Let's Build a Postgres Extension

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- Distributed Postgres
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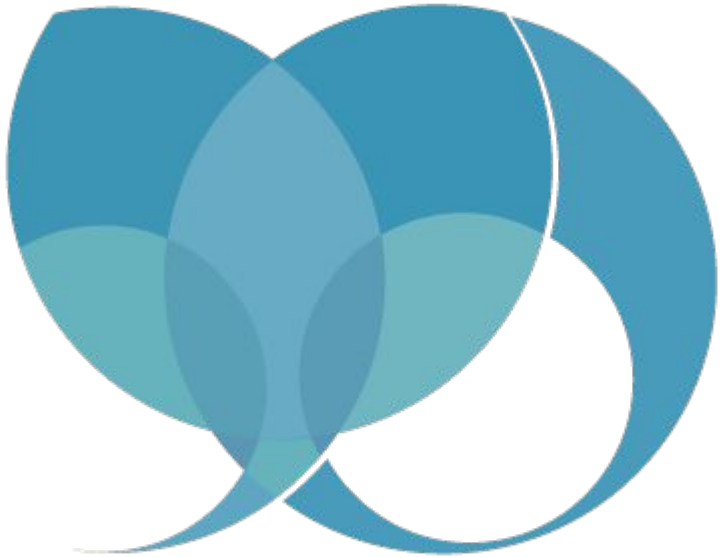

Who am I?

- Author
- Speaker
- Blogger
- Mentor
- Dev

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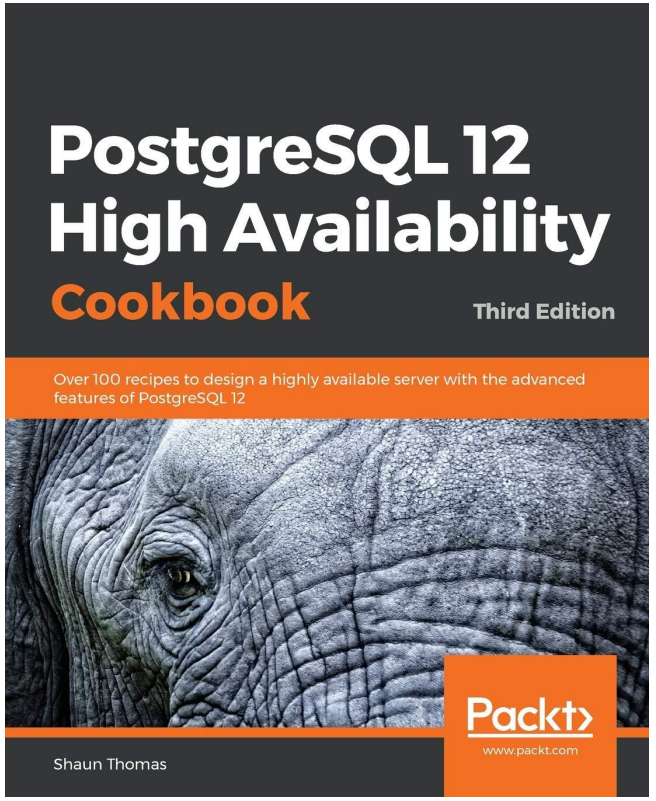
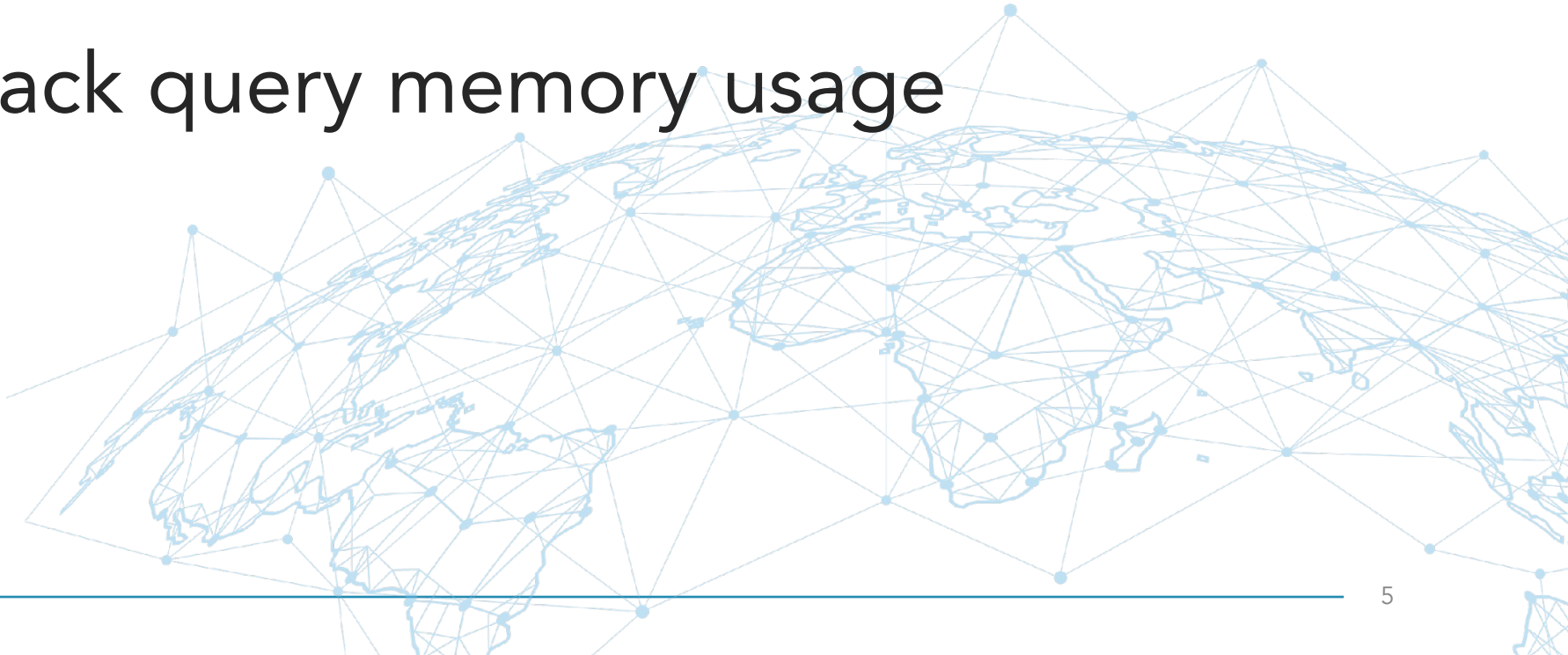


