

OGC® DOCUMENT: 22-047R1

External identifier of this OGC® document: <http://www.opengis.net/doc/IS/geosparql/1.3>



Open
Geospatial
Consortium

OGC GEOSPARQL - A GEOGRAPHIC QUERY LANGUAGE FOR RDF DATA

STANDARD
Profile

APPROVED

Version: 1.1

Submission Date: 2023-04-20

Approval Date: 2015-01-27

Publication Date: 2024-01-29

Editor: Nicholas J. Car, Timo Homburg, Matthew Perry

Notice: This document is an OGC Member approved international standard. This document is available on a royalty free, non-discriminatory basis. Recipients of this document are invited to submit, with their comments, notification of any relevant patent rights of which they are aware and to provide supporting documentation.

License Agreement

Use of this document is subject to the license agreement at <https://www.ogc.org/license>

Suggested additions, changes and comments on this document are welcome and encouraged. Such suggestions may be submitted using the online change request form on OGC web site: <http://ogc.standardstracker.org/>

Copyright notice

Copyright © 2024 Open Geospatial Consortium

To obtain additional rights of use, visit <https://www.ogc.org/legal>

Note

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. The Open Geospatial Consortium shall not be held responsible for identifying any or all such patent rights.

Recipients of this document are requested to submit, with their comments, notification of any relevant patent claims or other intellectual property rights of which they may be aware that might be infringed by any implementation of the standard set forth in this document, and to provide supporting documentation.

CONTENTS

I.	ABSTRACT	vii
II.	PREFACE	viii
III.	SECURITY CONSIDERATIONS	ix
IV.	SUBMITTERS	ix
V.	KEYWORDS	ix
VI.	CLARIFICATIONS	x
VII.	CHANGES TO THE OGC® ABSTRACT SPECIFICATION	x
VIII.	SUBMITTING ORGANIZATIONS	x
1.	SCOPE	2
2.	CONFORMANCE	4
3.	NORMATIVE REFERENCES	7
4.	TERMS AND DEFINITIONS	9
4.1.	Semantic Web	9
4.2.	spatial	10
6.	CONVENTIONS	13
6.1.	Symbols and abbreviated terms	13
6.2.	Namespaces	14
6.3.	Placeholder IRIs	15
6.4.	Data Types for Spatial Aggregate Functions	15
6.5.	RDF Serializations	15
7.	INTRODUCTION	17
7.1.	RDF	17
7.2.	SPARQL	18
7.3.	GeoSPARQL Standard structure	19
8.	CORE	24
8.1.	SPARQL	25
8.2.	Classes	25

8.3. Standard Properties for geo:SpatialObject	28
8.4. Standard Properties for geo:Feature	32
9. TOPOLOGY VOCABULARY EXTENSION	36
9.1. Parameters	36
9.2. Simple Features Relation Family	37
9.3. Egenhofer Relation Family	38
9.4. RCC8 and RCC*-9 Relation Family	39
9.5. Equivalent RCC8, Egenhofer and Simple Features Topological Relations	40
10. GEOMETRY EXTENSION	43
10.1. Rationale	45
10.2. GeoSPARQL and Simple Features (SFA-CA)	45
10.3. Recommendation for units of measure	46
10.4. Influence of Reference Systems on computations	47
10.5. Parameters	47
10.6. Geometry Class	47
10.7. Standard Properties for geo:Geometry	49
10.8. Geometry Serializations	54
10.9. Non-topological Query Functions	70
10.10. Non-topological Query Functions – 3D Extension	84
10.11. Spatial Aggregate Functions	85
11. GEOMETRY TOPOLOGY EXTENSION	88
11.1. Parameters	89
11.2. Common Query Functions	89
11.3. Simple Features Relation Family	89
11.4. Egenhofer Relation Family	90
11.5. RCC8 Relation Family	91
11.6. RCC*-9 Relation Family	92
12. RDFS ENTAILMENT EXTENSION	95
12.1. Parameters	95
12.2. Common Requirements	95
12.3. WKT Serialization	95
12.4. GML Serialization	97
13. QUERY REWRITE EXTENSION	99
13.1. Parameters	100
13.2. Simple Features Relation Family	100
13.3. Egenhofer Relation Family	101
13.4. RCC8 Relation Family	102
13.5. Special Considerations	103
14. FUTURE WORK	105
ANNEX A (NORMATIVE) ABSTRACT TEST SUITE	123

A.0. Overview	
A.1. Conformance Class: Core	123
A.2. Conformance Class: Topology Vocabulary Extension	126
A.3. Conformance Class: Geometry Extension	128
A.4. DGGS Conformance Class: Geometry Extension – DGGS	140
A.5. Conformance Class: Geometry Topology Extension	143
A.6. Conformance Class: RDFS Entailment Extension	146
A.7. Conformance Class: Query Rewrite Extension	147
 ANNEX B (NORMATIVE) FUNCTIONS SUMMARY	151
B.0. Overview	
B.1. Functions Summary Table	151
B.2. GeoSPARQL to SFA Functions Mapping	156
 ANNEX C (INFORMATIVE) GEOSPARQL EXAMPLES	160
C.0. Overview	
C.1. RDF Examples	160
C.2. Example SPARQL Queries & Rules	172
 ANNEX D (INFORMATIVE) USAGE OF SHACL SHAPES	181
D.0. Overview	
D.1. Tools	181
D.2. Scope of SHACL Shapes provided with GeoSPARQL	182
D.3. Table of SHACL Shapes	182
 ANNEX E (INFORMATIVE) ALIGNMENTS	188
E.0. Overview	
E.1. ISA Programme Location Core Vocabulary (LOCN)	189
E.2. WGS84 Geo Positioning: an RDF vocabulary (POS)	190
E.3. W3C Activity Streams Vocabulary	191
E.4. Geonames Ontology (GN)	191
E.5. NeoGeo Vocabulary	192
E.6. Juso Ontology	194
E.7. Time Ontology in OWL (TIME)	194
E.8. schema.org	195
E.9. Semantic Sensor Network Ontology (SSN)	197
E.10. DCMI Metadata Terms (DCTERMS)	197
E.11. The Provenance Ontology (PROV)	198
E.12. WikiData	199
E.13. OpenStreetMap Ontologies	201
E.14. Ordnance Survey UK Spatial Ontology	202
E.15. CIDOC CRM Geo	204
E.16. Basic Formal Ontology (BFO)	205
 ANNEX F (INFORMATIVE) CQL / GEOSPARQL MAPPING	208
F.0. Overview	
F.1. Accessing spatial Features in a SPARQL endpoint	208

F.2. Mappings from CQL2 statements to GeoSPARQL queries	209
F.3. Mappings from Simple Features for SQL	214
ANNEX G (INFORMATIVE) REVISION HISTORY	219
BIBLIOGRAPHY	222

ABSTRACT

GeoSPARQL contains a small spatial domain OWL ontology that allow literal representations of geometries to be associated with spatial features and for features to be associated with other features using spatial relations.

GeoSPARQL also contains SPARQL extension function definitions that can be used to calculate relations between spatial objects.

Several other supporting assets are also contained within GeoSPARQL such as vocabularies of Simple Feature types and data validators.

Example: The namespace for the GeoSPARQL ontology is <http://www.opengis.net/ont/geosparql#>

The suggested prefix for this namespace is geo

The namespace for the GeoSPARQL functions is <http://www.opengis.net/def/function/geosparql/>

The suggested prefix for this namespace is geof

The namespace for the GeoSPARQL RIF rules is <http://www.opengis.net/def/rule/geosparql/>

The suggested prefix for this namespace is geor

PREFACE

The OGC GeoSPARQL Standard defines:

- A formal *profile*;
- **this document**;
- A core RDF/OWL ontology for geographic information representation;
- A set of SPARQL extension functions;
- A Functions & Rules vocabulary, derived from the ontology;
- A Simple Features geometry types vocabulary;
- SHACL shapes for RDF data validation.

This document authoritatively defines many of the Standard's elements, including the ontology classes and properties, SPARQL functions, and function and rule vocabulary concepts. Complete descriptions of the Standard's parts and their roles are given in the Introduction in the section Clause 7.3.

III

SECURITY CONSIDERATIONS

No security considerations have been made for this document.

IV

SUBMITTERS

All questions regarding this submission should be directed to the editor or the submitters:

CONTACT	COMPANY
Simon J.D. Cox	CSIRO
Panagiotis (Peter) A. Vretanos	Cubewerx Inc.
Paul Cripps	DSTL
Linda van den Brink	Geonovum
Joseph Abhayaratna	Geoscape Australia
Irina Bastrakova	Geoscience Australia
Timo Homburg	Mainz University Of Applied Sciences
Matthew Perry	Oracle America
Nicholas J. Car	KurrawongAI

V

KEYWORDS

Open Geospatial Consortium, OGC, spatial, ontology, Knowledge Graph, Semantic Web, Linked Data, RDF, Resource Description Framework, Web Ontology Language, OWL, SPARQL, Simple Features, feature, geometry

VI

CLARIFICATIONS

- The terms Spatial Reference System (SRS) and Coordinate Reference System (CRS) are no longer interchangeable. Spatial Reference System is now taken to be a broader category than Coordinate Reference System. These are defined in the Clause 4 section.
- Class definitions were updated to be more self-contained and easier to understand for people without a background in geoinformatics. The definitions are no longer dependent on other standards' definitions, only informed by them.
- A section was added on the specification of units of measurement.
- A section was added on the influence of Reference Systems on computations.

VII

CHANGES TO THE OGC® ABSTRACT SPECIFICATION

The OGC® Abstract Specification does not require changes to accommodate this OGC® standard.

VIII

SUBMITTING ORGANIZATIONS

The following organizations submitted this Implementation Standard to the Open Geospatial Consortium Inc.:

- CSIRO
- Cubewerx Inc.
- Defence Science and Technology Laboratory (DSTL)
- Geonovum
- Geoscape Australia
- Geoscience Australia
- KurrawongAI

- Mainz University Of Applied Sciences
- Oracle America
- OSGeo

1

SCOPE

SCOPE

The OGC GeoSPARQL Standard is comprised of multiple parts. See the Introduction section Clause 7.3 for details of the parts.

GeoSPARQL does not define a comprehensive vocabulary for representing spatial information. Instead GeoSPARQL defines a core set of classes, properties and datatypes that can be used to construct query patterns. Many useful extensions to this vocabulary are possible, and we intend for the Semantic Web and Geospatial communities to develop additional vocabularies for describing spatial information.

2

CONFORMANCE

CONFORMANCE

Conformance with this Standard shall be checked using all the relevant tests specified in Annex A. The framework, concepts, and methodology for testing, and the criteria to be achieved to claim conformance are specified in *ISO 19105: Geographic information – Conformance and Testing ISO19105*.

This document establishes many individual Requirements and Conformance Classes which contain tests for one or more Requirements. GeoSPARQL implementations need not conform to all Conformance Classes but must state which individual ones they do conform to. GeoSPARQL implementations claiming conformance to a Conformance Class must pass all the tests defined for it in Annex A.

Requirements and Conformance Class tests have IRIs that are relative to versioned namespace IRIs. Requirements and Conformance Class tests that are defined in GeoSPARQL 1.0 have IRIs relative to <http://www.opengis.net/spec/geosparql/1.0/> and those added in GeoSPARQL 1.1 have IRIs relative to <http://www.opengis.net/spec/geosparql/1.1/>.

Many Conformance Classes are parameterized, and any parameters are explained in the detailed clauses for those Conformance Classes.

Table 1 – Conformance Classes

CONFORMANCE CLASS	DESCRIPTION	SUBCLAUSE OF THE ABSTRACT TEST SUITE
Core	Defines top-level spatial vocabulary components	Conformance class A.1: /conf/core
Topology Vocabulary Extension (relation_family)	Defines topological relation vocabulary	Conformance class A.2: /conf/topology-vocab-extension
Geometry Extension (serialization, version)	Defines geometry vocabulary and non-topological query functions	Conformance class A.3: /conf/geometry-extension
Geometry Extension – DGGS	Defines the properties and functions of the Geometry Extension Conformance Classes for use with Discrete Global Grid System geometry representations	Conformance class A.4: /conf/geometry-extension-dggs
Geometry Topology Extension (serialization, version, relation_family)	Defines topological query functions for geometry objects	Conformance class A.5: /conf/geometry-topology-extension
RDFS Entailment Extension (serialization, version , relation_family)	Defines a mechanism for matching implicit RDF triples that are derived based on RDF and RDFS semantics	Conformance class A.6: /conf/rdfs-entailment-extension

CONFORMANCE CLASS	DESCRIPTION	SUBCLAUSE OF THE ABSTRACT TEST SUITE
Query Rewrite Extension (serialization, version, relation_family)	Defines query transformation rules for computing spatial relations between spatial objects based on their associated geometries	Conformance class A.7: /conf/query-rewrite-extension

Dependencies between each GeoSPARQL Conformance Class are shown below in Figure 2. To support a Conformance Class for a given set of parameter values, an implementation must support each dependent Conformance Class with the same set of parameter values.



Figure 1 – Requirements Class Dependency Graph

3

NORMATIVE REFERENCES

NORMATIVE REFERENCES

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

International Organization for Standardization: ISO19125-1, *Geographic information – Simple feature access*. Geneva, CH (2005a). <https://www.iso.org/standard/40114.html>.

International Organization for Standardization: ISO19156, *Geographic information – Observations and measurements*. Geneva, CH (2011). <https://www.iso.org/standard/32574.html>.

