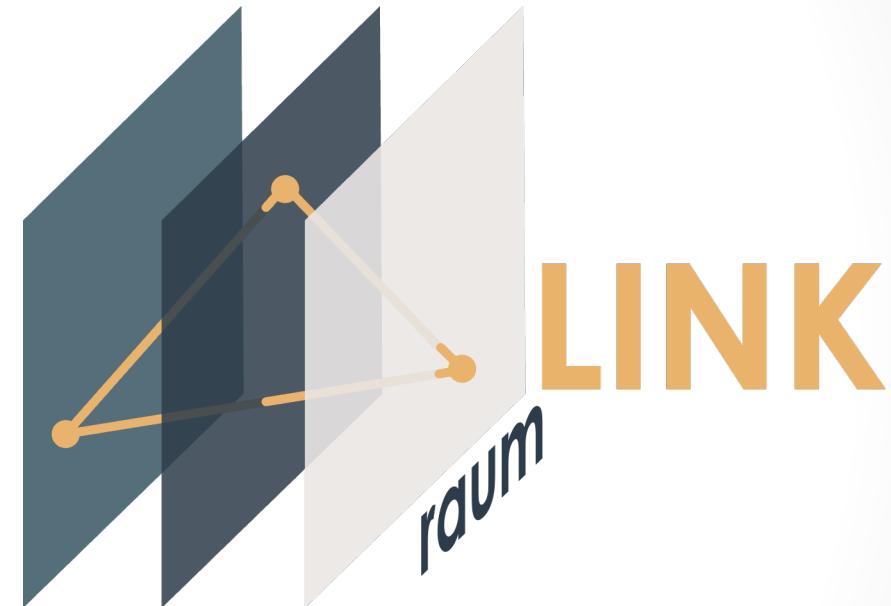


LBD and Spatial Querying

Or: How to bend SPARQL to your will

LDAC2024 Summer School Lecture

Oliver Schulz



About me

- Background in Architecture
 - (Focus: Existing Buildings)
- Several years of experience in BIM VR Development and BIM Coordination
- Research Assistant and PhD Candidate at Design Computation, RWTH Aachen
- Research focus on Common Data Environments



cc Formitas AG



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Oliver Schulz
LDAC 2024 Summer School, 12.06.2024

Content

- Introduction
- Basics
- Geospatial Queries
- Spatial 3D Queries
- Exercise
- Conclusion



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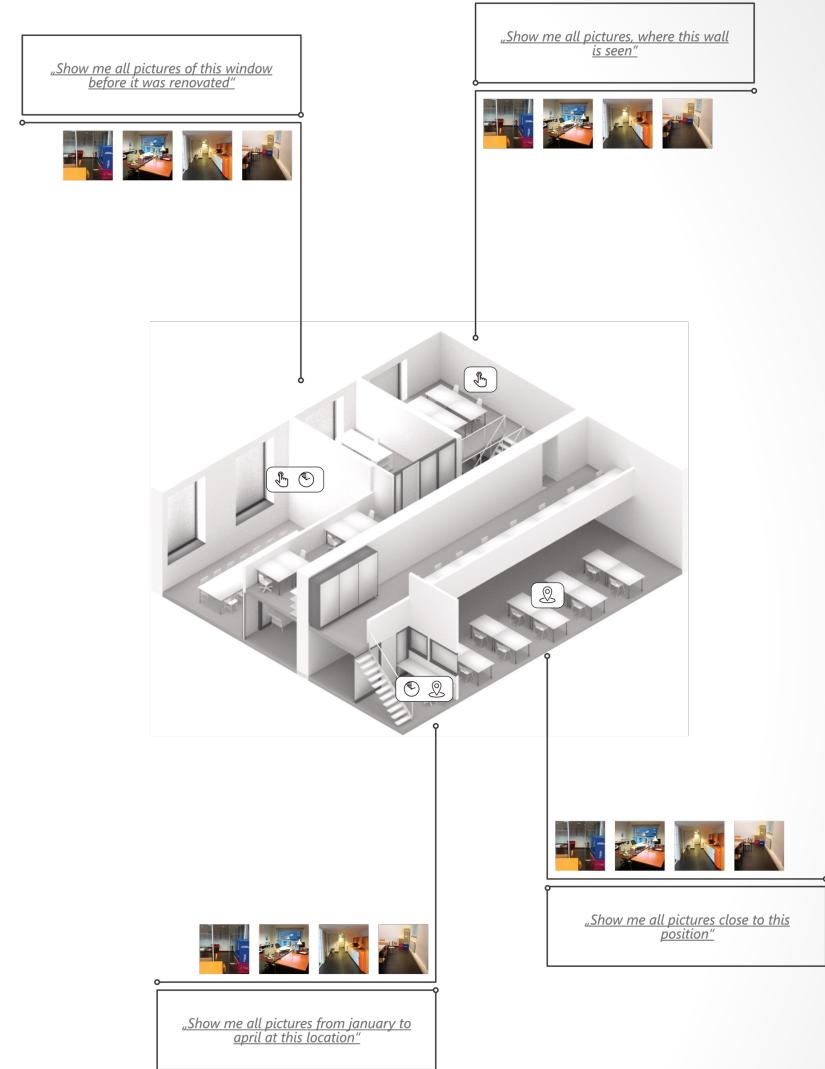
Spatial Queries?

Definition (for today):

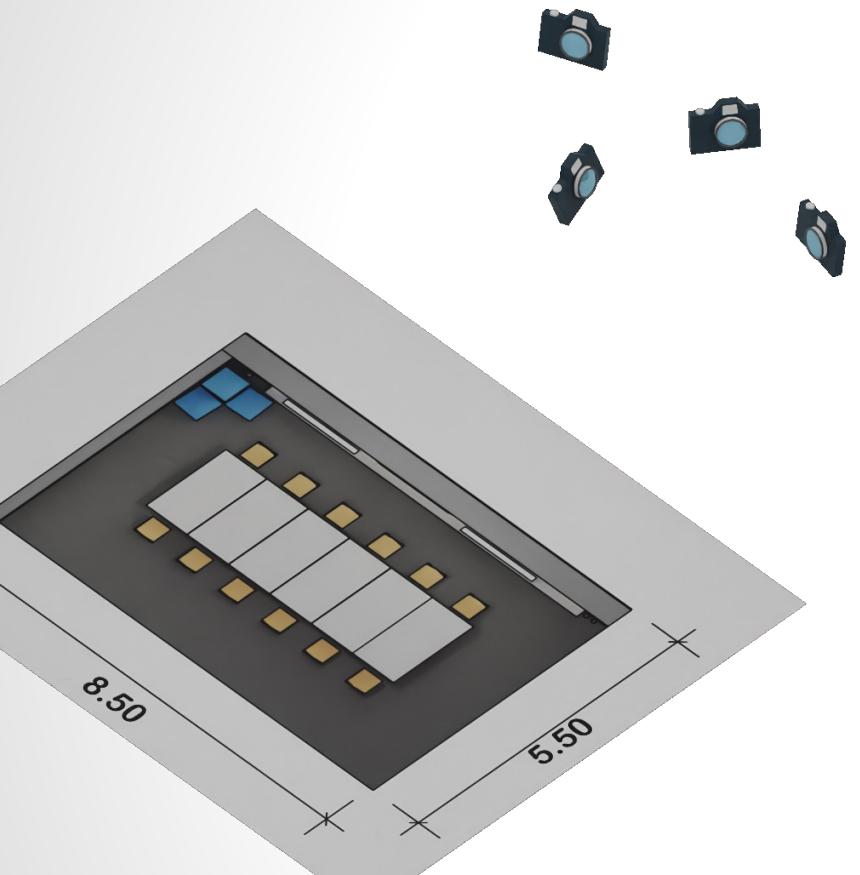
- Spatial queries involve querying objects based on distances, metrics, and spatial relationships within a 3D space.

