE FUNCTION sum_and_double (a numeric, b numeric)
  RETURNS numeric AS
$$
  Ok(Some((a + b) * 2))
$$ STRICT
LANGUAGE plrust;


CREATE FUNCTION moon_landing()
  RETURNS date AS
$$
  Ok(Some(Date::new(1969, 7, 20)?))
$$ STRICT
LANGUAGE plrust;
```

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Composite types

Uses PgHeapTuple as a structure with getter and setter methods

```
CREATE FUNCTION get_coords(x int, y int, z int)
  RETURNS coords AS
$$
  let mut c = PgHeapTuple::new_composite_type("coords")?;

  c.set_by_name("x", x)?;
  c.set_by_name("y", y)?;
  c.set_by_name("z", z)?;

  Ok(Some(c))
$$ STRICT
LANGUAGE plrust;
```

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Running Queries

PL/Rust accesses database objects through SPI

There are a number of functions exposed to simplify SPI access

```
CREATE FUNCTION is_plrust_trusted()
  RETURNS bool AS
$$
  Ok(Spi::get_one("SELECT lanpltrusted FROM
  pg_language WHERE lanname = 'plrust'")?)
$$ LANGUAGE plrust;
```

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Updating rows

SPI is fully available to do more complex things like changing rows or prepared statements

```
CREATE FUNCTION add_foo(input int)
  RETURNS void AS
$$
  Spi::connect(|mut client| {
    client.update(
      "INSERT INTO foo VALUES ($1)",
      None, Some(vec![(PgBuiltInOids::INT4OID.oid(),
                  input.into_datum())])).map(|_| ())
  })?;

  Ok(Some(()))
$$ STRICT
LANGUAGE plrust;
```

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Logging

PL/Rust uses the PostgreSQL logging infrastructure

It provides several macros for simplicity

Full ereport functionality is available when needed

```
CREATE OR REPLACE FUNCTION one()
  RETURNS int
AS
$$
  log!("This is a log message");
  notice!("This is a notice");
  warning!("This is a warning");

  ereport!(PgLogLevel::LOG,
 PgSqlErrorCode::ERRCODE_SUCCESSFUL_COMPLETION,
    "Full ereport is available");

  Ok(Some(1))
$$ LANGUAGE plrust;
```

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Dynamic function calling

Allows for calling other functions directly without going through SPI

Exposes the PostgreSQL function call interface to PL/Rust

Can call any function type including inbuilt, extensions and user defined from other languages

```
CREATE FUNCTION rsoundex(w text)
  RETURNS text AS
$$
  let result = fn_call("soundex",
                 &[&Arg::Value(w)])?;

  Ok(result)
$$ STRICT LANGUAGE plrust;
```

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Triggers

```
CREATE FUNCTION double_foo_trigger()
  RETURNS trigger AS
$$
    let tg_op = trigger.op()?;

    let my_new = match tg_op {
        INSERT => trigger.new().unwrap(),
        _ => error!("This trigger only applies to inserts")
    };
    let mut my_new = my_new.into_owned();

    let col_name = "a";
    match my_new.get_by_name::<i32>(col_name)? {
        Some(val) => my_new.set_by_name(col_name, val * 2)?,
        None => (),
    }

    Ok(Some(my_new))
$$
LANGUAGE plrust;
```

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Crates

Crates are packages that add capabilities to Rust

Trusted PL/Rust has an allow list of crates that can be used

These can be listed by the function plrust.allowed_dependencies

```
CREATE FUNCTION randint()
  RETURNS bigint AS
$$
[dependencies]
rand = "0.8"

[code]
use rand::Rng;
Ok(Some(rand::thread_rng().gen()))
$$ LANGUAGE plrust;
```

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Performance

Baseline plpgsql function inspired from HammerDB
https://github.com/TPC-Council/HammerDB

```
CREATE OR REPLACE FUNCTION dbms_random(start_int int, end_int int)
  RETURNS int AS
$$
BEGIN
  RETURN trunc(random() * (end_int-start_int + 1) + start_int);
END
$$ LANGUAGE plpgsql STRICT;
```

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Performance

```
postgres=> EXPLAIN ANALYZE SELECT dbms_random(1, g)
                   FROM generate_series(1, 1000000) g;
                      QUERY PLAN
-----------------------------------------------------------------
 Function Scan on generate_series g
    (cost=0.00..260000.00 rows=1000000 width=4)
    (actual time=53.588..590.151 rows=1000000 loops=1)
 Planning Time: 0.031 ms
 Execution Time: 620.852 ms
(3 rows)
```

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Performance

PL/Rust using SPI

```
CREATE FUNCTION dbms_random (start_int int, end_int int)
  RETURNS int AS
$$
  Ok(Spi::get_one_with_args(
                  "SELECT trunc(random() * ($1-$2 + 1) + $3)::int",
                  vec![(PgBuiltInOids::INT4OID.oid(),
                       end_int.into_datum()),
                      (PgBuiltInOids::INT4OID.oid(),
                       start_int.into_datum()),
                      (PgBuiltInOids::INT4OID.oid(),
                       start_int.into_datum())],
              )?)
$$ LANGUAGE plrust STRICT;
```

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Performance

