Web-Scale PostgreSQL

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NYC PostgreSQL User Group
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Who Are We?

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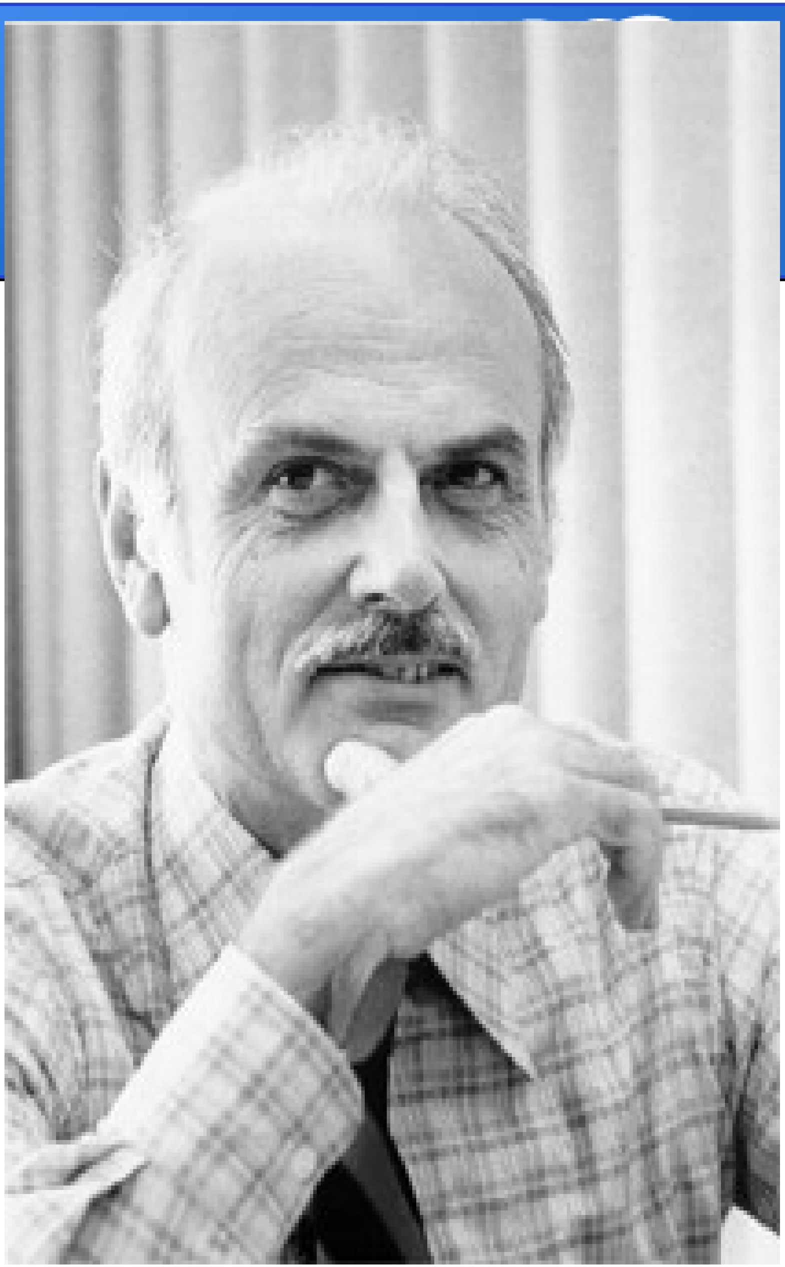
Edgar Frank “Ted” Codd

"A Relational Model of Data for Large Shared Data Banks"



The Relational Model

- All data => “n-ary relations”
- Relation => set of n-tuples
- Tuple => ordered set of attribute values
- Attribute Value => (attribute name, type name)
- Type => classification of the data (“domain”)
- Data is kept consistent via “constraints”
- Data is manipulated using “relational algebra”

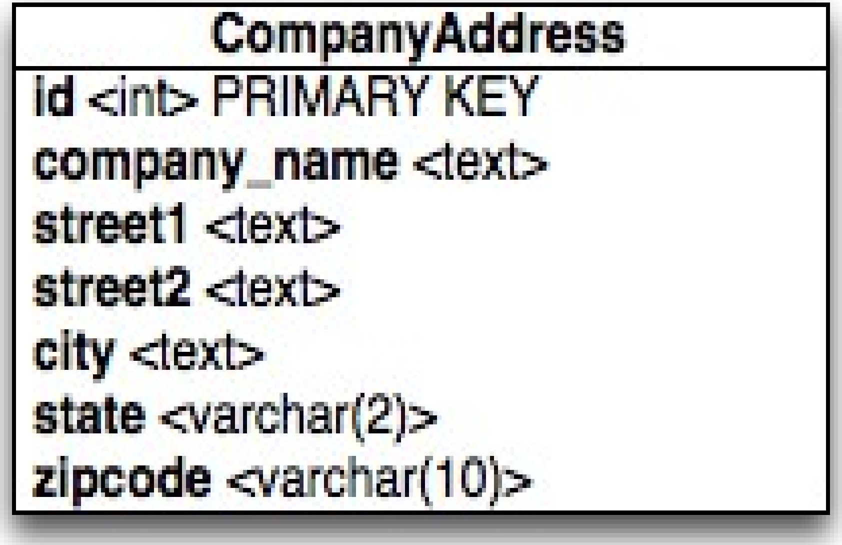
And This Gives Us…

- Math!
- Normalization!
- SQL!

