Advanced SQL

03 — Standard and Non-Standard Data Types

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1 ┆ Data Types in (Postgre)SQL

- The set of supported **data types** in PostgreSQL is varied:[1]

```
SELECT string_agg(t.typname, ' ') AS "data types"
FROM   pg_catalog.pg_type AS t
WHERE  t.typelem = 0 AND t.typrelid = 0;
```

data types
bool bytea char int8 int2 int4 regproc text oid tid oid tid xid cid json xml pg_node_tree pg_ddl_command smgr path polygon float4 float8 abstime reltime tinterval unknown circle money macaddr inet cidr …

[1] See https://www.postgresql.org/docs/current/datatype.html

2 ┆ SQL Type Casts

Convert type of value e to τ at *runtime* via a **type cast:**

CAST (e **AS** τ)	}		(SQL standard)
e :: τ	}	equivalent	(PostgreSQLism, cf. FP)
$\tau(e)$	}		(if τ valid func name)

- ⚠️ Type casts can fail at runtime.

- SQL performs **implicit casts** when the required target type is unambiguous (e.g. on insertion into a table column):

```
INSERT INTO T(a,b,c,d) VALUES (6.2, NULL, 'true', '0')
                                ↑     ↑       ↑      ↑
      -- implicitly casts to:  int   text  boolean  int
```

Literals (Casts From Type text)

SQL supports **literal syntax** for dozens of data types in terms of **casts from type** text:

`CAST ('`*‹literal›*`' AS` τ`)` `'`*‹literal›*`' ::` τ τ `'`*‹literal›*`'`	succeeds if *‹literal›* has a valid interpretation as τ (without cast ⇒ type text)

- Embed complex literals (e.g., dates/times, JSON, XML, geometric objects) in SQL source.

- Casts from text to τ attempted **implicitly** if target type τ known. Also vital when importing data from text or CSV files (*input conversion*).

3 ┆ Text Data Types

```
char          -- ≡ char(1)
char(n)       -- fixed length n, blank (␣) padded if needed
varchar(n)    -- varying length ≤ n characters
text          -- varying length, unlimited
```

- Length limits measured in characters, *not* bytes. (PostgreSQL: max size ≅ 1 Gb. Large text is "TOASTed.")

- For char(*n*), varchar(*n*) length limits are enforced:
  1. Excess characters (other than ␣) yield runtime errors.
  2. Explicit casts truncate to length *n*.

- char(*n*) always *printed/stored* using *n* characters: pad with ␣. ⚠️ Trailing blanks removed before computation.

4 ┆ NUMERIC:[2] Large Numeric Values with Exact Arithmetics

<u>numeric</u>(*precision*, *scale*)

$$\underbrace{1234567.\overbrace{890}^{\textit{scale}}}_{\textit{precision}\ \text{(\# of digits)}}$$

- Shorthand: numeric(*precision*,0) ≡ numeric(*precision*). numeric ≡ "∞ *precision*" (PostgreSQL limit: 100000+).
- Exact arithmetics, but computationally heavy.
- Leading/trailing 0s *not* stored ⇒ variable-length data.

[2] Synonymous: decimal.

Long NUMERICs Carry a Lot(!) of Bits (Tupper's Formula)

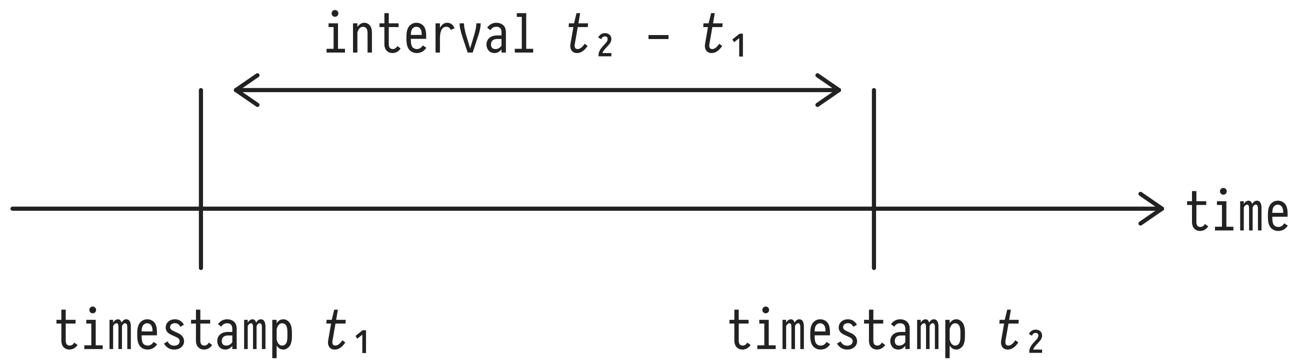
A numeric value of hundreds of digits can encode a lot of information in a single table cell. Consider:

Tupper's formula (with $x \in [0,106)$ and $y \in [k,k+17)$)

$$\frac{1}{2} < \left\lfloor \mathrm{mod}\left(\lfloor y/17 \rfloor\ 2^{-17\,\lfloor x \rfloor\ -\ \mathrm{mod}(\lfloor y \rfloor,\ 17)},\ 2\right)\right\rfloor$$

decodes *k = 9609397···‹530 digits omitted›···8404719* to give:

5 ¦ Timestamps and Time Intervals



- Types: timestamp ≡ (date, time). Casts between types: timestamp→time/date ✓, date→timestamp assumes 00:00:00. Optional timezone support: τ with time zone or ‹τ›tz.
- Type interval represents timestamp differences.
- Resolution: timestamp/time/interval: 1 µs, date: 1 day.

Date/Time Literals: PostgreSQL

- Literal input and output: flexible/human-readable, affected by `SET datestyle='{German,ISO},{MDY,DMY,YMD}'`

  output input

- `timestamp` literal ≡ `'‹date literal›␣‹time literal›'`

- `interval` literal (fields optional, *s* may be fractional) ≡ `'‹n›years ‹n›months ‹n›days ‹n›hours ‹n›mins ‹s›secs'`

- Special literals:
  - `timestamp`: `'epoch'`, `'[-]infinity'`, `'now'`
  - `date`: `'today'`, `'yesterday'`, `'tomorrow'`, `'now'`

Computing with Time

- Timestamp arithmetic via `+`, `-` (`interval` also `*`, `/`):

```
SELECT ('now'::timestamp - 'yesterday'::date)::interval
```

interval
1 day 17:27:47.454803

- PostgreSQL: *Extensive* library of date/time functions including:
  - `timeofday()` (⚠️ yields `text`)
  - `extract(field from •)`
  - `make_date(•,•,•)`, `make_time(…)`, `make_timestamp(…)`
  - comparisons (`=`, `<`, ...), `(•,•) overlaps (•,•)`

6 ┆ Enumerations

Create a *new* type τ, incomparable with any other. Explicitly **enumerate** the literals v_i of τ:

```
CREATE TYPE τ AS ENUM (v₁, …, vₙ);

SELECT vᵢ::τ;
```

- Literals v_i in case-sensitive quoted notation '…'. (Storage: 4 bytes, regardless of literal length.)
- Implicit ordering: $v_i < v_{i+1}$ (aggregates MIN, MAX ✓).

7 ¦ Bit Strings

- Data type bit(*n*) stores strings of *n* binary digits (storage: 1 byte per 8 bits + constant small overhead).

- Literals:

```
SELECT B'00101010', X'2A', '00101010'::bit(8), 42::bit(8)
```

$\underbrace{\texttt{X'2A'}}_{2 \times 4 \text{ bits}}$

- Bitwise operations: & (and), | (or), # (xor), ~ (not), <</>> (shift left/right), get_bit(·,·), set_bit(·,·)

- String-like operations: || (concatenation), length(·), bit_length(·), octet_length(·), position(· in ·), …

8 ¦ Binary Arrays (BLOBs)

Store **binary large object blocks** (BLOBs; 🖼, ♫♬ in column B of type bytea) inline with alpha-numeric data. BLOBs remain *uninterpreted* by DBMS:

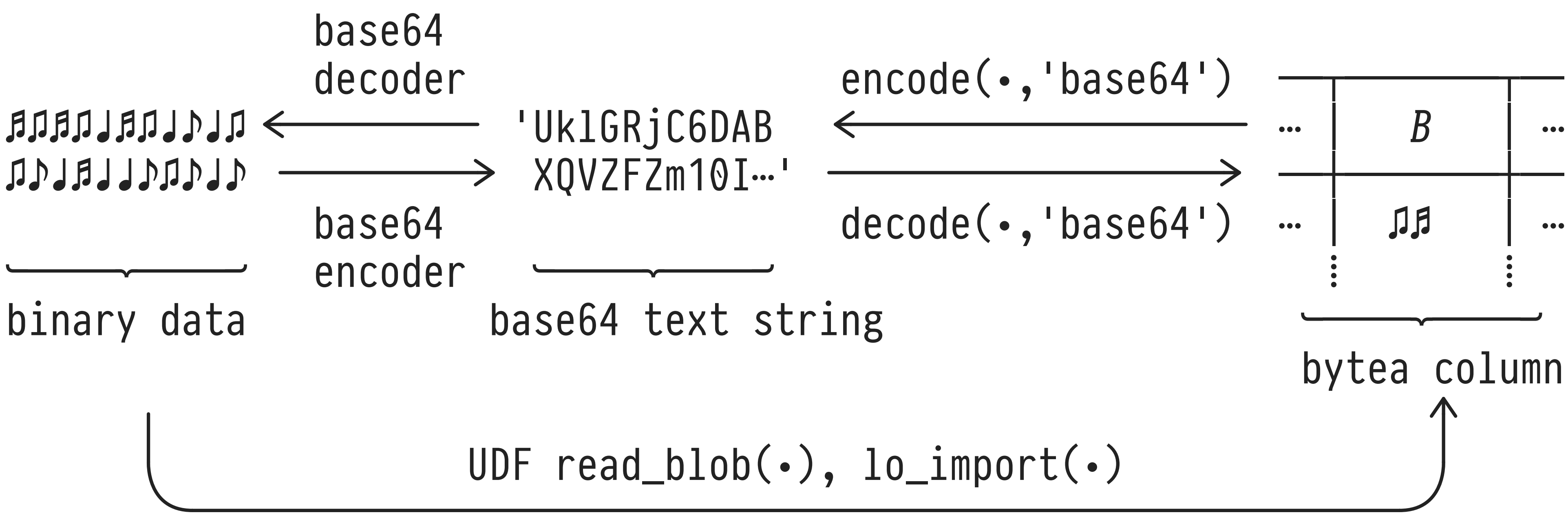
…	K	B :: **bytea**	P	…
	⋮	⋮	⋮	
	k_i	🖼	p_i	
	k_j	♫♬	p_j	
	⋮	⋮	⋮	

Table T

- Typical setup:
  - BLOBs stored alongside identifying **key** data (column K).
  - Additional **properties** (meta data, column(s) P) made explicit to filter/group/order BLOBs.

Encoding/Decoding BLOBs

- Import/export bytea data via textual encoding (*e.g.*, base64) or directly from/to binary files:



⚠️ File I/O performed by DBMS server (paths, permissions).

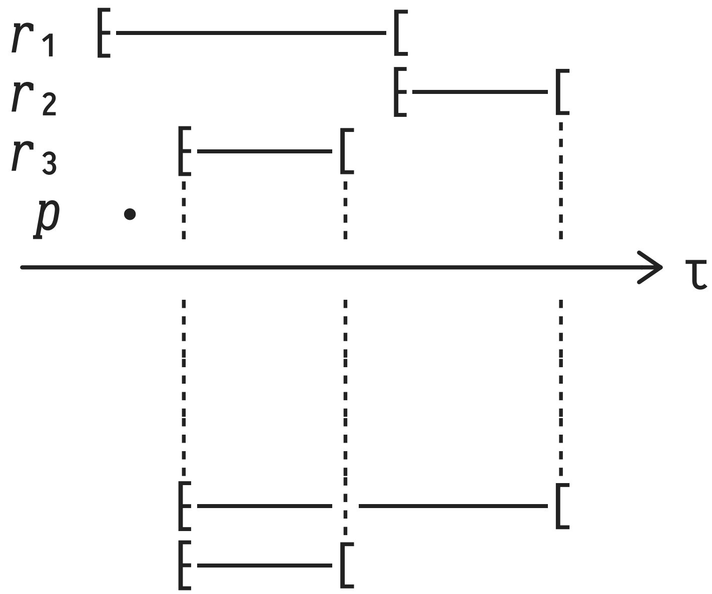
9 ¦ Ranges (Intervals)

Given lower and/or upper bounds ℓ, u of an ordered type $\tau \in$ {int4,int8,num(eric),timestamp,date}, construct **range** literals of type ‹τ›range via

[ℓ,u]	$\ell \leqslant x \leqslant u$	[————]
[ℓ,u)	$\ell \leqslant x < u$	[————[
(,u]	$x \leqslant u$	··————]
(ℓ,)	$\ell < x$	]————··
empty	ϕ	

- Alternatively use function ‹τ›range(ℓ,u,'[)'). NULL represents no bound (∞).