```
postgres=> EXPLAIN ANALYZE SELECT dbms_random(1, g)
                   FROM generate_series(1, 1000000) g;
                      QUERY PLAN
------------------------------------------------------------------
 Function Scan on generate_series g
    (cost=0.00..260000.00 rows=1000000 width=4)
    (actual time=55.461..14142.495 rows=1000000 loops=1)
 Planning Time: 0.049 ms
 Execution Time: 14191.605 ms
(3 rows)
```

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Performance

PL/Rust using a dynamic function call

```
CREATE FUNCTION dbms_random (start_int int, end_int int)
  RETURNS int AS
$$
  let r = fn_call::<f64>("random", &[])?;

  Ok(Some(f64::trunc((r.unwrap() *
                     ((end_int - start_int + 1) as f64))
                            + start_int as f64) as i32))
$$ LANGUAGE plrust STRICT;
```

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Performance

```
postgres=> EXPLAIN ANALYZE SELECT dbms_random(1, g)
                   FROM generate_series(1, 1000000) g;
                      QUERY PLAN
-----------------------------------------------------------------
 Function Scan on generate_series g
    (cost=0.00..260000.00 rows=1000000 width=4)
    (actual time=55.750..1851.216 rows=1000000 loops=1)
 Planning Time: 0.032 ms
 Execution Time: 1896.496 ms
(3 rows)
```

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Performance

PL/Rust using a native crate

```
CREATE FUNCTION DBMS_RANDOM (start_int int, end_int int)
  RETURNS int AS
$$
  [dependencies]
  rand = "0.8.5"

  [code]
  use rand::Rng;

  Ok(Some(rand::thread_rng().gen_range(start_int..(end_int + 1))))
$$ LANGUAGE plrust STRICT;
```

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Performance

```
postgres=> EXPLAIN ANALYZE SELECT dbms_random(1, g)
                   FROM generate_series(1, 1000000) g;
                      QUERY PLAN
-----------------------------------------------------------------
 Function Scan on generate_series g
    (cost=0.00..260000.00 rows=1000000 width=4)
    (actual time=55.754..309.444 rows=1000000 loops=1)
 Planning Time: 0.032 ms
 Execution Time: 339.965 ms
(3 rows)
```

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Better performance case

```
CREATE FUNCTION fib_plpgsql
                     (n numeric)
  RETURNS numeric AS
$$
DECLARE
  a numeric := 0;
  b numeric := 1;
  c numeric;
BEGIN
  IF n = 0 THEN
    RETURN a;
  END IF;
```

```
 FOR i IN 2..n LOOP
    c := a + b;
    a := b;
    b := c;
  END LOOP;

  RETURN b;
END
$$ IMMUTABLE
LANGUAGE plpgsql;
```

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Better performance case

```
CREATE FUNCTION fib_plrust
                  (n numeric)
  RETURNS numeric AS
$$
[dependencies]
num-bigint = "0.4.4"

[code]
  use num_bigint::BigUint;

  let mut a: BigUint = 0_u32.into();
  let mut b: BigUint = 1_u32.into();
  let ln: u32 =
           u32::try_from(n.unwrap())?;
```

```
  if ln <= 0 {
     return Ok(Some(
               AnyNumeric::try_from(
                   a.to_string()
                .as_str()).unwrap()));
   }

   for _ in 1..ln {
     let c = a + &b;
     a = b;
     b = c;
   }

   Ok(Some(AnyNumeric::try_from(
     b.to_string().as_str()).unwrap()))
$$ IMMUTABLE
LANGUAGE plrust;
```

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Better performance case

```
postgres=> SELECT fib_plpgsql(627177) = fib_plrust(627177);
 ?column?
----------
 t
(1 row)


postgres=> SELECT fib_plpgsql(627178);
ERROR:  value overflows numeric format
CONTEXT:  PL/pgSQL function fib_plpgsql(numeric) line 12 at
assignment
```

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Better performance case

```
postgres=> EXPLAIN ANALYZE SELECT fib_plpgsql(627177);
                         QUERY PLAN
-----------------------------------------------------------------
 Result  (cost=0.00..0.01 rows=1 width=32)
 (actual time=0.002..0.002 rows=1 loops=1)
 Planning Time: 61542.339 ms
 Execution Time: 0.018 ms
(3 rows)

Time: 61543.220 ms (01:01.543)
```

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Better performance case

```
postgres=> EXPLAIN ANALYZE SELECT fib_plrust(627177);
                                     QUERY PLAN
-----------------------------------------------------------------
 Result  (cost=0.00..0.01 rows=1 width=32)
 (actual time=0.002..0.002 rows=1 loops=1)
 Planning Time: 1181.729 ms
 Execution Time: 0.017 ms
(3 rows)

Time: 1182.533 ms (00:01.183)
```

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Thank you!

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