Last week

- We have discussed spatial data models;
  - Spaghetti (without topological storage);
  - Network (for linear structures);
  - Topological (storing the topological elements; full 2D space);
- We have discussed how consistency enforcement can be achieved with software topology or structural topology implementations;
- We have discussed how topological relationships are evaluated in principle;
- We have quickly shown how this is implemented in SQL.
  - We will now extend this knowledge and use the relationships to query data...

Geo875 | FS24
University of Zürich

4. Lecture Spatial Databases

Spatial queries

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Learning Objectives

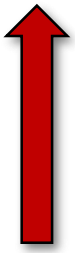
- ✓ You get to know the concept for dealing with staging (temporary) and target (productive) database tables
- ✓ You will learn about types of queries applied in spatial databases
- ✓ You will learn how to query data based on spatial relationships
- ✓ You get an insight on query executing models in a client-server environment

Overview

1. **Spatial Tables: definition and data loading**
2. Spatial queries
3. Where get queries executed?

Recall: spatial data types

	Postgis	Esri (ArcSDE)			Oracle Spatial
Abstract data type for Geometries	geometry	ST_GEOMETRY	SDO_GEOMETRY	BLOB	SDO_GEOMETRY
Database (underlying)	PostgreSQL	many possible	Oracle	Oracle	Oracle DB
Schema (owner)	public	SDE	MDSYS	Basic type of DB	MDSYS
Spatial table – data model	Attribute	Attribute	Attribute	in two tables	Attribute
Structure definition (DDL)	SQL	Esri SW, ±SQL	SQL, Esri SW	Esri SW	SQL
Data inputs (DML)	SQL, QGis, ...	Esri SW, SQL	SQL, Esri SW	Esri SW	SQL, ...
Spatial queries (DQL)	SQL, QGis, ...	Esri SW, SQL	SQL, Esri SW	Esri SW	SQL, ...



We cover this spatial datatype and setup;

Remember - additional Postgis types exist: geography, raster and topology;

Need data in spatial tables to show queries

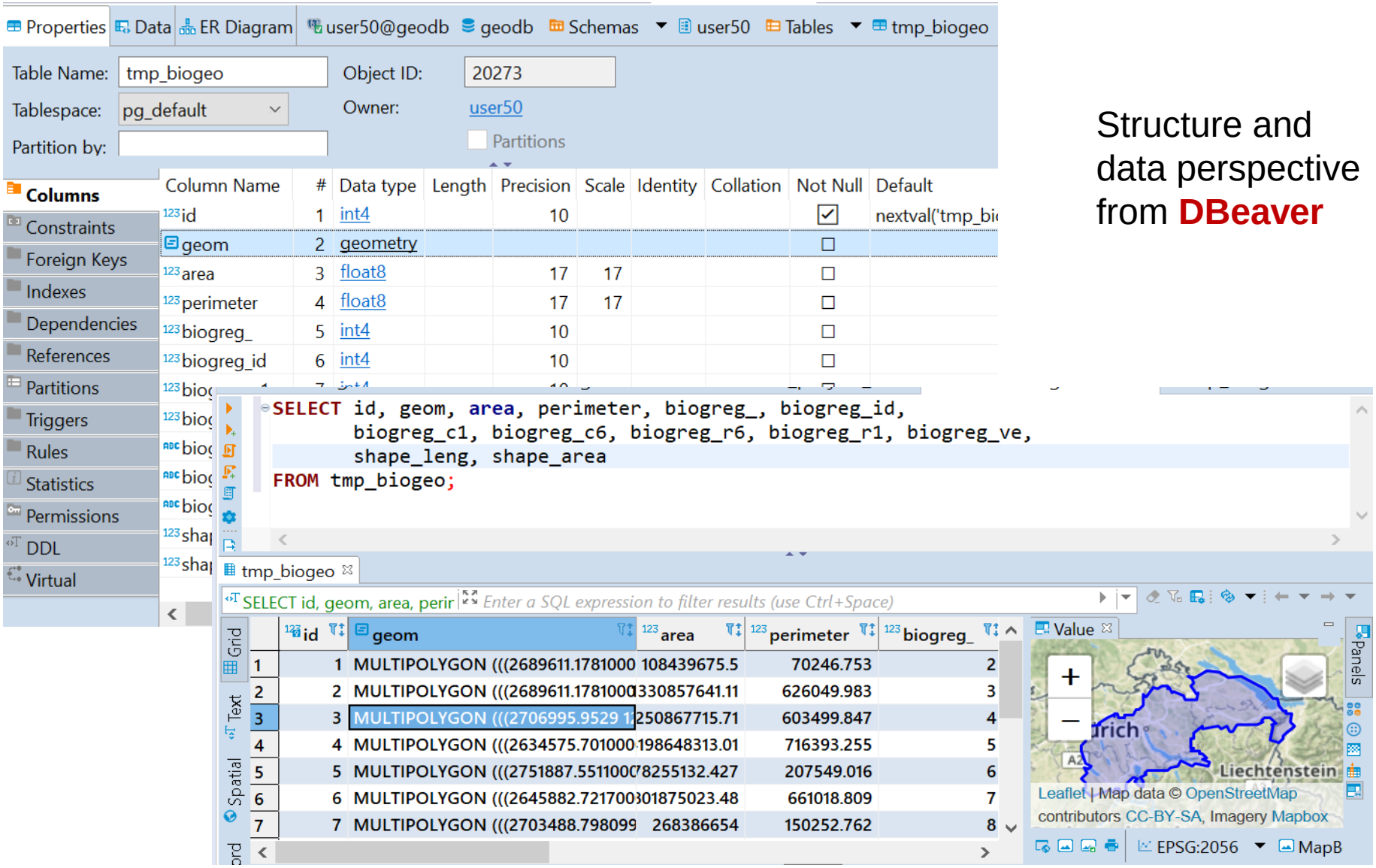
- **Several steps and options**
  - import file data to temporary (=staging) spatial table
  - create target spatial table
  - transfer data to target spatial table