Not a Focus Today:

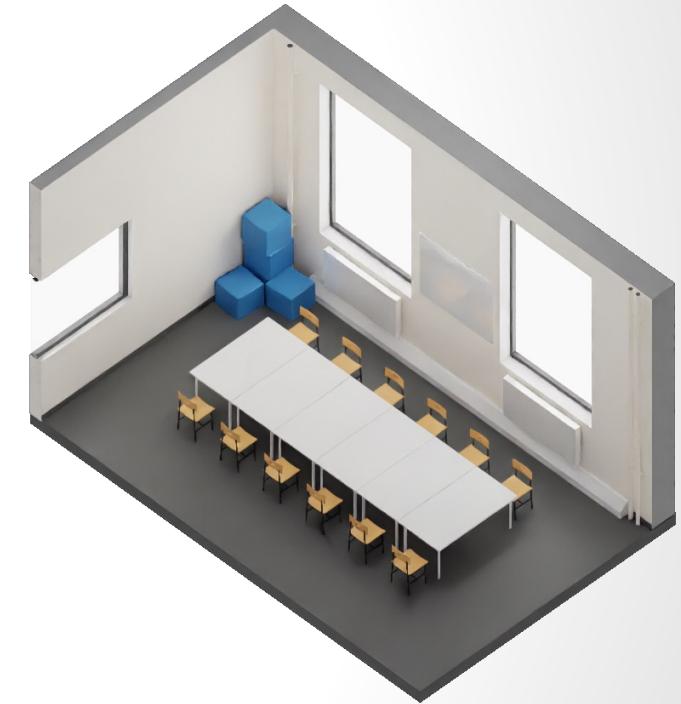
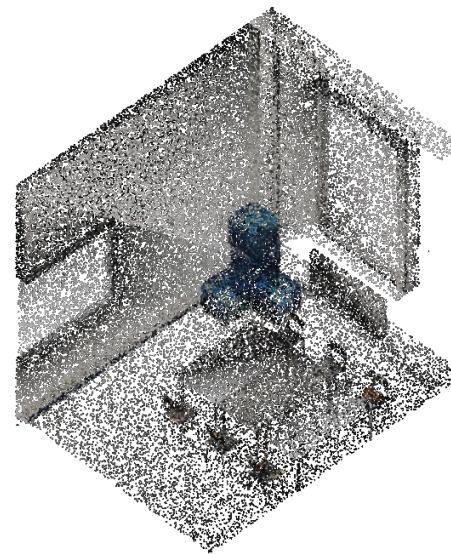
- Spatial queries that utilise natural language concepts like "above," "beside," "left," or "right."



Container Environments



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Raumlink

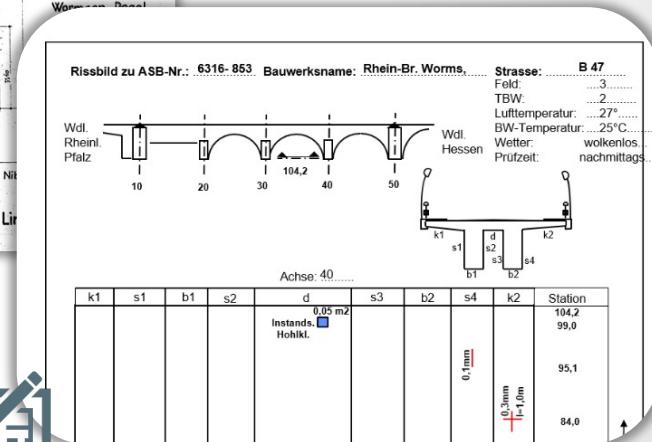
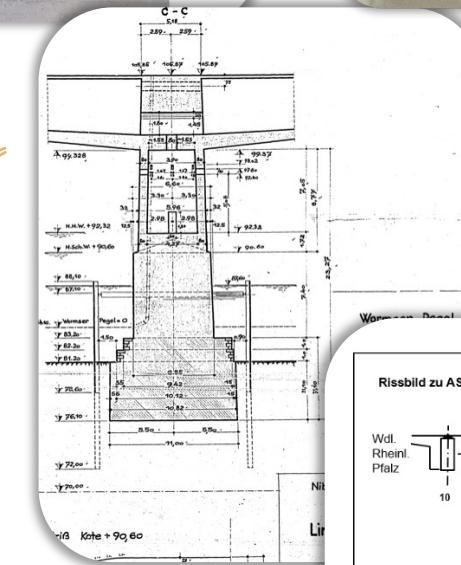
- (Spatial) Knowledge in existing data sources only implicit, not machine-readable
- Spatio-temporal classification only possible for individual experts → not scalable, knowledge is lost
- No cross-sectional views/analyses possible
- Superposition of heterogeneous information with existing methods, models and tools not possible.



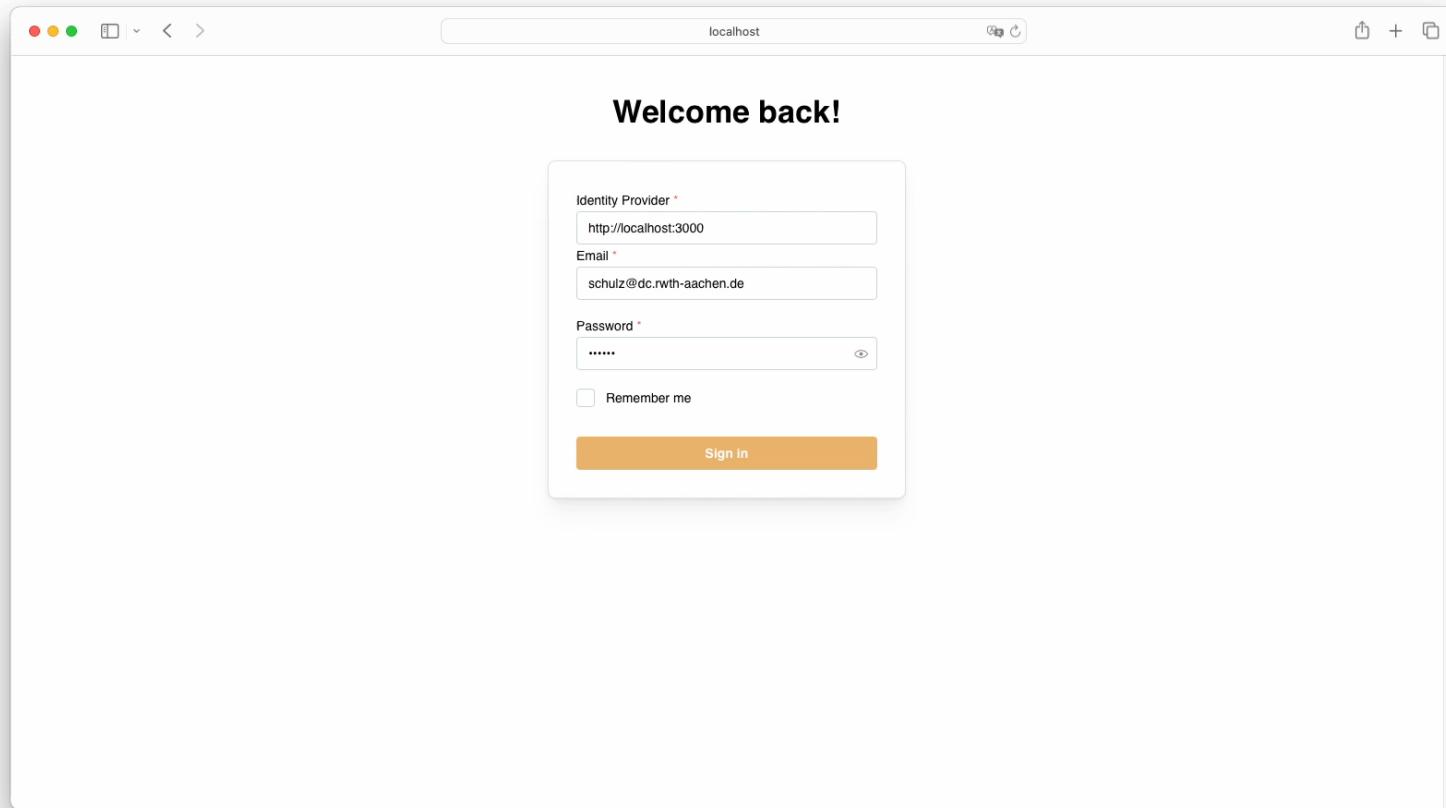
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[620] S=0, V=0, D=2 BSP-ID 025-04
Pfeilerschaft, Hohlquerschnitt, Beton, Vereinzelt,
Längsrisse Rissbreite 0,2 - < 0,4 mm, Achse Nr. 30, 1-tes
Bauteil von links, Rückseite, oben (unter dem Hohlsteg),
ca 2,0 m lang, Bild:BILD 21



