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)
‹τ›(‹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 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, 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

numeric(‹*precision*›, ‹*scale*›) $\underbrace{1234567.\overbrace{890}^{\textit{scale}}}_{\textit{precision}\ (\#\ \textbf{of}\ \text{digits})}$

- 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)

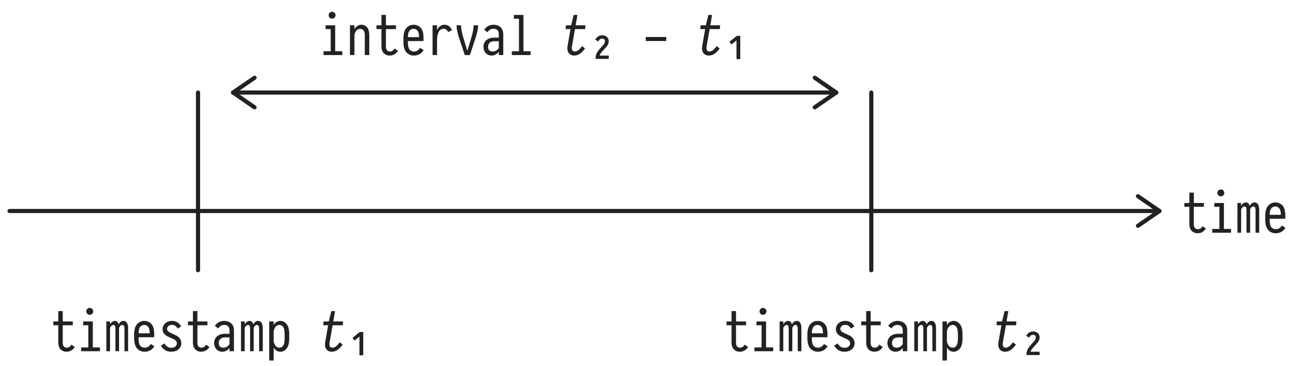
A numeric value of hundreds of digits can encode a lot of information in a single table cell. Consider:

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

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

decodes $k = 9609397 \cdots$ *‹530 digits omitted›* $\cdots 8404719$ 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='$\underbrace{\texttt{\{German,ISO\}}}_{\text{output}}$,$\underbrace{\texttt{\{MDY,DMY,YMD\}}}_{\text{input}}$'

