

INTRODUCTION TO RELATIONAL DATABASE SYSTEMS

DATENBANKSYSTEME 1 (INF 3131)

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DATABASE DESIGN

- Given a particular mini-world, almost always will there be plenty of options on how to choose
 - column data types,
 - table schemata, and
 - relationships between tables (e.g., foreign keys).
- The upcoming material discusses **table and database design** options, and introduces
 - **relational normal forms** that measure the redundancy of a given table design, and
 - the **Entity Relationship (ER)** model that translates a graphical sketch of a mini-world into table designs.
- Along the way, we will pick up plenty of further SQL constructs, some basic, some advanced.

ATOMIC VALUES IN TABLE CELLS

- The relational data model is **flat**: table cell values are **atomic**. Be more precise now.

Atomic Values, First Normal Form

We regard a value v as being **atomic** if v does *not* possess a tabular structure.

A table whose cell values are atomic is in **First Normal Form (1NF)**.

- Under this definition ...
 1. ... is a string (e.g., of type `text`) value in a table cell atomic?
 2. ... is a value of type `date` (with day, month, year components) atomic?
 3. ... is a value of a row type atomic?
 4. ... is an array of type `t[]` (with type `t` being atomic) atomic?
 5. ... is a table nested inside a table cell atomic?

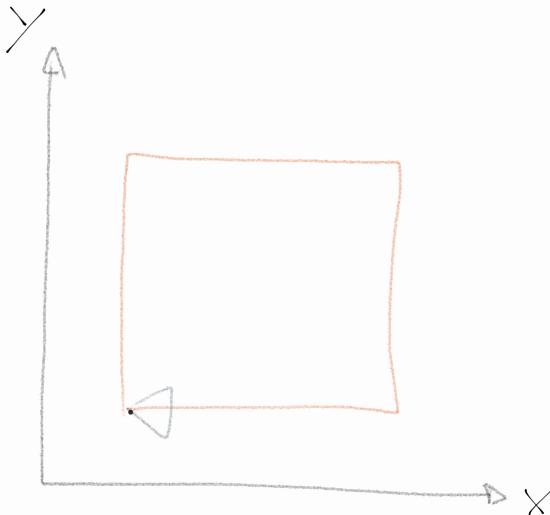
(STRUCTURED) TEXT IN TABLE CELLS

- Use column `turtle` of type `text` to hold a **list** of Logo-style drawing commands.


Text encoding of drawing commands: `'p,x,y; ...'`: put pen up/down ($p \in \{u,d\}$), then move pen by x units right and y units up across paper.

shapes

<u>id</u>	shape	turtle
1	square	'd,0,10; d,10,0; d,0,-10; d,-10,0'
2	triangle	'd,5,10; d,5,-10; d,-10,0'
3	cross	'd,0,10; u,-5,-5; d,10,0'
⋮	⋮	⋮



(STRUCTURED) TEXT IN TABLE CELLS

- If `r` is a row of table `shapes`, SQL DML commands can use `r.turtle` to **access the entire string of drawing commands** in SQL expressions. From the viewpoint of SQL, column `turtle` is atomic.
- PostgreSQL's library of string functions and operators can access selected individual parts of the string:
`https://www.postgresql.org/docs/current/functions-string.html`.
- To access the list of individual drawing command either requires
 1. **PostgreSQL-specific support** for regular expression matching (e.g., `regexp_split_to_table()`: return a table of substrings, i.e., generate a tabular structure that is accessible for SQL), or
 2. an **iterative or recursive SQL query** that chops off the leading '`p,x,y;`' triple until the drawing command string is empty.
- Both options are awkward and inefficient.
-  **Encoding structured content in text cells** is (all too) common but **definitely bad table design practice**. Interesting and relevant mini-world structure is hidden from SQL.