Open Geospatial Consortium: GML, *OpenGIS Geography Markup Language (GML) Encoding Standard*. (2007a). https://portal.ogc.org/files/?artifact_id=20509/.

Dürst MJ, Suignard M: IETF3987, *Internationalized Resource Identifiers (IRIs)*. RFC Editor (2005). <https://www.rfc-editor.org/info/rfc3987>.

Group WOW: OWL2, *OWL 2 Web Ontology Language Document Overview (Second Edition)*. (2012). <https://www.w3.org/TR/2012/REC-owl2-overview-20121211/>.

Lanthaler M, Cyganiak R, Wood D: RDF, *RDF 1.1 Concepts and Abstract Syntax*. (2014). <https://www.w3.org/TR/2014/REC-rdf11-concepts-20140225/>.

Guha R, Brickley D: RDFS, *RDF Schema 1.1*. (2014). <https://www.w3.org/TR/2014/REC-rdf-schema-20140225/>.

Boley H, Hallmark G, Reynolds D, Paschke A, Polleres A, Kifer M: RIFCORE, *RIF Core Dialect (Second Edition)*. (2013a). <https://www.w3.org/TR/2013/REC-rif-core-20130205/>.

Boley H, Hallmark G, Reynolds D, Paschke A, Polleres A, Kifer M: SPARQL, *RIF Core Dialect (Second Edition)*. (2013b). <https://www.w3.org/TR/2013/REC-rif-core-20130205/>.

Ogbuji C, Glimm B: SPARQLENT, *SPARQL 1.1 Entailment Regimes*. (2013). <https://www.w3.org/TR/2013/REC-sparql11-entailment-20130321/>.

Clark K, Williams G, Torres E, Feigenbaum L: SPARQLPROT, *SPARQL 1.1 Protocol*. (2013). <https://www.w3.org/TR/2013/REC-sparql11-protocol-20130321/>.

Beckett D, Broekstra J: SPARQLRESX, *SPARQL Query Results XML Format (Second Edition)*. (2013). <https://www.w3.org/TR/2013/REC-rdf-sparql-XMLres-20130321/>.

Seaborne A: SPARQLRESJ, *SPARQL 1.1 Query Results JSON Format*. (2013). <https://www.w3.org/TR/2013/REC-sparql11-results-json-20130321/>.

4

TERMS AND DEFINITIONS

TERMS AND DEFINITIONS

This document uses the terms defined in [OGC Policy Directive 49](#), which is based on the ISO/IEC Directives, Part 2, Rules for the structure and drafting of International Standards. In particular, the word "shall" (not "must") is the verb form used to indicate a requirement to be strictly followed to conform to this document and OGC documents do not use the equivalent phrases in the ISO/IEC Directives, Part 2.

This document also uses terms defined in the OGC Standard for Modular specifications ([OGC 08-131r3](#)), also known as the 'ModSpec'. The definitions of terms such as standard, specification, requirement, and conformance test are provided in the ModSpec.

For the purposes of this document, the following additional terms and definitions apply.

For the purposes of this document, the terms and definitions given in the above normative references apply, as well as those reproduced or created in this section.

4.1. Semantic Web

The following terms and their definitions relate to Semantic Web models, tools and methods.

4.1.1. RDF

The Resource Description Framework (RDF) is a framework for representing information in the Web. RDF graphs are sets of subject-predicate-object triples, where the elements may be IRIs, blank nodes, or datatyped literals. They are used to express descriptions of resources. RDF

4.1.2. RDFS

RDF Schema provides a data-modelling vocabulary for RDF data. RDF Schema is an extension of the basic RDF vocabulary. RDFS

4.1.3. OWL

The OWL 2 Web Ontology Language, informally OWL 2, is an ontology language for the Semantic Web with formally defined meaning. OWL 2 ontologies provide classes, properties, individuals, and data values and are stored as Semantic Web documents. OWL 2 ontologies can be used along with information written in RDF, and OWL 2 ontologies themselves are primarily exchanged as RDF documents. OWL2

4.1.4. SPARQL

SPARQL is a query language for RDF. The results of SPARQL queries can be result sets or RDF graphs. SPARQL

4.2. spatial

The following terms and their definitions relate to spatial science and data.

4.2.1. coordinate system

A coordinate system is a set of mathematical rules for specifying how coordinates are to be assigned to points.

4.2.2. coordinate reference system

A coordinate reference system (CRS) is a coordinate system that is related to an object by a datum.

4.2.3. datum

A datum is a parameter or set of parameters that define the position of the origin, the scale, and the orientation of a coordinate system.

4.2.4. discrete global grid system

A discrete global grid system (DGGS) is a spatial reference system that represents the Earth, or any other globe-like object, with a tessellation of nested cells. Generally, a DGGS will exhaustively partition the globe in closely packed hierarchical tessellations, each cell representing a homogenous value, with a unique identifier or indexing that allows for linear ordering, parent-child operations, and nearest neighbor algebraic operations.

4.2.5. spatial reference system

A spatial reference system (SRS) is a system for establishing spatial position. A spatial reference system can use geographic identifiers (place names, for example), coordinates (in which case it is a coordinate reference system), or identifiers with structured geometry (in which case it is a discrete global grid system).

6

CONVENTIONS

6.1. Symbols and abbreviated terms

In this specification, the following common acronyms are used:

CRS	Coordinate Reference System
DGGS	Discrete Global Grid System
GeoJSON	Geographic JavaScript Object Notation
GFM	General Feature Model (as defined in ISO 19109)
GIS	Geographic Information System
GML	Geography Markup Language
IRI	Internationalized Resource Identifier
KML	Keyhole Markup Language
OWL	OWL 2 Web Ontology Language
RCC	Region Connection Calculus
RDF	Resource Description Framework
RDFS	RDF Schema
RIF	Rule Interchange Format
SPARQL	SPARQL Protocol and RDF Query Language
SQL	Structured Query Language
SRS	Spatial Reference System
URI	Universal Resource Identifier

WKT	Well Known Text (as defined by Simple Features or ISO 19125)
W3C	World Wide Web Consortium (https://www.w3.org)
XML	Extensible Markup Language

6.2. Namespaces

The following IRI namespace prefixes are used throughout this document:

dcat:	http://www.w3.org/ns/dcat#
dcterms:	http://purl.org/dc/terms/
ex:	http://example.com/
geo:	http://www.opengis.net/ont/geosparql#
geof:	http://www.opengis.net/def/function/geosparql/
geor:	http://www.opengis.net/def/rule/geosparql/
gml:	http://www.opengis.net/ont/gml#
my:	http://example.org/ApplicationSchema#
ogc:	http://www.opengis.net/
owl:	http://www.w3.org/2002/07/owl#
rdf:	http://www.w3.org/1999/02/22-rdf-syntax-ns#
rdfs:	http://www.w3.org/2000/01/rdf-schema#
sf:	http://www.opengis.net/ont/sf#
skos:	http://www.w3.org/2004/02/skos/core#
xsd:	http://www.w3.org/2001/XMLSchema#

6.3. Placeholder IRIs

All of these namespace prefixes in the previous section resolve to resources that contain their namespace content except for eg: (<http://example.com/>), which is used just for examples, and ogc: (<http://www.opengis.net/>), which is used in requirement specifications as a placeholder for the geometry literal serialization used in a fully-qualified conformance class, e.g. <\a href="http://www.opengis.net/ont/geosparql#wktLiteral">.

6.4. Data Types for Spatial Aggregate Functions

In this specification we use the placeholder URI ogc:geomLiteral to describe any geometry literal that is defined in this specification. To express a list of such literals, for example as input parameters for spatial aggregate functions, we use the notation ogc:geomLiteral[]. We do not define the order of ogc:geomLiteral[]. The order is to be determined by implementers.

6.5. RDF Serializations

Three RDF serializations are used in this document. Terse RDF Triple Language (turtle) TURTLE is used for RDF snippets placed within the main body of the document, and turtle, JSON-LD JSON-LD & RDF/XML RDFXML is used for the examples in Annex C.

7

INTRODUCTION

INTRODUCTION

The W3C Semantic Web Activity defines a collection of technologies that enables a “web of data” where information is easily shared and reused across applications. Some key pieces of this technology stack are the Resource Description Framework (RDF) data model RDF, RDFS, the OWL Web Ontology Language OWL2 and the SPARQL Protocol and RDF Query Language SPARQL.

7.1. RDF

RDF is, among other things, a data model built on edge-node “graphs.” Each link in a graph consists of three elements (with many aliases depending on the mapping from other types of data models):

- Subject (start node, instance, entity, feature);
- Predicate (verb, property, attribute, relation, member, link, reference); and
- Object (value, end node, non-literal values can be used as a Subject).

Any of the three values in a triple can be represented with an Internationalized Resource Identifier (IRI) IETF3987, which globally and uniquely identifies the resource referenced. IRIs are an extension to Uniform Resource Identifiers (URIs) that allow for non-ASCII characters. In addition to functioning as identifiers, IRIs are usually, but not necessarily, resolvable. This means a person or machine can “dereference” them (*click on them* or otherwise execute them) and be taken to more information about the resource, perhaps in a web browser.

Subjects and objects within an RDF triple are called nodes and can also be represented with a blank node (a local identifier without meaning outside the graph it is defined within). Objects can further be represented with a literal value. RDF uses the basic literal values from XML XSD2 however the basic types can be extended for specialized purposes. Indeed, this document extends the basic types to include geometry data. The figure below shows a basic triple.



Figure 2 – An RDF Triple

Note that the same node may be a subject in some triples, and an object in others.

Almost all data can be presented or represented in RDF. In particular, there are similarities to the (feature-instance-by-id, attribute, value) tuples of the General Feature Model ISO19109, and to the relational model as well (table primary key, column, value).

7.2. SPARQL

From SPARQL:

SPARQL ... is a set of specifications that provide languages and protocols to query and manipulate RDF graph content on the Web or in an RDF store.

From Wikipedia¹:

SPARQL (pronounced “sparkle”, a recursive acronym for SPARQL Protocol and RDF Query Language) is an RDF query language — that is, a semantic query language for databases — able to retrieve and manipulate data stored in Resource

¹<https://en.wikipedia.org/wiki/SPARQL>

Description Framework (RDF) format. It was made a standard by the RDF Data Access Working Group (DAWG) of the World Wide Web Consortium, and is recognized as one of the key technologies of the semantic web. On 15 January 2008, SPARQL 1.0 was acknowledged by W3C as an official recommendation, and SPARQL 1.1 in March, 2013.

SPARQL queries work on RDF representations of data by finding patterns that match templates in the query, in effect finding information graphs in the RDF data based on the templates and filters (constraints on nodes and edges) expressed in the query. This query template is represented in the SPARQL query by a set of parameterized “query variables” appearing in a sequence of RDF triples and filters. If the query processor finds a set of triples in the data (converted to an RDF graph in some predetermined standard manner) then the values that the “query variables” take on in those triples become a solution to the query request. The values of the variables are returned in the query result in a format based on the “SELECT” clause of the query (similar to SQL).

In addition to predicates defined in this manner, the SPARQL query may contain filter functions that can be used to further constrain the query. Several mechanisms are available to extend filter functions to allow for predicates calculated directly on data values. Section 17.6² of the SPARQL specification SPARQL describes the mechanism for invocation of such a filter function.

The OGC GeoSPARQL Standard supports representing and querying geospatial data on the Semantic Web. GeoSPARQL defines a vocabulary for representing geospatial data in RDF. It also defines extensions to the SPARQL query language for processing geospatial data.

GeoSPARQL does not directly provide support for temporality. Predicates for temporal relations may be used from the OWL Time Ontology TIME, but query extension functions for spatiotemporal operations are not present in the GeoSPARQL standard.

7.3. GeoSPARQL Standard structure

The GeoSPARQL Standard consists of multiple parts, or *profile* resources. The comprehensive listing of these parts is given in the GeoSPARQL *profile definition*, (see <http://www.opengis.net/def/geosparql>). Below is an overview of the major parts:

1. *profile definition*
 - <http://www.opengis.net/def/geosparql>
 - Formally defined as an ontology, defined according to the *Profiles Vocabulary* PROF;
 - This relates the parts in the standard together, provides access to them, and declares dependencies on other standards.

²<https://www.w3.org/TR/sparql11-query/#extensionFunctions>

2. Standard document (this document)
 - <http://www.opengis.net/doc/IS/geosparql/1.1>
 - Defines many of the standard's parts;
 - Includes normative RDF/OWL RDF,OWL2 ontology element definitions, conformance requirements and function signatures based on the General Feature Model ISO19109, Simple Features OGCSFACA ISO19125-1 and SQL MM ISO13249;
 - Also includes non-normative examples and mappings to other modelling and function systems.
3. Domain model RDF/OWL RDF,OWL2 ontology
 - <http://www.opengis.net/ont/geosparql>;
 - For geographic information representation;
 - Based on the General Feature Model ISO19109, Simple Features Access OGCSFACA ISO19125-1, Geography Markup Language GML and SQL MM ISO13249
 - Defined within the specification document and also delivered in RDF.
4. Functions & Rules vocabulary
 - <http://www.opengis.net/def/geosparql/funcsrules>;
 - Derived from the ontology;
 - Presented as a SKOS taxonomy.
5. Simple Features vocabulary
 - <http://www.opengis.net/ont/sf>;
 - Derived from the class model defined in Simple Features Access OGCSFACA ISO19125-1;
 - Presented as an OWL2 ontology.
6. SPARQL extension functions defined within this document.
7. RDF data validator
 - <http://www.opengis.net/def/geosparql/validator>;
 - Defined using SHACL;

- Presented within a single RDF file.
8. SPARQL 1.1 Service description for GeoSPARQL
- <http://www.opengis.net/def/geosparql/servicedescription>;
 - Defined using SPARQLSERVDESC.
9. Extended Examples
- Example data in RDF files too long for this document
 - <https://github.com/opengeospatial/ogc-geosparql/tree/geosparql-1.1/examples>

This document follows a modular design and contains the following components:

- A *core* component defining the top-level RDFS/OWL classes for spatial objects.
- A *topology vocabulary* component defining the RDF properties for asserting and querying topological relationships between spatial objects.
- A *geometry* component defining RDFS data types for serializing geometry data, geometry-related RDF properties, and non-topological spatial query functions for geometry objects.
- A *geometry topology* component defining topological query functions.
- An *RDFS entailment* component defining mechanisms for matching implicit RDF triples that are derived based on RDF and RDFS semantics.
- A *query rewrite* component defining rules for transforming a simple triple pattern that tests a topological relationship between two features into an equivalent query involving concrete geometries and topological query functions.