Relation Model ≠ SQL

- (Well yeah, SQL is derived from relational algebra, but still…)
- SQL deviates from the relational model with:
  - duplicate rows
  - anonymous columns (think functions, operations)
  - strict column order with storage
  - NULL

Example: Business Locations



CompanyAddress

id <int> PRIMARY KEY

company_name <text>

street1 <text>

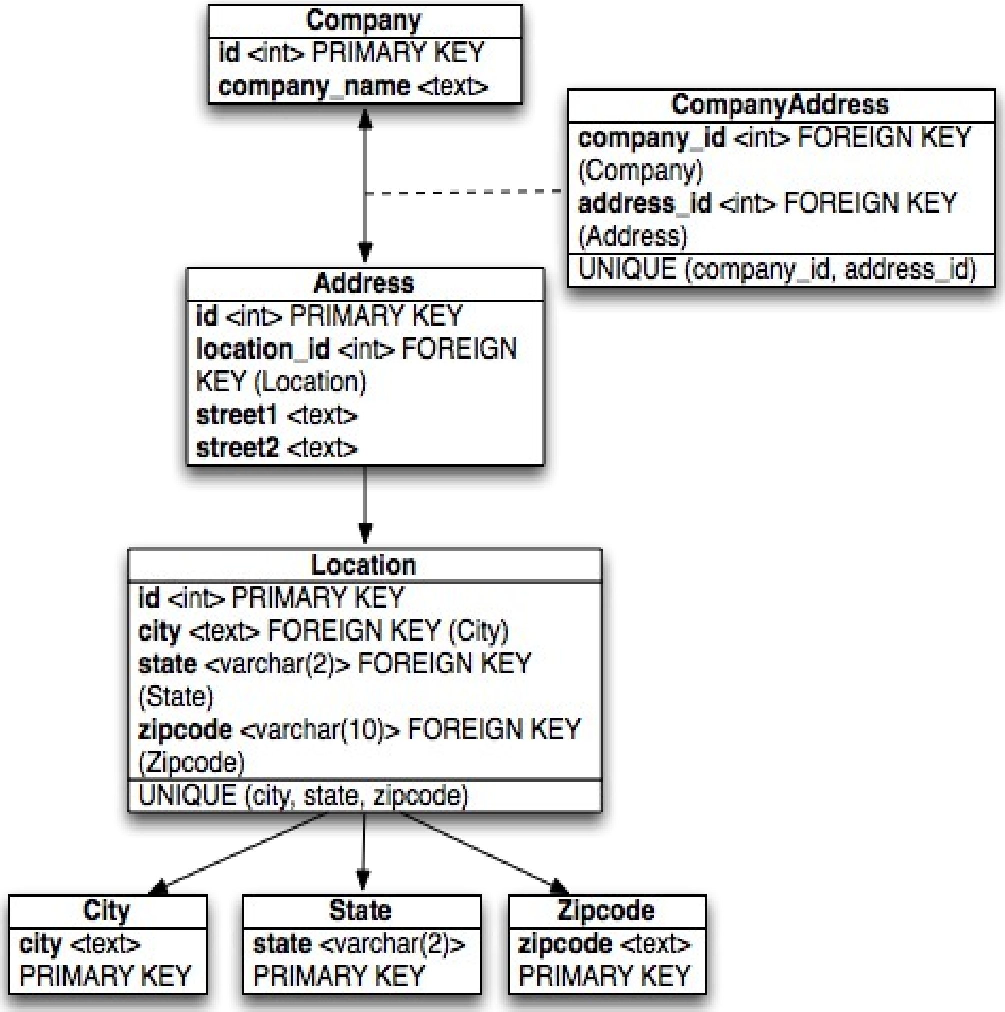
street2 <text>

city <text>

state <varchar(2)>

zipcode <varchar(10)>

Example: Business Locations



Company
id <int> PRIMARY KEY
company_name <text>

CompanyAddress
company_id <int> FOREIGN KEY (Company)
address_id <int> FOREIGN KEY (Address)
UNIQUE (company_id, address_id)

Address
id <int> PRIMARY KEY
location_id <int> FOREIGN KEY (Location)
street1 <text>
street2 <text>

Location
id <int> PRIMARY KEY
city <text> FOREIGN KEY (City)
state <varchar(2)> FOREIGN KEY (State)
zipcode <varchar(10)> FOREIGN KEY (Zipcode)
UNIQUE (city, state, zipcode)

City
city <text> PRIMARY KEY

State
state <varchar(2)> PRIMARY KEY

Zipcode
zipcode <text> PRIMARY KEY

Now Back in the Real World…

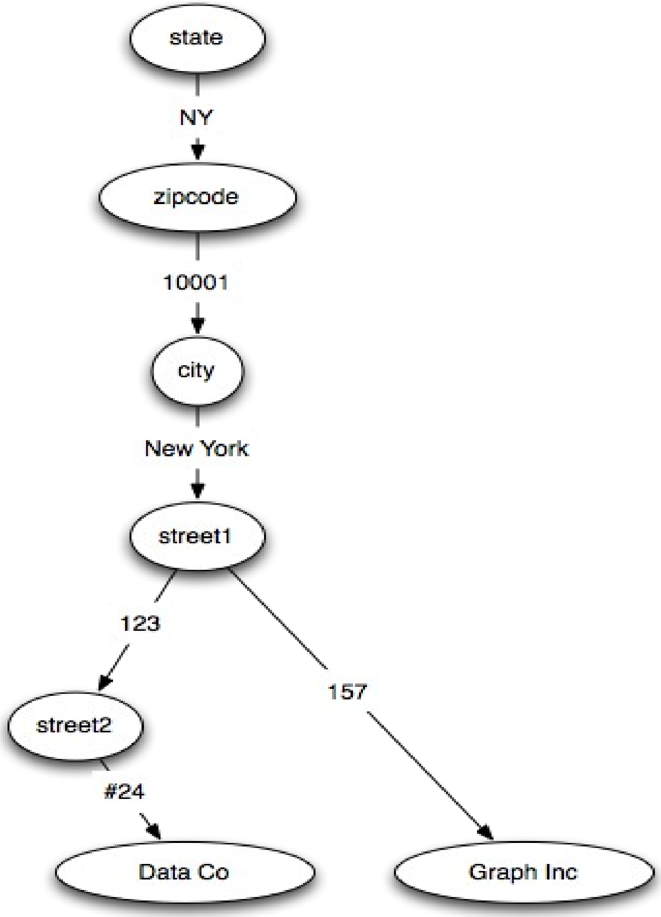
- Data is imperfect
- Data is stored imperfectly
- Data is sometimes transferred between different systems
- And sometimes we just don’t want to go through the hassle of SQL