What's Our Agenda?

What we're Doing

Building an extension to track query memory usage

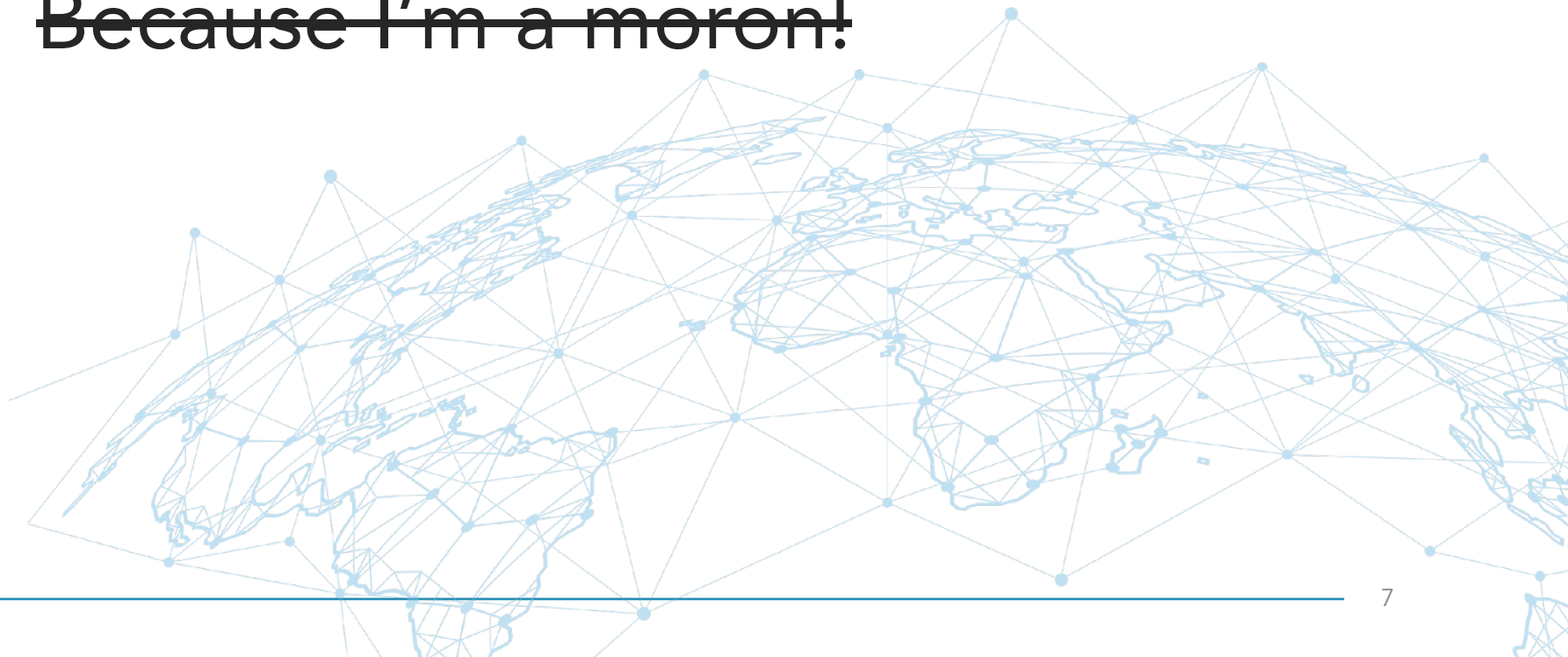


How are we Doing This?

By going on an adventure!

Why Should we Listen to You?

~~Because I'm a moron!~~



Why Should we Listen to You?

I learned by building this extension.

You can too.

First Things First

Things We'll Need

1. Postgres source
2. Build tools and libraries
3. A rough template
4. Luck

Getting the Postgres Source

Option 1: Packaging / Installer

https://www.postgresql.org/download/

Option 2: git (mirror)

https://github.com/postgres/postgres

Build Tools and Libraries

Debian-based systems:

```
sudo apt install build-essential \
     libreadline-dev zlib1g-dev flex bison libxml2-dev \
     libxslt-dev libssl-dev libxml2-utils xsltproc \
     ccache pkg-config libicu-dev
```

RHEL-based systems:

```
sudo yum install -y bison-devel readline-devel \
     zlib-devel openssl-devel wget ccache libicu-devel

sudo yum groupinstall -y 'Development Tools'
```

https://wiki.postgresql.org/wiki/Compile_and_Install_from_source_code

Basic Postgres Build

```
cd postgres
./configure --prefix=/custom
make -j8
make install
```