- **Important tasks in these steps**
  a) Converting data types of tables and their data (geometry subtypes but also others; if needed)
  b) Reprojecting
  c) Applying transforming functions in SQL
  d) SQL-inserting records in normal tables having no geometry type (e.g. lookup tables the spatial table depends on)
  e) SQL-inserting records in spatial tables
  f) Digitizing records in spatial tables with QGIS

Import data to staging table (also see project website)

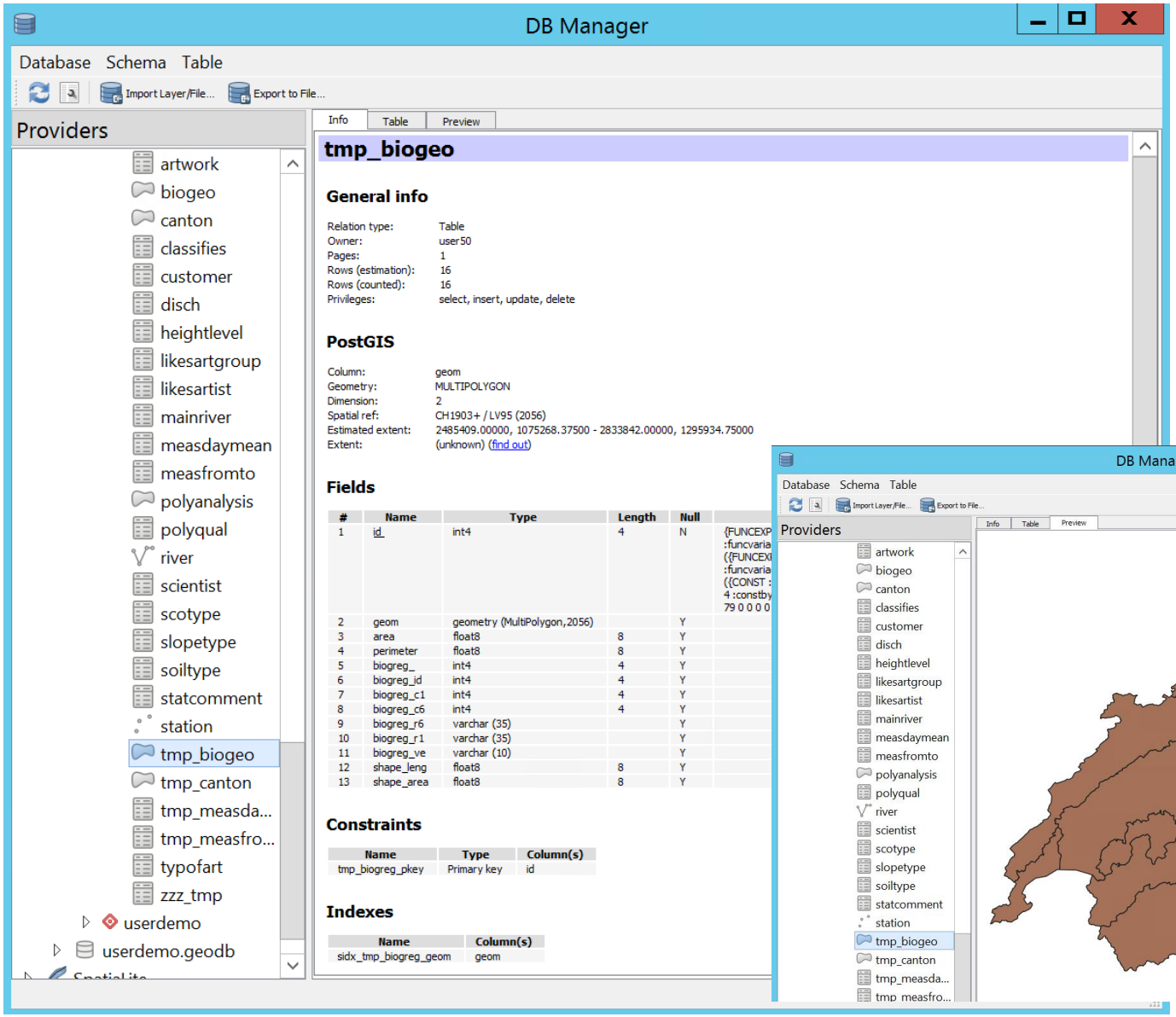
1. **Import dataset to a temporary, staging spatial table in database**
   - QGIS project [with appropriate projection] references file-based datasets
   - Processing toolbox; search for postgres in the processing toolbox;
   - Use 'Export to PostgreSQL' function to export (from QGIS perspective) local data to DB; table in the DB gets created "automatically";
   - In the tool: change schema name from public to your schema e.g. project20
   - Needs QGIS-connection to DB, first; see Browser window; [restart of QGIS required to use it in toolbox...]
2. **Check the temporary spatial table**
   - What was automatically created? What was loaded? Further transformations needed? Errors but still imported? Analyze.
   - Different perspectives!
     Data centric -> DBeaver
     Graphically, GIS centric -> QGIS