In Short

There are many different ways to represent data

```
1 => 7
"a" => "b"
TRUE => ["car", "boat", "plane"]
```

Key-Value Pairs
(or a “hash”)
(also Postgres supports this - see “hstore”)



Graph Database (sorry for the bad example)

```
<?xml version=“1.0”?>
<addresses>
  <address company_name=“Data Co.”>
    <street1>123 Fake St</street1>
    <street2>#24</street2>
    <city>New York</city>
    <state>NY</state>
    <zip>10001</zip>
  </address>
  <address company_name=“Graph Inc.”>
    <street1>157 Fake St</street1>
    <street2></street2>
    <city>New York</city>
    <state>NY</state>
    <zip>10001</zip>
  </address>
</addresses>
```

XML
(sorry)
(and Postgres
supports this)

```
[
    {
        “company_name”: “Data Co.”,
        “street1”: “123 Fake St”,
        “street2”: “#24”,
        “city”: “New York”,
        “state”: “NY”,
        “zip”: “10001”
    },
    {
        “company_name: “Graph Inc.”,
        “street1”: “157 Fake St”,
        “city”: “New York”,
        “state”: “NY”,
        “zip”: “10001”
    }
]
```

JSON
(which is why we’re
here tonight, right?)

JSON and PostgreSQL

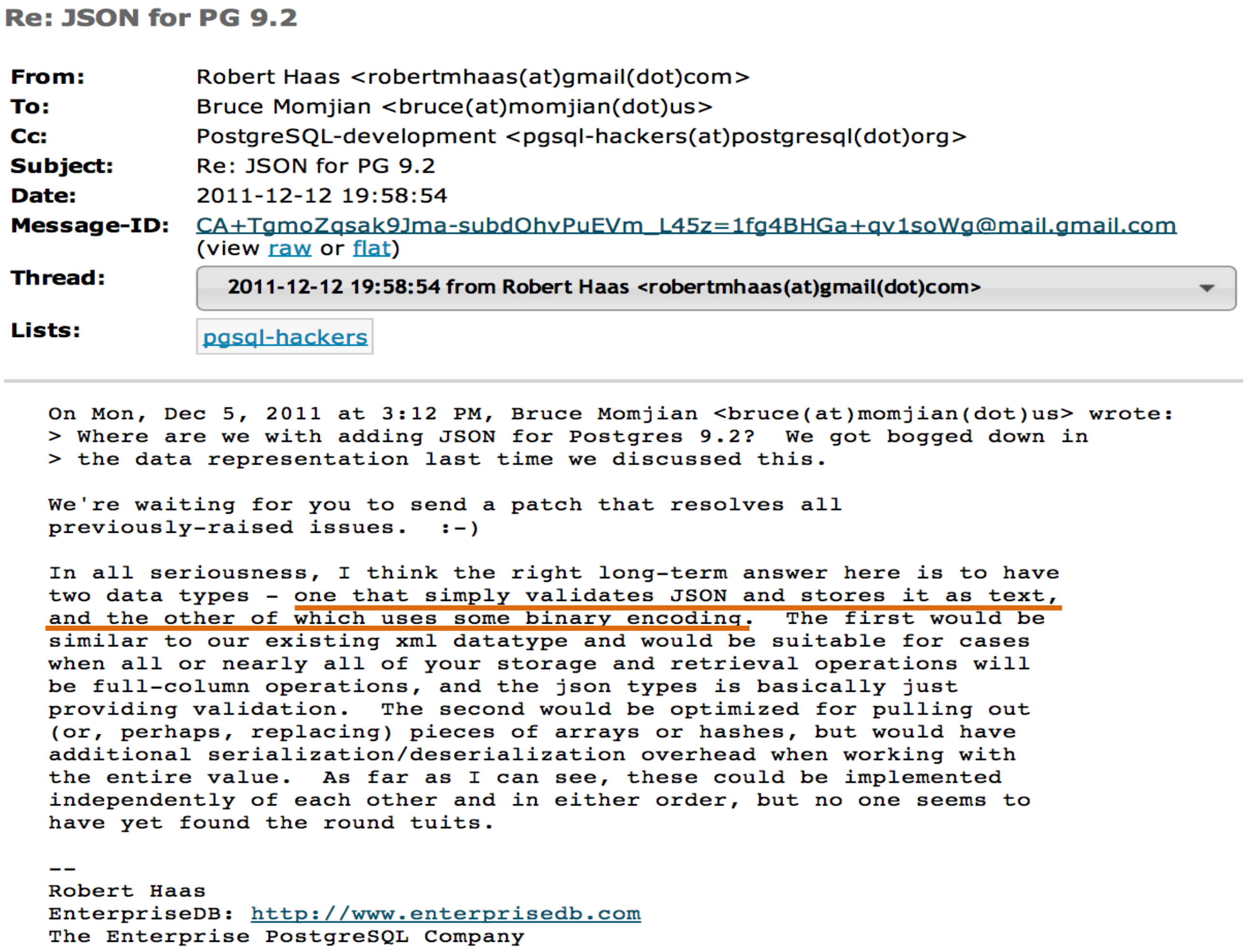
- Started in 2010 as a Google Summer of Code Project
  - https://wiki.postgresql.org/wiki/JSON_datatype_GSoC_2010
- Goal: be similar to XML data type functionality in Postgres
- Be committed as an extension for PostgreSQL 9.1

What Happened?