Each of these components forms a set of Requirements known as a *GeoSPARQL Conformance Class*. Implementations can provide various levels of functionality by choosing which *Conformance Classes* to support. For example, a system based purely on qualitative spatial reasoning may support only the core and topological vocabulary Classes.

In addition, GeoSPARQL is designed to accommodate systems based on qualitative spatial reasoning and systems based on quantitative spatial computations. Systems based on qualitative spatial reasoning, (e.g., those based on Region Connection Calculus QUAL, [4]) do not usually model explicit geometries, so queries in such systems will likely test for binary spatial relationships between features rather than between explicit geometries. To allow queries for spatial relationships between features in quantitative systems, GeoSPARQL defines a series of query transformation rules that expand a feature-only query into a geometry-based query. With these transformation rules, queries about spatial relationships between features will have the same specification in both qualitative systems and quantitative systems. The qualitative system will likely evaluate the query with a backward-chaining spatial “reasoner”, and the

quantitative system can transform the query into a geometry-based query that can be evaluated with computational geometry.

8

CORE

This clause establishes the **Core Requirements** class, with IRI /req/core, which has a corresponding Conformance Class, **Core**, with IRI /conf/core. These Requirements define a set of classes and properties for representing geospatial data. The resulting vocabulary – an ontology – can be used to construct SPARQL graph patterns for querying appropriately modeled geospatial data. The RDFS and OWL vocabularies have both been used so that the vocabulary can be understood by systems that support only RDFS entailment and by systems that support OWL-based reasoning.

The figure below gives an overview of the classes and properties defined by GeoSPARQL in the **Core**, **Topology Vocabulary Extension** and **Geometry Extension**, **Geometry Topology Extension** and **RDFS Entailment Extension** Conformance Classes.



Figure 3 – An overview of the Classes and Properties defined in GeoSPARQL. Where specific Classes and Properties are indicated, the prefixed forms of their ontology identifiers (IRIs) are given. Where types or collections of properties are given, they are described in italics. Where unspecified Classes are given, they are represented with a question mark. For cardinalities and other ontology restrictions, see the ontology document. Subproperties of **geo:hasSize**, its metric equivalent and **geo:hasSerialization** are not shown for clarity.

8.1. SPARQL

REQUIREMENT 1: SPARQL PROTOCOL

IDENTIFIER /req/core/sparql-protocol

STATEMENT Implementations shall support the SPARQL Query Language for RDF SPARQL, the SPARQL Protocol SPARQLPROT and the SPARQL Query Results XML SPARQLRESX and JSON SPARQLRESJ Formats.

8.2. Classes

Two main classes are defined: geo:SpatialObject and Feature.

Two container classes are defined: Spatial Object Collection and Feature Collection.

8.2.1. Class: geo:SpatialObject

The class geo:SpatialObject is defined by the following:

```
geo:SpatialObject
  a rdfs:Class, owl:Class ;
  rdfs:isDefinedBy geo: ;
  skos:prefLabel "Spatial Object"@en ;
  skos:definition "Anything spatial (being or having a shape, position or an extent)."@en ;
  skos:note "Subclasses of this class are expected to be used for instance data."@en ;
.
```

REQUIREMENT 2: SPATIAL OBJECT CLASS

IDENTIFIER /req/core/spatial-object-class

STATEMENT Implementations shall allow the RDFS class geo:SpatialObject to be used in SPARQL graph patterns.

Example:

```
eg:x
  a geo:SpatialObject ;
  skos:prefLabel "Object X";
.
```

8.2.2. Class: geo:Feature

The class `geo:Feature` is equivalent to the class GFI_Feature ISO19115 and is defined by the following:

```
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 ;
.
```

REQUIREMENT 3: FEATURE CLASS

IDENTIFIER /req/core/feature-class

STATEMENT Implementations shall allow the RDFS class Feature to be used in SPARQL graph patterns.

8.2.3. Class: geo:SpatialObjectCollection

The class `Spatial Object Collection` is defined by the following:

```
geo:SpatialObjectCollection
  a owl:Class ;
  rdfs:isDefinedBy geo: ;
  skos:prefLabel "Spatial Object Collection" ;
  skos:definition "A collection of individual Spatial Objects."@en ;
  skos:note "This is the superclass of Feature Collection and Geometry
Collection."@en ;
  rdfs:subClassOf rdfs:Container ;
  rdfs:subClassOf [
    a owl:Restriction ;
    owl:allValuesFrom geo:SpatialObject ;
    owl:onProperty rdfs:member ;
  ] ;
.
```

Membership of the generic `rdfs:Container` that defines this class is restricted to instances of Spatial Object. Spatial Object Collection members are to be indicated with the `rdfs:member` property.

REQUIREMENT 4: SPATIAL OBJECT COLLECTION CLASS

IDENTIFIER	/req/core/spatial-object-collection-class
STATEMENT	Implementations shall allow the RDFS class Spatial Object Collection to be used in SPARQL graph patterns.

8.2.4. Class: geo:FeatureCollection

The class `geo:FeatureCollection` is defined by the following:

```
geo:FeatureCollection
  a owl:Class ;
  rdfs:isDefinedBy geo: ;
  skos:prefLabel "Feature Collection" ;
  skos:definition "A collection of individual Features."@en ;
  rdfs:subClassOf geo:SpatialObjectCollection , geo:Feature ;
  rdfs:subClassOf [
    a owl:Restriction ;
    owl:allValuesFrom :Feature ;
    owl:onProperty rdfs:member ;
  ] ;
.
```

This class is indicated to be a collection of spatial objects by being a subclass of the general Spatial Object Collection. That it contains only Feature class instances is indicated by the restriction `rdfs:member` predicate. That it can be used as a Feature, for example as the domain value for the has geometry predicate, is indicated by it being a subclass of the Geometry class.

NOTE: Many spatial standards, such as OGC17-069r3, contain a grouping mechanism for Features called *layers* or *feature collections* or *feature types*. These are commonly used to contain similar types of, or otherwise relates, Features. The Feature Collection class can be used for this purpose and, where it is, the bounding box geometry or other summary spatial projection of it can be indicated with a geometry directly. See

REQUIREMENT 5: FEATURE COLLECTION CLASS

IDENTIFIER	/req/core/feature-collection-class
STATEMENT	Implementations shall allow the RDFS class Feature Collection to be used in SPARQL graph patterns.

8.3. Standard Properties for geo:SpatialObject

Properties are defined for associating Spatial Objects with scalar spatial measurements (sizes).

REQUIREMENT 6: SPATIAL OBJECT PROPERTIES

IDENTIFIER /req/core/spatial-object-properties

STATEMENT Implementations shall allow the properties geo:hasSize, geo:hasMetricSize, geo:hasLength, geo:hasMetricLength, geo:hasPerimeterLength, geo:hasMetricPerimeterLength, geo:hasArea, geo:hasMetricArea, geo:hasVolume and geo:hasMetricVolume to be used in SPARQL graph patterns.

8.3.1. Property: geo:hasSize

The property `geo:hasSize` is the superproperty of all properties that can be used to indicate the size of a Spatial Object in case (only) metric units (meter, square meter or cubic meter) can not be used. If it is possible to express size in metric units, subproperties of `geo:hasMetricSize` should be used. This property has no range specification. This makes it possible to use other vocabularies for expressions of size, for example vocabularies for units of measurement or vocabularies for specifying measurement quality.

GeoSPARQL 1.1 defines the following subproperties of this property: `geo:hasLength`, `geo:hasPerimeterLength`, `geo:hasArea` and `geo:hasVolume`.

```
geo:hasSize
  a rdf:Property, owl:ObjectProperty ;
  rdfs:isDefinedBy geo: ;
  rdfs:domain geo:SpatialObject ;
  skos:definition "Subproperties of this property are used to indicate the size of a
    Spatial Object as a measurement or estimate of one or more
    dimensions
    of the Spatial Object's spatial presence."@en ;
  skos:prefLabel "has size"@en ;
  .
```

8.3.2. Property: geo:hasMetricSize

The property `geo:hasMetricSize` is the superproperty of all properties that can be used to indicate the size of a Spatial Object using metric units (meter, square meter or cubic meter). Using a subproperty of this property is the recommended way to specify size, because using a standard unit of length (meter) benefits data interoperability and simplicity. Subproperties of `geo:hasSize` can be used if more complex expressions are necessary, for example if the unit of length can not be converted to meter, or if additional data are needed to describe the measurement or estimate of size.

GeoSPARQL 1.1 defines the following subproperties of this property: geo:hasMetricLength, geo:hasMetricPerimeterLength, geo:hasMetricArea and geo:hasMetricVolume.

```
geo:hasMetricSize
  a rdf:Property, owl:DatatypeProperty ;
  rdfs:isDefinedBy geo: ;
  rdfs:domain geo:SpatialObject ;
  rdfs:range xsd:double ;
  skos:definition "Subproperties of this property are used to indicate the size of a Spatial Object, as a measurement or estimate of one or more dimensions of the Spatial Object's spatial presence. Units are always metric (meter, square meter or cubic meter)."@en ;
  skos:prefLabel "has metric size"@en ;
.
```

8.3.3. Property: geo:hasLength

The property `geo:hasLength` can be used to indicate the length of a Spatial Object if it is not possible to use the property `geo:hasMetricLength`. It is a subproperty of `geo:hasSize`.

```
geo:hasLength
  a rdf:Property, owl:ObjectProperty ;
  rdfs:isDefinedBy geo: ;
  rdfs:subPropertyOf geo:hasSize ;
  rdfs:domain geo:SpatialObject ;
  skos:definition "The length of a Spatial Object."@en ;
  skos:prefLabel "has length"@en ;
.
```

8.3.4. Property: geo:hasMetricLength

The property `geo:hasMetricLength` can be used to indicate the length of a Spatial Object in meters (m). It is a subproperty of `geo:hasMetricSize`. This property can be used for Spatial Objects having one, two, or three dimensions.

```
geo:hasMetricLength
  a rdf:Property, owl:DatatypeProperty ;
  rdfs:isDefinedBy geo: ;
  rdfs:subPropertyOf geo:hasMetricSize ;
  rdfs:domain geo:SpatialObject ;
  rdfs:range xsd:double ;
  skos:definition "The length of a Spatial Object in meters."@en ;
  skos:prefLabel "has length in meters"@en ;
.
```

8.3.5. Property: geo:hasPerimeterLength

The property `geo:hasPerimeterLength` can be used to indicate the length of the outer boundary of a Spatial Object if it is not possible to use the property `geo:hasMetricPerimeterLength`. It is a subproperty of `geo:hasSize`.

```

geo:hasPerimeterLength
    a rdf:Property, owl:ObjectProperty ;
    rdfs:isDefinedBy geo: ;
    rdfs:subPropertyOf geo:hasSize ;
    skos:definition "The length of the perimeter of a Spatial Object."@en ;
    skos:prefLabel "has perimeter length"@en ;
.

```

8.3.6. Property: geo:hasMetricPerimeterLength

The property `geo:hasMetricPerimeterLength` can be used to indicate the length of the outer boundary of a Spatial Object in meters (m). It is a subproperty of `geo:hasMetricSize`. Circumference is considered a type of perimeter, so this property can be used for circular or curved objects too. This property can be used for Spatial Objects having two or three dimensions.

```

geo:hasMetricPerimeterLength
    a rdf:Property, owl:DatatypeProperty ;
    rdfs:isDefinedBy geo: ;
    rdfs:subPropertyOf geo:hasMetricSize ;
    rdfs:domain geo:SpatialObject ;
    rdfs:range xsd:double ;
    skos:definition "The length of the perimeter of a Spatial Object in meters."@en
;
    skos:prefLabel "has perimeter length in meters"@en ;
.

```

A consistency check can be applied to Geometry instances indicating both this property and the property `geo:dimension`: if supplied, the `geo:dimension` property's range value must be the literal integer 2 or 3. The following SPARQL query will return `true` if applied to a graph where this is not the case for all Geometries:

```

PREFIX geo: <http://www.opengis.net/ont/geosparql#>
ASK
WHERE {
    ?g geo:hasMetricPerimeterLength ?p ;
        geo:dimension ?d .
    FILTER (?d < 2)
}

```

8.3.7. Property: geo:hasArea

The property `geo:hasArea` can be used to indicate the area of a Spatial Object if it is not possible to use the property `geo:hasMetricArea`. It is a subproperty of `geo:hasSize`.

```

geo:hasArea
    a rdf:Property, owl:ObjectProperty ;
    rdfs:isDefinedBy geo: ;
    rdfs:subPropertyOf geo:hasSize ;
    rdfs:domain geo:SpatialObject ;
    skos:definition "The area of a Spatial Object."@en ;
    skos:prefLabel "has area"@en ;
.