Staging table for biogeo region geometries



Structure and data perspective from **DBeaver**

More on the staging table for biogeo region geometries



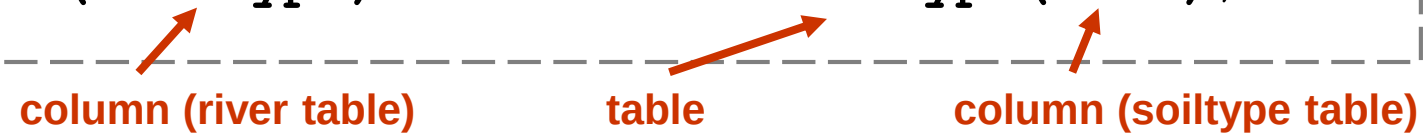
Structural and visual perspective from **QGIS**;
even more info!
see data types;

Lookup tables 1: Create and fill with data

```
-- need to create a 'lookup' table with primary key
CREATE TABLE soiltype
(
  code            smallint,
  description     varchar(64)
);
ALTER TABLE soiltype ADD CONSTRAINT soiltype_pk
PRIMARY KEY (code); -- every table with primary key

-- we need to define and insert the lookupvalues
-- two records at a time in one SQL
INSERT INTO soiltype (code, desription)
VALUES
  (2, 'karbonatisch'),
  (1, 'silikatisch');
```

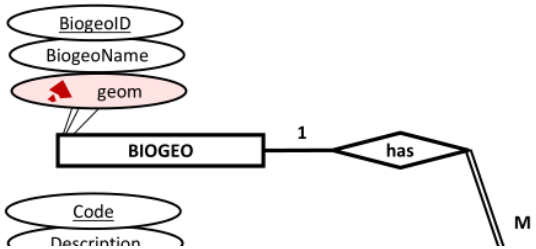
Lookup tables 2: Adjust target table to reference lookup table

```
/*
a) RIVER target table (created beforehand - no DDL sample
code here) needs a foreign key (ER model = N:1)
b) river.soiltype column was introduced as a
consequence of ER model N:1 [river vs. soiltype];
same type but different name in the lookup table:
soiltype.code column;
*/

-- if ER asked for a 'must', we would
ALTER TABLE river ALTER COLUMN soiltype SET NOT NULL;

-- creating foreign key on table river 'glueing' to
   table soiltype
ALTER TABLE river ADD CONSTRAINT river_soiltype_fk
FOREIGN KEY (soiltype) REFERENCES soiltype(code);
```



Create target spatial table biogeo according to my ER derivation

```
-- my destination/target table
CREATE TABLE biogeo
(
  biogeoid    int2,
  biogeoname  varchar(512),
  geom        geometry(multipolygon,2056)
);

-- primary key - always
ALTER TABLE biogeo ADD CONSTRAINT biogeo_pk PRIMARY
KEY (biogeoid);

-- spatial index - mandatory! for spatial columns
CREATE INDEX biogeo_geom_sidx ON biogeo USING
GIST(geom);
```



Data input - transfer records from staging table

Transforming and transfering from one to another table

- Data types from staging tables need to fit the defined ones in target table
- We have to cast the types; e.g. from text to integer; e.g. from 3D to 2D
- We need modifications in the SELECT clause to 'fit' the records

```
INSERT INTO biogeo (biogeoid, biogeoname, geom)
SELECT
  ROW_NUMBER() OVER (ORDER BY 1) biogeoid, -- number up
  CASE WHEN q.deregionna ILIKE '%Zentralalpen%' THEN
  'Zentralalpen' ELSE q.deregionna END AS biogeoname,
  ST_Force2D(ST_multi(ST_union(q.geom))) geom -- grouping
FROM tmp_biogeo q
GROUP BY
      CASE WHEN q.deregionna ILIKE '%Zentralalpen%' THEN
      'Zentralalpen' ELSE q.deregionna END;
```

Data input - with geometry construction SQL

```
-- manually inserting a 'selfmade' polygon to the
polyanalysis spatial table

INSERT INTO polyanalysis (sciid, polyqual, patext,
geom)
VALUES (3, 1, 'an invented multipart analysis poly',
ST_GeomFromText('MULTIPOLYGON(
((2683846 1250116, 2755970 1246114, 2756725 1241991,
2683846 1250116)),
((2700001 1240199, 2346734 1771966, 2700001 1240199)),
)',2056));
```

