Writing a user-defined datatype

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What is a datatype?

A datatype encapsulates semantics and rules.
PostgreSQL offers many built-in datatypes, e.g:

- integer
- text
- timestamp
- point

Other datatypes can be derived from the base types:

- domains
- arrays
- ranges

This presentation

PART 1

- Creating a new base type from scratch
- Define basic functions and operators
- B-tree indexing support

PART 2

- Advanced indexing

Creating a new base type

PostgreSQL stores data as opaque Datums

- Fixed or variable length (varlena) chunk of memory
- Can be copied around the system and stored on disk

All other operations are defined by the data type author. Minimum:

- Input and output functions. These convert between string representation and the internal format.

Example

A datatype for representing colours

- As a 24-bit RGB value.
- For convenience, stored in a 32-bit integer
- String representation in hex:
  #000000 – black
  #FF0000 – red
  #0000A0 – dark blue
  #FFFFFF –

Input function

```
Datum
colour_in(PG_FUNCTION_ARGS)
{
   const char *str = PG_GETARG_CSTRING(0);
   int32       result;

   sscanf(str, "#%X", &result);
   PG_RETURN_INT32(result);
}
```

Input function, with error checking

```
Datum
colour_in(PG_FUNCTION_ARGS)
{
   const char *str = PG_GETARG_CSTRING(0);
   int32       result;

   if (str[0] != ’#’ ||
             strspn(&str[1], "01234567890ABCDEF") != 6)
   {
      ereport(ERROR,
        (errcode(ERRCODE_INVALID_TEXT_REPRESENTATION),
         errmsg("invalid input syntax for colour: \"%s\"",
            str)));
   }
   sscanf(str, "#%X", &result);
   PG_RETURN_INT32(result);
}
```

Output function

```
Datum
colour_out(PG_FUNCTION_ARGS)
{
    int32   val = PG_GETARG_INT32(0);
    char   *result = palloc(8);

    snprintf(result, 8, "#%06X", val);
    PG_RETURN_CSTRING(result);
}
```

Register type with PostgreSQL

```
CREATE OR REPLACE FUNCTION colour_in(cstring)
 RETURNS colour
 AS ’MODULE_PATHNAME’ LANGUAGE ’C’ IMMUTABLE STRICT;

CREATE OR REPLACE FUNCTION colour_out(colour)
 RETURNS cstring
 AS ’MODULE_PATHNAME’ LANGUAGE ’C’ IMMUTABLE STRICT;

CREATE TYPE colour (
  INPUT = colour_in,
  OUTPUT = colour_out,
  LIKE = pg_catalog.int4
);
```

The type is ready!

```
postgres=# CREATE TABLE colour_names (
  name text,
  rgbvalue colour
);
CREATE TABLE
postgres=# INSERT INTO colour_names
    VALUES (’red’, ’#FF0000’);
INSERT 0 1
postgres=# SELECT * FROM colour_names ;
 name | rgbvalue
------+----------
 red  | #FF0000
(1 row)
```

CREATE TYPE syntax

```
CREATE TYPE name (
    INPUT = input_function,
    OUTPUT = output_function
    [ , RECEIVE = receive_function ]
    [ , SEND = send_function ]
    [ , TYPMOD_IN = type_modifier_input_function ]
    [ , TYPMOD_OUT = type_modifier_output_function ]
    [ , ANALYZE = analyze_function ]
    [ , INTERNALLENGTH = { internallength | VARIABLE } ]
    [ , PASSEDBYVALUE ]
    [ , ALIGNMENT = alignment ]
    [ , STORAGE = storage ]
    [ , LIKE = like_type ]
    [ , CATEGORY = category ]
    [ , PREFERRED = preferred ]
    [ , DEFAULT = default ]
    [ , ELEMENT = element ]
```

Operators

A type needs operators:

```
postgres=#
    SELECT * FROM colour_names WHERE rgbvalue = ’#FF0000’;
ERROR:  operator does not exist: colour = unknown
```

Equality operator

We can borrow the implementation from built-in integer operator:

```
CREATE FUNCTION colour_eq (colour, colour) RETURNS bool
  LANGUAGE internal AS 'int4eq' IMMUTABLE STRICT;

CREATE OPERATOR = (
  PROCEDURE = colour_eq,
  LEFTARG = colour, RIGHTARG = colour,
  HASHES, MERGES
);
```

Operators

Ok, now it works:

```
postgres=# SELECT * FROM colour_names WHERE rgbvalue = ’#FF
 name | rgbvalue
------+----------
 red  | #FF0000
(1 row)
```