- Different proposals over how to finalize the implementation
  - binary vs. text

- Core vs Extension
  - Discussions between “old” vs. “new” ways of packaging for extensions

Foreshadowing



Re: JSON for PG 9.2

From:	Robert Haas <robertmhaas(at)gmail(dot)com>
To:	Bruce Momjian <bruce(at)momjian(dot)us>
Cc:	PostgreSQL-development <pgsql-hackers(at)postgresql(dot)org>
Subject:	Re: JSON for PG 9.2
Date:	2011-12-12 19:58:54
Message-ID:	CA+TgmoZqsak9Jma-subdOhvPuEVm_L45z=1fg4BHGa+qv1soWg@mail.gmail.com (view raw or flat)
Thread:	2011-12-12 19:58:54 from Robert Haas <robertmhaas(at)gmail(dot)com>
Lists:	pgsql-hackers

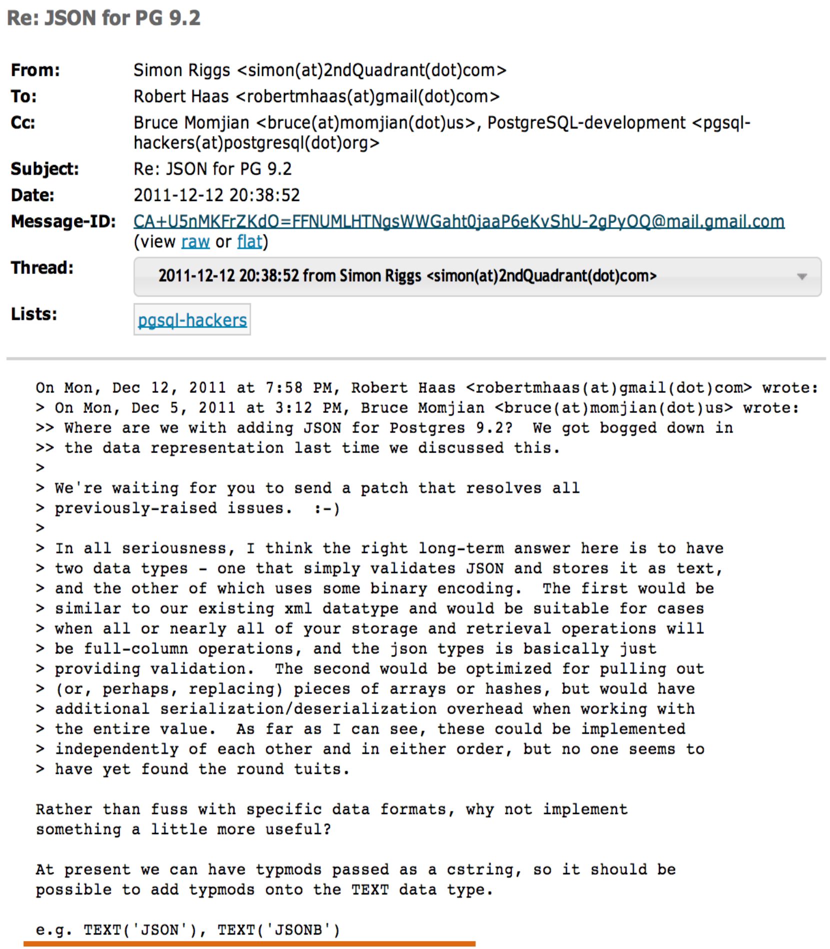
```
On Mon, Dec 5, 2011 at 3:12 PM, Bruce Momjian <bruce(at)momjian(dot)us> wrote:
> Where are we with adding JSON for Postgres 9.2?  We got bogged down in
> the data representation last time we discussed this.

We're waiting for you to send a patch that resolves all
previously-raised issues.  :-)

In all seriousness, I think the right long-term answer here is to have
two data types - one that simply validates JSON and stores it as text,
and the other of which uses some binary encoding.  The first would be
similar to our existing xml datatype and would be suitable for cases
when all or nearly all of your storage and retrieval operations will
be full-column operations, and the json types is basically just
providing validation.  The second would be optimized for pulling out
(or, perhaps, replacing) pieces of arrays or hashes, but would have
additional serialization/deserialization overhead when working with
the entire value.  As far as I can see, these could be implemented
independently of each other and in either order, but no one seems to
have yet found the round tuits.

--
Robert Haas
EnterpriseDB: http://www.enterprisedb.com
The Enterprise PostgreSQL Company
```

Foreshadowing



Re: JSON for PG 9.2

From:	Simon Riggs <simon(at)2ndQuadrant(dot)com>
To:	Robert Haas <robertmhaas(at)gmail(dot)com>
Cc:	Bruce Momjian <bruce(at)momjian(dot)us>, PostgreSQL-development <pgsql-hackers(at)postgresql(dot)org>
Subject:	Re: JSON for PG 9.2
Date:	2011-12-12 20:38:52
Message-ID:	CA+U5nMKFrZKdO=FFNUMLHTNgsWWGaht0jaaP6eKvShU-2gPyOQ@mail.gmail.com (view raw or flat)
Thread:	2011-12-12 20:38:52 from Simon Riggs <simon(at)2ndQuadrant(dot)com>
Lists:	pgsql-hackers

```
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> the entire value.  As far as I can see, these could be implemented
> independently of each other and in either order, but no one seems to
> have yet found the round tuits.

Rather than fuss with specific data formats, why not implement
something a little more useful?

At present we can have typmods passed as a cstring, so it should be
possible to add typmods onto the TEXT data type.

e.g. TEXT('JSON'), TEXT('JSONB')
```

PostgreSQL 9.2: JSON

- JSON data type in core PostgreSQL
  - based on RFC 4627
    - only “strictly” follows if your database encoding is UTF-8
  - text-based format
  - checks for validity

PostgreSQL 9.2: JSON

```
SELECT '[{"PUG": "NYC"}]'::json;
       json
------------------
 [{"PUG": "NYC"}]

SELECT '[{"PUG": "NYC"]'::json;
ERROR:  invalid input syntax for type json at character 8
DETAIL:  Expected "," or "}", but found "]".
CONTEXT:  JSON data, line 1: [{"PUG": "NYC"]
```

PostgreSQL 9.2: JSON

- array_to_json

```
SELECT array_to_json(ARRAY[1,2,3]);
 array_to_json
---------------
 [1,2,3]
```

PostgreSQL 9.2: JSON

- row_to_json

```
SELECT row_to_json(category)FROM category;
               row_to_json
               ------------
{"cat_id":652,"cat_pages":35,"cat_subcats":17,"cat_files
":0,"title":"Continents"}
(1 row)
```