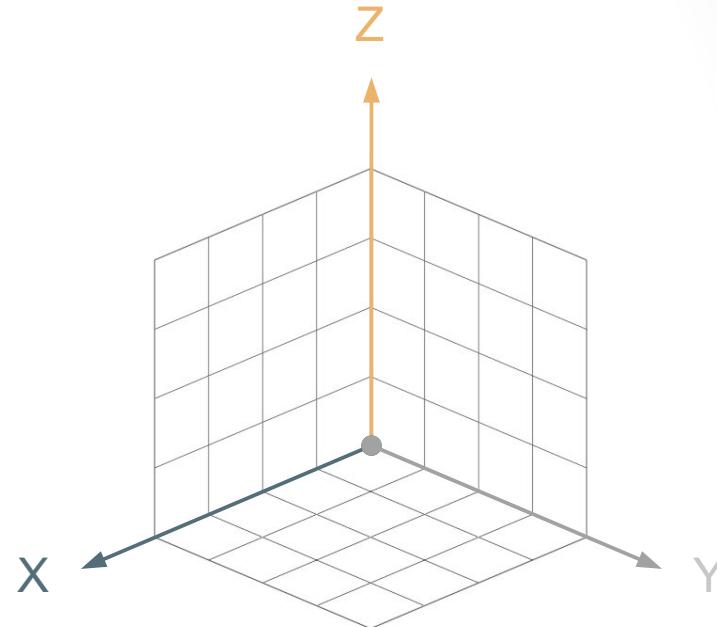
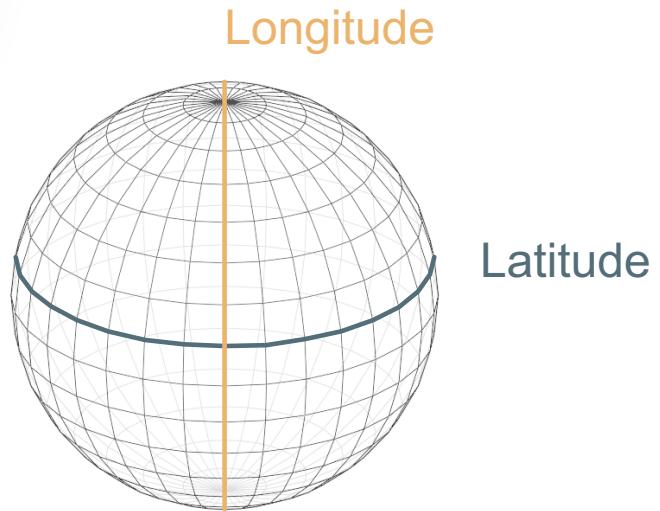
Use Case: Spatial CDE



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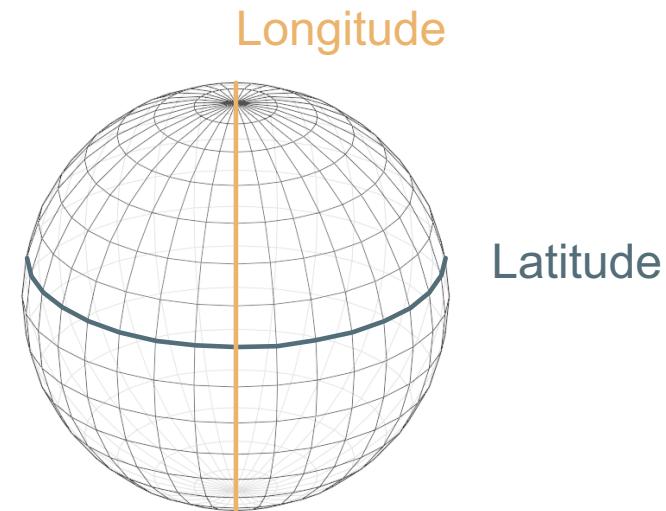
Basics

Types of Space



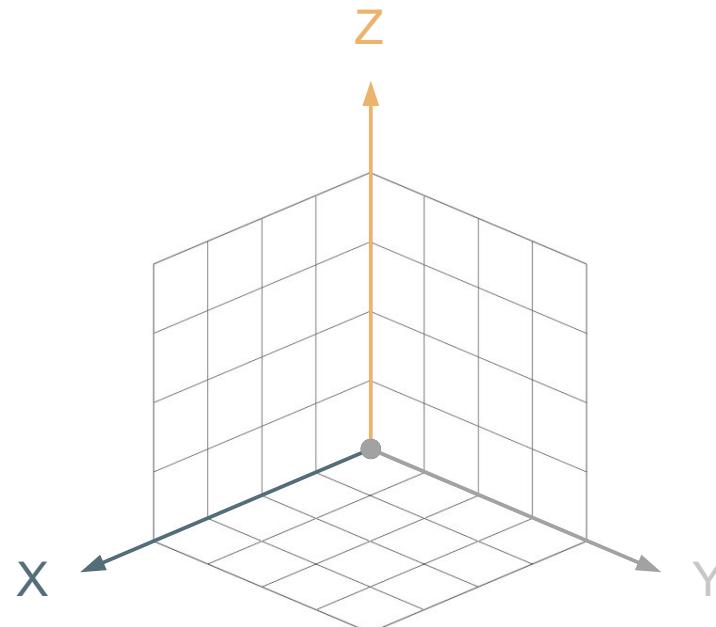
Geographic Coordinate System

- Earth is simplified by a datum, an ellipsoid that approximates the irregular shape of the Earth.
- Multiple datums exist, each optimized for accuracy in specific regions.
- Longitude and latitude lines divide the Earth into a grid system.
- They can be used to describe locations on the Earth's surface.
- Coordinates are usually given in degrees of latitude and longitude.
- The z-coordinate (height) is less commonly used but important in applications like aviation and surveying.