```

8.3.8. Property: geo:hasMetricArea

The property `geo:hasMetricArea` can be used to indicate the area of a Spatial Object in square meters (m^2). It is a subproperty of `geo:hasMetricSize`. This property can be used for Spatial Objects having two or three dimensions.

```
geo:hasMetricArea
  a rdf:Property, owl:DatatypeProperty ;
  rdfs:isDefinedBy geo: ;
  rdfs:subPropertyOf geo:hasMetricSize ;
  rdfs:domain geo:SpatialObject ;
  rdfs:range xsd:double ;
  skos:definition "The area of a Spatial Object in square meters."@en ;
  skos:prefLabel "has area in meters"@en ;
```

A consistency check can be applied to Geometry instances indicating both this property and the property `geo:dimension`: if supplied, the `geo:dimension` property's range value must be the literal integer 2 or 3. The following SPARQL query will return *true* if applied to a graph where this is not the case for all Geometries:

```
PREFIX geo: <http://www.opengis.net/ont/geosparql#>

ASK
WHERE {
  ?g geo:hasMetricArea ?a ;
  geo:dimension ?d .

  FILTER (?d < 2)
}
```

8.3.9. Property: geo:hasVolume

The property `geo:hasVolume` can be used to indicate the volume of a Spatial Object if it is not possible to use the property `geo:hasMetricVolume`. It is a subproperty of `geo:hasSize`.

```
geo:hasVolume
  a rdf:Property, owl:ObjectProperty ;
  rdfs:isDefinedBy geo: ;
  rdfs:subPropertyOf geo:hasSize ;
  rdfs:domain geo:SpatialObject ;
  skos:definition "The volume of a three-dimensional Spatial Object."@en ;
  skos:prefLabel "has volume"@en ;
```

8.3.10. Property: geo:hasMetricVolume

The property `geo:hasMetricVolume` can be used to indicate the volume of a Spatial Object in cubic meters (m^3). It is a subproperty of `geo:hasMetricSize`. This property can be used for Spatial Objects having three dimensions.

```
geo:hasMetricVolume
  a rdf:Property, owl:DatatypeProperty ;
  rdfs:isDefinedBy geo: ;
  rdfs:subPropertyOf :hasMetricSize ;
  rdfs:domain geo:SpatialObject ;
  rdfs:range xsd:double ;
  skos:definition "The volume of a Spatial Object in cubic meters."@en ;
  skos:prefLabel "has area in meters"@en ;
.
```

A consistency check can be applied to Geometries indicating both this property and the property `geo:dimension`: if supplied, the property `geo:dimension` property's range value must be the literal integer 3. The following SPARQL query will return *true* if applied to a graph where this is not the case for all Geometries:

```
PREFIX geo: <http://www.opengis.net/ont/geosparql#>

ASK
WHERE {
  ?g geo:hasMetricVolume ?v ;
  geo:dimension ?d .

  FILTER (?d != 3)
}
```

8.4. Standard Properties for geo:Feature

Properties are defined for associating Feature instances with geo:Geometry instances.

REQUIREMENT 7: FEATURE PROPERTIES

IDENTIFIER /req/core/feature-properties

STATEMENT Implementations shall allow the properties `geo:hasGeometry`, `geo:hasDefaultGeometry`, `geo:hasCentroid` and `geo:hasBoundingBox` to be used in SPARQL graph patterns.

8.4.1. Property: geo:hasGeometry

The property `geo:hasGeometry` is used to link a Feature with a Geometry that represents a spatial projection of it.

A Feature may be linked to Geometry Collection instead of a simple Geometry.

A Feature may also be associated with multiple individual Geometries or even multiple individual Geometry Collections, or any combinations of Geometries or Geometry Collections.

```
geo:hasGeometry
  a rdf:Property, owl:ObjectProperty ;
  rdfs:isDefinedBy geo: ;
  rdfs:domain geo:Feature ;
  rdfs:range geo:Geometry ;
  skos:prefLabel "has Geometry"@en ;
  skos:definition "A spatial representation for a given Feature."@en ;
.
```

8.4.2. Property: geo:hasDefaultGeometry

The property `geo:hasDefaultGeometry` is used to link a Feature with its default Geometry. The default geometry is the Geometry that should be used for spatial calculations in the absence of a request for a specific geometry (e.g. in the case of query rewrite).

```
geo:hasDefaultGeometry
  a rdf:Property, owl:ObjectProperty ;
  rdfs:isDefinedBy geo: ;
  rdfs:domain geo:Feature ;
  rdfs:range geo:Geometry ;
  skos:prefLabel "has Default Geometry"@en ;
  skos:definition "The default geometry to be used in spatial calculations,
    usually the most detailed geometry."@en ;
  rdfs:subPropertyOf geo:hasGeometry ;
.
```

GeoSPARQL does not restrict the cardinality of the has default geometry property. It is thus possible for a Feature to have more than one distinct default geometry or to have no default geometry. This situation does not result in a query processing error; SPARQL graph pattern matching simply proceeds as normal. Certain queries may, however, give logically inconsistent results. For example, if a Feature `my:f1` has two asserted default geometries, and those two geometries are disjoint polygons, the query below could return a non-zero count on a system supporting the GeoSPARQL Query Rewrite Extension (rule `geor:sfDisjoint`).

```
PREFIX geo: <http://www.opengis.net/ont/geosparql#>

SELECT (COUNT(*) AS ?cnt)
WHERE { :f1 geo:sfDisjoint :f1 }
```

Such cases are application-specific data modeling errors and are therefore outside of the scope of the GeoSPARQL specification., however it is recommended that multiple geometries indicated with `geo:hasDefaultGeometry` should be differentiated by Geometry class properties, perhaps relating to precision, SRS etc.

8.4.3. Property: geo:hasBoundingBox

The property `geo:hasBoundingBox` is used to link a Feature with a simplified geometry-representation corresponding to the envelope of the feature's geometry. Bounding-boxes are typically used in indexing and discovery.

```
geo:hasBoundingBox
  a rdf:Property, owl:ObjectProperty ;
  rdfs:isDefinedBy geo: ;
  rdfs:subPropertyOf geo:hasGeometry ;
  rdfs:domain geo:Feature ;
  rdfs:range geo:Geometry ;
  skos:prefLabel "has bounding box"@en ;
  skos:definition "The minimum or smallest bounding or enclosing box of a
given Feature."@en ;
  skos:scopeNote "The target is a geometry that defines a rectilinear region
whose edges are
  aligned with the axes of the coordinate reference system,
which exactly
  contains the geometry or Feature e.g. sf:Envelope"@en ;
.
```

GeoSPARQL does not restrict the cardinality of the `geo:hasBoundingBox` property. A Feature may be associated with more than one bounding-box, for example in different coordinate reference systems.

8.4.4. Property: geo:hasCentroid

The property `geo:hasCentroid` is used to link a Feature with a point geometry corresponding with the centroid of its geometry. The centroid is typically used to show location on a low-resolution image, and for some indexing and discovery functions.

```
geo:hasCentroid
  a rdf:Property, owl:ObjectProperty ;
  rdfs:isDefinedBy geo: ;
  rdfs:subPropertyOf geo:hasGeometry ;
  rdfs:domain geo:Feature ;
  rdfs:range geo:Geometry ;
  skos:prefLabel "has centroid"@en ;
  skos:definition "The arithmetic mean position of all the geometry points
of a given Feature."@en ;
  skos:scopeNote "The target geometry shall describe a point, e.g. sf:Point"@en
;
.
```

GeoSPARQL does not restrict the cardinality of the `geo:hasCentroid` property. A Feature may be associated with more than one centroid, for example computed using different rules or in different coordinate reference systems.

9

TOPOLOGY VOCABULARY EXTENSION

TOPOLOGY VOCABULARY EXTENSION

This clause establishes the *Topology Vocabulary Extension* parameterized Requirements class. The IRI base is `/req/topology-vocab-extension`, which has a single corresponding Conformance Class *Topology Vocabulary Extension*, with IRI `/conf/topology-vocab-extension`. This Requirements class defines a vocabulary for asserting and querying topological relations between spatial objects. The class is parameterized so that different families of topological relations may be used, such as RCC9 [rcc9] and Egenhofer. These relations are generalized so that they may connect features as well as geometries.

REQUIREMENTS CLASS 1: TOPOLOGY VOCABULARY EXTENSION

IDENTIFIER	<code>/req/topology-vocab-extension</code>
TARGET TYPE	Implementation Specification
CONFORMANCE CLASS	Conformance class A.2: <code>/conf/topology-vocab-extension</code>
	<code>/req/topology-vocab-extension/sf-spatial-relations</code>
REQUIREMENT	<code>/req/topology-vocab-extension/eh-spatial-relations</code>
	<code>/req/topology-vocab-extension/rcc8-spatial-relations</code>

A Dimensionally Extended 9-Intersection Model [2] pattern, which specifies the spatial dimension of the intersections of the interiors, boundaries and exteriors of two geometric objects, is used to describe each spatial relation. Possible pattern values are -1 (empty), 0, 1, 2, T (true) = {0, 1, 2}, F (false) = {-1}, * (don't care) = {-1, 0, 1, 2}. In the following descriptions, the notation X/Y is used to denote applying a spatial relation to geometry types X and Y (i.e., x relation y where x is of type X and y is of type Y). The symbol P is used for 0-dimensional geometries (e.g. points). The symbol L is used for 1-dimensional geometries (e.g. lines), and the symbol A is used for 2-dimensional geometries (e.g. polygons). Consult the Simple Features specification OGCSFACA ISO19125-1 for a more detailed description of DE-9IM intersection patterns.

9.1. Parameters

The following parameter is defined for the *Topology Vocabulary Extension* Requirements.

relation_family: Specifies the set of topological spatial relations to support.

9.2. Simple Features Relation Family

This clause defines Requirements for the *Simple Features* relation family.

REQUIREMENT 8: SIMPLE FEATURE SPATIAL RELATIONS

IDENTIFIER /req/topology-vocab-extension/sf-spatial-relations

STATEMENT Implementations shall allow the properties geo:sfEquals, geo:sfDisjoint, geo:sfIntersects, geo:sfTouches, geo:sfCrosses, geo:sfWithin, geo:sfContains and geo:sfOverlaps to be used in SPARQL graph patterns.

Topological relations in the *Simple Features* family are summarized in Table 2. Multi-row intersection patterns should be interpreted as a logical OR of each row.

Table 2 – Simple Features Topological Relations

RELATION NAME	RELATION IRI	DOMAIN/ RANGE	APPLIES TO GEOMETRY TYPES	DE-9IM INTERSECTION PATTERN
equals	geo:sfEquals	geo:Spatial Object	All	(TFFFFFFFFFF)
disjoint	geo:sfDisjoint	geo:Spatial Object	All	(FF***FF****)
intersects	geo:sfIntersects	geo:Spatial Object	All	(T*****T***** *T***** ***T***** ****T****)
touches	geo:sfTouches	geo:Spatial Object	All except P/P	(FT***** F**T***** F***T****)
within	geo:sfWithin	geo:Spatial Object	All	(T*F**F***)
contains	geo:sfContains	geo:Spatial Object	All	(T*****FF*)
overlaps	geo:sfOverlaps	geo:Spatial Object	A/A, P/P, L/L	(T*T***T**) for A/A, P/P; (1*T***T**) for L/L
crosses	geo:sfCrosses	geo:Spatial Object	P/L, P/A, L/A, L/L	(T*T***T**) for P/L, P/A, L/A; (0*****) for L/L

9.3. Egenhofer Relation Family

This clause defines Requirements for the 9-intersection model for the binary topological relations (*Egenhofer*) relation family. The reader should consult references [3] and CATEG for a more detailed discussion of *Egenhofer* relations.

REQUIREMENT 9: EGENHOFER SPATIAL RELATIONS

IDENTIFIER	/req/topology-vocab-extension/eh-spatial-relations
STATEMENT	Implementations shall allow the properties geo:ehEquals, geo:ehDisjoint, geo:ehMeet, geo:ehOverlap, geo:ehCovers, geo:ehCoveredBy, geo:ehInside and geo:ehContains to be used in SPARQL graph patterns.

Topological relations in the *Egenhofer* family are summarized in Table 3. Multi-row intersection patterns should be interpreted as a logical OR of each row.

Table 3 – Egenhofer Topological Relations

RELATION NAME	RELATION IRI	DOMAIN/ RANGE	APPLIES TO GEOMETRY TYPES	DE-9IM INTERSECTION PATTERN
equals	geo:ehEquals	geo:Spatial Object	All	(TFFFFFFFFFF)
disjoint	geo:ehDisjoint	geo:Spatial Object	All	(FF*FF****)
meet	geo:ehMeet	geo:Spatial Object	All except P/P	(FT***** F**T**** F***T****)
overlap	geo:ehOverlap	geo:Spatial Object	All	(T*T***T***)
covers	geo:ehCovers	geo:Spatial Object	A/A, A/L, L/L	(T*TFT*FF*)
covered by	geo:ehCoveredBy	geo:Spatial Object	A/A, L/A, L/L	(TFF*TFT**) (TFF*TFT***)
inside	geo:ehInside	geo:Spatial Object	All	(TFF*FFT**) (TFF*FFT***)
contains	geo:ehContains	geo:Spatial Object	All	(T*TFF*FF*) (T*TFF*FF***)

9.4. RCC8 and RCC*-9 Relation Family

This clause defines Requirements for the region connection calculus basic 8 and 9 (RCC8, RCC*-9) relation family. The reader should consult references QUAL and [4] for a more detailed discussion of RCC8 and [5] for a discussion of RCC*-9 relations.