More functions

```
CREATE FUNCTION red(colour) RETURNS int4
  LANGUAGE C AS ’MODULE_PATHNAME’ IMMUTABLE STRICT;

CREATE FUNCTION green(colour) RETURNS int4
  LANGUAGE C AS ’MODULE_PATHNAME’ IMMUTABLE STRICT;

CREATE FUNCTION blue(colour) RETURNS int4
  LANGUAGE C AS ’MODULE_PATHNAME’ IMMUTABLE STRICT;
```

Extracting the components

```
postgres=# select name, rgbvalue,
           red(rgbvalue), green(rgbvalue), blue(rgbvalue)
           from colour_names ;

    name    | rgbvalue | red | green | blue
------------+----------+-----+-------+------
 red        | #FF0000  | 255 |     0 |    0
 green      | #00FF00  |   0 |   255 |    0
 blue       | #0000FF  |   0 |     0 |  255
 white      | #FFFFFF  | 255 |   255 |  255
 black      | #000000  |   0 |     0 |    0
 light grey | #C0C0C0  | 192 |   192 |  192
 lawn green | #87F717  | 135 |   247 |   23
 dark grey  | #808080  | 128 |   128 |  128
(8 rows)
```

Luminence

The human eye is more sensitive to green light.

```
CREATE FUNCTION luminence(colour) RETURNS numeric AS
$$
  SELECT (0.30 * red($1) +
          0.59 * green($1) +
          0.11 * blue($1))
     / 255.0
$$
LANGUAGE SQL IMMUTABLE STRICT;
```

Luminence

```
postgres=# select name, rgbvalue,
           red(rgbvalue), green(rgbvalue), blue(rgbvalue),
           round( luminence(rgbvalue), 6) as luminence
           from colour_names ;
    name    | rgbvalue | red | green | blue | luminence
------------+----------+-----+-------+------+-----------
 red        | #FF0000  | 255 |     0 |    0 |  0.300000
 green      | #00FF00  |   0 |   255 |    0 |  0.590000
 blue       | #0000FF  |   0 |     0 |  255 |  0.110000
 white      | #FFFFFF  | 255 |   255 |  255 |  1.000000
 black      | #000000  |   0 |     0 |    0 |  0.000000
 light grey | #C0C0C0  | 192 |   192 |  192 |  0.752941
 lawn green | #87F717  | 135 |   247 |   23 |  0.740235
 dark grey  | #808080  | 128 |   128 |  128 |  0.501961
(8 rows)
```

Summary so far

We have created a type

- With input and output functions
- With equality operator
- With functions for splitting a colour into components and calculating luminence

Ordering

```
postgres=# SELECT * FROM colour_names ORDER BY rgbvalue;
ERROR:  could not identify an ordering operator for type
colour
```

Ordering operator

What is an ordering operator?

- <
- <=
- = (we already did this)
- >=
- >

We're going define these in terms of luminence

Implementing ordering functions

```
CREATE FUNCTION colour_lt (colour, colour)
RETURNS bool AS $$
  SELECT luminence($1) < luminence($2);
$$ LANGUAGE SQL IMMUTABLE STRICT;
```

Implementing ordering functions

```
CREATE FUNCTION colour_le (colour, colour)
RETURNS bool AS $$
  SELECT luminence($1) <= luminence($2);
$$ LANGUAGE SQL IMMUTABLE STRICT;

CREATE FUNCTION colour_ge (colour, colour)
RETURNS bool AS $$
  SELECT luminence($1) >= luminence($2);
$$ LANGUAGE SQL IMMUTABLE STRICT;

CREATE FUNCTION colour_gt (colour, colour)
RETURNS bool AS $$
  SELECT luminence($1) > luminence($2);
$$ LANGUAGE SQL IMMUTABLE STRICT;
```

Create operators

```
CREATE OPERATOR < (
  LEFTARG=colour, RIGHTARG=colour,
  PROCEDURE=colour_lt);

CREATE OPERATOR <= (
  LEFTARG=colour, RIGHTARG=colour,
  PROCEDURE=colour_le);

CREATE OPERATOR >= (
  LEFTARG=colour, RIGHTARG=colour,
  PROCEDURE=colour_ge);

CREATE OPERATOR > (
  LEFTARG=colour, RIGHTARG=colour,
  PROCEDURE=colour_gt);
```

One more thing. . .