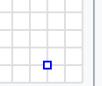
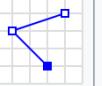
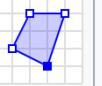
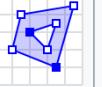


Cartesian Coordinate System

- Uses a grid of perpendicular lines
- Consists of two or three axis with an origin at $\begin{pmatrix} 0 \\ 0 \end{pmatrix}$ or $\begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix}$
- Axis are named, and coordinates described using $\begin{pmatrix} X \\ Y \\ Z \end{pmatrix}$ vectors
- Units are usually described in length
- Commonly used in computer graphics



Serialisation of Coordinates in Linked Data

Geometry primitives (2D)	
Type	Examples
Point	 POINT (30 10)
LineString	 LINESTRING (30 10, 10 30, 40 40)
Polygon	 POLYGON ((30 10, 40 40, 20 40, 10 20, 30 10))  POLYGON ((35 10, 45 45, 15 40, 10 20, 35 10), (20 30, 35 35, 30 20, 20 30))

Source: [Well-known text representation of geometry, Wikipedia](#)

* POINTZ (30 10 20)

gom:has
TransformationMatrix → "[m₁₁,m₁₂,m₁₃,m₁₄,
m₂₁,m₂₂,m₂₃,m₂₄,
m₃₁,m₃₂,m₃₃,m₃₄,
0,0,0,1]" ^^gom:rowMajorArray

Source: [Wagner & Bonduel, 2023](#)

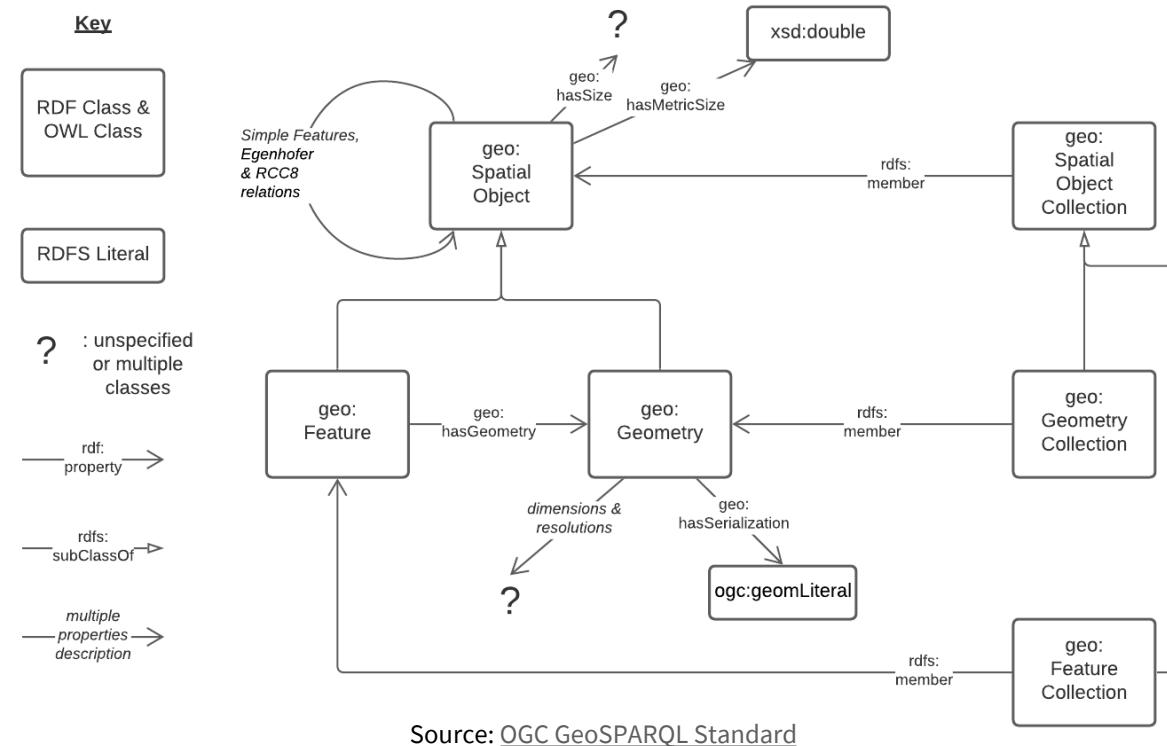
```
top:1edf15de-85be-5120-9ac7-187656f4f0f7 a bot:Space ;  
rdfs:label "1edf15de-85be-5120-9ac7-187656f4f0f7" ;  
top:hasVolume "18.0"^^xsd:float ;  
top:hasX "6.5"^^xsd:float ;  
top:hasY "5.0"^^xsd:float ;  
top:hasZ "4.5"^^xsd:float ;  
[ . . . ]
```

Source: [topologicpy, GitHub](#)



GeoSPARQL

GeoSPARQL Overview



GeoSPARQL Feature

```
geo:Feature
  a rdfs:Class, owl:Class ;
  rdfs:isDefinedBy geo: ;
  skos:prefLabel "Feature"@en ;
  rdfs:subClassOf geo:SpatialObject ;
  owl:disjointWith geo:Geometry ;
  skos:definition "A discrete spatial phenomenon in a universe of discourse."@en ;
  skos:note "A Feature represents a uniquely identifiable phenomenon, for example
    a river or an apple. While such phenomena (and therefore the Features
    used to represent them) are bounded, their boundaries may be crisp
    (e.g., the declared boundaries of a state), vague (e.g., the
    delineation of a valley versus its neighboring mountains), and change
    with time (e.g., a storm front). While discrete in nature, Features
    may be created from continuous observations, such as an isochrone
    that determines the region that can be reached by ambulance within
    5 minutes."@en ;
```

Source: [OGC GeoSPARQL Standard](#)



GeoSPARQL Geometry

```
geo:Geometry
  a rdfs:Class, owl:Class ;
  rdfs:isDefinedBy geo: ;
  skos:prefLabel "Geometry"@en ;
  rdfs:subClassOf geo:SpatialObject ;
  owl:disjointWith geo:Feature;
  skos:definition "A coherent set of direct positions in space. The positions
    are held within a Spatial Reference System (SRS)."@en ;
  skos:note "Geometry can be used as a representation of the shape, extent or
    location of a Feature and may exist as a self-contained entity."@en ;
```

Source: [OGC GeoSPARQL Standard](#)



GeoSPARQL Functions

Non-Topological Function:

- Distance
- Union
- Difference
- Etc...

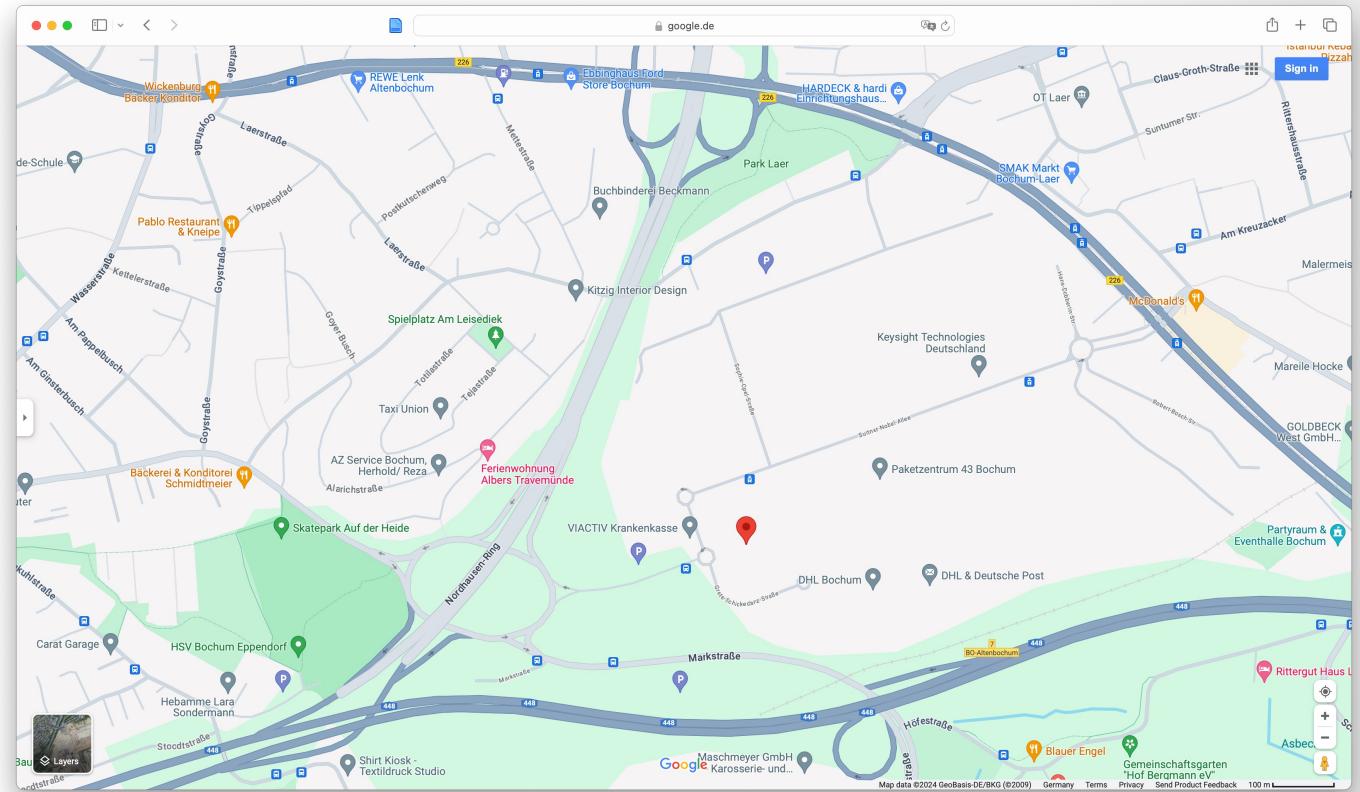
Topological Function:

- Equal
- Disjoint
- Contains
- Etc...



GeoSPARQL Example Use Case

- Restaurants in the vicinity of RUB Makerspace



GeoSPARQL Graph

- Graph of "RUB-Makerspace" and five restaurant locations.

```
@prefix ex: <http://example.org/> .  
@prefix geo: <http://www.opengis.net/ont/geosparql#> .  
@prefix xsd: <http://www.w3.org/2001/XMLSchema#> .  
  
ex:Makerspace a geo:Feature ;  
    ex:name "RUB-Makerspace" ;  
    geo:hasGeometry ex:MakerspaceGeom .  
  
ex:MakerspaceGeom a geo:Geometry ;  
    geo:asWKT "POINT(7.259804 51.465457)"^^geo:wktLiteral .
```

```
ex:Schmidtmeier a ex:Restaurant ;  
    ex:name "Schmidtmeier" ;  
    geo:hasGeometry ex:Restaurant1Geom .
```

[...] [Link to GitHub Repository](#)



GeoSPARQL Query

- Query to find distances between "RUB-Makerspace" and nearby restaurants.

```
PREFIX geo: <http://www.opengis.net/ont/geosparql#>
PREFIX geof: <http://www.opengis.net/def/function/geosparql/>
PREFIX uom: <http://www.opengis.net/def/uom/OGC/1.0/>
PREFIX ex: <http://example.org/>

SELECT ?restaurant ?name ?distance
WHERE {
    ex:Makerspace geo:hasGeometry ?MakerspaceGeom .
    ?MakerspaceGeom geo:asWKT ?makerspaceWKT .

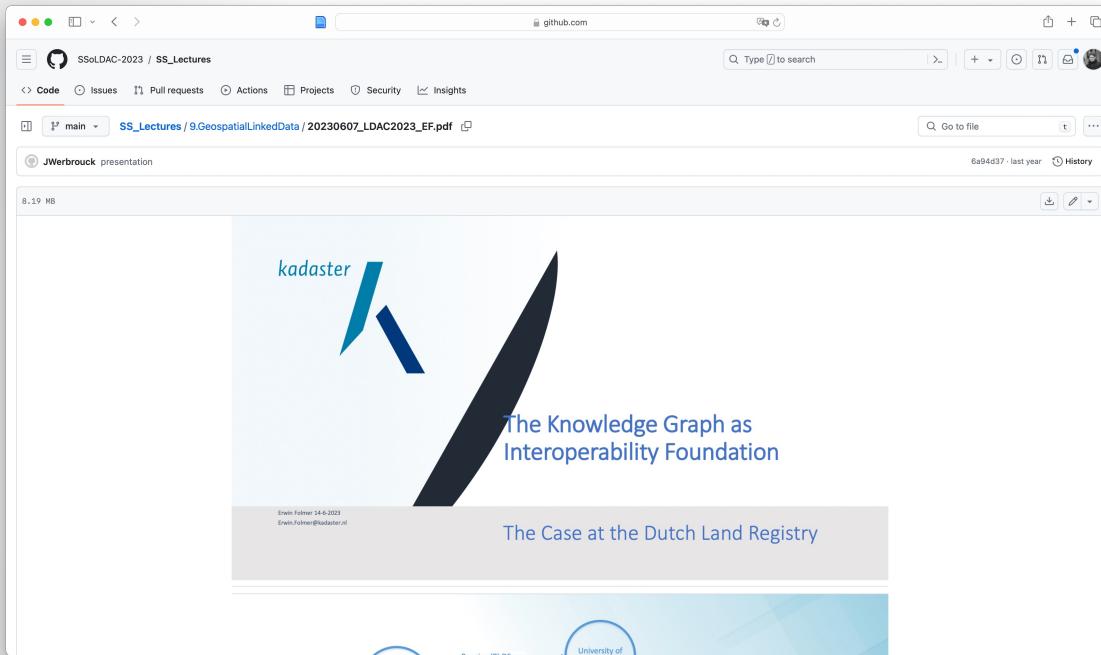
    ?restaurant a ex:Restaurant ;
        ex:name ?name ;
        geo:hasGeometry ?restaurantGeom .
    ?restaurantGeom geo:asWKT ?wkt .

    BIND(geof:distance(?makerspaceWKT, ?wkt, uom:metre) as ?distance)
}
```

[Link to GitHub Repository](#)