Basic Extension Build

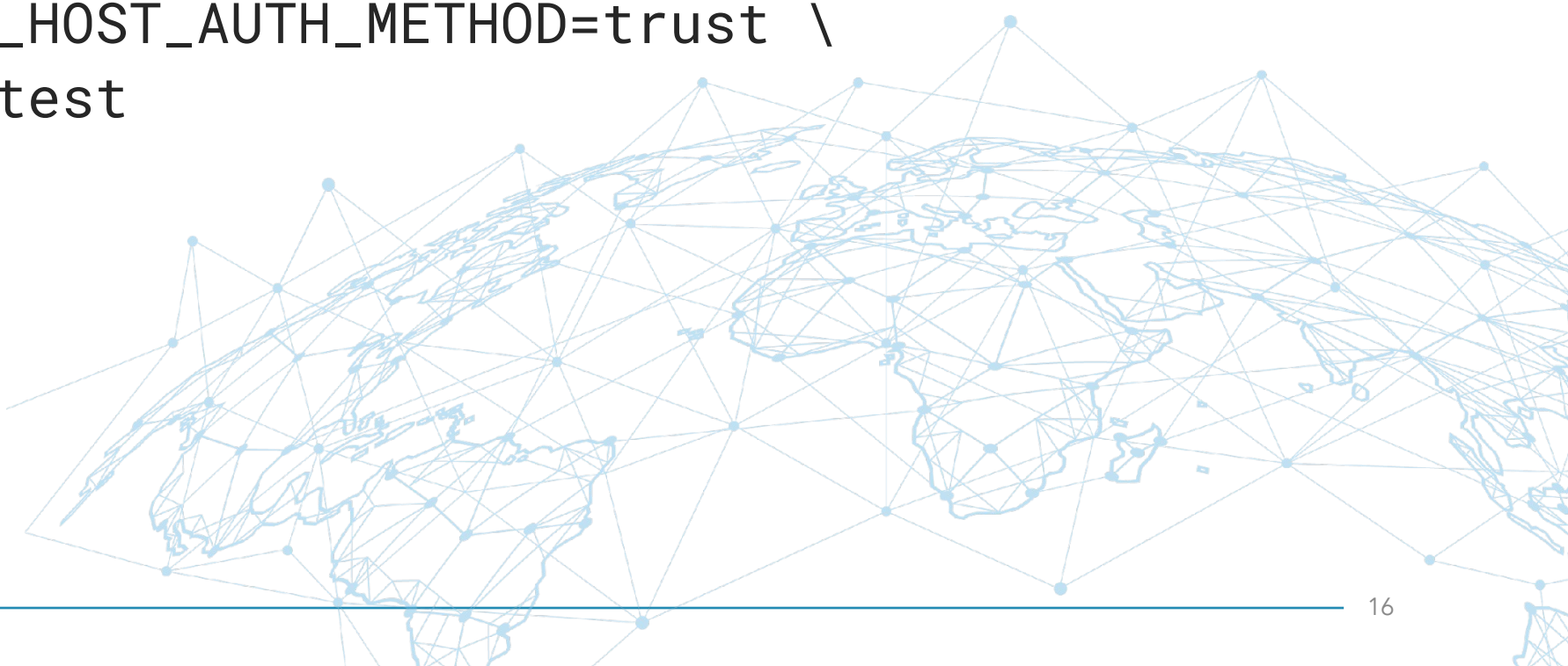
```
cd querymem
PATH=/my/postgres/bin:$PATH make install
make
make install
```

Consider Using Docker

```
FROM postgres:18

RUN apt-get -y update && apt-get -y upgrade && \
    apt-get -y install build-essential clang postgresql-server-dev-18 \
        libreadline-dev zlib1g-dev flex bison libxml2-dev \
        libxslt-dev libssl-dev libxml2-utils xsltproc \
        ccache pkg-config libicu-dev && \
    apt-get clean

COPY . /build

RUN cd /build && make && make install
```

Launching the Docker Env

```
cd querymem
docker build -t querymem:latest .

docker run -d --name=querymem \
    -e POSTGRES_HOST_AUTH_METHOD=trust \
    querymem:latest
```



The Makefile That Does Everything

```
MODULE_big = querymem

PGFILEDESC = "Extension to view query memory usage"
EXTENSION = querymem
DATA = querymem--1.0.sql
OBJS = querymem.o

PG_CONFIG = pg_config
PGXS := $(shell $(PG_CONFIG) --pgxs)
include $(PGXS)
```

The Extension Control File

```
# querymem.control
comment = 'PG Query Memory Extension'
default_version = '1.0'
module_pathname = '$libdir/querymem'
relocatable = true
```

A SQL Installer Stub

```
-- Postgres will execute this SQL file upon invoking
-- the "CREATE EXTENSION querymem" command.

/* SQL CODE TBA */
```

The Theory

The Problem With work_mem

It multiplies by the amount

of nodes in a query, per session

What we Want:

A tool that predicts maximum memory usage per query

Now What?

Here's What we Actually Need:

- The ability to parse a query
- A way to transform a parsed query into the expected plan
- A method to walk the plan
- The values of **`work_mem`** and **`hash_mem_multiplier`**
- A new function users can execute on any query

First Steps

Remember the Postgres Source?

We’re going to need it…

The User Docs are Great

Extending SQL

https://www.postgresql.org/docs/current/extend.html

C-Language Functions

https://www.postgresql.org/docs/current/xfunc-c.html

But they only really cover the basics.