PostgreSQL 9.2: JSON

In summary, within core PostgreSQL,
it was a starting point

PostgreSQL 9.3: JSON Ups its Game

- Added operators and functions to read / prepare JSON
- Added casts from hstore to JSON

PostgreSQL 9.3: JSON

Operator	***Description***	***Example***

->	***return JSON array element OR JSON object field***	***'[1,2,3]'::json -> 0;***
		'{"a": 1, "b": 2, "c": 3}'::json -> 'b';

->>	***return JSON array element OR JSON object field AS text***	***['1,2,3]'::json ->> 0;***
		'{"a": 1, "b": 2, "c": 3}'::json ->> 'b';

#>	***return JSON object using path***	***'{"a": 1, "b": 2, "c": [1,2,3]}'::json #> '{c, 0}';***
#>>	***return JSON object using path AS text***	***'{"a": 1, "b": 2, "c": [1,2,3]}'::json #> '{c, 0}';***

Operator Gotchas

```
SELECT * FROM category_documents
WHERE data->'title' = 'PostgreSQL';
```

```
ERROR:  operator does not exist: json = unknown

LINE 1: ...ECT * FROM category_documents WHERE data-
>'title' = 'Postgre...
                             ^HINT:  No operator
matches the given name and argument type(s). You
might need to add explicit type casts.
```

Operator Gotchas

```
SELECT * FROM category_documents
WHERE data->>'title' = 'PostgreSQL';
-----------------------
{"cat_id":252739,"cat_pages":14,"cat_subcats":0,
"cat_files":0,"title":"PostgreSQL"}
(1 row)
```

For the Upcoming Examples

- Wikipedia English category titles – all 1,823,644 that I downloaded
- Relation looks something like:

```
   Column    |  Type   |      Modifiers
-------------+---------+--------------------
 cat_id      | integer | not null
 cat_pages   | integer | not null default 0
 cat_subcats | integer | not null default 0
 cat_files   | integer | not null default 0
 title       | text    |
```

Performance?

```
EXPLAIN ANALYZE SELECT * FROM category_documents
WHERE data->>'title' = 'PostgreSQL';
---------------------
 Seq Scan on category_documents
(cost=0.00..57894.18 rows=9160 width=32) (actual
time=360.083..2712.094 rows=1 loops=1)
   Filter: ((data ->> 'title'::text) =
'PostgreSQL'::text)
   Rows Removed by Filter: 1823643
 Total runtime: 2712.127 ms
```

Performance?

```
CREATE INDEX category_documents_idx ON
category_documents (data);
```

```
ERROR:  data type json has no default operator
class for access method "btree"
```

```
HINT:  You must specify an operator class for
the index or define a default operator class for
the data type.
```

Let’s Be Clever

- json_extract_path, json_extract_path_text
  - LIKE (#>, #>>) but with list of args

```
SELECT json_extract_path(
   '{"a": 1, "b": 2, "c": [1,2,3]}’::json,
   'c', ‘0’);
---------
 1
```

Performance Revisited

```
CREATE INDEX category_documents_data_idx
ON category_documents
    (json_extract_path_text(data, ‘title'));

EXPLAIN ANALYZE
SELECT * FROM category_documents
WHERE json_extract_path_text(data, 'title') = 'PostgreSQL';

--------------------
 Bitmap Heap Scan on category_documents  (cost=303.09..20011.96 rows=9118
width=32) (actual time=0.090..0.091 rows=1 loops=1)
   Recheck Cond: (json_extract_path_text(data, VARIADIC '{title}'::text[]) =
'PostgreSQL'::text)
   ->  Bitmap Index Scan on category_documents_data_idx  (cost=0.00..300.81
rows=9118 width=0) (actual time=0.086..0.086 rows=1 loops=1)
         Index Cond: (json_extract_path_text(data, VARIADIC '{title}'::text[])
= 'PostgreSQL'::text)

 Total runtime: 0.105 ms
```

The Relation vs JSON

- Size on Disk
  - category (relation) - 136MB
  - category_documents (JSON) - 238MB
- Index Size for “title”
  - category - 89MB
  - category_documents - 89MB
- Average Performance for looking up “PostgreSQL”
  - category - 0.065ms
  - category_documents - 0.070ms

JSON => SET

- to_json
- json_each, json_each_text

```
SELECT * FROM
  json_each('{"a": 1, "b": [2,3,4], "c":
  "wow"}'::json);

 key |  value
-----+----------
 a   | 1
 b   | [2,3,4]
 c   | "wow"
```

JSON Keys

- json_object_keys

```
SELECT * FROM json_object_keys(
   '{"a": 1, "b": [2,3,4], "c": { "e":
"wow" }}’::json
);
--------
 a
 b
 c
```

Populating JSON Records

- json_populate_record

```
CREATE TABLE stuff (a int, b text, c int[]);

SELECT *
FROM json_populate_record(
  NULL::stuff, '{"a": 1, "b": “wow"}'
);

 a |  b  | c
---+-----+---
 1 | wow |


SELECT *
FROM json_populate_record(
  NULL::stuff, '{"a": 1, "b": "wow", "c": [4,5,6]}’
);
ERROR:  cannot call json_populate_record on a nested object
```

Populating JSON Records

- json_populate_recordset

```
SELECT *
FROM json_populate_recordset(NULL::stuff, ‘[
{"a": 1, "b": "wow"},
{"a": 2, "b": "cool"}
]');

 a |  b   | c
---+------+---
 1 | wow  |
 2 | cool |
```

JSON Aggregates

- (this is pretty cool)
- json_agg

```
SELECT b, json_agg(stuff)
FROM stuff
GROUP BY b;

  b   |             json_agg
------+----------------------------------
 neat | [{"a":4,"b":"neat","c":[4,5,6]}]
 wow  | [{"a":1,"b":"wow","c":[1,2,3]}, +
      |  {"a":3,"b":"wow","c":[7,8,9]}]
 cool | [{"a":2,"b":"cool","c":[4,5,6]}]
```

hstore gets in the game

- hstore_to_json
  - converts *hstore* to *json*, treating all values as strings

- hstore_to_json_loose
  - converts *hstore* to *json*, but also tries to distinguish between data types and “convert” them to proper JSON representations

```
 SELECT hstore_to_json_loose(‘"a key"=>1, b=>t, c=>null,
d=>12345, e=>012345, f=>1.234, g=>2.345e+4');
 ----------------
  {"b": true, "c": null, "d": 12345, "e": "012345", "f":
1.234, "g": 2.345e+4, "a key": 1}
```

Next Steps?