GeoSPARQL Further Reading



SSoLDAC 2023 Geospatial Linked Data



OGC GeoSPARQL Standard

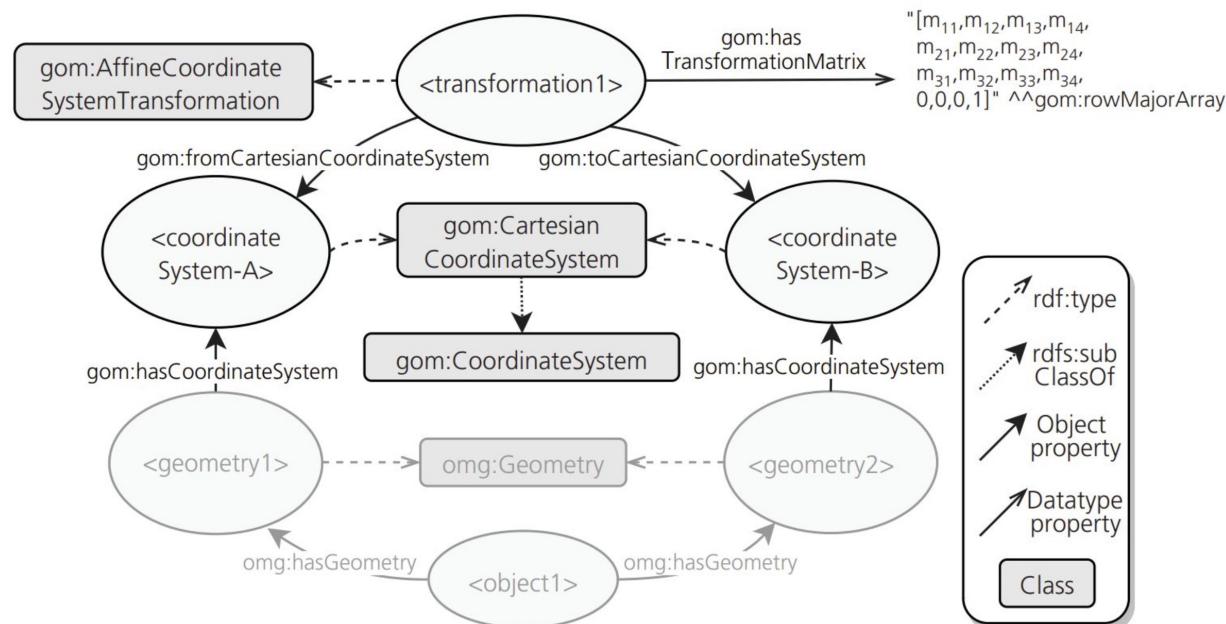


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Spatial Queries in SPARQL

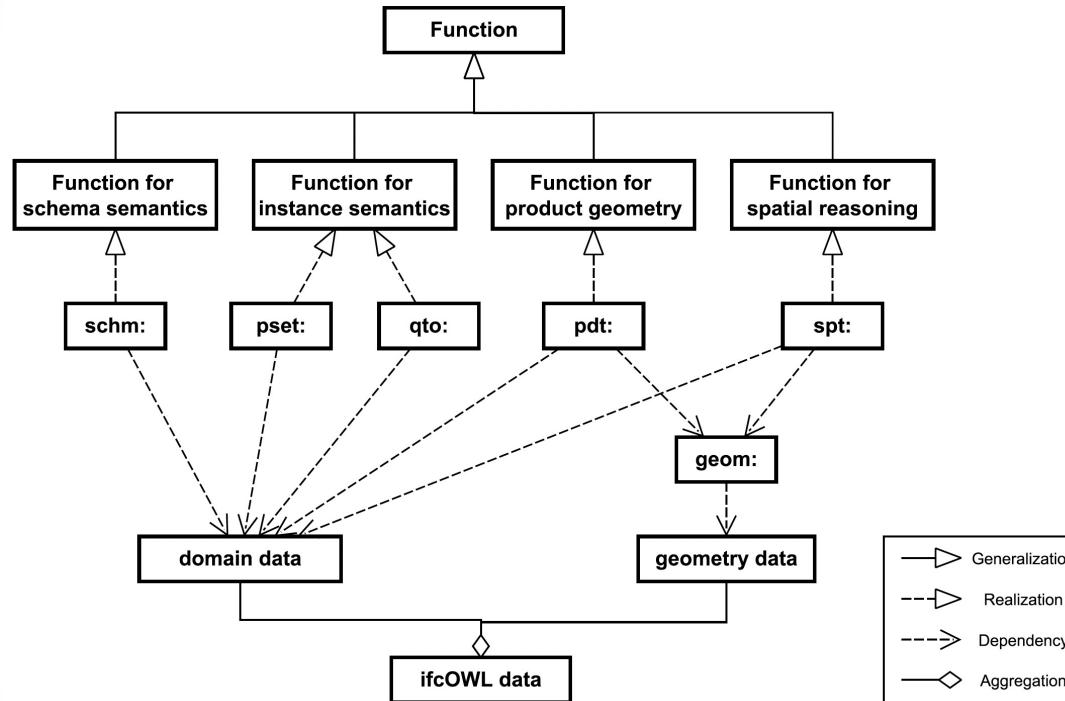
Geometry Metadata Ontology (GOM)

<https://www.w3id.org/gom#>



Source: [Wagner & Bonduel, 2023](#)

BIMSPARQL

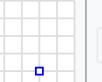
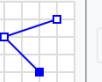
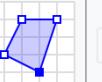
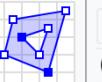


Source: Zhang et al., 2018

```
SELECT DISTINCT ?ceiling
WHERE {
    ?ceiling a ifc:IfcCovering .
    ?ceiling ifc:predefinedType ifc:CEILING
    .
    ?ceiling schrn:isContainedIn ?storey1 .
    ?storey1 spt:hasUpperStorey ?storey2 .
    ?slab schrn:isContainedIn ?storey2 .
    ?slab a ifc:IfcSlab .
    ?slab ifc:predefinedType ifc:FLOOR .
    (?slab ?ceiling) spt:distanceZ
    ?distance .
    FILTER (?distance < 0.4)
}
```



Serialisation of Coordinates in Linked Data

Geometry primitives (2D)	
Type	Examples
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LineString	 LINESTRING (30 10, 40 40)
Polygon	 POLYGON ((30 10, 40 40, 20 40, 10 20, 30 10))  POLYGON ((35 10, 45 45, 15 40, 10 20, 35 10), (20 30, 35 35, 30 20, 20 30))

Source: [Well-known text representation of geometry, Wikipedia](#)

* POINTZ (30 10 20)

gom:has TransformationMatrix → "[m₁₁,m₁₂,m₁₃,m₁₄, m₂₁,m₂₂,m₂₃,m₂₄, m₃₁,m₃₂,m₃₃,m₃₄, 0,0,0,1]" ^^gom:rowMajorArray

Source: [Wagner & Bonduel, 2023](#)

top:[1edf15de-85be-5120-9ac7-187656f4f0f7](#) a bot:Space ;
rdfs:label "1edf15de-85be-5120-9ac7-187656f4f0f7" ;
top:hasVolume "18.0"^^xsd:float ;
top:hasX "6.5"^^xsd:float ;
top:hasY "5.0"^^xsd:float ;
top:hasZ "4.5"^^xsd:float ;
[...]

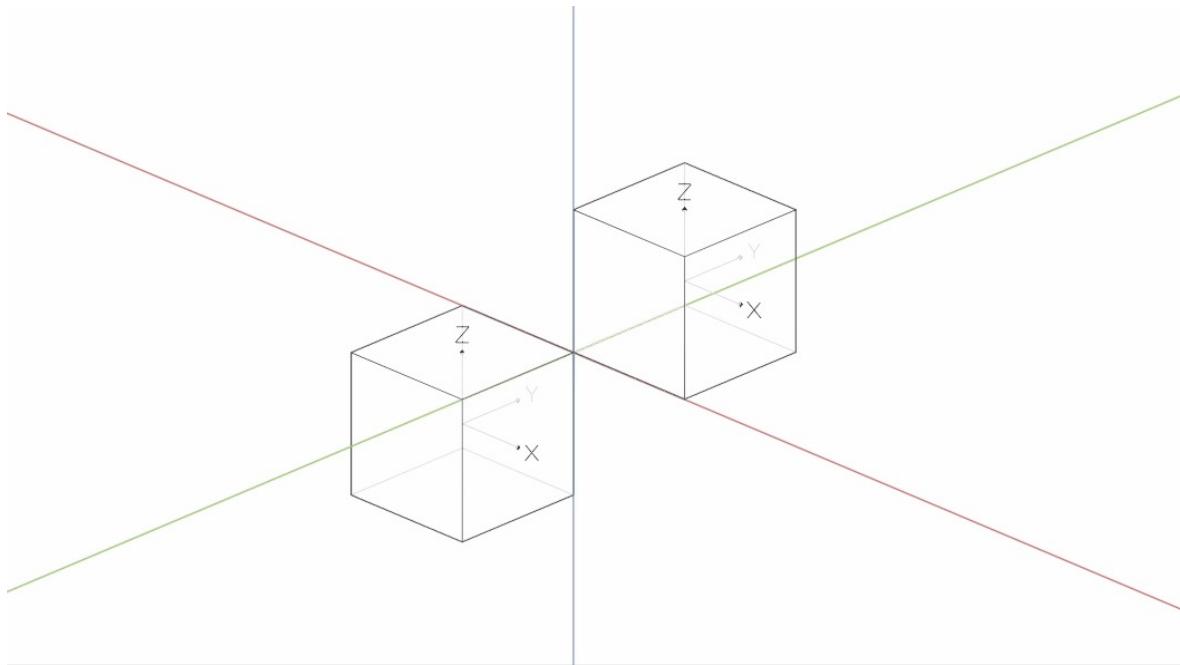
Source: [topologicpy, GitHub](#)