The REAL Dev Docs

src/tutorial/README
src/pl/plperl/README
src/backend/replication/README
src/backend/lib/README
src/backend/regex/README
src/backend/statistics/README
src/backend/access/brin/README
src/backend/access/hash/README
src/backend/access/gist/README
src/backend/access/transam/README
src/backend/access/gin/README
src/backend/access/rmgrdesc/README
src/backend/access/nbtree/README
src/backend/access/spgist/README
src/backend/executor/README
src/backend/jit/README

src/backend/utils/misc/README
src/backend/utils/mmgr/README
src/backend/utils/mb/README
src/backend/utils/resowner/README
src/backend/utils/fmgr/README
src/backend/nodes/README
src/backend/snowball/README
src/backend/parser/README
src/backend/optimizer/plan/README
src/backend/optimizer/README
src/backend/storage/buffer/README
src/backend/storage/smgr/README
src/backend/storage/freespace/README
src/backend/storage/page/README
src/backend/storage/lmgr/README

src/common/unicode/README
src/tools/pg_bsd_indent/README
src/tools/ci/README
src/tools/pgindent/README
src/tools/pginclude/README
src/tools/ifaddrs/README
src/bin/pg_amcheck/README
src/bin/pgevent/README
src/interfaces/ecpg/test/connect/README
src/interfaces/libpq/README
src/interfaces/libpq-oauth/README
src/timezone/tznames/README
src/timezone/README
src/include/catalog/README
src/port/README

Other Good Options

/contrib

- Extensions written by the core devs.
- Great examples of working, updated code.

/src/include

- Struct definitions and function declarations.
- Extensive code comments as explanation.

The Initial Code

```
PG_MODULE_MAGIC;
PG_FUNCTION_INFO_V1(get_query_mem);

Datum get_query_mem(PG_FUNCTION_ARGS)
{
    char *query_arg = text_to_cstring(PG_GETARG_TEXT_PP(0));
    PG_RETURN_INT32(DatumGetInt32(0));
} // get_query_mem
```

The Initial SQL Wrapper

```
CREATE FUNCTION get_query_mem(text)
RETURNS INT
     AS 'MODULE_PATHNAME', 'get_query_mem'
     LANGUAGE C VOLATILE;
```

The Scavenger Hunt

How do we Parse Queries?

1. **`backend/parser/README`** says start at **`parser.c`**
2. **`raw_parser`** function is the first thing in `parser.c`
3. raw_parser returns a **`List`** of parse trees
4. A parse tree is just a **`RawStmt`** node
5. `RawStmt` is defined in **`include/nodes/parsenodes.h`**

How do we Work with Nodes?

1. **`backend/nodes/README`** explains how nodes work
2. **`include/nodes/pg_list.h`** defines helper macros
3. We only need the first node in the parse tree
4. Use **`linitial`** to “unwrap” the first `List` item

See Raw Parse Trees

```
Datum get_query_mem(PG_FUNCTION_ARGS)
{
    char *query_arg = text_to_cstring(PG_GETARG_TEXT_PP(0));

    List *parse_tree = raw_parser(query_arg, RAW_PARSE_DEFAULT);
    RawStmt *parsed = (RawStmt *)linitial(parse_tree);
    pprint(parsed);

    PG_RETURN_INT32(DatumGetInt32(0));
} // get_query_mem
```

What a Plan Comes Together

1. **`backend/optimizer/README`** says **`planner()`** does it all
2. `planner()` is declared in **`optimizer/optimizer.h`**
3. `planner()` takes a **`Query`**, not a `RawStmt`
4. Need to convert `RawStmt` into a `Query`
5. **`transformTopLevelStmt()`** in **`parser/analyze.h`** does this!
6. But `transformTopLevelStmt()` needs a **`ParseState`**
7. `ParseState` is defined in **`parser/parse_node.h`**
8. We can initialize `ParseState` with **`make_parsestate()`**

Checking the Plan

```
Datum get_query_mem(PG_FUNCTION_ARGS)
{
    ParseState  *pstate = make_parsestate(NULL);
    /* … */

    query = transformTopLevelStmt(pstate, parsed);
    plan = planner(query, query_arg, 0, NULL);
    pprint(plan);

    /* … */
} // get_query_mem
```

Figuring out the Plan

1. **`planner()`** returns a **`PlannedStmt`** struct
2. `PlannedStmt` is defined in **`nodes/plannodes.h`**
3. `PlannedStmt` has a **`planTree`** of type **`Plan`**
4. Also contains a `List` of **`subplans`**
5. Each `Plan` contains a **`lefttree`** and **`righttree`** `Plan` node
6. It's recursive function time!

Walking in the Trees

```c
typedef struct
{
    uint16_t node_count;
    double multiplier;
} WalkContext;

static void walk_plan(Plan *plan, WalkContext *ctx)
{
    if (plan == NULL) return;

    /* TODO: Count nodes */

    walk_plan(plan->lefttree, ctx);
    walk_plan(plan->righttree, ctx);
}
```

The Docs For work_mem Say

Sets the base maximum amount of memory to be used by a query operation (such as a sort or hash table) before writing to temporary disk files.

But then:

The memory limit for a hash table is computed by multiplying **`work_mem`** by **`hash_mem_multiplier`**.