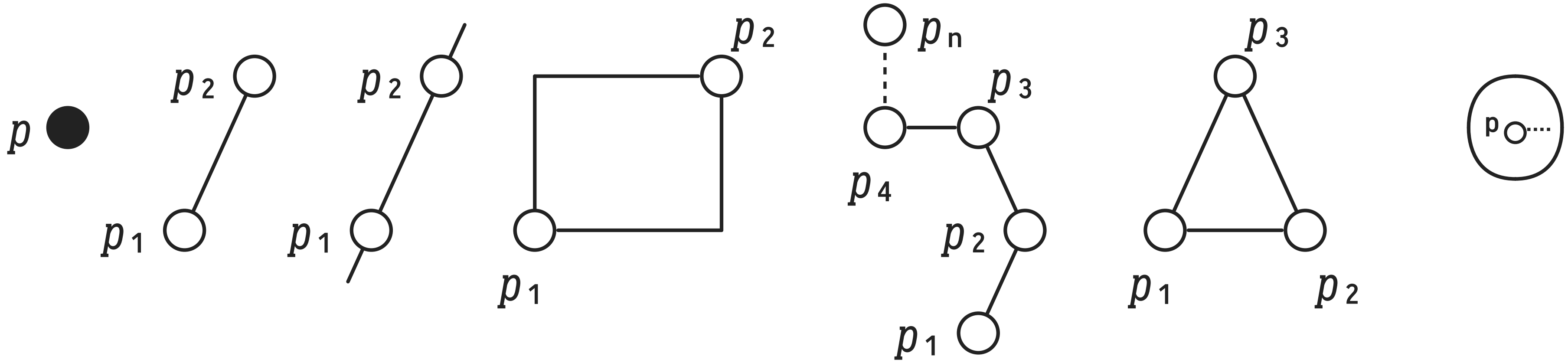
Range Operations



r_1 @> p	r_3 <@ r_1	contains, contained by
r_1 -|- r_2		is adjacent to
r_3 << r_2	r_1 << r_2	strictly left of
r_2 + r_3		union
r_1 * r_3		intersection
r_1 && r_3		overlaps

- Additional family of range-supporting functions:
  - `lower(·)`, `upper(·)` (bound extraction)
  - `lower_inc(·)` (bound closed?), `lower_inf(·)` (unbounded?)
  - `isempty(·)`

Constructing **geometric objects** in PostgreSQL:



'(x,y)'
point(x,y) line(p_1,p_2) box(p_1,p_2) '[$p_1,\ldots,p_n$]' (open path) '($p_1,\ldots,p_n$)' (polygon) circle(p,r)

lseg(p_1,p_2)

- Alternative quoted literal syntax (see PostgreSQL docs):
  - '$((x_1,y_1),(x_2,y_2))$'::lseg, '<$(x,y),r$>'::circle, ...