More on transfering/inserting data

Things to keep in mind

- Recap https://www.geo.uzh.ch/microsite/geo875/faq.html with an example of reprojection of a complete table (subtype SRID and all records)
- ER-model -> Relations -> DB tables; this process leads to hierarchy in the resulting tables because foreign key columns are linked to primary key columns;
- 'Parent' tables have to be filled with records first; E.g. the lookup table soiltype is a parent table to river;
- Tables having no foreign keys pointing to other tables are **on top or at the end of branches [parents without parents]** of an ER-model hierarchy tree
- Use geometry editor functions – if needed; examples: ST_Force2D() or ST_Multi()
- Have a look at ST_Dump family of functions to find a way to e.g. create **singlepart** subtype from a **multipart** subtype aka 'exploding'

Validating data (geometries)

- There are **checking functions** for your geometries ST_IsValid(), ST_IsValidReason() and ST_IsValidDetail()

```
-- check consistency of
SELECT b.id, ST_IsValidDetail(b.geom) FROM tmp_biogeo
b;
```

id	st_isvaliddetail		
	valid	reason	location
1	[ ]	Self-intersection	POINT (2560100.639928136 1138436.6918350607)
2	[ ]	Self-intersection	POINT (2679075.7745317444 1121979.9632743374)
3	[ ]	Self-intersection	POINT (2771039.8912299313 1143390.6823539622)
4	[ ]	Self-intersection	POINT (2526910.0001321808 1168780.0000384077)
5	[v]	[NULL]	[NULL]
6	[v]	[NULL]	[NULL]

```
-- check: is it possible to make them valid? -> yes
SELECT ST_IsValidDetail(ST_MakeValid(b.geom)) FROM
tmp_biogeo b;
-- do replace the geometries with the fixed ones
UPDATE tmp_biogeo SET geom = ST_MakeValid(geom);
```

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Examples used for spatial queries

The following spatial queries are based on these spatial tables

- pubstoppoint (**stop points** of VBZ public transport system in Zurich, point); target final table in my database model;
- tmp_pedline (**pedestrian road** network of Zurich, multipart line) staging table
- tmp_district (**districts** of Zurich, multipart polygon) staging table

Spatial queries

- Thematic queries
  - Selection and filtering of spatial objects based on attribute values (the same as in Geo874)
- Topological queries
  - Selection, filtering of objects based on qualitative spatial relationships (recall last lecture)
- Geometrical queries - includes geometry processing
  - Selection, creation and filtering of objects based on their shape, area, distance, direction,…

PostGIS Reference
https://postgis.net/docs/reference.html
Recall Geo243, see GITTA:
http://www.gitta.info/SpatialQueries/en/html/index.html