Finding Hash Plan Nodes

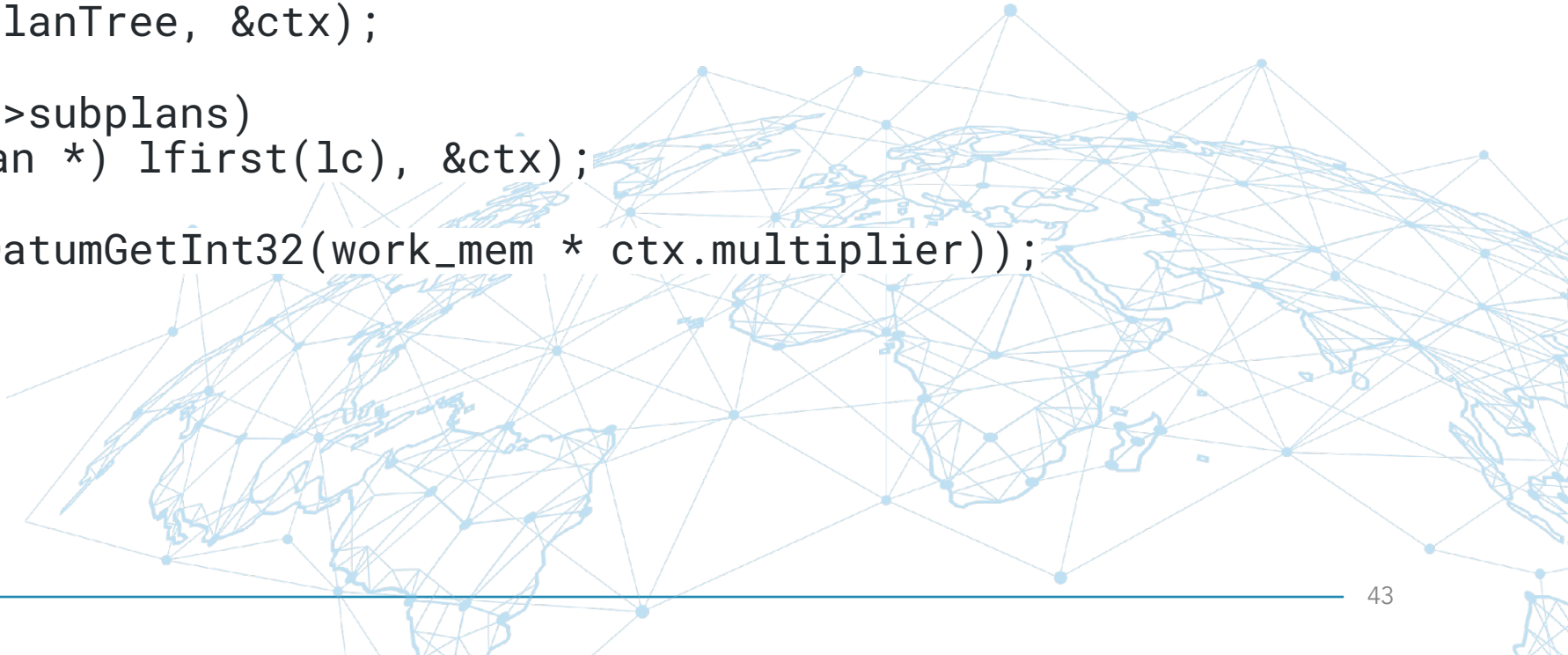
1. **`Plan`** nodes contain **`NodeTag type`** field
2. All `NodeTags` are defined in **`nodes/nodetags.h`**
3. Hash types include: **`T_HashPath`**, **`T_HashJoin`**, **`T_Hash`**, **`T_HashJoinState`**, and **`T_HashState`**
4. Everything else counts normally

The “Algorithm”

```
switch (nodeTag(plan))
{
    case T_Hash:
    case T_HashJoin:
    case T_HashJoinState:
    case T_HashPath:
    case T_HashState:
        ctx->node_count++;
        ctx->multiplier += hash_mem_multiplier;
        break;
    default:
        ctx->node_count++;
        ctx->multiplier += 1.0;
        break;
}
```

Integrating the Plan Traversal

```
Datum get_query_mem(PG_FUNCTION_ARGS)
{
    /* … */
    WalkContext  ctx = {0, 0.0};
    ListCell    *lc;

    /* … */
    walk_plan(plan->planTree, &ctx);

    foreach(lc, plan->subplans)
       walk_plan((Plan *) lfirst(lc), &ctx);

    PG_RETURN_INT32(DatumGetInt32(work_mem * ctx.multiplier));
} // get_query_mem
```



Does it Work?

Let's use Docker

```
cd querymem
docker build -t querymem:latest .

docker run -d --name=querymem \
    -e POSTGRES_HOST_AUTH_METHOD=trust \
    querymem:latest
```

Add Sample Data and Connect

```
docker exec -it -u postgres querymem \
       pgbench -i -s 10 postgres


docker exec -it -u postgres querymem psql
```

Create the Extension

```
CREATE EXTENSION querymem;
SET log_min_messages = NOTICE;
```

Try Something Simple

```
SELECT get_query_mem($$
  SELECT a.* FROM pgbench_accounts a
$$);

 get_query_mem
---------------
          4096
```

Add a Sort

```
SELECT get_query_mem($$
  SELECT a.* FROM pgbench_accounts a ORDER BY a.bid;
$$);

 get_query_mem
---------------
          8192
```

How About a Join?