- In PostgreSQL 9.3, JSON became much more useful, but…
  - Difficult to search within JSON
  - Difficult to build new JSON objects

“Nested hstore”

- Proposed at PGCon 2013 by Oleg Bartunov and Teodor Sigaev
- Hierarchical key-value storage system that supports arrays too and stored in binary format
- Takes advantage of GIN indexing mechanism in PostgreSQL
  - “Generalized Inverted Index”
  - Built to search within composite objects
    - Arrays, fulltext search, hstore
    - …JSON?

How JSONB Came to Be

- JSON is the “lingua franca per trasmissione la data nella web”
- The PostgreSQL JSON type was in a text format and preserved text exactly as input
  - e.g. duplicate keys are preserved
- Create a new data type that merges the nested Hstore work to create a JSON type stored in a binary format: **JSONB**

JSONB ≠ BSON

BSON is a data type created by MongoDB
as a “superset of JSON”

JSONB lives in PostgreSQL and is just JSON
that is stored in a binary format on disk

JSONB Gives Us More Operators

- a @> b - is b contained within a?
  - `{ "a": 1, "b": 2 } @> { "a": 1} -- TRUE`
- a <@ b - is a contained within b?
  - `{ "a": 1 } <@ { "a": 1, "b": 2 } -- TRUE`
- a ? b - does the key “b” exist in JSONB a?
  - `{ "a": 1, "b": 2 } ? 'a' -- TRUE`
- a ?| b - does the array of keys in “b” exist in JSONB a?
  - `{ "a": 1, "b": 2 } ?| ARRAY['b', 'c'] -- TRUE`
- a ?& b - does the array of keys in "b" exist in JSONB a?
  - `{ "a": 1, "b": 2 } ?& ARRAY['a', 'b'] -- TRUE`

JSONB Gives Us Flexibility

```
SELECT * FROM category_documents WHERE
   data @> '{"title": "PostgreSQL"}';
----------------
 {"title": "PostgreSQL", "cat_id": 252739,
"cat_files": 0, "cat_pages": 14, "cat_subcats": 0}


SELECT * FROM category_documents WHERE
   data @> '{"cat_id": 5432 }';
----------------
  {"title": "1394 establishments", "cat_id": 5432,
"cat_files": 0, "cat_pages": 4, "cat_subcats": 2}
```

JSONB Gives us GIN

- Recall - GIN indexes are used to "look inside" objects
- JSONB has two flavors of GIN:

  - Standard - supports @>, ?, ?|, ?&

```
   CREATE INDEX category_documents_data_idx USING
gin(data);
```

  - "Path Ops" - supports only @>

```
   CREATE INDEX category_documents_path_data_idx
     USING gin(data jsonb_path_ops);
```

JSONB Gives Us Speed

```
EXPLAIN ANALYZE SELECT * FROM category_documents
    WHERE data @> '{"title": "PostgreSQL"}';
```

```
------------
 Bitmap Heap Scan on category_documents  (cost=38.13..6091.65 rows=1824
width=153) (actual time=0.021..0.022 rows=1 loops=1)
   Recheck Cond: (data @> '{"title": "PostgreSQL"}'::jsonb)
   Heap Blocks: exact=1
   ->  Bitmap Index Scan on category_documents_path_data_idx
(cost=0.00..37.68 rows=1824 width=0) (actual time=0.012..0.012 rows=1
loops=1)
         Index Cond: (data @> '{"title": "PostgreSQL"}'::jsonb)
 Planning time: 0.070 ms
 Execution time: 0.043 ms
```

JSONB + Wikipedia Categories: By the Numbers

- Size on Disk
  - category (relation) - 136MB
  - category_documents (JSON) - 238MB
  - category_documents (JSONB) - 325MB
- Index Size for “title”
  - category - 89MB
  - category_documents (JSON with one key using an expression index) - 89MB
  - category_documents (JSONB, all GIN ops) - 311MB
  - category_documents (JSONB, just @>) - 203MB
- Average Performance for looking up “PostgreSQL”
  - category - 0.065ms
  - category_documents (JSON with one key using an expression index) - 0.070ms
  - category_documents (JSONB, all GIN ops) - 0.115ms
  - category_documents (JSONB, just @>) - **0.045ms**

JSONB Gives Us WTF: A Note On Operator Indexability

```
EXPLAIN ANALYZE SELECT * FROM documents WHERE data @> ’{ "f1": 10 }’;
QUERY PLAN
-----------
 Bitmap Heap Scan on documents  (cost=27.75..3082.65 rows=1000 width=66) (actual time=0.029..0.
rows=1 loops=1)
   Recheck Cond: (data @> ’{"f1": 10}’::jsonb)
   Heap Blocks: exact=1
   ->  Bitmap Index Scan on documents_data_gin_idx  (cost=0.00..27.50 rows=1000 width=0)
(actual time=0.014..0.014 rows=1 loops=1)
         Index Cond: (data @> ’{"f1": 10}’::jsonb)

Execution time: 0.084 ms

EXPLAIN ANALYZE SELECT * FROM documents WHERE ’{ "f1": 10 }’ <@ data;

QUERY PLAN
-----------
 Seq Scan on documents  (cost=0.00..24846.00 rows=1000 width=66) (actual time=0.015..245.924 ro
   Filter: (’{"f1": 10}’::jsonb <@ data)
   Rows Removed by Filter: 999999

Execution time: 245.947 ms
```

JSON ≠ Schema-less

Some agreements must be made about the document
The document must be validated somewhere
Ensure that all of your code no matter who writes it conforms to a basic document structure