ARRAYS IN TABLE CELLS

- For any type *t* (including the user-defined types, e.g., composite types), PostgreSQL also supports *t[]*, its associated **array type**. All elements of a *t[]* array are of type *t*:

```
ARRAY[v1 :: t, v2 :: t, ...]    -- array of t elements, printed as {v1,v2,...}  
ARRAY[] :: t[]                    -- empty array of t elements, printed as {}
```

- **Accessing array *xs*:**

```
xs[i]          -- indexed access, i ≥ 1 (NULL if outside bounds)  
xs[i:j]        -- array slice
```

- **Array operations:**

```
=, <>, <, >      -- array to array comparison  
expression {=|<|>|...} {ANY|ALL}(xs) -- element to array comparison  
@>, <@, &&      -- contains, is contained by, overlaps  
||              -- concatenation
```

ARRAYS IN TABLE CELLS

- Encode the list of turtle drawing commands in terms of
 1. user-defined row type (down boolean, x integer, y integer) named `cmd`, and
 2. column `turtle` of array type `cmd[]`:

`shapes`

id	shape	turtle
1	square	{(t,0,10), (t,10,0), (t,0,-10), (t,-10,0)}
2	triangle	{(t,5,10), (t,5,-10), (t,-10,0)}
3	cross	{(t,0,10), (f,-5,-5), (t,10,0)}

- Access the individual elements of an array via PostgreSQL's table-generating function `unnest()`. Function call `unnest(ARRAY[v1, v2, v3, ...])` yields

v_1
v_2
v_3
\vdots

TABLES IN TABLE CELLS

- **Recursively** apply the idea of structuring information in tabular form: use a **nested table** to represent the turtle drawing command lists. We end up with a table in **Non-First Normal Form (NFNF, NF²)**.

shapes

<u>id</u>	shape	turtle	
1	square	<u>pos</u>	command
		1	(t,0,10)
		2	(t,10,0)
		3	(t,0,-10)
		4	(t,-10,0)
2	triangle	<u>pos</u>	command
		1	(t,5,10)
		2	(t,5,-10)
		3	(t,-10,0)
3	cross	<u>pos</u>	command
		1	(t,0,10)
		2	(f,-5,-5)
		3	(t,10,0)


TABLES IN TABLE CELLS (NF²)

- Notes:

1. Column `pos` encodes command order (list semantics) in the nested tables.
2. Outer table `shape` has 3 rows. Type of `turtle`: `table(pos int, command cmd)`.
3. NF² admits recursion to arbitrary depth. “NF² SQL” queries reflect this recursion:

```
-- Find shapes drawn with multiple strokes
SELECT s.id, s.shape
FROM   shapes AS s
WHERE  EXISTS (SELECT 1
                FROM   s.turtle AS c
                WHERE  NOT (c.command).down);
```

-- s.turtle has type table(...)

4.  **No off-the-shelf RDBMS supports the NF² model** (mostly a 1980s research idea). Still a powerful/modular way to think about data modelling.
- Possible: Systematic (algorithmic) conversion of any NF² table into (a bundle of) equivalent 1NF tables.

FROM NF² TO 1NF

nf2to1nf(R) (input: table R , output: a table bundle of size ≥ 1):

```
for each  $a \in \text{sch}(R)$  do
  if  $\text{type}(a) = \text{table}(b_1 \ t_1, \dots, b_k \ t_k, \dots, b_m \ t_m)$  then      } see [★]
    Create a new table  $R_a(a \text{ surrogate}, b_1 \ t_1, \dots, b_k \ t_k, \dots, b_m \ t_m)$  } below
    for each row  $r \in \text{inst}(R)$  do
      Create a new value  $\tau$  of type surrogate
      if table  $r.a$  is not empty then
        for each row  $(v_1, \dots, v_m) \in r.a$  do
          [ Insert row  $(\tau, v_1, \dots, v_m)$  into  $R_a$ 
          [ Set  $r.a$  to  $\tau$  ] if  $r.a$  is empty,  $\tau$  will not have a match in  $R_a$ 
      Set  $\text{type}(a)$  to surrogate
    nf2to1nf( $R_a$ )
```

Notes:

- [★]: If $\{b_1, \dots, b_k\}$ is the key of the table nested in column a , the key of new table R_a will be $\{a, b_1, \dots, b_k\}$.