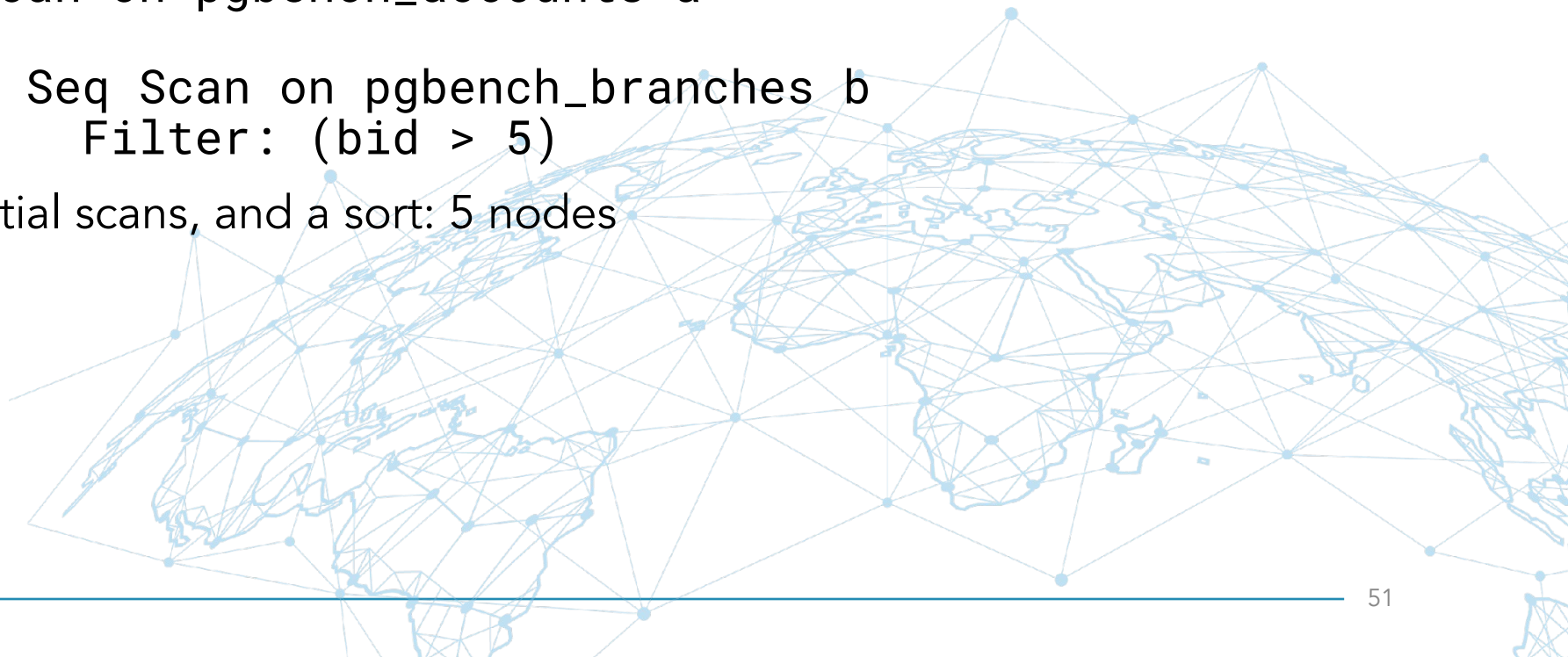
```
SELECT get_query_mem($$
  SELECT a.* FROM pgbench_accounts a
    JOIN pgbench_branches b ON (b.bid = a.bid)
   WHERE b.bid > 5 ORDER BY b.bid;
$$);

 get_query_mem
---------------
         28672
```

Why so High?

This is the query plan:

```
Sort
   Sort Key: a.bid
   ->  Hash Join
         Hash Cond: (a.bid = b.bid)
         ->  Seq Scan on pgbench_accounts a
         ->  Hash
               ->  Seq Scan on pgbench_branches b
                     Filter: (bid > 5)
```

Two hashes, two sequential scans, and a sort: 5 nodes



It Builds up Fast!

```
SELECT get_query_mem($$
  WITH bdata AS MATERIALIZED (SELECT * FROM pgbench_branches WHERE bid > 5)
  SELECT a.*
    FROM pgbench_accounts a
    JOIN bdata b ON (b.bid = a.bid)
   WHERE EXISTS (SELECT * FROM pgbench_tellers t
                  WHERE t.bid = b.bid)
   ORDER BY b.bid;
$$);

 get_query_mem
---------------
         57344
```

What Else Can We Do?

Extra Feature Ideas

1. Log query memory usage
2. Block queries with excessively high estimates

What We'll Need

1. GUC: querymem.log_size
2. GUC: querymem.max_query_size
3. A Pre-execute hook

No Longer Pinocchio

Let's turn this extension

into a *real boy*

Starting with GUCs

- Extensions with GUCs must be in **`shared_preload_libraries`**
- We need a **`_PG_Init`** function
- Check **`utils/guc.h`** for:
  - registration functions
  - signal flags
  - unit definitions
- Lots of examples in the code