REQUIREMENT 10: RCC8 SPATIAL RELATIONS

IDENTIFIER /req/topology-vocab-extension/rcc8-spatial-relations

STATEMENT Implementations shall allow the properties geo:rcc8eq, geo:rcc8dc, geo:rcc8ec, geo:rcc8po, geo:rcc8tppi, geo:rcc8tpp, geo:rcc8ntpp, geo:rcc8ntppi to be used in SPARQL graph patterns.

Topological relations in the RCC8 family are summarized in Table 4.

REQUIREMENT 11: RCC*-9 SPATIAL RELATIONS

IDENTIFIER /req/topology-vocab-extension/rcc9-spatial-relations

STATEMENT Implementations shall allow the properties geo:rcc9eq, geo:rcc9dc, geo:rcc9ec, geo:rcc9po, geo:rcc9tppi, geo:rcc9tpp, geo:rcc9ntpp, geo:rcc9ntppi, geo:rcc9cr, to be used in SPARQL graph patterns.

Topological relations in the RCC*-9 family are summarized in Table 5.

Table 4 – RCC8 Topological Relations

RELATION NAME	RELATION IRI	DOMAIN/ RANGE	APPLIES TO GEOMETRY TYPES	DE-9IM INTERSECTION PATTERN
equals	geo:rcc8eq	geo:Spatial Object	A/A	(TFFFFFFFFFF)
disconnected	geo:rcc8dc	geo:Spatial Object	A/A	(FFFTFFTTTT)
externally connected	geo:rcc8ec	geo:Spatial Object	A/A	(FFFTFTTTTT)
partially overlapping	geo:rcc8po	geo:Spatial Object	A/A	(TTTTTTTTTT)
tangential proper part inverse	geo:rcc8tppi	geo:Spatial Object	A/A	(TTTFTTTFFT)
tangential proper part	geo:rcc8tpp	geo:Spatial Object	A/A	(TFFTTFTTT)

RELATION NAME	RELATION IRI	DOMAIN/ RANGE	APPLIES TO GEOMETRY TYPES	DE-9IM INTERSECTION PATTERN
non-tangential proper part	geo:rcc8ntp	geo:Spatial Object	A/A	(TFFTFFFTT)
non-tangential proper part inverse	geo:rcc8ntppi	geo:Spatial Object	A/A	(TTTFFTFFT)

Table 5 – RCC*-9 Topological Relations

RELATION NAME	RELATION IRI	DOMAIN/ RANGE	APPLIES TO GEOMETRY TYPES	DE-9IM INTERSECTION PATTERN
equals	geo:rcc9eq	geo:Spatial Object	A/A	(TFFF*FFFT)
disconnected	geo:rcc9dc	geo:Spatial Object	A/A	(FF*FF**) (FF*)
externally connected	geo:rcc9ec	geo:Spatial Object	A/A	(F*TTT) v (FTTT*)
partially overlapping	geo:rcc9po	geo:Spatial Object	A/A	(TTTTT) v (T*T*T*T**) (T*T*T*T*)
tangential proper part inverse	geo:rcc9tppi	geo:Spatial Object	A/A	(T) v (**T*FF*) v \neg (TFFFFFFFFFF)
tangential proper part	geo:rcc9tpp	geo:Spatial Object	A/A	(TFF) v (F*TF*) v \neg (TFFFFFFFFFF)
non-tangential proper part	geo:rcc9ntp	geo:Spatial Object	A/A	(FF*FFT*)
non-tangential proper part inverse	geo:rcc9ntppi	geo:Spatial Object	A/A	(*TFF*FF)
crosses	geo:rcc9cr	geo:Spatial Object	A/A	(TFFF*FFFT)

9.5. Equivalent RCC8, Egenhofer and Simple Features Topological Relations

Table 6 summarizes the equivalences between *Egenhofer*, *RCC8* and *Simple Features* spatial relations for closed, non-empty regions. The symbol + denotes logical OR, and the symbol \neg denotes negation.

Table 6 – Equivalent Simple Features, RCC8 and Egenhofer relations

SIMPLE FEATURES RCC9		EGENHOFER
equals	equals	equals
disjoint	disconnected	disjoint
intersects	\neg disconnected	\neg disjoint
touches	externally connected	meet
within	non-tangential proper part + tangential proper part	inside + covered by
contains	non-tangential proper part inverse + tangential proper part inverse	contains + covers
overlaps	partially overlapping	overlap

10

GEOMETRY EXTENSION

This clause defines the *Geometry Extension* parameterized Requirements class with the base IRI `/req/geometry-extension`. There is a single corresponding conformance class *Geometry Extension*, with the IRI `/conf/geometry-extension`. These Requirements define a vocabulary for asserting and querying information about geometry data, and define query functions for operating on geometry data.

REQUIREMENTS CLASS 2: GEOMETRY EXTENSION

IDENTIFIER	<code>/req/geometry-extension</code>
TARGET TYPE	Implementation Specification
CONFORMANCE CLASS	<code>Conformance class A.3: /conf/geometry-extension</code>
	<code>/req/geometry-extension/geometry-class</code>
	<code>/req/geometry-extension/geometry-collection-class</code>
	<code>/req/geometry-extension/feature-properties</code>
	<code>/req/geometry-extension/geometry-properties</code>
	<code>/req/geometry-extension/query-functions</code>
	<code>/req/geometry-extension/srid-function</code>
	<code>/req/geometry-extension/query-functions-3D</code>
REQUIREMENT	<code>/req/geometry-extension/sa-functions</code>
	<code>/req/geometry-extension/wkt-literal</code>
	<code>/req/geometry-extension/wkt-literal-default-srs</code>
	<code>/req/geometry-extension/wkt-axis-order</code>
	<code>/req/geometry-extension/wkt-literal-empty</code>
	<code>/req/geometry-extension/geometry-as-wkt-literal</code>
	<code>/req/geometry-extension/asWKT-function</code>
	<code>/req/geometry-extension/gml-literal</code>

REQUIREMENTS CLASS 2: GEOMETRY EXTENSION

```
/req/geometry-extension/gml-literal-empty  
  
/req/geometry-extension/gml-profile  
  
/req/geometry-extension/geometry-as-gml-literal  
  
/req/geometry-extension/asGML-function  
  
/req/geometry-extension/geojson-literal  
  
/req/geometry-extension/geojson-literal-srs  
  
/req/geometry-extension/geojson-literal-empty  
  
/req/geometry-extension/geometry-as-geojson-literal  
  
/req/geometry-extension/asGeoJSON-function  
  
/req/geometry-extension/kml-literal  
  
/req/geometry-extension/kml-literal-srs  
  
/req/geometry-extension/kml-literal-empty  
  
/req/geometry-extension/geometry-as-kml-literal  
  
/req/geometry-extension/asKML-function  
  
/req/geometry-extension/geocode-literal  
  
/req/geometry-extension/geocode-literal-srs  
  
/req/geometry-extension/geocode-literal-empty  
  
/req/geometry-extension/geometry-as-geocode-literal  
  
/req/geometry-extension/asGeocode-function
```

As part of the vocabulary, RDFS datatypes are defined for encoding detailed geometry information as a literal value. A literal representation of a geometry is needed so that geometric values may be treated as a single unit. Such a representation allows geometries to be passed to external functions for computations and to be returned from a query.

10.1. Rationale

Other schemes for encoding simple geometry data in RDF have been implemented. The W3C Basic Geo vocabulary³ was an early (2003) RDF vocabulary for “representing lat(itude), long(itude) and other information about spatially-located things. Geo specifies WGS84 as the reference datum”. Further, many widely used Semantic Web vocabularies contain some spatial data support. For example, *Dublin Core Terms* provides a *Location* class⁴ for “A spatial region or named place.” and *schema.org* provides a number of spatial object and geometry classes, such as *GeoCoordinates*⁵ and *GeoShape*⁶.

Many vocabularies such as the above provide little specific support for detailed geometries and only specify using the WGS84 Coordinate Reference System (CRS).

Since the first version of GeoSPARQL, many ontologies have imported GeoSPARQL. For example, the *ISA Programme Location Core Vocabulary*⁷ whose usage notes provide examples containing GeoSPARQL literals and the use of GeoSPARQL’s “geometry class”. The W3C’s more recent *Data Catalog Vocabulary, Version 2* (DCAT2) standard⁸ similarly contains usage notes for geometry, bbox and other properties that suggest the use of GeoSPARQL literals.

Some of the properties defined in these vocabularies, such as DCAT2’s `dcat:spatialResolution` have motivated the inclusion of new properties in this version of GeoSPARQL. In this case the equivalent property is `geo:hasSpatialResolution`. The GeoSPARQL 1.1 Standards Working Group charter CHARTER contains references to a number of vocabularies/ontologies that were influential in the generation of this version of GeoSPARQL.

10.2. GeoSPARQL and Simple Features (SFA-CA)

The GeoSPARQL Geometry Extension is largely based on the ISO/OGC Simple Features Access – Common Architecture (SFA-CA) Standard OGCSFACA. Contrary to what the name may imply, SFA-CA is about Geometry and not about Features. SFA-CA describes simple geometry,

³<http://www.w3.org/2003/01/geo/>

⁴<http://purl.org/dc/terms/Location>

⁵<https://schema.org/GeoCoordinates>

⁶<https://schema.org/GeoShape>

⁷<https://www.w3.org/ns/locn>

⁸<https://www.w3.org/TR/vocab-dcat/#spatial-properties>

meaning that geometric shapes are based on points and straight lines (linear interpolations) between points. Within a single Geometry, these lines may not cross.

Neither GeoSPARQL nor SFA-CA support full three-dimensional geometry. Coordinates may be three-dimensional, which means that points may have a Z-coordinate next to an X- and Y-coordinate. The Z-coordinate then holds the value of height or depth. However, lines or surfaces can only have one Z value for any explicit or interpolated X,Y pair. This approach is often referred to as 2.5 dimensional geometry. Geometric functions working with Geometries that have Z values will ignore Z values in calculations and first project geometry onto the Z=0 level.

SFA-CA also describes M coordinate values that may be part of geometry encodings. The M value represents a measure, a value that can be used in information systems that support linear referencing. GeoSPARQL at the moment does not support linear referencing. Like Z values in coordinates, M values are to be ignored.

SFA-CA specifies a class hierarchy for Geometry. Although these classes are not part of the GeoSPARQL ontology, the GeoSPARQL SWG does publish a vocabulary of Simple Features geometry: <http://www.opengis.net/ont/sf>. Geometry types defined in this vocabulary can be considered safe to use with GeoSPARQL. The two Geometry serializations that were specified in GeoSPARQL 1.0, WKT and GML, fully support all SFA-CA geometry types. However, the two Geometry serializations that were introduced in GeoSPARQL 1.1 do not. Some SFA-CA geometry types are not supported by either the OGC KML OGC12-007r2 or the GeoJSON format. For example, neither KML nor GeoJSON support the Triangulated Integrated Network (TIN) or Triangle geometry types.

10.3. Recommendation for units of measure

For geometric data to be interpreted and used correctly, the units of measure should be known. Typically, the particular Spatial Reference System (SRS) that is associated with a Geometry instance will specify a unit of measurement. However, some elements of GeoSPARQL allow arbitrary units of distance to be used, for example the property geo:hasSpatialResolution or the function geof:buffer. In those cases it is advisable to make use of a well-known web vocabulary for units of measurement. Making the unit of measurement explicit will improve data interoperability. The recommended vocabulary for units of measurement for GeoSPARQL is the *Quantities, Units, Dimensions and Types (QUDT)* ontology⁹ but others may be used, as long as they are well-described.

⁹<http://www.qudt.org>

10.4. Influence of Reference Systems on computations

A Geometry object consists of a set of coordinates and a specification on how the coordinates should be interpreted. This specification is known as a Spatial reference System (SRS). Taken together, coordinates and SRS allow performing computations on Geometry objects. For example, sizes can be calculated or new Geometry objects can be created. Some Spatial Reference Systems describe a two-dimensional flat space. In that case, coordinates are understood to be Cartesian, and Cartesian geometric computations can be performed. But Spatial Reference Systems can describe other types of spaces, to which Cartesian computations are not applicable. For example, if CRS <http://www.opengis.net/def/crs/OGC/1.3/CRS84> is used, coordinates are to be interpreted as decimal degrees of latitude and longitude, designating positions on a spheroid. The distance between two points using this CRS is different from the distance between two points that have the same coordinates but are based on a Cartesian CRS or other SRS.

To avoid erroneous computations involving Geometry, data publishers are recommended to clearly indicate the type of space that is described by the SRS.

10.5. Parameters

The following parameters are defined for the *Geometry Extension Requirements*.

serialization	Specifies the serialization standard to use when generating geometry literals as well as the supported geometry types.
---------------	--

NOTE: A serialization strongly affects the geometry conceptualization. The WKT serialization aligns the geometry types with *ISO 19125 Simple Features OGCSFACA ISO19125-1*; the GML serialization aligns the geometry types with *ISO 19107 Spatial Schema ISO19107*.

version	Specifies the version of the serialization format used.
---------	---

10.6. Geometry Class

A single root geometry class is defined: geo:Geometry. In addition, properties are defined for describing geometry data and for associating geometries with features.