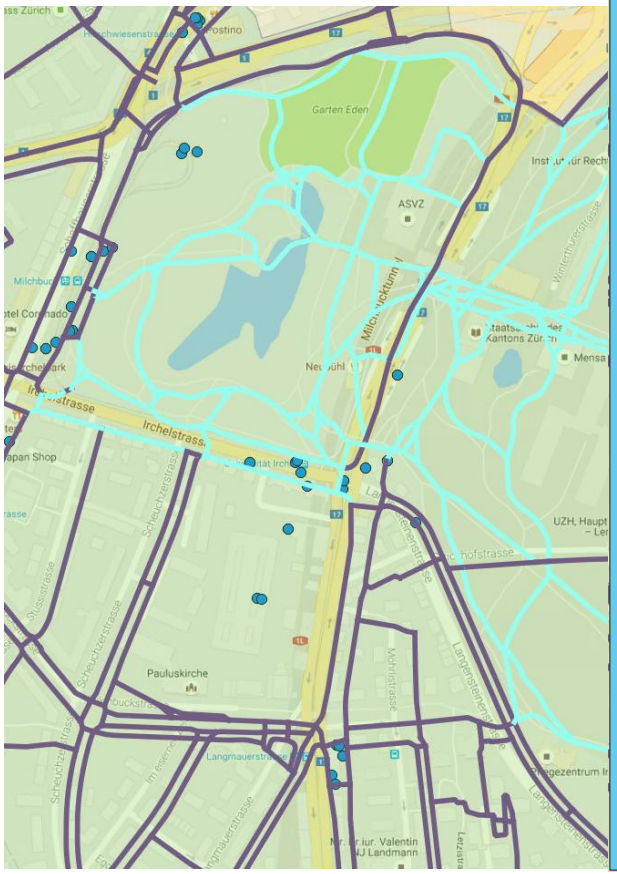
Thematic queries

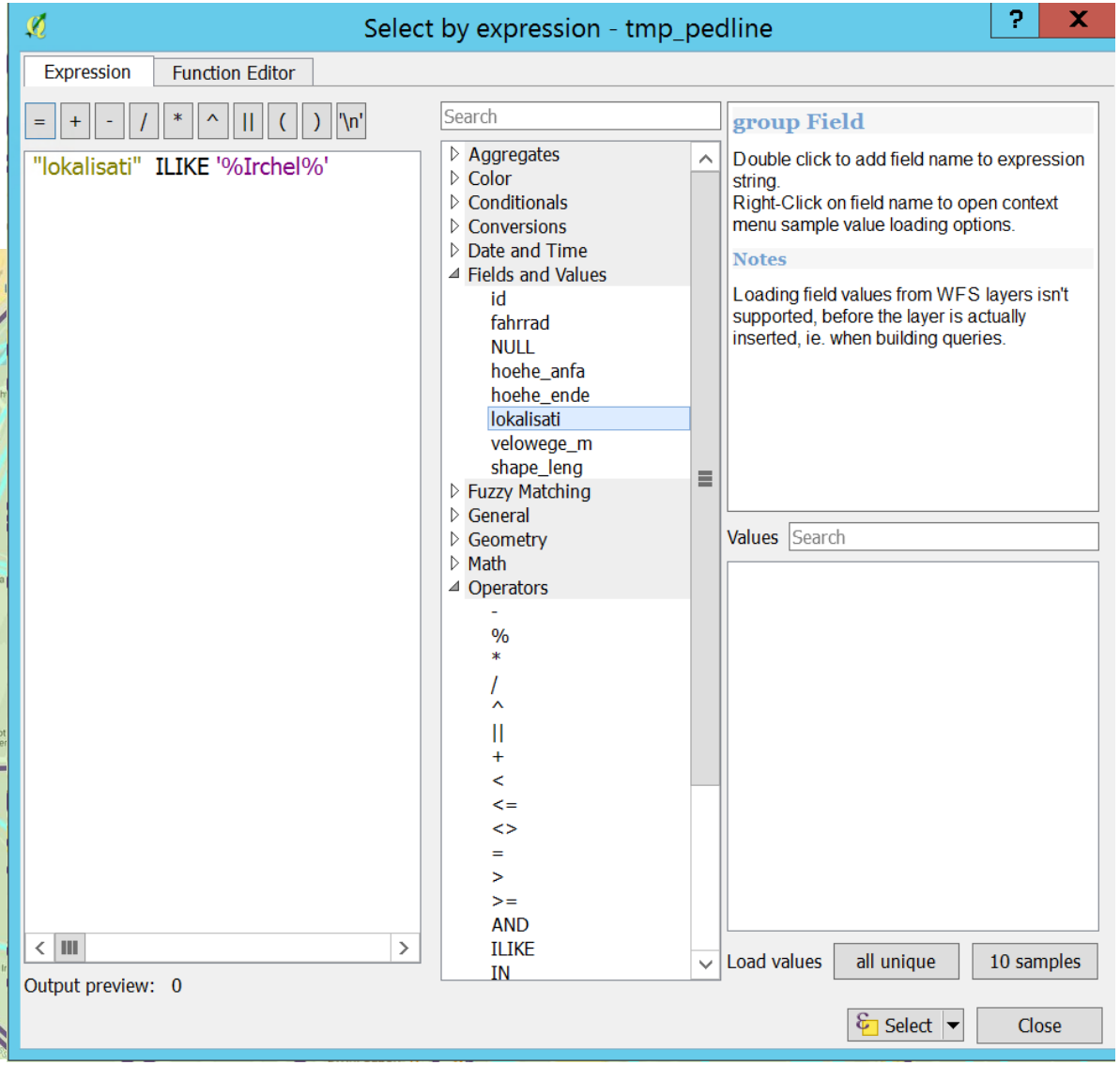
Attribute value restrictions

```
SELECT l.id, l.lokalisati, ST_AsText(l.geom) gtxt
FROM   tmp_pedline l
WHERE  l.lokalisati ILIKE '%Irchel%';

-- divisions of integers get truncated -> cast to numeric
SELECT l.id, CAST(l.id AS numeric)/2 AS liddiv,
       l.lokalisati,
       ST_AsText(l.geom) gtxt
FROM   tmp_pedline l
WHERE  CAST(l.id AS numeric)/2 = 12;

-- regexp expressions impact WHERE clause!!! See docs
SELECT l.id, l.lokalisati,
regexp_matches(l.lokalisati, E'^..chel') AS pattfound,
ST_AsText(l.geom) gtxt
FROM   tmp_pedline l;
```

Thematic queries cont.

Attribute value restrictions in QGIS





Topological queries from last week

Returns objects satisfying a qualitative spatial relationship;

The single query geometry here is created on-the-fly with a constructor;

```
SELECT l.id, l.lokalisati, ST_astext(l.geom) gtxt
FROM   tmp_pedline l
WHERE  ST_Intersects(l.geom,
ST_GeomFromText('LINESTRING(2683846 1250116,
2685846 1249812)',2056)
);

-- returns some multiline geometries
```

Spatial join - base version

Topological queries can be applied between geometries of allowed dimensionalities (here two sets: 2D-multilines against 2D-points)

```
SELECT l.id, l.lokalisati, p.pstopid, p.atycode
FROM   tmp_pedline l
JOIN   pubstoppoint p
ON     ST_Intersects(l.geom, p.geom);
```

What's exactly happening here?

- Similar joining as we know it from standard SQL
- Cartesian product for spatial comparison of **two spatial tables**
- Each geometry with each geometry - binary geometry comparing with regard to 'intersects'; others possible, e.g. 'contains'
- This query type is also called **spatial join** (with all 8+ kinds of topo relationships: intersects, contains, within, overlaps, ...)