The _PG_init Shell

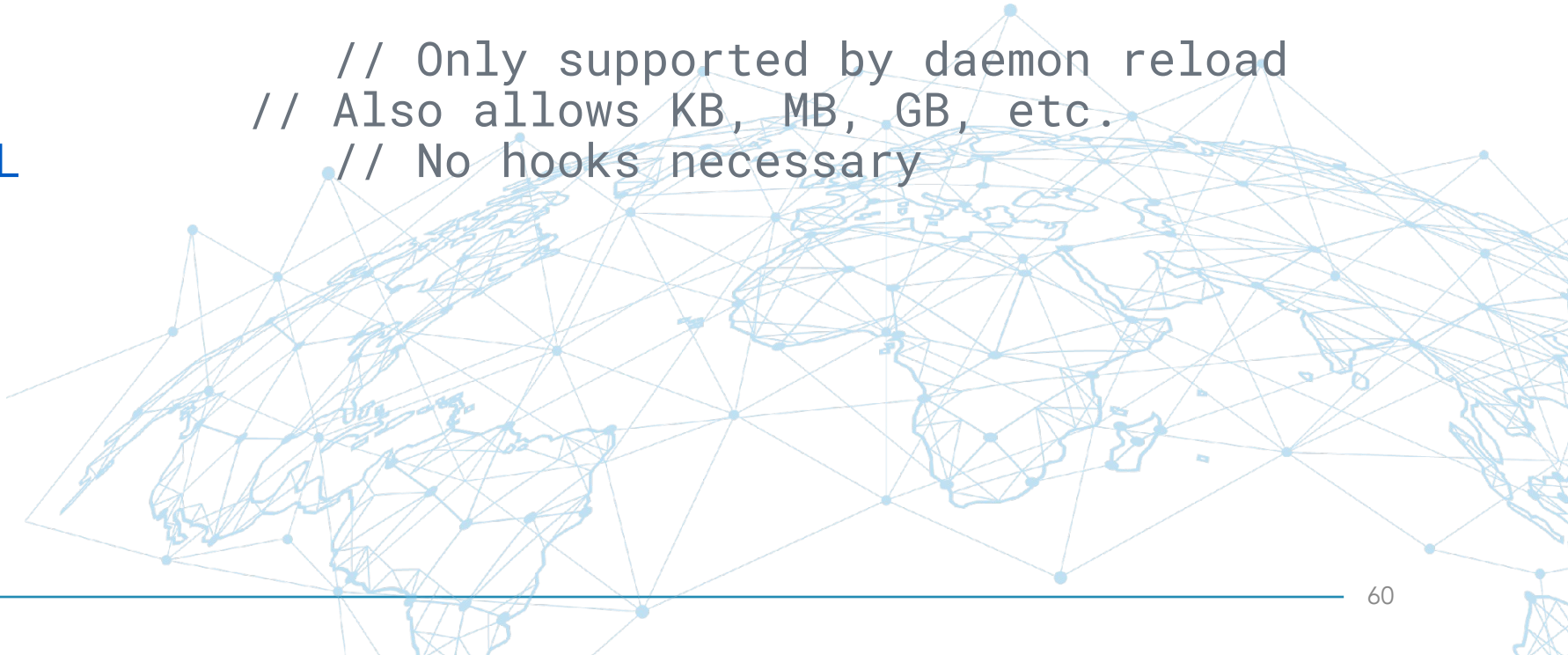
```
// 1. Define GUC global variables and pre-execution hook

void _PG_init(void)
{
    // 2. Define custom GUCs
    // 3. Reserve our extension's GUC prefix
    // 4. Set pre-execution hook

} // _PG_init
```

1. Define GUCs and Exec Hook

```
int querymem_log_size;
int querymem_max_query_size;

static ExecutorStart_hook_type next_ExecutorStart_hook = NULL;
```

2a. Define log_size GUC

```
DefineCustomIntVariable(
    "querymem.log_size",
    "Log any queries exceeding this amount of estimated memory.",
    "Default: 10x work_mem. Set to -1 to disable.",
    &querymem_log_size,
    work_mem * 10, work_mem,// Same limits as work_mem
    MAX_KILOBYTES,
    PGC_SIGHUP,                    // Only supported by daemon reload
    GUC_UNIT_KB,                // Also allows KB, MB, GB, etc.
    NULL, NULL, NULL               // No hooks necessary
);
```



2b. Define max_query_size GUC

```
DefineCustomIntVariable(
    "querymem.max_query_size",
    "Prevent execution of queries over this work_mem limit.",
    "Default: 100x work_mem. Set to -1 to disable.",
    &querymem_max_query_size,
    work_mem * 100, work_mem,  // Same limits as work_mem
    MAX_KILOBYTES,
    PGC_SIGHUP,                // Only supported by daemon reload
    GUC_UNIT_KB,             // Also allows KB, MB, GB, etc.
    NULL, NULL, NULL           // No hooks necessary
);
```

3. Reserve GUC prefix

```
// Prevent other extensions from using our prefix
MarkGUCPrefixReserved("querymem");
```

4. Set pre-execution hook

```
// Preserve the hook set by some other extension
if (ExecutorStart_hook)
    next_ExecutorStart_hook = ExecutorStart_hook;

// Replace it with our own hook
ExecutorStart_hook = querymem_ExecutorStart;
```

Important Hook Note!

Preserving hooks is only *encouraged*

not required!

Once Again For Emphasis!

There is no

`register_executor_hook()`

or similar built-in enforcement!