One container class is defined: Geometry Collection.

10.6.1. Class: geo:Geometry

The class `geo:Geometry` is conceptually derived from UML class Geometry in ISO19107 which is that standard's "root class of the geometric object taxonomy and supports interfaces common to all geographically referenced geometric objects". `geo:Geometry` is defined by the following:

```
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
;
.
```

REQUIREMENT 12: GEOMETRY CLASS

IDENTIFIER /req/geometry-extension/geometry-class

STATEMENT Implementations shall allow the RDFS class `geo:Geometry` to be used in SPARQL graph patterns.

10.6.2. Class: geo:GeometryCollection

The class Geometry Collection is defined by the following:

```
geo:GeometryCollection
  a owl:Class ;
  rdfs:isDefinedBy geo: ;
  skos:prefLabel "Geometry Collection"@en ;
  skos:definition "A collection of individual Geometries."@en ;
  rdfs:subClassOf geo:SpatialObjectCollection , geo:Geometry ;
  rdfs:subClassOf [
    a owl:Restriction ;
    owl:allValuesFrom geo:Geometry ;
    owl:onProperty rdfs:member ;
  ] ;
.
```

This class is indicated to be a collection of spatial objects by being a subclass of the general Spatial Object Collection. That it contains only Geometry class instances is indicated by the restriction `rdfs:member` predicate. That it can be used as a Geometry, for example as the range value for the has geometry predicate, is indicated by it being a subclass of the Geometry class.

NOTE: There is no RDF/ontology relationship between this `geo:GeometryCollection` class and the Simple Features Vocabulary's `sf:GeometryCollection` class since the former is a collection of `geo:Geometry` objects and the latter is to be used for compound geometry literals.

`sf:GeometryCollection` instances can act as input or output of GeoSPARQL functions whereas `geo:GeometryCollection` instances are more likely to be used for grouping `geo:Geometry` objects for other purposes.

Many geometry literal formats also have the ability to represent multiple geometries. Both the OGC Geography Markup Language (GML) and KML use a *MultiGeometry* type and Well Known Text (WKT) and GeoJSON use a *GeometryCollection* type. While the names of some of these objects are the same as this class' and all the concepts are similar, there is also no RDF/ontology relationship between this class and these literals. This class contains whole `geo:Geometry` instances, which may have more information within them than just a geometry serialization.

As per the expected use of `sf:GeometryCollection` instances mentioned above, the uses of multi-geometry literals and `geo:GeometryCollection` instances is expected to be different too.

REQUIREMENT 13: GEOMETRY COLLECTION CLASS

IDENTIFIER /req/geometry-extension/geometry-collection-class

STATEMENT Implementations shall allow the RDFS class `geo:GeometryCollection` to be used in SPARQL graph patterns.

10.7. Standard Properties for `geo:Geometry`

Properties are defined for describing geometry metadata.

REQUIREMENT 14: GEOMETRY PROPERTIES

IDENTIFIER /req/geometry-extension/geometry-properties

STATEMENT Implementations shall allow the properties `geo:dimension`, `geo:coordinateDimension`, `geo:spatialDimension`, `geo:hasSpatialResolution`, `geo:hasMetricSpatialResolution`, `geo:hasSpatialAccuracy`, `geo:hasMetricSpatialAccuracy`, `geo:isClosed`, `geo:isEmpty`, `geo:isRing`, `geo:isSimple` and `geo:hasSerialization` to be used in SPARQL graph patterns.

10.7.1. Property: `geo:dimension`

The property `geo:dimension` is used to link a Geometry object to its topological dimension, which must be less than or equal to the coordinate dimension. In non-homogeneous collections, this will return the largest topological dimension of the contained objects.

```
geo:dimension
  a rdf:Property, owl:DatatypeProperty ;
```

```

rdfs:isDefinedBy geo: ;
skos:prefLabel "dimension"@en ;
skos:definition "The topological dimension of this geometric object, which
must be less than or equal to the coordinate dimension. In
non-homogeneous collections, this is the largest
topological dimension of the contained objects."@en ;
rdfs:domain geo:Geometry ;
rdfs:range xsd:integer ;
.

```

10.7.2. Property: geo:coordinateDimension

The property `geo:coordinateDimension` is defined to link a Geometry object to the dimension of direct positions (coordinate tuples) used in the Geometry's definition.

```

geo:coordinateDimension
a rdf:Property, owl:DatatypeProperty;
rdfs:isDefinedBy geo: ;
skos:prefLabel "coordinate dimension"@en ;
skos:definition "The number of measurements or axes needed to describe the
position of this Geometry in a coordinate system."@en ;
rdfs:domain geo:Geometry ;
rdfs:range xsd:integer ;
.

```

10.7.3. Property: geo:spatialDimension

The property `geo:spatialDimension` is defined to link a Geometry object to the dimension of the spatial portion of the direct positions (coordinate tuples) used in its serializations. If the direct positions do not carry a measure coordinate, this will be equal to the coordinate dimension.

```

geo:spatialDimension
a rdf:Property, owl:DatatypeProperty;
rdfs:isDefinedBy geo: ;
skos:prefLabel "spatial dimension"@en ;
skos:definition "The number of measurements or axes needed to describe the
spatial position of this Geometry in a coordinate system."@en
;
rdfs:domain geo:Geometry ;
rdfs:range xsd:integer ;
.

```

10.7.4. Property: geo:hasSpatialResolution

The property `geo:hasSpatialResolution` is defined to indicate the spatial resolution of the elements within a Geometry. Spatial resolution specifies the level of detail of a Geometry. It is the smallest distinguishable distance between adjacent coordinate sets. This property is not applicable to a point Geometry, because a point consists of a single coordinate set.

Since this property is defined for a `geo:Geometry`, all literal representations of that Geometry instance must have the same spatial resolution.

```

geo:hasSpatialResolution
  a rdf:Property, owl:ObjectProperty;
  rdfs:isDefinedBy geo: ;
  skos:prefLabel "has spatial resolution"@en ;
  skos:definition "The spatial resolution of a Geometry"@en ;
  rdfs:domain geo:Geometry ;
.

```

NOTE: See the Clause 10.3.

10.7.5. Property: geo:hasMetricSpatialResolution

The property `geo:hasMetricSpatialResolution` is similar to `geo:hasSpatialResolution`, except that the unit of resolution is always meter (the standard distance unit of the International System of Units).

```

geo:hasMetricSpatialResolution
  a rdf:Property, owl:ObjectProperty;
  rdfs:isDefinedBy geo: ;
  skos:prefLabel "has spatial resolution in meters"@en ;
  skos:definition "The spatial resolution of a Geometry in meters."@en ;
  rdfs:domain geo:Geometry ;
  rdfs:range xsd:double ;
.

```

10.7.6. Property: geo:hasSpatialAccuracy

The property `geo:hasSpatialAccuracy` is applicable when a Geometry is used to represent a Feature. It is expressed as a distance that indicates the truthfulness of the positions (coordinates) that define the Geometry. In this case accuracy defines a zone surrounding each coordinate within which the real positions are known to be. The accuracy value defines this zone as a distance from the coordinate(s) in all directions (e.g. a line, a circle or a sphere, depending on spatial dimension).

```

geo:hasSpatialAccuracy
  a rdf:Property, owl:ObjectProperty;
  rdfs:isDefinedBy geo: ;
  skos:prefLabel "has spatial accuracy"@en ;
  skos:definition "The positional accuracy of the coordinates of a Geometry.
"@en ;
  rdfs:domain geo:Geometry ;
.

```

NOTE: See the Clause 10.3.

10.7.7. Property: geo:hasMetricSpatialAccuracy

The property `geo:hasMetricSpatialAccuracy` is similar to `has spatial accuracy`, but is easier to specify and use because the unit of distance is always meter (the standard distance unit of the International System of Units).

```

geo:hasMetricSpatialAccuracy
  a rdf:Property, owl:ObjectProperty;

```

```

rdfs:isDefinedBy geo: ;
skos:prefLabel "has spatial accuracy in meters"@en ;
skos:definition "The positional accuracy of the coordinates of a Geometry in
meters."@en ;
rdfs:domain geo:Geometry ;
rdfs:range xsd:double ;
.
```

10.7.8. Property: geo:isClosed

The property `geo:isClosed` will indicate a Boolean object set to true if and only if the Geometry is closed, i.e. its start and end point are the same.

```

geo:isClosed
  a rdf:Property, owl:DatatypeProperty ;
  rdfs:isDefinedBy geo: ;
  skos:prefLabel "is closed"@en ;
  skos:definition "(true) if this geometric object is closed. If
                  true, then this geometric object's start point equals its
end point."@en ;
  rdfs:domain geo:Geometry ;
  rdfs:range xsd:boolean ;
.
```

Listing 1

10.7.9. Property: geo:isEmpty

The property `geo:isEmpty` will indicate a Boolean object set to true if and only if the Geometry contains no information.

```

geo:isEmpty
  a rdf:Property, owl:DatatypeProperty ;
  rdfs:isDefinedBy geo: ;
  skos:prefLabel "is empty"@en ;
  skos:definition "(true) if this geometric object is the empty Geometry. If
                  true, then this geometric object represents the empty point
                  set for the coordinate space."@en ;
  rdfs:domain geo:Geometry ;
  rdfs:range xsd:boolean ;
.
```

10.7.10. Property: geo:isRing

The property `geo:isRing` will indicate a Boolean object set to true if and only if the Geometry is closed and simple.

```

geo:isRing
  a rdf:Property, owl:DatatypeProperty ;
  rdfs:isDefinedBy geo: ;
  skos:prefLabel "is ring"@en ;
  skos:definition "(true) if this geometric object is a ring. If
                  true, then this geometric object's start point equals its
end point, i.e. it is closed and it is simple, i.e. it has no self-intersections.
"@en ;
```

```
rdfs:domain geo:Geometry ;  
rdfs:range xsd:boolean ;
```

Listing 2

10.7.11. Property: geo:isSimple

The property `geo:isSimple` will indicate a Boolean object set to true if and only if the Geometry contains no self-intersections, with the possible exception of its boundary.

```
geo:isSimple  
  a rdf:Property, owl:DatatypeProperty ;  
  rdfs:isDefinedBy geo: ;  
  skos:prefLabel "is simple"@en ;  
  skos:definition "(true) if this geometric object has no anomalous geometric  
  points, such as self intersection or self tangency."@en ;  
  rdfs:domain geo:Geometry ;  
  rdfs:range xsd:boolean ;
```

10.7.12. Property: geo:hasSerialization

The property `geo:hasSerialization` is defined to connect a Geometry with its text-based serialization.

It can be used to indicate a literal value, for example a GeoJSON `geo:geoJSONLiteral` or Well Known-Text `ge:wktLiteral` value, or it can be used to indicate a `dcat:Distribution` object which, as per that class' definition, is “A specific representation of a Dataset...” where, within GeoSPARQL, the Dataset is the Geometry.

```
geo:hasSerialization  
  a rdf:Property, owl:DatatypeProperty ;  
  rdfs:isDefinedBy geo: ;  
  skos:prefLabel "has serialization"@en ;  
  skos:definition "Connects a Geometry object with its text-based  
  serialization."@en ;  
  rdfs:domain geo:Geometry ;  
  rdfs:range rdfs:Resource ;
```

NOTE: This property is the generic property used to connect a Geometry with its serialization. GeoSPARQL also contains a number of sub properties of this property for connecting literal serializations of common types with geometries, for example as GeoJSON which can be used for GeoJSON literals.

If used to indicate a literal value, the sub properties are preferred.

If used to indicate a `dcat:Distribution` object, the format and/or the conformance of that distribution to a data model or standard should be given as per DCAT Distribution norms, i.e. use of `dcterms:format` and `dcterms:conformsTo` predicates.

`dcat:accessURL` is the preferred predicate to indicate a file location or URL that links to the distribution data.

See the Distributions example.

10.8. Geometry Serializations

This section establishes the Requirements class for representing Geometry data in RDF literals, according to different non-RDF systems.

GeoSPARQL presents specializations of the `geo:hasSerialization` property for indicating particular serializations and specialized datatype literals for containing them. It does not provide comprehensive definitions of their content since these are given in standards external to GeoSPARQL, all of which are referenced.

GeoSPARQL does present some Requirements for literal structure which extend the serialization-defining standards, for example the requirement to allow indications of spatial reference systems within WKT geometry representations.

Example: GeoSPARQL's expectation of RDF literal representations of geometry data is that it is related to the *Simple Features Access* (SFA) OGCSFACA ISO19125-1 standard's conceptualization of geometry which defines classes such as Point, Curve and Surface and specialized variants of them which it presents in a hierarchy. All SFA classes are represented in OWL in the *Simple Features Vocabulary* presented within GeoSPARQL as an independent profile element, see GeoSPARQL Standard structure.

Some geometry representation systems given here do not use the same terminology as SFA, in particular Discrete Global Grid Systems. To know the extent to which geometry literal representations listed here support SFA, or map to SFA, please see their definitions.

10.8.1. Well-Known Text

This section establishes the requirements for representing Geometry data in RDF based on Well-Known Text (WKT) as defined by *Simple Features Access* OGCSFACA ISO19125-1. It defines one RDFS Datatype: WKT Literal and one property, as WKT.