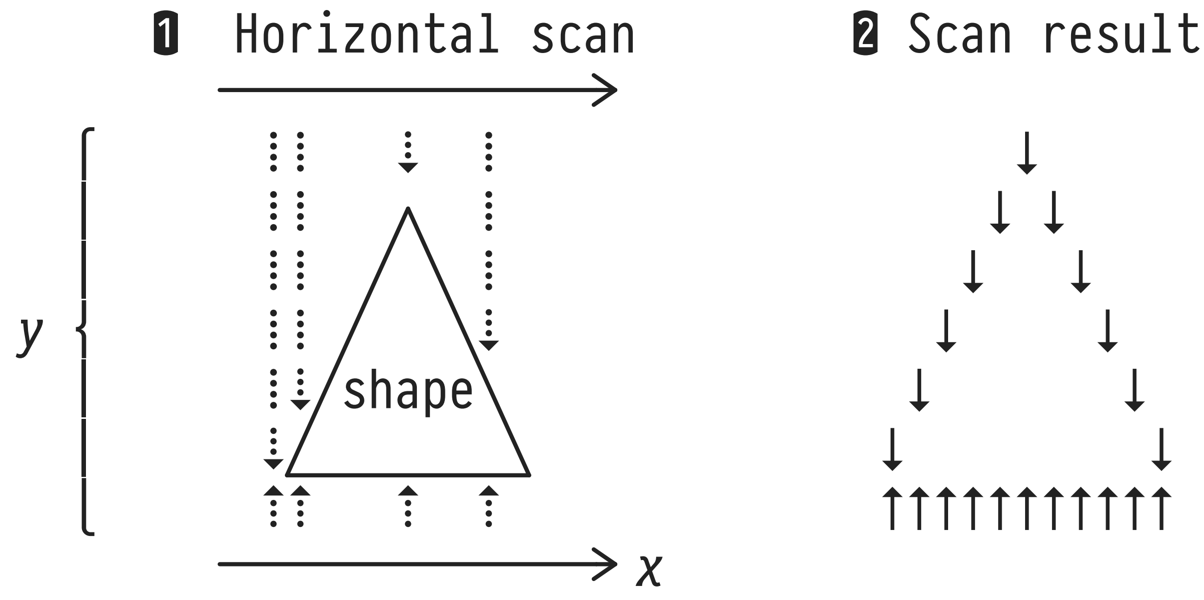
Querying Geometric Objects

- A vast library of geometric operations (excerpt):

	Operation		Operation
+, -	translate	area(·)	area
*	scale/rotate	height(·)	height of box
@-@	length/circumference	width(·)	width of box
@@	center	bound_box(·,·)	bounding box
<->	distance between	diameter(·)	diameter of circle
&&	overlaps?	center(·)	center
<<	strictly left of?	isclosed(·)	path closed?
?-|	is perpendicular?	npoints(·)	# of points in path
@>	contains?	pclose(·)	close an open path

- Use *p*[0], *p*[1] to access x/y coordinates of point *p*.

Use Case: Shape Scanner



- Given an unknown shape (a polygon geometric object):
  1. Perform horizontal “scan” to trace minimum/maximum (*i.e.*, bottom/top) y values for each x.
  2. Use bottom/top traces to render the shape.

11 ¦ JSON (JavaScript Object Notation)

JSON defines a textual data interchange format. Easy for humans to write and machines to parse (see http://json.org):

```
‹object›   ::= {} | { ‹members› }
‹members›  ::= ‹pair› | ‹pair› , ‹members›
‹pair›     ::= ‹string› : ‹value›
‹array›    ::= [] | [ ‹elements› ]
‹elements› ::= ‹value› | ‹value› , ‹elements›
‹value›    ::= ‹string› | ‹number› | true | false | null
             | ‹array› | ‹object›
```

- SQL:2016 defines SQL↔JSON interoperability. JSON ‹*value*›s may be constructed/traversed and held in table cells (we still consider 1NF to be intact).

JSON Sample ‹*value*›s

```
                    ‹members›
   { "title":"The Last Jedi", "episode":8 }
   ↑
‹object›                           ‹pair›
```

Table T (see Chapter 02):

```
             [ { "a":1, "b":"x", "c":true,  "d":10   },
               { "a":2, "b":"y", "c":true,  "d":40   },
‹elements›     { "a":3, "b":"x", "c":false, "d":30   },
               { "a":4, "b":"y", "c":false, "d":20   },
               { "a":5, "b":"x", "c":true,  "d":null } ]
                      ↑                                ↑
                  ‹number›                ‹array› (of ‹object›s)
```

JSON in PostgreSQL: Type jsonb[3]

Quoted literal syntax embeds JSON values in SQL queries.
Casting to type jsonb validates and encodes JSON syntax:

```
VALUES (1, '{ "b":1, "a":2 }'              ::jsonb),
       (2, '{ "a":1, "b":2, "a":3 }'             ),
       (3, '[ 0,   false,null ]'                 );
```

column1	column2
1	{"a": 2, "b": 1}
2	{"a": 3, "b": 2}
3	[0, false, null]

[3] Alternative type json preserves member order, duplicate fields, and whitespace.
⚠️ Reparses JSON values on each access, no index support.