- 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 *, /):

```sql
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 string notation '…'. (Storage: 4 bytes, regardless of literal length.)

- Implicit ordering: $v_i < v_j$ (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) in-line with alpha-numeric data. BLOBs remain *uninterpreted* by DBMS:

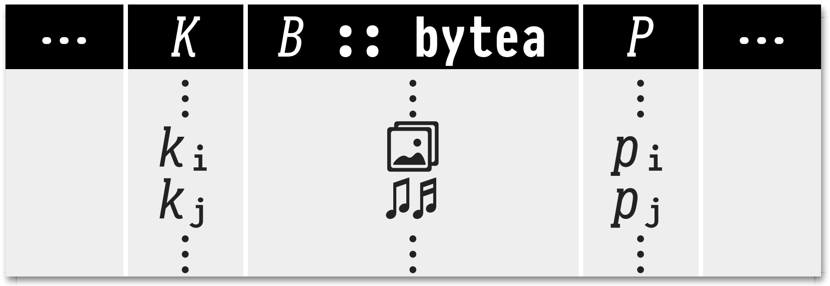
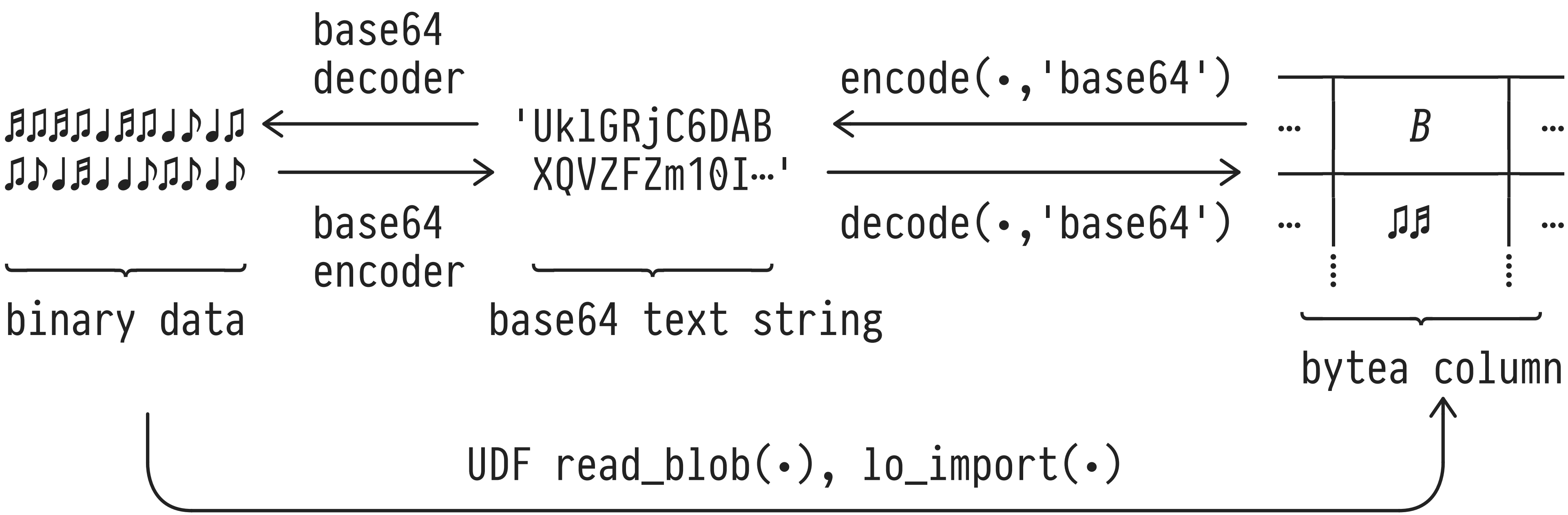


Table T

- 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).

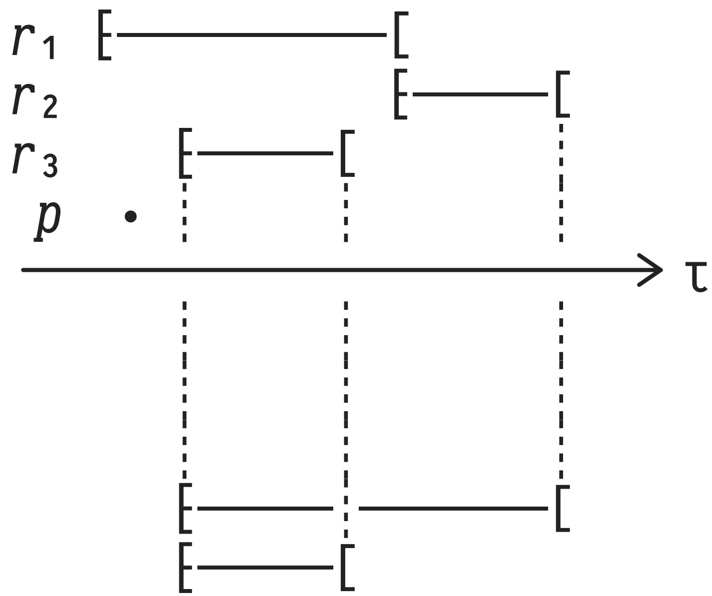
9 ¦ Ranges (Intervals)

Given lower and/or upper bounds ℓ, u of an ordered type ‹τ› ∈ {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 (∞).

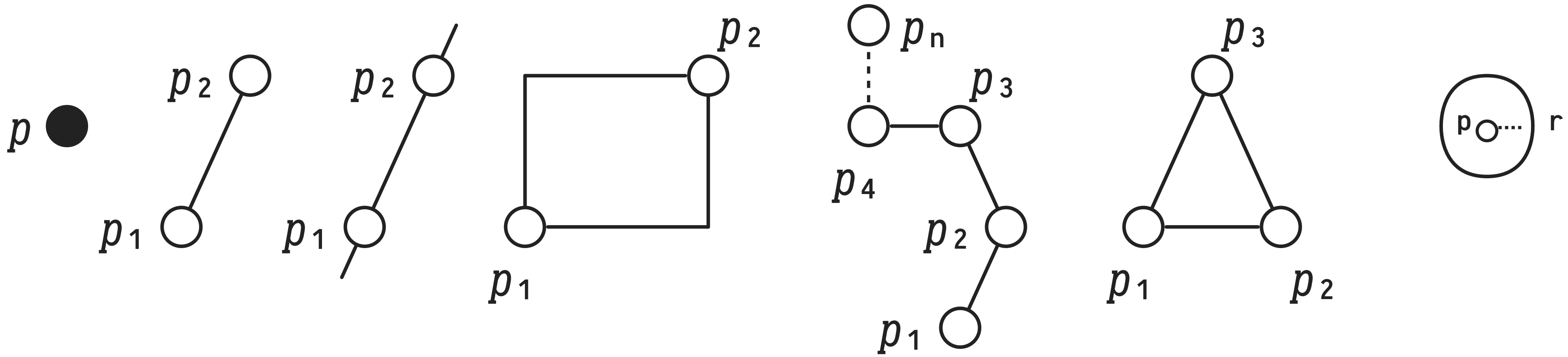
Range Operations



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,…,p_n]' (open path) '(p_1,…,p_n)' (polygon) circle(p,r)

lseg(p_1,p_2)

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

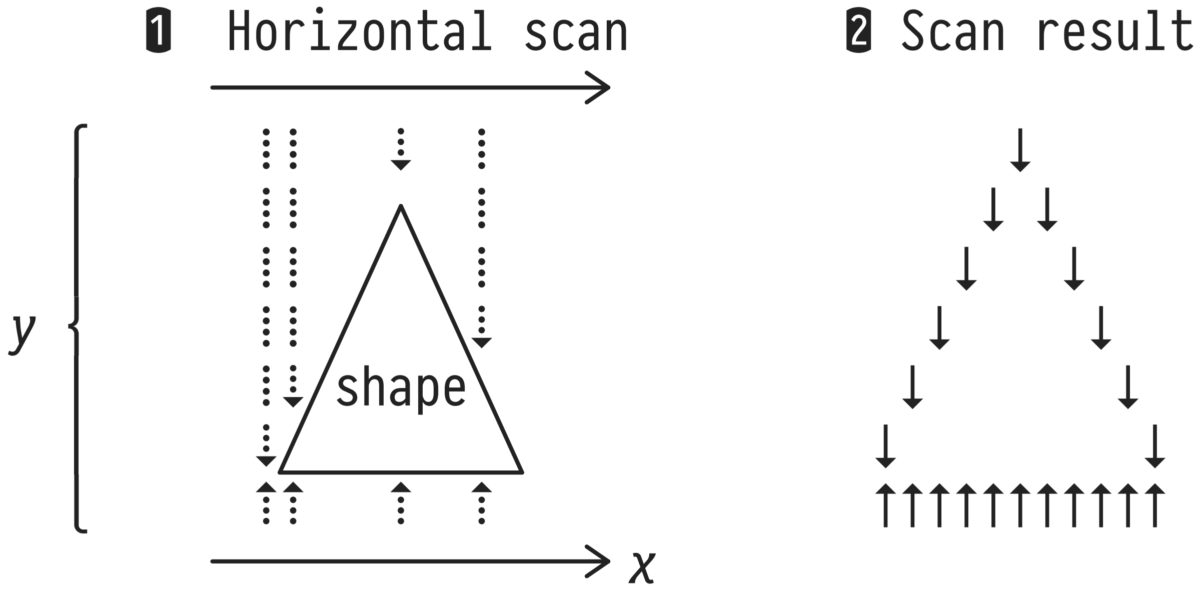
Querying Geometric Objects

- 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

- ‹*p*›[0], ‹*p*›[1] to access x/y coordinate 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):