Enter PL/V8

- Write your database functions in Javascript
- Validate your JSON inside of the database
- http://pgxn.org/dist/plv8/doc/plv8.html

```
CREATE EXTENSION plv8;
```

Create A Validation Function

```
CREATE OR REPLACE FUNCTION has_valid_keys(doc json)
    RETURNS boolean AS
$$
    if (!doc.hasOwnProperty('data'))
        return false;

    if (!doc.hasOwnProperty('meta'))
        return false;

    return true;
$$ LANGUAGE plv8 IMMUTABLE;
```

Add A Constraint

```
ALTER TABLE collection
    ADD CONSTRAINT collection_key_chk
      CHECK (has_valid_keys(doc::json));

scale=# INSERT INTO collection (doc) VALUES ('{"name":
"postgresql"}');
ERROR:  new row for relation "collection" violates check
constraint "collection_key_chk"
DETAIL:  Failing row contains (ea438788-b2a0-4ba3-b27d-
a58726b8a210, {"name": "postgresql"}).
```

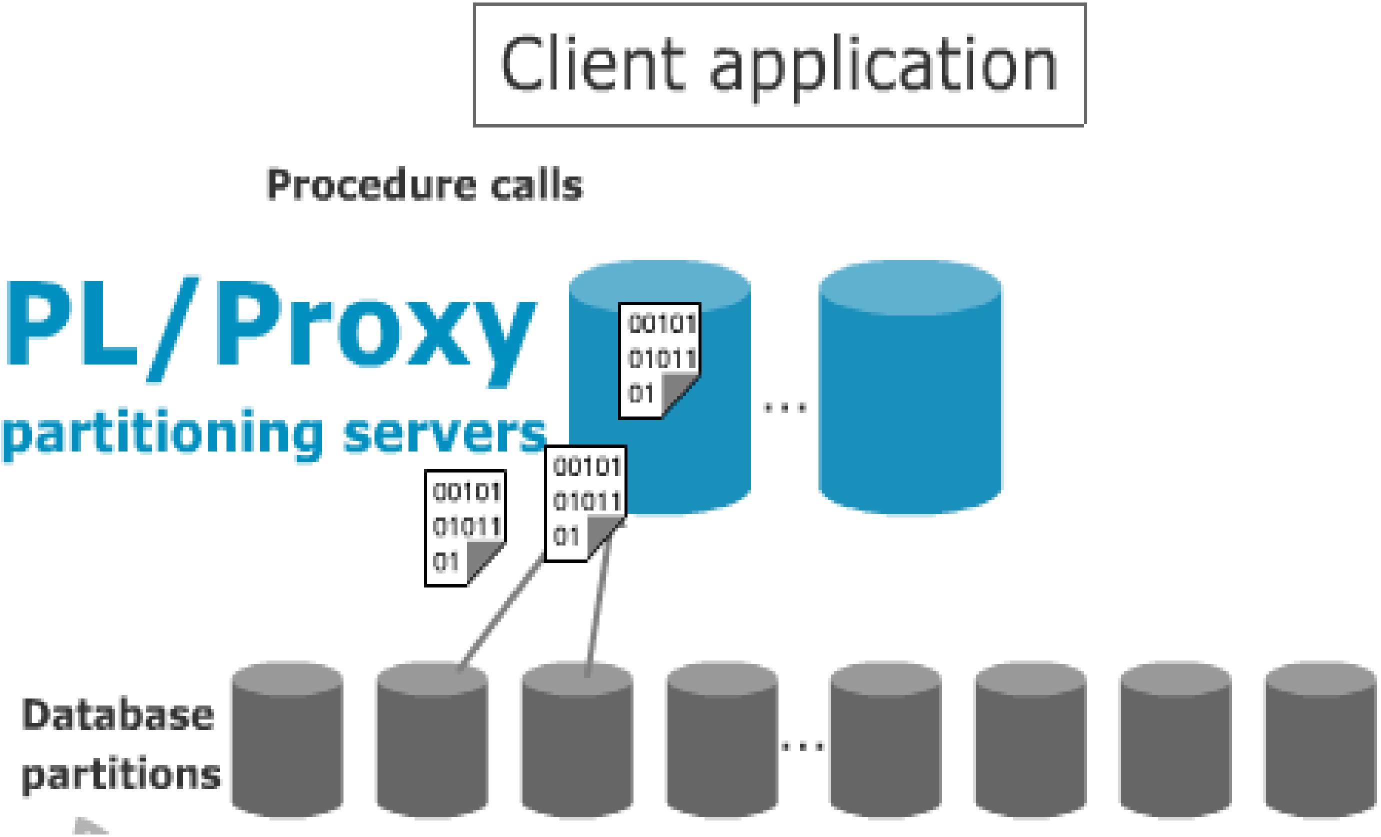
Schema-Less ≠ Web-Scale

Web-Scale needs to run on commodity hardware or the cloud
Web-Scale needs horizontal scalability
Web-Scale needs no single point of failure

Enter PL/Proxy

- Developed by Skype
- Allows for scalability and parallelization
- http://pgfoundry.org/projects/plproxy/
- Used by many large organizations around the world

PL/Proxy


Client application
Procedure calls
PL/Proxy
partitioning servers
00101
01011
01
...
Database
partitions
...