We'll also need a comparison function that returns -1, 0, or 1 depending on which argument is greater;

```
CREATE FUNCTION luminence_cmp(colour, colour)
RETURNS integer AS $$
 SELECT CASE WHEN $1 = $2 THEN 0
  WHEN luminence($1) < luminence($2) THEN 1
    ELSE --1 END;
$$ LANGUAGE SQL IMMUTABLE;
```

Operator class

An operator class ties the individual operators together. Operator classes are defined for indexing support, but the B-tree operator class is a bit special.

```
CREATE OPERATOR CLASS luminence_ops
  DEFAULT FOR TYPE colour
  USING btree AS
    OPERATOR 1 <,
    OPERATOR 2 <=,
    OPERATOR 3 =,
    OPERATOR 4 >=,
    OPERATOR 5 >,
    FUNCTION 1 luminence_cmp(colour, colour);
```

Ready to order!

```
postgres=# SELECT * FROM colour_names ORDER BY rgbvalue;

    name    | rgbvalue
------------+----------
 white      | #FFFFFF
 light grey | #C0C0C0
 lawn green | #87F717
 green      | #00FF00
 dark grey  | #808080
 red        | #FF0000
 blue       | #0000FF
 black      | #000000
(8 rows)
```

Indexing

We already created the B-tree operator class:

```
CREATE INDEX colour_lum_index ON colour_names (rgbvalue);

EXPLAIN SELECT * FROM colour_names
        WHERE rgbvalue='#000000'
        ORDER BY rgbvalue;

                QUERY PLAN
-----------------------------------------------------------
 Index Scan using colour_lum_index on colour_names
      (cost=0.13..8.20 rows=4 width=36)
   Index Cond: (rgbvalue = '#000000'::colour)
(2 rows)
```

postgres=#

Summary so far

We have created a type:

- With input and output functions
- With functions for splitting a colour into components and calculating luminence

Index support:

- Operators: > >= = <= <
- A comparison function: colour_cmp
- A B-tree operator class to tie the above together

Wait, there's more!

- Hash function and operator class
  - for hash index support
  - for hash joins and aggregates
- Casts
- Cross-datatype operators
- Binary I/O routines
- Analyze function
- typmod
  - VARCHAR(50)
  - NUMERIC(1,5)

Packaging

```
~/presentations/PGConfEU2013/src (master)$ ls -l
total 16
-rw-r--r-- 1 heikki heikki 2523 loka  25 11:11 colour--1.0.s
-rw-r--r-- 1 heikki heikki 1618 loka  25 11:15 colour.c
-rw-r--r-- 1 heikki heikki  144 loka  25 11:10 colour.contro
-rw-r--r-- 1 heikki heikki  185 loka  25 11:09 Makefile
```

Upload to PGXN

PART 2: advanced indexing

Ordering by luminence is nice..
But what about finding a colour that's the closes match to given colour?

Distance function

$$\sqrt{(R_1 - R_2)^2 + (G_1 - G_2)^2 + (B_1 - B_2)^2}$$

```
CREATE FUNCTION colour_diff (colour, colour)
RETURNS float AS $$
  SELECT sqrt((red($1) - red($2))^2 +
              (green($1) - green($2))^2 +
              (blue($1) - blue($2))^2)
$$ LANGUAGE SQL IMMUTABLE STRICT;

CREATE OPERATOR <-> (
  PROCEDURE = colour_diff,
  LEFTARG=colour,
  RIGHTARG=colour
);
```

Order by distance

```
postgres=#
SELECT * FROM colour_names ORDER BY rgbvalue <-> ’#00FF00’;

    name    | rgbvalue
------------+----------
 green      | #00FF00
 lawn green | #87F717
 dark grey  | #808080
 black      | #000000
 light grey | #C0C0C0
 white      | #FFFFFF
 blue       | #0000FF
 red        | #FF0000
(8 rows)
```

But can we index that?

```
postgres=# explain SELECT * FROM colour_names
                   ORDER BY rgbvalue <-> '#00FF00';

                                QUERY PLAN
----------------------------------------------------------
 Sort  (cost=1.46..1.48 rows=8 width=36)
   Sort Key: (sqrt(((((red(rgbvalue) - 0))::double precisi
   ->  Seq Scan on colour_names  (cost=0.00..1.38 rows=8 wi
(3 rows)
```

Oh, a seqscan. With a billion colours, that could be slow..

Advanced index types

PostgreSQL offers three kinds of generalized index types:

- GIN
- GiST (Generalized Search Tree)
- SP-GiST (Space-partitioned GiST)

PostgreSQL provides:

- WAL-logging
- Concurrency
- Isolation
- Durability
- Transactions

GIN

Generalized Inverted Index.
Splits input key into multiple parts, and indexes the parts.
For example:

- Full text search - extract each word from text, index the words
- Arrays - index the array elements
- Word similarity (pg_trgm) - extract trigrams from text, index trigrams

GiST

General tree structure

- Extremely flexible
- You define the layout

Used for:

- Full-text search
- Trigrams
- Hierarchical labels, ltree contrib module
- B-tree emulation
- Points (R-tree)

B-tree refresher

Five operators:

- <
- <=
- =
- >
- >=

One support function;