Navigating JSON Values

- Given a JSON value *value*, **access** object field *f* (or array element at index *i*) using **subscripting** via [·]:[4]

value[*f*]	}	yields a jsonb value, navigate further or
value[*i*]		cast to atomic type for further computation

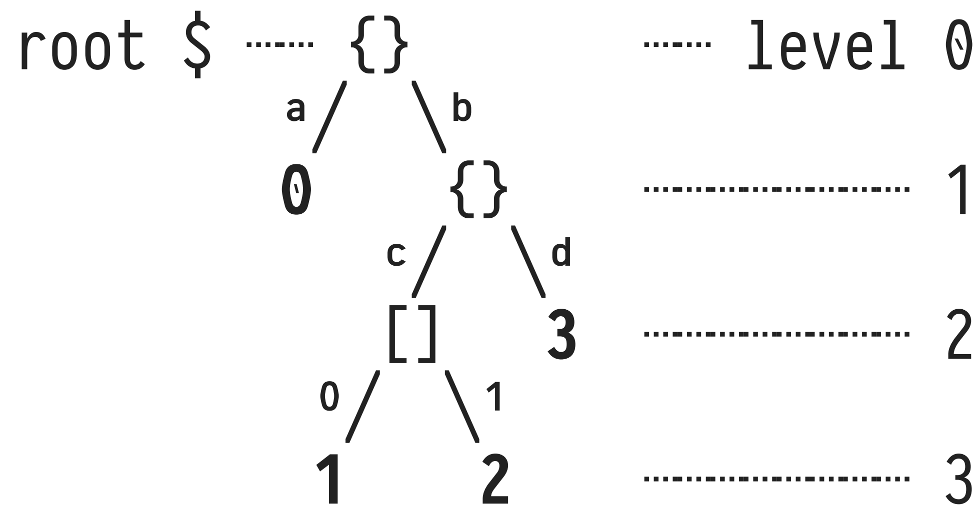
- **Path navigation:**
  1. Chain navigation steps via *value*[f_1][f_2]⋯[f_n].
  2. Use SQL/JSON Path, see jsonb_path_* function family.

[4] Accessing non-existent *f*/*i* yields NULL. Arrays are 0-based, negative indexes count from array end.

Navigating JSON Values: The SQL/JSON Path Language

- JSON values describe **tree-shaped** data:

```
o ≡ { "a": 0,
      "b": { "c": [1,2],
             "d": 3
           }
    }
```

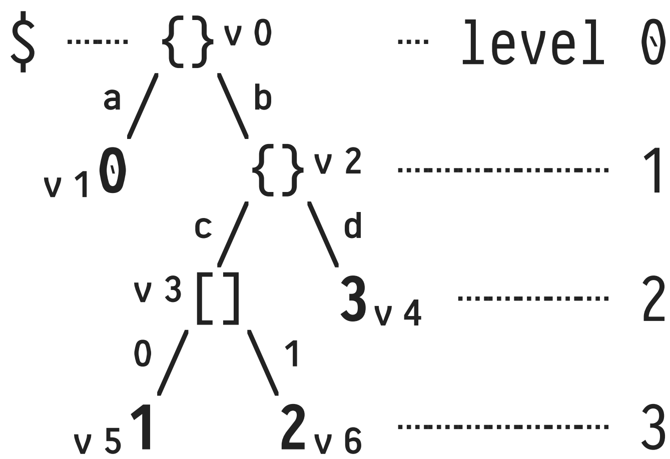


- Navigate from root $, return table of jsonb values *j*:

```
SELECT j
FROM   jsonb_path_query(o, path) AS j
```

embed JSON/SQL Path expression as quoted literal

Navigating JSON Values: The SQL/JSON Path Language




```
SELECT j
FROM   json_path_query(o, path) AS j
```

path	**results** *j*	
$	v_0	root
$.*	v_1 v_2	all child values of the root
$.a	v_1	child a of the root
$.b.d	v_4	grandchild c below child b
$.b.c[1]	v_6	2nd array element of array c
$.b.c[*]	v_5 v_6	all array elements in array c
$.**	v_0 v_1 v_2 v_3 v_5 v_6 v_4	recursion: all values including root
$.**{3}	v_5 v_6	all values at level 3
$.**{last}	v_1 v_5 v_6 v_4	all leaf values

Bridging between JSON and SQL

Turn the fields and/or nested values inside JSON object $o \equiv \{ f_1{:}v_1, \ldots, f_n{:}v_n \}$ or array $a \equiv [v_1, \ldots, v_n]$ **into tables** which we can query:[5]

```
SELECT *
FROM   jsonb_each(o)
```

key	value
f_1	v_1
⋮	⋮
f_n	v_n

```
SELECT *
FROM   jsonb_array_elements(a)
```

value
v_1
⋮
v_n

[5] Re jsonb_each(·): jsonb_to_record(·) or jsonb_populate_record(τ,·) help to create typed records.