```
<elements> [ { "a":1, "b":"x", "c":true,  "d":10   },
             { "a":2, "b":"y", "c":true,  "d":40   },
             { "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]

Literal string syntax embeds JSON ‹*value*›s 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 *‹value›*s

- **Access** field *f* / element at index *i* in array *‹value›* via `->` or `->>`:[4]

‹value›->*‹f›* *‹value›*->*‹i›*	yields a jsonb value, permits further navigation steps via ->, ->>
‹value›->>*‹f›* *‹value›*->>*‹i›*	yields a text value (cast to atomic type for further computation)

- **Path navigation:** chain multiple navigation steps via `#>` or `#>>`: *‹value›* `#>` '{*‹f* or *i›*,...,*‹f* or *i›*}'.

[4] Extracting non-existing fields yields NULL. JSON arrays are 0-based.

Bridging between JSON and SQL

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

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

key	value
$\langle f_1 \rangle$	$\langle v_1 \rangle$
$\vdots$	$\vdots$
$\langle f_n \rangle$	$\langle v_n \rangle$

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

value
$\langle v_1 \rangle$
$\vdots$
$\langle v_n \rangle$

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

Constructing JSON ‹*value*›s

- 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 ‹*object*›s 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>
```

```
                 movie
                /     \
         release       title
           /          /     \
"Dec 18" @epsiode "The Last Jedi"
                :
               "8"
```

- 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*.

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›, ↓‹max›)
  [ [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 1st class in SQL
```

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