FROM NF² TO 1NF

- Result of `nf2to1nf(shapes)`, `shapes.turtle` refers to `turtles.turtle` (⚠ in the FK relationship, `turtle` is the source while `shapes` is the target):

`shapes` (R)

<u>id</u>	shape	turtle
1	square	τ_1
2	triangle	τ_2
3	cross	τ_3

`turtles` (R_{turtle})

<u>turtle</u>	<u>pos</u>	command
τ_1	1	(t,0,10)
τ_1	2	(t,10,0)
τ_1	3	(t,0,-10)
τ_1	4	(t,-10,0)
τ_2	1	(t,5,10)
τ_2	2	(t,5,-10)
τ_2	3	(t,-10,0)
τ_3	1	(t,0,10)
τ_3	2	(f,-5,-5)
τ_3	3	(t,10,0)

FROM NF² TO 1NF

The surrogate-based approach ...

1. ... comes with a natural representation of **empty nested tables**, and
2. ... allows to “share” surrogates if **nested tables repeat**.

Add the following two rows to the NF² **shapes** table and consider the consequences (note: existing shape **square** and new shape **rect** use identical drawing commands):

<u>id</u>	shape	turtle	
⋮	⋮	⋮	
4	empty	<u>pos</u>	command
5	rect	<u>pos</u>	command
		1	(t,0,10)
		2	(t,10,0)
		3	(t,0,-10)
		4	(t,-10,0)

FROM NF² TO 1NF

- Transforming data from NF² to 1NF? `nf2to1nf()` ✓
- Transforming queries over NF² data to queries over 1NF data?

```
-- NF2: Find shapes drawn with multiple strokes
SELECT s.id, s.shape
FROM   shapes AS s
WHERE  EXISTS (SELECT 1
                FROM   s.turtle AS c           -- s.turtle has type table(...)
                WHERE  NOT (c.command).down);
```

```
-- 1NF: Find shapes drawn with multiple strokes
SELECT s.id, s.shape
FROM   shapes AS s
WHERE  EXISTS (SELECT 1
                FROM   (SELECT t.*
                        FROM   turtles AS t
                        WHERE  t.turtle = s.turtle) AS c
                WHERE  NOT (c.command).down);
```

} translation of expression
s.turtle

FROM NF² TO 1NF

Simulate a NF² RDBMS

- NF² to 1NF query transformation can be approached systematically as well. If we can transform data *and* queries automatically, we can **simulate a NF²-model RDBMS using a regular 1NF RDBMS**. (Hot research topic of the early 1990s.)
 1. Accept **table and schema definitions** with table-valued columns.
Behind the scenes: apply `nf2to1nf()` to generate equivalent 1NF table bundles.
 2. Accept **DML** statements that insert (delete) table-valued column values.
Behind the scenes: split inserted row into atomic/table-valued column values, distribute inserts between the 1NF tables of the bundle.
 3. Accept **NF² SQL** queries that include functions over tables of values *xs*, e.g., `EMPTY(xs)`, `LENGTH(xs)`, `xs[i]`, `FORALL x IN xs: p(x)`, `EXISTS x IN xs: p(x)`, ...
Behind the scenes: rewrite into regular SQL constructs that operate over the tables of the bundle.

FROM NF² TO 1NF

Simulate a NF² RDBMS

- Sample “NF² SQL” queries (► marks NF² language constructs we have invented). Rewrite into regular SQL queries over 1NF table bundle `shapes`, `turtles` (see above).

```
-- What are the shapes with an empty drawing command list?
SELECT s.id, s.shape
FROM   shapes AS s
WHERE  ►EMPTY(s.turtle);
```

```
-- Which shapes are drawn with the pen down all the time?
SELECT s.id, s.shape
FROM   shapes AS s
WHERE  ►FORALL c IN s.turtle: (c.command).down
```

```
-- Which shapes contain strokes longer than 10 units?
SELECT s.id, s.shape
FROM   shapes AS s
WHERE  ►EXISTS c IN s.turtle: sqrt((c.command).x2 + (c.command).y2) > 10
```

FROM NF² TO 1NF

Simulate a NF² RDBMS

- More sample “NF² SQL” queries:

```
-- First drawing command for each shape
SELECT s.id, s.shape, s.turtle[1].command AS head
FROM   shapes AS s;
```

```
-- Length of drawing command list for each shape ⚠
SELECT s.id, s.shape, LENGTH(s.turtle)
FROM   shapes AS s;
```

- Most of these have a variety of translations to plain SQL (e.g., consider correlated subqueries vs. joins).
- ⚠ Watch out for edge cases, in particular empty nested tables (see shape `empty` in table `shapes`)!