Scenario 1: Absolute Positions

$$Cube_2 = \begin{pmatrix} -1 \\ -1 \\ -1 \end{pmatrix}$$

```
inst:cube_2 a bot:element ;  
spatial:hasX -1 ;  
spatial:hasY -1 ;  
spatial:hasZ -1 .
```



$$Cube_1 = \begin{pmatrix} 1 \\ 1 \\ 1 \end{pmatrix}$$

```
inst:cube_1 a bot:element ;  
spatial:hasX 1 ;  
spatial:hasY 1 ;  
spatial:hasZ 1 .
```

Scenario 1: Hands-on

- Write a query to select all elements in the range of 0.5 to 1.5 for X, Y and Z

```
SELECT ?element
WHERE {
    ?element a bot:element ;
        spatial:hasX ?x ;
        spatial:hasY ?y ;
        spatial:hasZ ?z .
    FILTER (
        ?x >= 0.5 && ?x <= 1.5 &&
        ?y >= 0.5 && ?y <= 1.5 &&
        ?z >= 0.5 && ?z <= 1.5
    )
}
```

[Link to the Query](#)
[Link to the Graph](#)

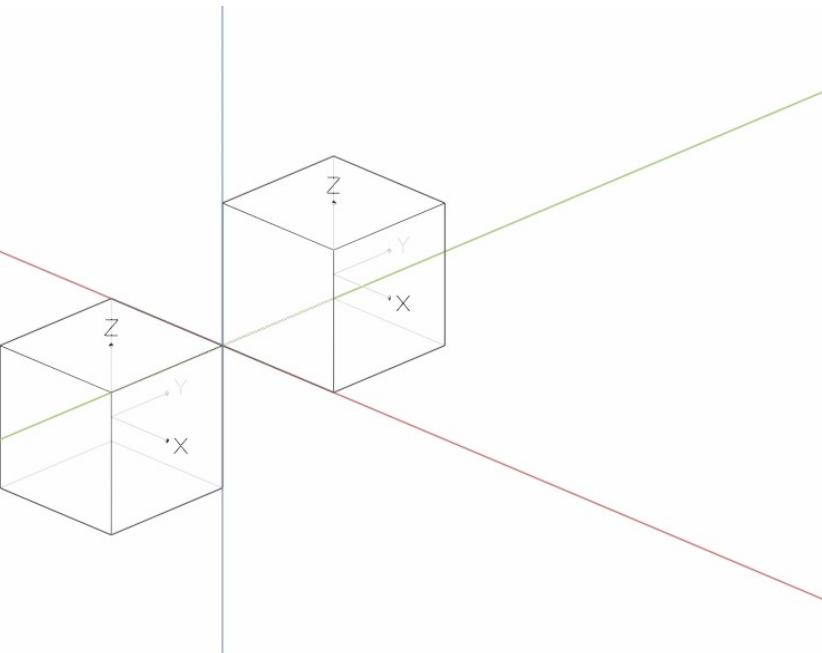


Scenario 2: Relative Positions

$$Cube_{2abs} = \begin{pmatrix} -1 \\ -1 \\ -1 \end{pmatrix}$$

$$Cube_{2rel} = \begin{pmatrix} -2 \\ -2 \\ -2 \end{pmatrix}$$

```
inst:cube_2 a bot:element ;  
  spatial:hasParent inst:cube_1 ;  
  spatial:hasX -2 ;  
  spatial:hasY -2 ;  
  spatial:hasZ -2 .
```



$$Cube_1 = \begin{pmatrix} 1 \\ 1 \\ 1 \end{pmatrix}$$

```
inst:cube_1 a bot:element ;  
  spatial:hasX 1 ;  
  spatial:hasY 1 ;  
  spatial:hasZ 1 .
```

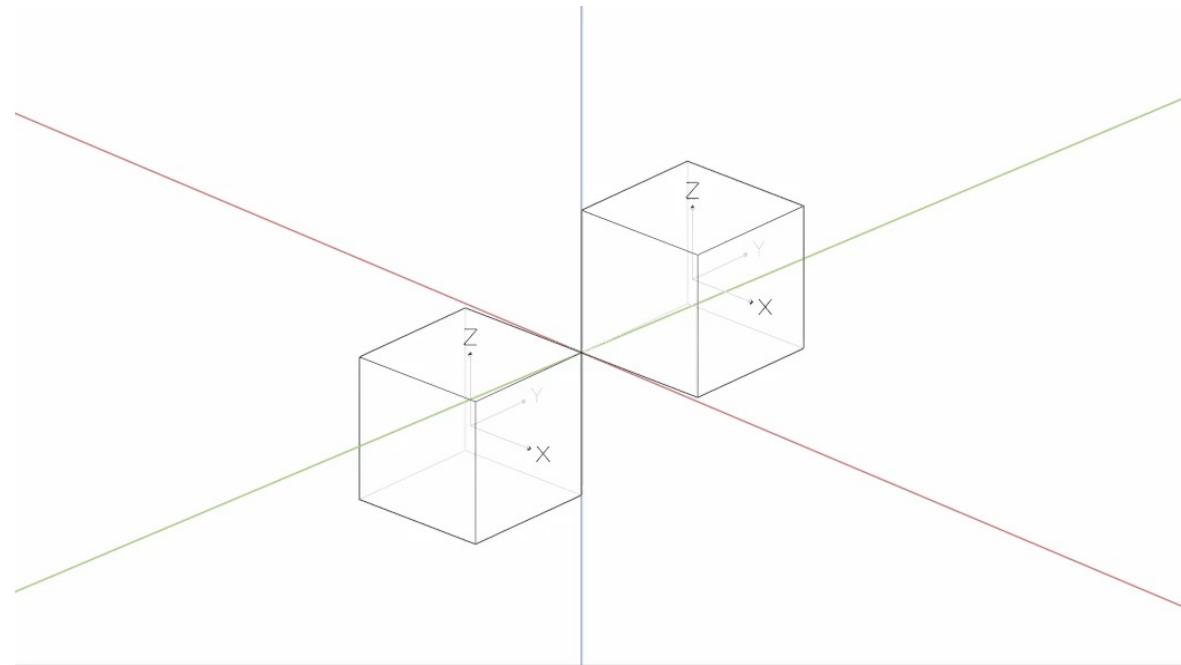
Scenario 2: Hands-on

- Write a query to select all elements in the range of 0.5 to 1.5 for X, Y and Z for their absolute positions

```
SELECT ?s (sum(?_absX) as ?absX) (sum(?_absY) as ?absY) (sum(?_absZ) as ?absZ)
FROM <http://example.org/relative-position>
WHERE {
    ?s a bot:element ;
        spatial:hasX ?relX ;
        spatial:hasY ?relY ;
        spatial:hasZ ?relZ .
    ?s spatial:hasParent* ?sp.
    ?sp spatial:hasX ?_absX .
    ?sp spatial:hasY ?_absY .
    ?sp spatial:hasZ ?_absZ .
}
GROUP BY ?s
HAVING (
    ?absX >= -0.5 && ?absX <= 1.5 &&
    ?absY >= -0.5 && ?absY <= 1.5 &&
    ?absZ >= -0.5 && ?absZ <= 1.5
)
Link to the Query
Link to the Graph
```



Scenario 3: Relative Rotated Positions



Scenario 3: Rotations

- With rotations, calculations get more complex
- Especially when storing them as a 3x1 Vector

$$Cube_{trans} = \begin{pmatrix} 1 \\ 1 \\ 1 \end{pmatrix} \quad Cube_{rot} = \begin{pmatrix} 45^\circ \\ 45^\circ \\ 45^\circ \end{pmatrix}$$

$$R_x(\theta) = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos(\theta) & \sin(\theta) & 0 \\ 0 & -\sin(\theta) & \cos(\theta) & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

$$R_y(\theta) = \begin{pmatrix} \cos(\theta) & 0 & -\sin(\theta) & 0 \\ 0 & 1 & 0 & 0 \\ \sin(\theta) & 0 & \cos(\theta) & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

$$R_z(\theta) = \begin{pmatrix} \cos(\theta) & -\sin(\theta) & 0 & 0 \\ \sin(\theta) & \cos(\theta) & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

$$R(\theta) = R_z(\theta) * (R_y(\theta) * R_x(\theta))$$



Scenario 3: Transformation Matrix

- We can store all transformations (scaling, rotation, translation, etc.) in one 4x4 matrix.
- Matrix multiplication can efficiently calculate the resulting transformation from relative transformations.