Need a Helper Estimation Function

```
int32_t estimate_from_plan(PlannedStmt *plan)
{
   ListCell    *lc;
   WalkContext ctx = {0, 0.0};

   walk_plan(plan->planTree, &ctx);

   foreach(lc, plan->subplans)
      walk_plan((Plan *) lfirst(lc), &ctx);

   return work_mem * ctx.multiplier;

} // estimate_from_plan
```

The Executor Hook Shell

```
static void
querymem_ExecutorStart(QueryDesc *queryDesc, int eflags)
{
    // 1. Get a plan estimate
    // 2. Abort any statement over the max query size
    // 3. Log any statement over the log size
    // 4. Call the next Executor hook

} // querymem_ProcessUtility
```

1. Get a plan estimate

```
int32_t estimate = 0;

if (querymem_log_size > -1 || querymem_max_query_size > -1)
    if (!(eflags & EXEC_FLAG_EXPLAIN_ONLY))
        estimate = estimate_from_plan(queryDesc->plannedstmt);
```

2. Abort statements over max query size

```
// The ereport function automatically:
//    - aborts further action.
//    - logs the query for context.
if (querymem_max_query_size > -1 && estimate > querymem_max_query_size)
    ereport(ERROR,
        (errcode(ERRCODE_STATEMENT_TOO_COMPLEX),
         errmsg("This query may use too much work_mem (%dk).", estimate),
         errhint("Increase the querymem.max_query_size GUC to continue."))
    );
```

3. Log statements over the log size

```
// The elog function automatically:
//   - logs the query for context.
if (querymem_log_size > -1 && estimate > querymem_log_size)
   elog(LOG, "Estimated peak memory usage: %d kB", estimate);
```

4. Call the next Executor hook

```
// 1. ALWAYS call the next (or previous) hook!
// 2. Use the “standard” hook if there isn’t one.
// 3. A badly behaving extension can ruin it for EVERYONE!

if (next_ExecutorStart_hook)
    next_ExecutorStart_hook(queryDesc, eflags);
else
    standard_ExecutorStart(queryDesc, eflags);
```

Does it Work?

Setting the Stage

```
-- The defaults are too high to test
ALTER SYSTEM SET querymem.log_size = '8MB';
ALTER SYSTEM SET querymem.max_query_size = '20MB';
SELECT pg_reload_conf();
```

A Logged Query

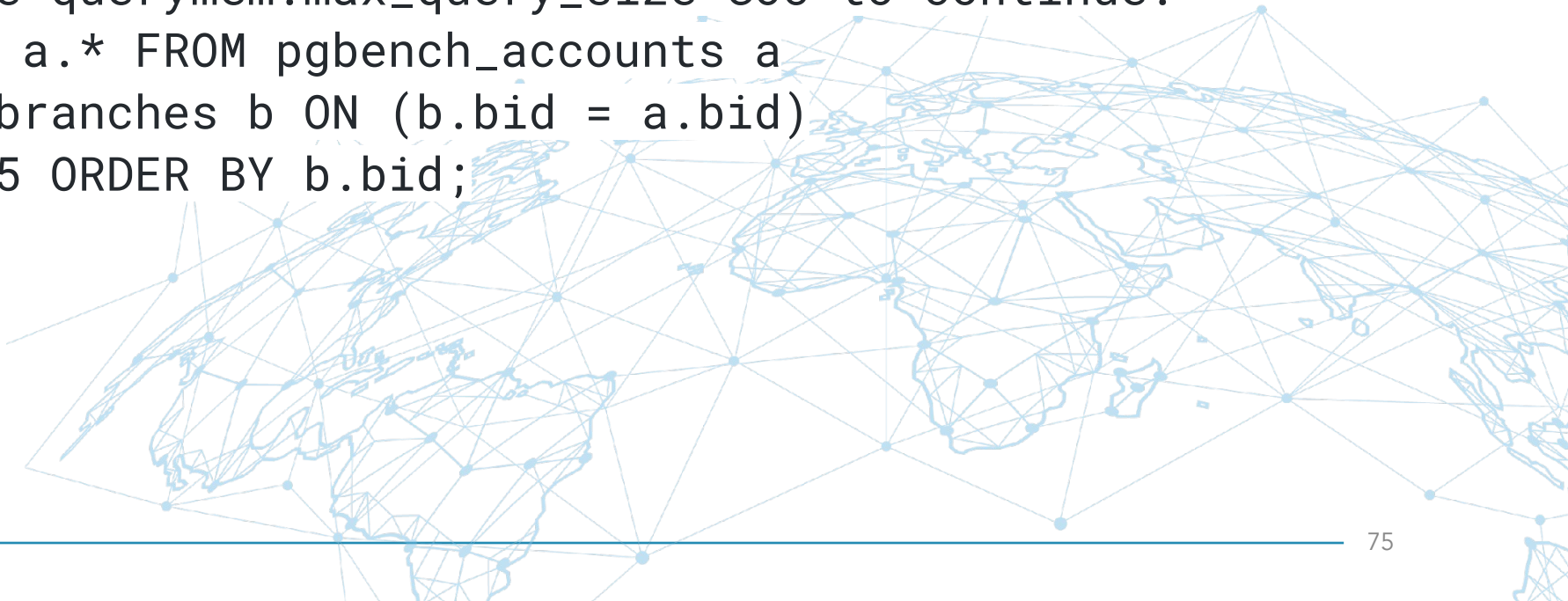
```
SELECT a.* FROM pgbench_accounts a ORDER BY a.bid;
```

```
LOG:  Estimated peak memory usage: 12288 kB
STATEMENT:  SELECT a.* FROM pgbench_accounts a ORDER BY a.bid;
```

A Blocked Query

```
SELECT a.* FROM pgbench_accounts a
  JOIN pgbench_branches b ON (b.bid = a.bid)
 WHERE b.bid > 5 ORDER BY b.bid;
```

```
ERROR:  This query may use too much work_mem (32768k).
HINT:  Increase the querymem.max_query_size GUC to continue.
STATEMENT:  SELECT a.* FROM pgbench_accounts a
     JOIN pgbench_branches b ON (b.bid = a.bid)
    WHERE b.bid > 5 ORDER BY b.bid;
```



Questions?

Grab the Code

github.com/pgEdge/querymem