10.8.1.1. RDFS Datatype: `geo:wktLiteral`

The datatype `geo:wktLiteral` is used to contain the Well-Known Text (WKT) serialization of a Geometry.

```
geo:wktLiteral
  a rdfs:Datatype ;
  rdfs:isDefinedBy geo: ;
  skos:prefLabel "Well-known Text literal"@en ;
  skos:definition "A Well-known Text serialization of a Geometry object."@en ;
```

REQUIREMENT 15: WKT LITERAL

IDENTIFIER /req/geometry-extension/wkt-literal

STATEMENT All RDFS Literals of type geo:wktLiteral shall consist of an optional IRI identifying the coordinate reference system and a required Well Known Text (WKT) description of a geometric value. Valid geo:wktLiteral instances are formed by either a WKT string as defined in ISO13249 or by concatenating a valid absolute IRI, as defined in IETF3987, enclosed in angled brackets (< & >) followed by whitespace as a separator, and a WKT string as defined in ISO13249.

The following ABNF IETF5234 syntax specification formally defines this literal:

```
wktLiteral ::= opt-iri-and-whitespace geometry-data  
opt-iri-and-space = "<" IRI ">" LWSP / ""
```

The token opt-iri-and-whitespace may be either an IRI and whitespace (spaces, tabs, newlines) or nothing (" "), the token IRI (Internationalized Resource Identifier) is essentially a web address and is defined in IETF3987 and the token LWSP, is one or more white space characters, as defined in IETF5234. geometry-data is the Well-Known Text representation of the Geometry, defined in ISO13249.

In the absence of a leading spatial reference system IRI, the following spatial reference system IRI will be assumed: <http://www.opengis.net/def/crs/OGC/1.3/CRS84>. This IRI denotes WGS 84 longitude-latitude.

REQUIREMENT 16: WKT LITERAL DEFAULT SRS

IDENTIFIER /req/geometry-extension/wkt-literal-default-srs

STATEMENT The IRI <http://www.opengis.net/def/crs/OGC/1.3/CRS84> shall be assumed as the spatial reference system for geo:wktLiteral instances that do not specify an explicit spatial reference system IRI.

The OGC maintains a set of SRS IRIs under the <http://www.opengis.net/def/crs/> namespace and IRIs from this set are recommended for use. However others may also be used, as long as they are valid IRIs.

REQUIREMENT 17: WKT LITERAL AXIS ORDER

IDENTIFIER /req/geometry-extension/wkt-axis-order

STATEMENT Coordinate tuples within geo:wktLiteral shall be interpreted using the axis order defined in the spatial reference system used.

The example WKT Literal below encodes a point Geometry using the default WGS84 geodetic longitude-latitude spatial reference system:

```
"Point(-83.38 33.95)"^^<http://www.opengis.net/ont/geosparql#wktLiteral>
```

A second example below encodes the same point as encoded in the example above but using a SRS identified by <http://www.opengis.net/def/crs/EPSC/0/4326>: a WGS 84 geodetic latitude-longitude spatial reference system (note that this spatial reference system defines a different axis order):

```
"<http://www.opengis.net/def/crs/EPSC/0/4326> Point(33.95 -83.38)"^^<http://www.opengis.net/ont/geosparql#wktLiteral>
```

REQUIREMENT 18: EMPTY WKT LITERAL

IDENTIFIER /req/geometry-extension/wkt-literal-empty

STATEMENT An empty RDFS Literal of type geo:wktLiteral shall be interpreted as an empty Geometry.

10.8.1.2. Property: geo:asWKT

The property geo:asWKT is defined to link a Geometry with its WKT serialization.

REQUIREMENT 19: ASWKT PROPERTY

IDENTIFIER /req/geometry-extension/geometry-as-wkt-literal

STATEMENT Implementations shall allow the RDF property geo:asWKT to be used in SPARQL graph patterns.

```
geo:asWKT
  a rdf:Property, owl:DatatypeProperty ;
  rdfs:subPropertyOf geo:hasSerialization ;
  rdfs:isDefinedBy geo: ;
  skos:prefLabel "as WKT"@en ;
  skos:definition "The WKT serialization of a Geometry."@en ;
  rdfs:domain geo:Geometry ;
  rdfs:range geo:wktLiteral ;
.
```

10.8.1.3. Function: geof:asWKT

```
geof:asWKT (geom: ogc:geomLiteral): geo:wktLiteral
```

The function geof:asWKT converts geom to an equivalent WKT representation preserving the spatial reference system.

REQUIREMENT 20: ASWKT FUNCTION

IDENTIFIER /req/geometry-extension/asWKT-function

STATEMENT Implementations shall support geof:asWKT as a SPARQL extension function.

10.8.2. Extended Well-Known Binary

This section establishes the requirements for representing Geometry data in RDF based on Extended Well-Known Binary (EWKB) as defined by *Simple Features Access OGCSFACA ISO19125-1*. It defines the RDFS Datatype: EWKB Literal and one property, as EWKB. The literal definition in addition, allows for 3D types present in the Extended Well-Known Binary specification.

10.8.2.1. RDFS Datatypes: geo:ewkbLiteral

The datatype `geo:ewkbLiteral` is used to contain the Extended Well-Known Binary (EWKB) serialization of a Geometry.

```
geo:ewkbLiteral
  a rdfs:Datatype ;
  rdfs:isDefinedBy geo: ;
  skos:prefLabel "(Extended) Well-known Binary literal"@en ;
  skos:definition "An (Extended) Well-known Binary serialization of a Geometry object."@en ;
.
```

Listing 3

Table 7

Req 1 All RDFS Literals of type `geo:ewkbLiteral` shall consist of an optional IRI identifying the coordinate reference system and a required Extended Well-Known Binary (EWKB) description of a geometric value encoded in Base64. Valid `geo:ewkbLiteral` instances are formed by a EWKB string as defined in ISO13249 or by concatenating a valid absolute IRI, as defined in IETF3987, enclosed in angled brackets (< >) followed by whitespace as a separator and a EWKB string as defined in ISO13249. The Extended Well-Known Binary description shall allow the dimensionality flags defined in the Extended Well-Known Binary specification to represent 3D geometries.

<http://www.opengis.net/spec/geosparql/1.0/req/geometry-extension/ewkb-literal>

The following ABNF IETF5234 syntax specification formally defines this literal:

```
ewkbLiteral ::= opt-iri-and-whitespace geometry-data
opt-iri-and-space = "<" IRI ">" LWSP / ""
```

Listing 4

The token opt-iri-and-whitespace may be either an IRI and whitespace (spaces, tabs, newlines) or nothing (" "), the token IRI (Internationalized Resource Identifier) is essentially a web address and is defined in IETF3987 and the token LWSP, a binary representation in EWKB serialized as Base64. geometry-data is the Extended Well-Known Binary representation of the Geometry, defined in ISO13249.

In the absence of a leading spatial reference system IRI, the following spatial reference system IRI will be assumed: `<\http://www.opengis.net/def/crs/OGC/1.3/CRS84>`. This IRI denotes WGS 84 longitude-latitude.

Table 8

Req 2 The IRI `<\http://www.opengis.net/def/crs/OGC/1.3/CRS84>` shall be assumed as the spatial reference system for geo:ewkbLiteral instances that do not specify an explicit spatial reference system IRI. IRIs defined as SRIDs in an Extended Well-Known Binary format shall be ignored.

<http://www.opengis.net/spec/geosparql/1.0/req/geometry-extension/ewkb-literal-default-srs>

The OGC maintains a set of SRS IRIs under the `http://www.opengis.net/def/crs/` namespace, and IRIs from this set are recommended for use. However, others may also be used as long as they are valid IRIs.

Table 9

Req 3 Coordinate tuples within geo:ewkbLiteral shall be interpreted using the axis order defined in the spatial reference system used.

<http://www.opengis.net/spec/geosparql/1.0/req/geometry-extension/ewkb-axis-order>

The example EWKB Literal below encodes a point Geometry using the default WGS84 geodetic longitude-latitude spatial reference system:

`"Point(-83.38 33.95)"^^<http://www.opengis.net/ont/geosparql#ewkbLiteral>`

Listing 5

A second example below encodes the same point as encoded in the example above but using a SRS identified by `http://www.opengis.net/def/SRS/EPSG/0/4326`: a WGS 84 geodetic latitude-longitude spatial reference system (note that this spatial reference system defines a different axis order):

`"<http://www.opengis.net/def/crs/EPSC/0/4326> Point(33.95 -83.38)"^^<http://www.opengis.net/ont/geosparql#ewkbLiteral>`

Listing 6

Table 10

Req 18 An empty RDFS Literal of type geo:ewkbLiteral shall be interpreted as an empty Geometry.

<http://www.opengis.net/spec/geosparql/1.0/req/geometry-extension/ewkb-literal-empty>

10.8.2.2. Property: geo:asEWKB

The property `geo:asEWKB` is defined to link a Geometry with its EWKB serialization.

Table 11

Req 4 Implementations shall allow the RDF property `geo:asEWKB` to be used in SPARQL graph patterns.

<http://www.opengis.net/spec/geosparql/1.0/req/geometry-extension/geometry-as-wkb-literal>

```
geo:asEWKB
  a rdf:Property, owl:DatatypeProperty ;
  rdfs:subPropertyOf geo:hasSerialization ;
  rdfs:isDefinedBy geo: ;
  skos:prefLabel "as EWKB"@en ;
  skos:definition "The EWKB serialization of a Geometry."@en ;
  rdfs:domain geo:Geometry ;
  rdfs:range geo:ewkbLiteral ;
.
```

Listing 7

10.8.2.3. Function: geof:asEWKB

`geof:asEWKB (geom: ogc:geomLiteral): geo:ewkbLiteral`

Listing 8 – asEWKB Function

The function `geof:asEWKB` converts geom to an equivalent EWKB representation preserving the spatial reference system.

Table 12

Req 5 Implementations shall support `geo:asEWKB` as a SPARQL extension function.

<http://www.opengis.net/spec/geosparql/1.1/req/geometry-extension/asEWKB-function>

10.8.3. Geography Markup Language

This section establishes a Requirements class for representing Geometry data in RDF based on GML as defined by the Geography Markup Language Encoding Standard OGC07-036. It defines one RDFS Datatype: GML Literal and one property, as GML.

10.8.3.1. RDFS Datatype: geo:gmlLiteral

The datatype `geo:gmlLiteral` is used to contain the Geography Markup Language (GML) serialization of a Geometry.

```
geo:gmlLiteral
  a rdfs:Datatype ;
  rdfs:isDefinedBy geo: ;
  skos:prefLabel "GML literal"@en ;
  skos:definition "The datatype of GML literal values"@en ;
.
```

Valid GML Literal instances are formed by encoding Geometry information as a valid element from the GML schema that implements a subtype of `GM_Object`. For example, in GML 3.2.1 this is every element directly or indirectly in the substitution group of the element `{http://www.opengis.net/ont/gml/3.2}AbstractGeometry`. In GML 3.1.1 and GML 2.1.2 this is every element directly or indirectly in the substitution group of the element `{http://www.opengis.net/ont/gml}_Geometry`.

REQUIREMENT 21: GML LITERAL

IDENTIFIER /req/geometry-extension/gml-literal

STATEMENT All `geo:gmlLiteral` instances shall consist of a valid element from the GML schema that implements a subtype of `GM_Object` as defined in OGC07-036.

The example GML Literal below encodes a point Geometry in the WGS 84 geodetic longitude-latitude spatial reference system using GML version 3.2:

```
"""
<gml:Point
  srsName=\"http://www.opengis.net/def/crs/OGC/1.3/CRS84\"/>
  <gml:pos>-83.38 33.95</gml:pos>
</gml:Point>
""""^<http://www.opengis.net/ont/geosparql#gmlLiteral>
```

REQUIREMENT 22: EMPTY GML LITERAL

IDENTIFIER /req/geometry-extension/gml-literal-empty

STATEMENT An empty `geo:gmlLiteral` shall be interpreted as an empty Geometry.

REQUIREMENT 23: GML PROFILE

IDENTIFIER /req/geometry-extension/gml-profile

REQUIREMENT 23: GML PROFILE

STATEMENT	Implementations shall document supported GML profiles.
-----------	--

10.8.3.2. Property: geo:asGML

The property `geo:asGML` is defined to link a Geometry with its GML serialization.

REQUIREMENT 24: ASGML PROPERTY

IDENTIFIER	/req/geometry-extension/geometry-as-gml-literal
STATEMENT	Implementations shall allow the RDF property <code>geo:asGML</code> to be used in SPARQL graph patterns.

```
geo:asGML
  a rdf:Property ;
  rdfs:subPropertyOf geo:hasSerialization ;
  rdfs:isDefinedBy geo: ;
  skos:prefLabel "as GML"@en ;
  skos:definition "The GML serialization of a Geometry."@en ;
  rdfs:domain geo:Geometry ;
  rdfs:range geo:gmlLiteral ;
.
```

10.8.3.3. Function: geof:asGML

`geof:asGML (geom: ogc:geomLiteral, gmlProfile: xsd:string): geo:gmlLiteral`

The function `geof:asGML` converts `geom` to an equivalent GML representation defined by a `gmlProfile` version string preserving the coordinate reference system.

REQUIREMENT 25: ASGML FUNCTION

IDENTIFIER	/req/geometry-extension/asGML-function
STATEMENT	Implementations shall support <code>geof:asGML</code> as a SPARQL extension function.

10.8.4. GeoJSON

This section establishes a Requirements class for representing Geometry data in RDF based on Geographic JavaScript Object Notation (GeoJSON) as defined by GEOJSON. It defines one RDFS Datatype: GeoJSON Literal and one property, as GeoJSON.