Exercise 1

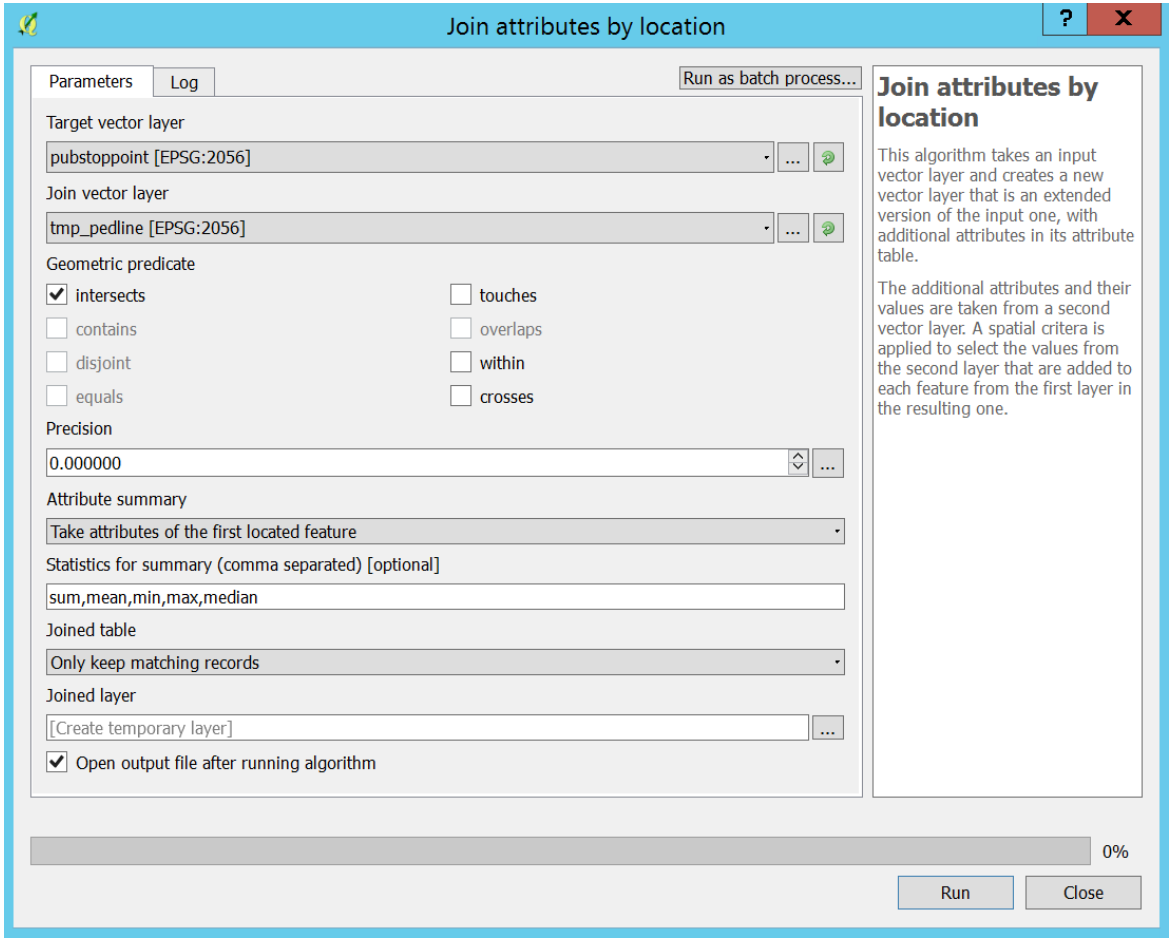
- What do you think happens in a database when we execute the previous query having 100'000 stops and 5'000'000 pedestrian roads? Debate with me.

- How long will such a query run in our database?

- How long will such a query run with two shape files?

Using QGIS for topological queries

Which stops lay on pedestrian roads (spatial join)?



Spatial join cont.

```
SELECT l.id, l.lokalisati, p.pstopid, p.atycode
FROM   tmp_pedline l
JOIN   pubstoppoint p
ON     ST_Intersects(l.geom, p.geom); -- no records out..... makes sense!
```

We should apply some buffer to our stop points; or any other method?

```
SELECT l.id, l.lokalisati, p.pstopid, p.atycode
FROM   tmp_pedline l  JOIN   pubstoppoint p
ON     ST_Intersects(l.geom, ST_Buffer(p.geom,100));
-- long searching... Why?

SELECT l.id, l.lokalisati, p.pstopid, p.atycode
FROM   tmp_pedline l  JOIN   pubstoppoint p
ON     ST_DWithin(l.geom, p.geom, 100)
-- this is it!
```

Spatial join cont.

Testing with stop points and districts; more joining for more info;

```
SELECT d.id, d.distname, p.pstopid, p.atycode
FROM   tmp_district d  JOIN pubstoppoint p
ON     ST_Intersects(d.geom, p.geom);
-- 140ms, perfectly fast, 10870 recs; ST_Contains;

SELECT d.id, d.distname, p.pstopid, p.atycode
FROM   tmp_district d  JOIN pubstoppoint p
ON     ST_DWithin(d.geom, p.geom, 10);
-- same speed with more (why?) resulting records;

SELECT d.id, d.distname, p.pstopid, p.atycode,
lk.atydesc
FROM   tmp_district d  JOIN pubstoppoint p
ON     ST_Intersects(d.geom, p.geom)
INNER JOIN soiltype lk ON p.atycode=lk.atycode
WHERE  p.atycode=1;  -- spatial join + join + where
```

Topological queries cont.