Constructing JSON Values

- row_to_json(•)::jsonb

  Convert a single **SQL row into a JSON object.** Column names turn into JSON field names:

```
SELECT row_to_json(t)::jsonb -- yields objects of the form
FROM   T AS t;               -- {"a":•,"b":•,"c":•,"d":•}
```

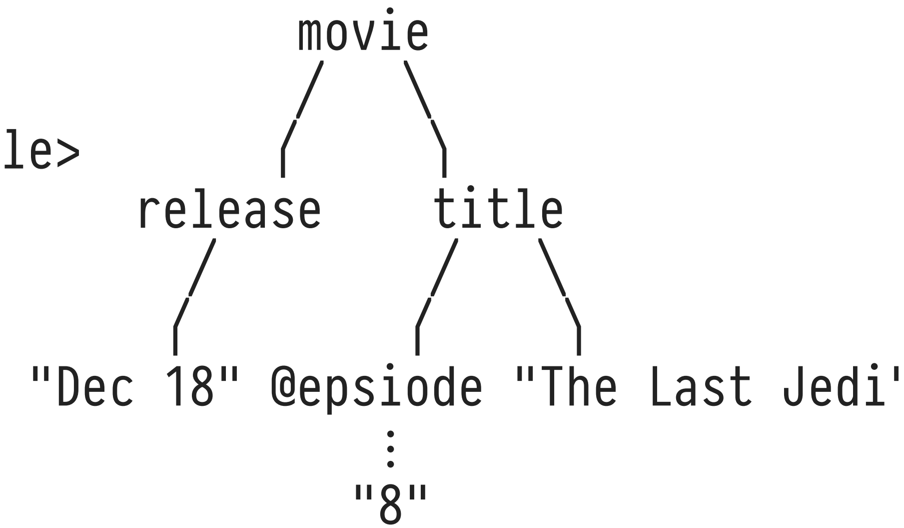
- array_to_json(array_agg(•))::jsonb

  Aggregate **JSON objects into a JSON array:**

```
--  a unity for now, see Chapter 04
--
SELECT array_to_json(array_agg(row_to_json(t)))::jsonb
FROM   T AS t;
```

XML defines a textual format describing ordered *n*-ary trees:

```
<movie>
  <release>Dec 18, 2017</release>
  <title episode="8">The Last Jedi</title>
</movie>
```



- XML support in SQL predates JSON support. Both are similar in nature. XML not discussed further here.[6]

[6] See the course *Database-Supported XML Processors*.

13 ¦ Sequences

Sequences represent counters of type bigint ($-2^{63}\ldots2^{63}-1$).
Typically used to implement row identity/name generators:

```
CREATE SEQUENCE seq     -- sequence name
  [ INCREMENT inc ]     -- advance by inc (default: 1≡↑)
  [ MINVALUE min ]      -- range of valid counter values
  [ MAXVALUE max ]      --   (defaults: [1…2⁶³-1])
  [ START start ]       -- start (default: min if ↑, max if ↓)
  [ [NO] CYCLE ]        -- wrap around or error(≡ default)?
```

- Columns can be tied to a sequence for key generation:

```
CREATE TABLE T (…,c int GENERATED ALWAYS AS IDENTITY,…)
                ⇩
CREATE SEQUENCE T_c_seq;
```

Advancing and Inspecting Sequence State

- Counter state can be (automatically) advanced and inspected:

```
CREATE SEQUENCE seq START 41 MAXVALUE 100 CYCLE;
   ⋮
SELECT nextval('seq');        --  ⇛ 41
SELECT nextval('seq');        --  ⇛ 42
SELECT currval('seq');        --  ⇛ 42
SELECT setval ('seq',100);    --  ⇛ 100 (+ side effect)
SELECT nextval('seq');        --  ⇛ 1   (wrap-around)
                ↑
   ⚠️  sequence/table names are not first class in SQL
```

- GENERATED ALWAYS AS IDENTITY creates a sequence and automatically draws values to populate key columns.