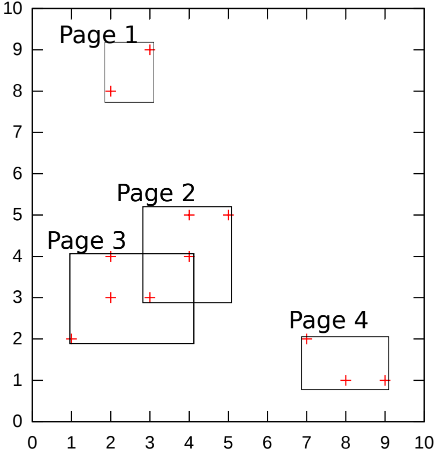
- colour_cmp() - returns -1, 0 or 1

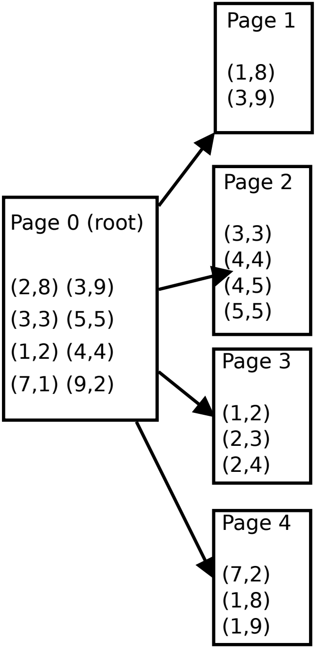
GiST

GiST has 8 support functions:

- consistent - when searching, decide which child nodes to visit
- union - create a new inner node from a set of entries
- compress - converts a data item to internal format, for storing
- decompress - the reverse of compress
- penalty - used to decide where to insert new tuple
- picksplit - when page becomes full, how to split tuples on new pages?
- same - returns true if index entries are equal
- distance - returns the distance of an index entry from query (optional)

R-Tree





Page 0 (root)

(2,8) (3,9)
(3,3) (5,5)
(1,2) (4,4)
(7,1) (9,2)

Page 1

(1,8)
(3,9)

Page 2

(3,3)
(4,4)
(4,5)
(5,5)

Page 3

(1,2)
(2,3)
(2,4)

Page 4

(7,2)
(1,8)
(1,9)

R-Tree using GiST

Support functions:

- consistent - Return true if point falls in the bounding box
- union - Expand bounding box to cover the new point
- penalty - Return distance of given point from bounding box
- picksplit - Divide points minimizing overlap
- same - trivial equality check
- distance - distance of given point from bounding box or point
- compress/decompress - do nothing

R-Tree for colours using GiST

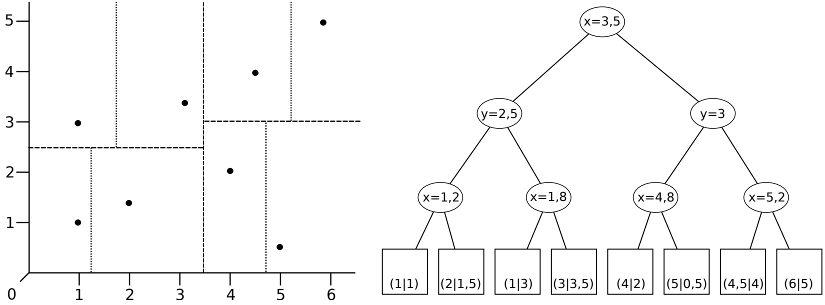
- Treat colours as 3d points.
- In internal nodes, store a bounding box
- In leaf nodes, store the colour itself

Space-Partitioned GiST (SP-GiST)

New index type in PostgreSQL 9.2
Like GiST, but SP-GiST totally partitions the key space. * No overlapping pages.
Can be used to implement e.g:

- prefix tries for text
- Quad-tree for points
- KD-tree for points

KD-tree



(2dbaum.svg, Wikimedia Commons / Public Domain)

Implementing SP-GiST operator class for colours

- KD-tree.
- Each colour is a point in 3-D space. Each component, Red, Green, Blue, is one dimension.

SP-GiST support functions

SP-GiST requires 5 support functions:

- *config* - Returns static information about the implementation
- *choose* - How to insert a new value into an inner tuple?
- *picksplit* - How to create a new inner tuple over a set of leaf tuples.
- *inner_consistent* - Returns set of nodes (branches) to follow during tree search.
- *leaf_consistent* - Returns true if a leaf tuple satisfies a query.

Advanced indexes summary

PostgreSQL offers three kinds of generalized index types:

- GIN (Generalized Inverted Index)
- GiST (Generalized Search Tree)
- SP-GiST (Space-partitioned GiST)

PostgreSQL provides:

- WAL-logging
- Concurrency
- Isolation
- Durability
- Transactions

The end

You're the expert in your problem domain!
You define the semantics!
PostgreSQL handles the rest!