Rotation, Scale, Shear

$$M_{Trans} = \begin{pmatrix} a1 & a2 & a3 & a4 \\ a5 & a6 & a7 & a8 \\ a9 & a10 & a11 & a12 \\ a13 & a14 & a15 & a16 \end{pmatrix}$$

Translation

$$M_{abs} = M_{parent} * M_{child}$$

```
inst:cube_1 a bot:element ;
spatial:m1 -4.371138828673793e-08 ;
spatial:m2 -1 ;
spatial:m3 0 ;
spatial:m4 1 ;
spatial:m5 1 ;
spatial:m6 -4.371138828673793e-08 ;
[...]
spatial:m13 0 ;
spatial:m14 0 ;
spatial:m15 0 ;
spatial:m16 1 .
```



Scenario 3: Hands-on

- Write a query to select an element, its parent and its absolute coordinates in a transformation matrix

```
SELECT DISTINCT ?element ?parent ?absM1Test ?absM2Test ?absM3Test ?absM4Test  
FROM <http://example.org/rotate-position>  
WHERE {  
?element a bot:element ;  
    spatial:parent ?parent ;  
    spatial:m1 ?m1 ;  
    spatial:m2 ?m2 ;  
    spatial:m3 ?m3 ;  
    spatial:m4 ?m4 ;  
    spatial:m5 ?m5 ;  
    spatial:m6 ?m6 ;  
    spatial:m7 ?m7 ;  
    spatial:m8 ?m8 ;  
    spatial:m9 ?m9 ;  
    spatial:m10 ?m10 ;  
    spatial:m11 ?m11 ;  
    spatial:m12 ?m12 ;  
    spatial:m13 ?m13 ;  
    spatial:m14 ?m14 ;  
    spatial:m15 ?m15 ;  
    spatial:m16 ?m16 .
```

[Link to GitHub Repository](#)



Exercise

- In Graph “Absolute”, calculate and return the distance of inst:cube_1 to inst:cube_2
- If no parent is available, calculate the distance to the origin
- Hint 1: Calculate the distance between two points
- Hint 2: GraphDB supports Math functions

$$distance = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2}$$

```
PREFIX ofn: <http://www.ontotext.com/sparql/functions/>  
BIND (ofn:sqrt (?sumOfSquares) AS ?distance)
```



Possible Solution

- Take Math functions with a grain of salt:
 - They are often specific to the provider of the Graph Database

```
PREFIX bot: <http://example.org/bot#>
PREFIX spatial: <http://example.org/spatial#>
PREFIX inst: <http://example.org/instances#>
PREFIX ofn: <http://www.ontotext.com/sparql/functions/>

SELECT ?distance
FROM <http://example.org/absolute-position>
WHERE {

    inst:cube_1 a bot:element ;
        spatial:hasX ?x1 ;
        spatial:hasY ?y1 ;
        spatial:hasZ ?z1 .

    inst:cube_2 a bot:element ;
        spatial:hasX ?x2 ;
        spatial:hasY ?y2 ;
        spatial:hasZ ?z2 ;
        BIND((?x2 - ?x1) AS ?dx)
        BIND((?y2 - ?y1) AS ?dy)
        BIND((?z2 - ?z1) AS ?dz)

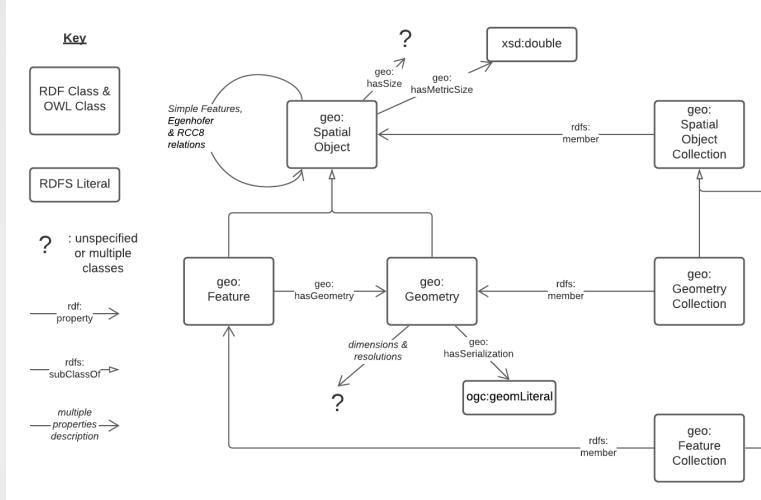
        BIND((?dx * ?dx) + (?dy * ?dy) + (?dz * ?dz) AS
            ?sumOfSquares)
        BIND(ofn:sqrt(?sumOfSquares) AS ?distance)
}

Link to the Query
```



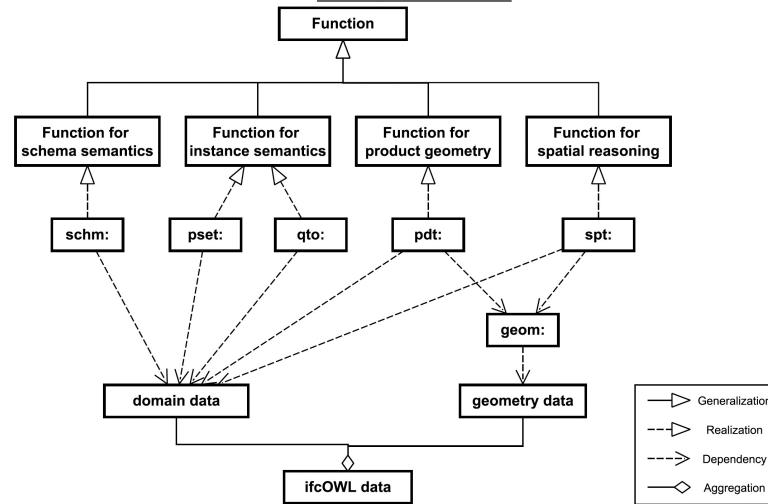
Spatial Queries Summarize

Source: [OGC GeoSPARQL Standard](#)



- + Feature rich
- Limited to 2D (as of now)

Source: [Zhang et al., 2018](#)



- + Feature rich (includes 3D)
- Not standardised

```

SELECT DISTINCT ?element ?parent ?absM1Test ?absM2Test ?absM3Test
FROM <http://example.org/rotate-position>
WHERE {
?element a bot:element ;
  spatial:parent ?parent ;
  spatial:m1 ?m1 ;
  spatial:m2 ?m2 ;
  spatial:m3 ?m3 ;
  spatial:m4 ?m4 ;
  spatial:m5 ?m5 ;
  spatial:m6 ?m6 ;
  spatial:m7 ?m7 ;
  spatial:m8 ?m8 ;
  spatial:m9 ?m9 ;
  spatial:m10 ?m10 ;
  spatial:m11 ?m11 ;
  spatial:m12 ?m12 ;
  spatial:m13 ?m13 ;
  spatial:m14 ?m14 ;
  spatial:m15 ?m15 ;
  spatial:m16 ?m16 .
}
[...]

```

- + Not based on extensions
- Math operations are very limited (and not performant)



Solution?



Thank you for your attention

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