Setting Up A Proxy Server

```
CREATE EXTENSION plproxy;

CREATE SERVER datacluster FOREIGN DATA WRAPPER plproxy
OPTIONS (connection_lifetime '1800',
         p0 'dbname=data1 host=localhost',
         p1 'dbname=data2 host=localhost' );

CREATE USER MAPPING FOR PUBLIC SERVER datacluster;
```

Create a “Get” Function

```
CREATE OR REPLACE FUNCTION get_doc(i_id uuid)
RETURNS SETOF jsonb AS $$
    CLUSTER 'datacluster';
    RUN ON hashtext(i_id::text) ;
    SELECT doc FROM collection WHERE id = i_id;
$$ LANGUAGE plproxy;
```

Create a “Put” Function

```
CREATE OR REPLACE FUNCTION put_doc(
    i_doc jsonb,
    i_id uuid DEFAULT uuid_generate_v4())
RETURNS uuid AS $$
    CLUSTER 'datacluster';
    RUN ON hashtext(i_id::text);
$$ LANGUAGE plproxy;
```

Need a “Put” Function on the Shard

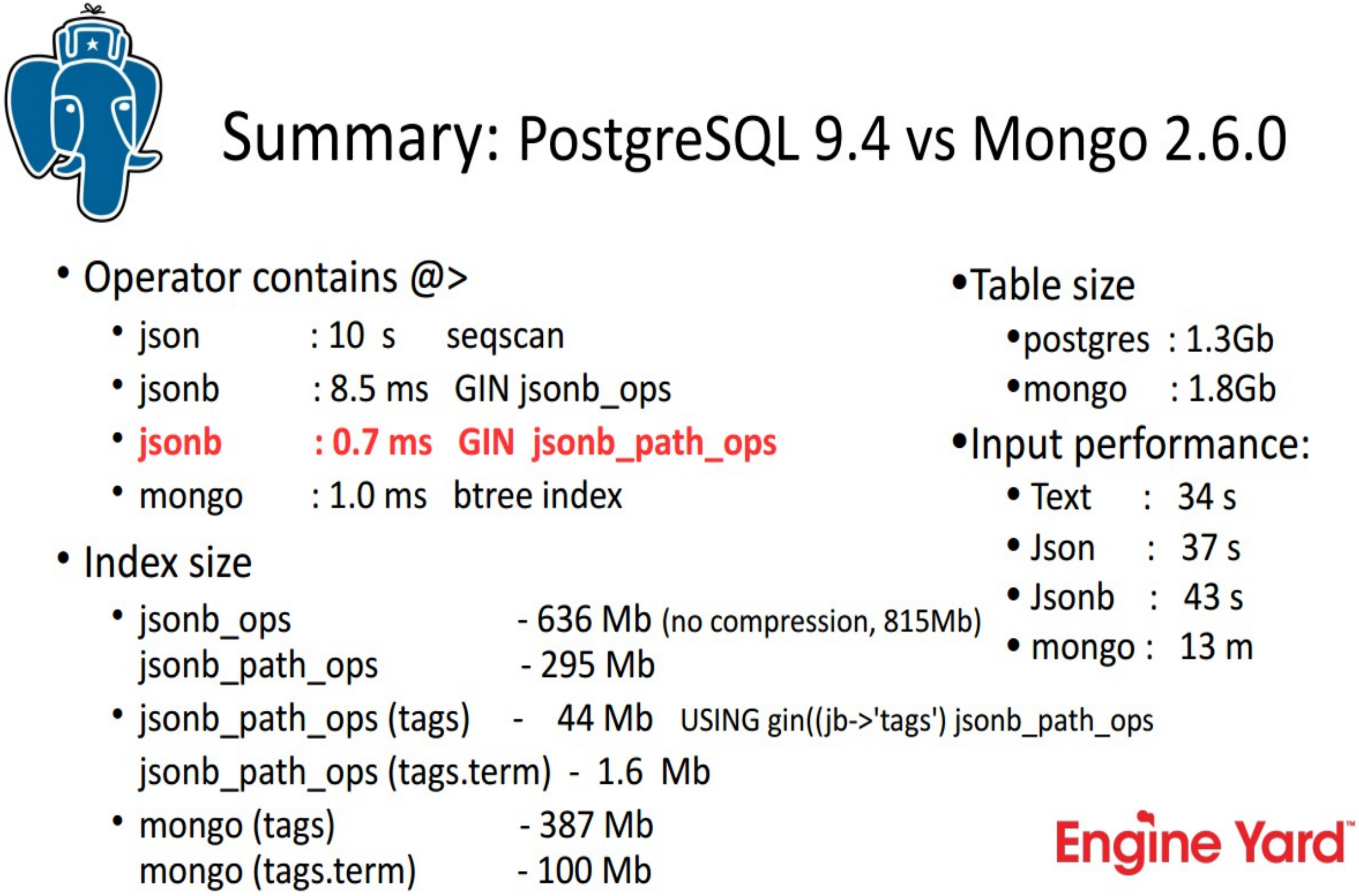
```
CREATE OR REPLACE FUNCTION
put_doc(i_doc jsonb, i_id uuid)
  RETURNS uuid AS $$
       INSERT INTO collection (id, doc)
           VALUES ($2,$1);
       SELECT $2;
$$ LANGUAGE SQL;
```

Parallelize A Query

```
CREATE OR REPLACE FUNCTION get_doc_by_id (v_id varchar)
RETURNS SETOF jsonb AS $$
CLUSTER 'datacluster';
RUN ON ALL;
SELECT doc FROM collection
WHERE doc @> CAST('{"id" : "' || v_id || '"}' AS
jsonb);
$$ LANGUAGE plproxy;
```

Is PostgreSQL Web-Scale

Faster than MongoDB?



Summary: PostgreSQL 9.4 vs Mongo 2.6.0

- Operator contains @>
  - json : 10 s seqscan
  - jsonb : 8.5 ms GIN jsonb_ops
  - **jsonb : 0.7 ms GIN jsonb_path_ops**
  - mongo : 1.0 ms btree index
- Index size
  - jsonb_ops - 636 Mb (no compression, 815Mb)
    jsonb_path_ops - 295 Mb
  - jsonb_path_ops (tags) - 44 Mb USING gin((jb->'tags') jsonb_path_ops
    jsonb_path_ops (tags.term) - 1.6 Mb
  - mongo (tags) - 387 Mb
    mongo (tags.term) - 100 Mb

- Table size
  - postgres : 1.3Gb
  - mongo : 1.8Gb
- Input performance:
  - Text : 34 s
  - Json : 37 s
  - Jsonb : 43 s
  - mongo : 13 m

Engine Yard™

http://www.pgcon.org/2014/schedule/attachments/318_pgcon-2014-vodka.pdf

Who is running PostgreSQL?

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Questions?