Topological queries can even be applied between geometries of the same dataset (self join...)

```
SELECT d1.id, d1.distname, d2.id, d2.distname
FROM   tmp_district d1 JOIN tmp_district d2
ON     ST_Touches(d1.geom, d2.geom);

-- with further filtering in the where clause
SELECT d1.id, d1.distname, d2.id, d2.distname
FROM   tmp_district d1 JOIN tmp_district d2
ON     ST_Touches(d1.geom, d2.geom)
WHERE  d1.distname = 'Kreis 1';
```

Geometrical queries

- **Distance**: rewrite slow buffer queries…
- Use ST_DWithin: distance within in the join/where clause; makes use of a spatial index (**topological operator!**)
- ST_Distance (**geometrical operator**) or **<->** is to be used in SELECT and the ORDER BY part for nearest-neighbour Queries (also see exercises)

```
-- All stops/pedestrian path within 10cm distance
SELECT l.id, l.lokalisati, p.pstopid, p.atycode
FROM   tmp_pedline l  JOIN   pubstoppoint p
ON     ST_DWithin(l.geom, p.geom, 0.1);

SELECT l.id, l.lokalisati, p.pstopid, p.atycode,
       -- show the distance
       ST_Distance(l.geom, p.geom) AS dist
FROM   tmp_pedline l  JOIN   pubstoppoint p
ON     ST_DWithin(l.geom, p.geom, 0.1);
```

Exercise 2

What does this query do/return?

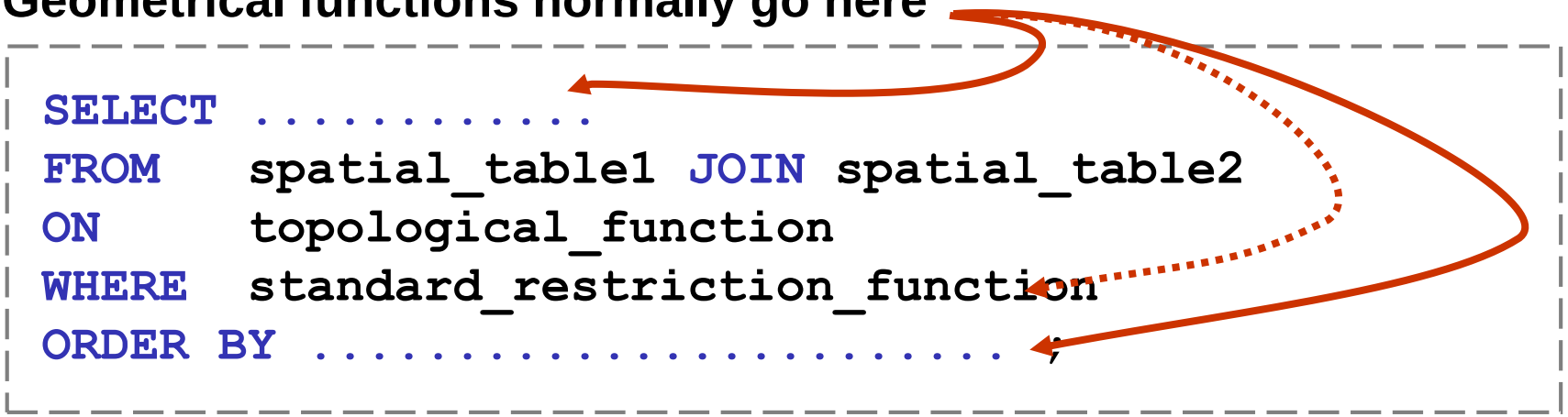
```
SELECT l.id, l.lokalisati, p.pstopid, p.atycode,
       ST_Distance(l.geom, p.geom) AS dist
FROM   tmp_pedline l  JOIN   pubstoppoint p
ON     ST_DWithin(l.geom, p.geom, 25)
ORDER BY ST_Distance(l.geom, p.geom) ASC
LIMIT 5;
```

Geometrical queries cont.

Some further examples of geometrical functions

- Shortest Line calculation (between 2 geometries): creates a line as a result
- Centroid calculation (for one geometry): a point geometry
- Maximum distance (between 2 geometries): distance in SRID-unit
- Concave hull, shrink wrapping (for one geometry): a polygon geometry
- Difference (between 2 geometries): geometric difference

Geometrical functions normally go here



Geometrical queries cont.

- ST_UNION to **spatially aggregate**: building Zurich as one multipolygon record
- A spatial option for grouping geometries; similar and often used together with aggregate functions of standard SQL like max, min, avg with a **group by** expression

```
-- just the geometry
SELECT ST_AsText(ST_Union(d.geom)) AS zuerigeomtxt
FROM   tmp_district d
GROUP BY 1; -- a constant, means: group all records;

-- with a more complex aggregate text function
SELECT string_agg(d.distname,', ') AS aggrtxt,
round(CAST(ST_Area(ST_Union(d.geom))/1000/1000) AS
numeric,2) AS aera_km2
FROM   tmp_district d GROUP BY 1;
```

Wrap up: Query types & PostGIS functions

- Tons of functionality to directly apply to your spatial data in a database
- Functionality & data transforming speed is high (few context switches)
- Some knowledge about data organization (ER diagram, tables diagram, indexes) are essential
- Gain clever prearranged data out of the honeypot by SQL; do smart things with this data using R, Phyton, Julia, Matlab…
- Let's quickly check the possibilities from the docs: https://postgis.net/docs/reference.html

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SQL-Client + Spatial DB

Client: DBeaver

```
SELECT r.riverid, r.geom riv_geom, tn.statname, tn.geom AS stat_geom
FROM river r JOIN station tn ON st_dwithin(r.geom,tn.geom, 5);
```

riverid	riv_geom	statname
174243	MULTILINESTRING ((2632836.14469	Lütschine-Gsteig

User generates a SQL-Query using a spatial operator on two spatial tables

Just text being sent to the server

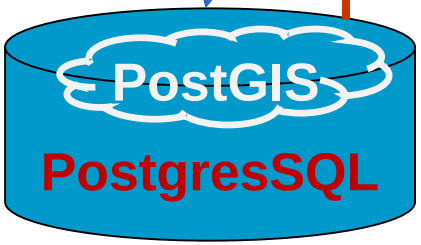
Listing of rows and the selected attributes

Data are passed to client

Data and metadata are retrieved

Secondary selection: Refine: with detailed geometry comparison.

Primary selection based on coarse filter (bbox), using a spatial index



Management

DB Explain Plan

SQLs executed

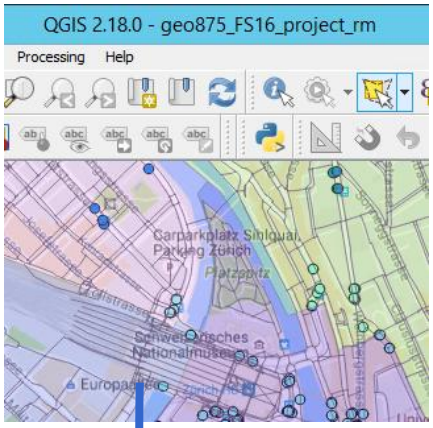
QGIS + Spatial DB

Client: QGIS

User performs a spatial function from the toolbox e.g. join attributes by location

x,y coordinates of the bbox of geometries and metadata (IDs) are being sent to the server

this happens in the form of multiple SQLs - built on the client side



Management DB Explain Plan

SQLs executed

Memory caching applies

Visualization or saving results (geometries)

Secondary selection: Refine: with detailed geometry comparison.

Why here?

- Performance
- Same libraries local as on server!
- Distributed vs centralized

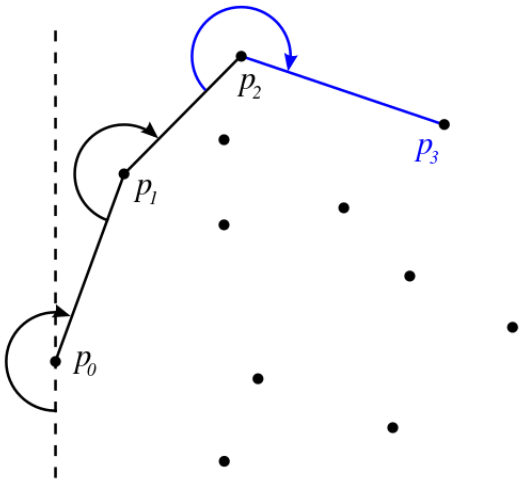
Preliminary data are passed to client

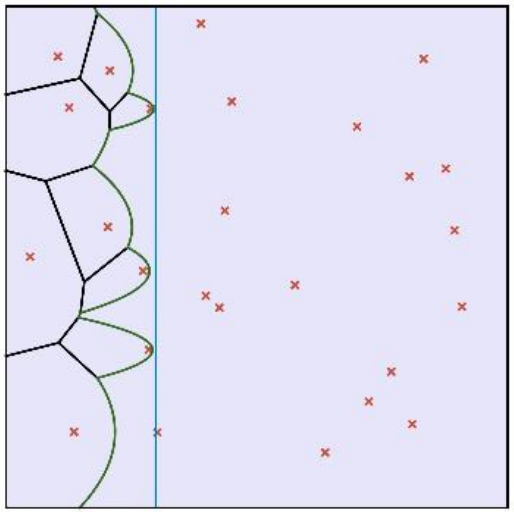
Data (IDs of potential features) and metadata are retrieved

Primary selection based on coarse filter (bbox), using the spatial index in the DB

Computational Geometry

- The discipline exploring algorithms for efficient execution of geometrical problems (see geo872, Ross Purves, Spatial Programming).
  - Intersections of geometries
  - Point in Polygon, Polygon in Polygon tests
  - Convex Hull (gift wrapping), Voronoi polygons (sweep line)
  - kNN (nearest neighbour)





https://en.wikipedia.org/wiki/Gift_wrapping_algorithm
https://brilliant.org/wiki/intersections-line-segments/ https://www.youtube.com/watch?v=k2P9yWSMaXE

Summary

- We have seen the process of reading data to staging tables and then transforming to target tables.
- We have discussed querying (thematic, topological, geometrical) of spatial data in PostgreSQL database with PostGIS extension.
- We have explored where queries are executed.
- You got a glimpse of the Filter-Refine approach to efficient query execution (tbc, in spatial indexing).
- You understand that computational geometry algorithms underpin the execution of the queries in the DB.