10.8.4.1. RDFS Datatype: geo:geoJSONLiteral

The datatype `geo:geoJSONLiteral` is used to contain the GeoJSON serialization of a Geometry.

```
geo:geoJSONLiteral a rdfs:Datatype ;  
    rdfs:isDefinedBy geo: ;  
    skos:prefLabel "GeoJSON Literal"@en ;  
    skos:definition "A GeoJSON serialization of a Geometry object."@en .
```

Valid GeoJSON Literal instances are formed by encoding Geometry information as a Geometry object as defined in the GeoJSON specification GEOJSON.

REQUIREMENT 26: GEOJSON LITERAL

IDENTIFIER /req/geometry-extension/geojson-literal

STATEMENT All `geo:geoJSONLiteral` instances shall consist of the Geometry objects as defined in the Geo JSON specification GEOJSON.

REQUIREMENT 27: GEOJSON LITERAL SRS

IDENTIFIER /req/geometry-extension/geojson-literal-srs

STATEMENT RDFS Literals of type `geo:geoJSONLiteral` do not contain a SRS definition. All literals of this type shall, according to the GeoJSON specification, be encoded only in, and be assumed to use, the WGS84 geodetic longitude-latitude spatial reference system (<http://www.opengis.net/def/crs/OGC/1.3/CRS84>).

The example GeoJSON Literal below encodes a point Geometry using the default WGS84 geodetic longitude-latitude spatial reference system for Simple Features 1.0:

```
"""  
{"type": "Point", "coordinates": [-83.38,33.95]}  
"""^<http://www.opengis.net/ont/geosparql#geoJSONLiteral>
```

REQUIREMENT 28: EMPTY GEOJSON LITERAL

IDENTIFIER /req/geometry-extension/geojson-literal-empty

STATEMENT An empty RDFS Literal of type `geo:geoJSONLiteral` shall be interpreted as an empty Geometry, i.e. `{"geometry": null}` in GeoJSON.

10.8.4.2. Property: geo:asGeoJSON

The property `geo:asGeoJSON` is defined to link a Geometry with its GeoJSON serialization.

REQUIREMENT 29: ASGEOJSON PROPERTY

IDENTIFIER /req/geometry-extension/geometry-as-geojson-literal

STATEMENT Implementations shall allow the RDF property `geo:asGeoJSON` to be used in SPARQL graph patterns.

```
geo:asGeoJSON
  a rdf:Property, owl:DatatypeProperty ;
  rdfs:subPropertyOf geo:hasSerialization ;
  rdfs:isDefinedBy geo: ;
  skos:prefLabel "as GeoJSON"@en ;
  skos:definition "The GeoJSON serialization of a Geometry."@en ;
  rdfs:domain geo:Geometry ;
  rdfs:range geo:geoJSONLiteral ;
```

.

10.8.4.3. Function: geof:asGeoJSON

`geof:asGeoJSON (geom: ogc:geomLiteral): geo:geoJSONLiteral`

The function `geof:asGeoJSON` converts `geom` to an equivalent GeoJSON representation. Coordinates are converted to the CRS84 coordinate system, the only valid coordinate system to be used in a GeoJSON literal.

REQUIREMENT 30: ASGEOJSON FUNCTION

IDENTIFIER /req/geometry-extension/asGeoJSON-function

STATEMENT Implementations shall support `geof:asGeoJSON` as a SPARQL extension function.

10.8.5. Keyhole Markup Language

This section establishes the Requirements class for representing Geometry data in RDF based on KML as defined by OGC12-007r2. It defines one RDFS Datatype: KML Literal and one property, as KML.

10.8.5.1. RDFS Datatype: geo:kmlLiteral

The datatype `geo:kmlLiteral` is used to contain the Keyhole Markup Language (KML) serialization of a Geometry.

```
geo:kmlLiteral
  a rdfs:Datatype ;
  rdfs:isDefinedBy geo: ;
  skos:prefLabel "KML Literal"@en ;
  skos:definition "A KML serialization of a Geometry object."@en ;
.
```

Valid KML Literal instances are formed by encoding Geometry information as a Geometry object as defined in the KML specification OGC12-007r2.

REQUIREMENT 31: KML LITERAL

IDENTIFIER /req/geometry-extension/kml-literal

STATEMENT All geo:kmlLiteral instances shall consist of the Geometry objects as defined in the KML specification OGC12-007r2.

REQUIREMENT 32: KML LITERAL SRS

IDENTIFIER /req/geometry-extension/kml-literal-srs

STATEMENT RDFS Literals of type geo:kmlLiteral do not contain a SRS definition. All literals of this type shall according to the KML specification only be encoded in and assumed to use the WGS84 geodetic longitude-latitude spatial reference system (<http://www.opengis.net/def/crs/OGC/1.3/CRS84>).

The example KML Literal below encodes a point Geometry using the default WGS84 geodetic longitude-latitude spatial reference system for Simple Features 1.0:

```
"""
<Point xmlns="http://www.opengis.net/kml/2.2">
  <coordinates>-83.38,33.95</coordinates>
</Point>
"""\^<http://www.opengis.net/ont/geosparql#kmlLiteral>
```

REQUIREMENT 33: EMPTY KML LITERAL

IDENTIFIER /req/geometry-extension/kml-literal-empty

STATEMENT An empty RDFS Literal of type geo:kmlLiteral shall be interpreted as an empty Geometry.

10.8.5.2. Property: geo:asKML

The property `geo:asKML` is defined to link a Geometry with its KML serialization.

REQUIREMENT 34: ASKML PROPERTY

IDENTIFIER	/req/geometry-extension/geometry-as-kml-literal
STATEMENT	Implementations shall allow the RDF property <code>geo:asKML</code> to be used in SPARQL graph patterns.

The property as KML is used to link a geometric element with its KML serialization.

```
geo:asKML
  a rdf:Property, owl:DatatypeProperty;
  rdfs:subPropertyOf geo:hasSerialization ;
  rdfs:isDefinedBy geo: ;
  skos:prefLabel "as KML"@en ;
  skos:definition "The KML serialization of a Geometry."@en ;
  rdfs:domain geo:Geometry ;
  rdfs:range geo:kmlLiteral ;
.
```

10.8.5.3. Function: geof:asKML

`geof:asKML (geom: ogc:geomLiteral): geo:kmlLiteral`

The function `geof:asKML` converts geom to an equivalent KML representation. Coordinates are converted to the CRS84 coordinate system, the only valid coordinate system to be used in a KML literal.

REQUIREMENT 35: ASKML FUNCTION

IDENTIFIER	/req/geometry-extension/asKML-function
STATEMENT	Implementations shall support <code>geof:asKML</code> as a SPARQL extension function.

10.8.6. Geocode Literal

This section establishes the Requirements class for representing geocode data in RDF based on a Literal type that can encompass different Geocodes. It defines one RDFS Datatype: Geocode Literal and one property, as GeoCode.

10.8.6.1. RDFS Datatype: geo:geocodeLiteral

The datatype `geo:geocodeLiteral` is used to contain a geocode serialization of a Geometry.

```
geo:geocodeLiteral
  a rdfs:Datatype ;
  rdfs:isDefinedBy geo: ;
  skos:prefLabel "Geocode Literal"@en ;
  skos:definition "A Geocode serialization of a Geometry object."@en ;
.
```

The following ABNF IETF5234 syntax specification formally defines this literal:

```
geocodeLiteral ::= opt-iri-and-whitespace geocode-data
opt-iri-and-space = "<" IRI ">" LWSP / ""
```

The token `opt-iri-and-whitespace` may be either an IRI and whitespace (spaces, tabs, newlines) or nothing (""), the token `IRI` (Internationalized Resource Identifier) is essentially a web address and is defined in IETF3987 and the token `LWSP`, is one or more white space characters, as defined in IETF5234. `geocode-data` is the Geocode representation of the Geometry, in the way it is defined in the definition of the respective Geocoding standard, as identified by its IRI.

REQUIREMENT 36: GEOCODE LITERAL TYPE

IDENTIFIER /req/geometry-extension/geocode-literal-srs

STATEMENT RDFS Literals of type `geo:geocodeLiteral` contain a Geocoding system definition in the form of an IRI.

The example Geocode Literal below encodes a point Geometry (point 27 19' 32S, 153 4' 59"E) in the GeoHash encoding:

```
"<https://w3id.org/geohashes/geohash> r7hue3x9jepv"^^<http://www.opengis.net/ont/geosparql#geocodeLiteral>
```

REQUIREMENT 37: EMPTY GEOCODE LITERAL

IDENTIFIER /req/geometry-extension/geocode-literal-empty

STATEMENT An empty RDFS Literal of type `geo:geocodeLiteral` shall be interpreted as an empty Geometry .

10.8.6.2. Property: geo:asGeocode

The property `geo:asGeocode` is defined to link a Geometry with a Geocode serialization.

REQUIREMENT 38: ASGEOCODE PROPERTY

IDENTIFIER	/req/geometry-extension/geometry-as-geocode-literal
STATEMENT	Implementations shall allow the RDF property geo:asGeocode to be used in SPARQL graph patterns.

The property as Geocode is used to link a geometric element with a Geocode serialization.

```
geo:asGeocode
  a rdf:Property, owl:DatatypeProperty;
  rdfs:subPropertyOf geo:hasSerialization ;
  rdfs:isDefinedBy geo: ;
  skos:prefLabel "as Geocode"@en ;
  skos:definition "The Geocode serialization of a Geometry."@en ;
  rdfs:domain geo:Geometry ;
  rdfs:range geo:geocodeLiteral ;
.
```

10.8.6.3. Function: geof:asGeocode

```
geof:asGeocode (geom: ogc:geomLiteral, geocode: rdfs:Resource): geo:geocodeLiteral
```

The function `geof:asGeocode` converts geom to an equivalent Geocode representation in the Geocoding system as defined by the geocode parameter.

REQUIREMENT 39: ASGEOCODE FUNCTION

IDENTIFIER	/req/geometry-extension/asGeocode-function
STATEMENT	Implementations shall support <code>geof:asGeocode</code> as a SPARQL extension function.

10.8.7. Discrete Global Grid System

REQUIREMENTS CLASS 3: GEOMETRY DGGS EXTENSION

IDENTIFIER	/req/geometry-extension-dggs
TARGET TYPE	Implementation Specification
CONFORMANCE CLASS	Conformance class A.4: /conf/geometry-extension-dggs
REQUIREMENT	/req/geometry-extension-dggs/query-functions

REQUIREMENTS CLASS 3: GEOMETRY DGGS EXTENSION

/req/geometry-extension-dggs/query-functions-non-sf

/req/geometry-extension-dggs/srid-function

/req/geometry-extension-dggs/sa-functions

/req/geometry-extension-dggs/dggs-literal

/req/geometry-extension-dggs/dggs-literal-empty

/req/geometry-extension-dggs/geometry-as-dggs-literal

/req/geometry-extension-dggs/asDGGS-function

This section establishes the Requirements class for representing Discrete Global Grid System (DGGS) Geometry data as RDF literals. The form of geometry data representation is specific to individual DGGS implementations: known DGGSes are not compatible or even very similar.

The Requirements class defines one RDFS Datatype <http://www.opengis.net/ont/geosparql#dggsLiteral> and one property, <http://www.opengis.net/ont/geosparql#asDGGS>.

10.8.7.1. RDFS Datatype: geo:dggsLiteral

The datatype `geo:dggsLiteral` is used to contain the Discrete Global Grid System (DGGS) serialization of a Geometry.

```
geo:dggsLiteral
  a rdfs:Datatype ;
  rdfs:isDefinedBy geo: ;
  skos:prefLabel "DGGS Literal"@en ;
  skos:definition "A textual serialization of a Discrete Global Grid System (DGGS) Geometry object."@en
  .
```

Valid DGGS Literal instances are formed by encoding Geometry information according to a specific DGGS implementation. The specific implementation should be indicated by use of a subclass of the `geo:dggsLiteral` datatype.

REQUIREMENT 40: DGGS LITERAL

IDENTIFIER /req/geometry-extension-dggs/dggs-literal

STATEMENT All RDFS Literals of type `geo:dggsLiteral` shall consist of an IRI identifying the specific DGGS and a representation of the DGGS geometry data. The IRI shall be enclosed in angled brackets (< & >) followed by whitespace as a separator, and then the DGGS geometry data, formulated according to the identified DGGS.

The following ABNF IETF5234 syntax specification formally defines this literal:

```
dggsLiteral ::= iri-and-whitespace dggs-geometry-data  
iri-and-whitespace = "<" IRI ">" LWSP
```

The token `iri-and-whitespace` is an IRI and whitespace. The token `IRI` (Internationalized Resource Identifier) is essentially a web address and is defined in IETF3987. The token `LWSP` is one or more whitespace characters, as defined in IETF5234. `dggs-geometry-data` is geometry data formulated according to the DGGS identified by `IRI`.

An example of a DGGS literal for the AusPIX DGGS could be:

```
"<https://w3id.org/dggs/auspix> CELL (R3234)"^^geo:dggsLiteral
```

Where AusPIX is identified with the IRI `https://w3id.org/dggs/auspix` and `CELL (R3234)` is the representation of a geometry according to AUSPIX.

NOTE: What R3234 means, or the meaning of any other element within a DGGS' geometry data is not handled by GeoSPARQL, just as GeoPSARQL does not delve into the internals of other Geometry formats such as WKT or GeoJSON.

REQUIREMENT 41: EMPTY DGGS LITERAL

IDENTIFIER	/req/geometry-extension-dggs/dggs-literal-empty
STATEMENT	An empty RDFS Literal of type geo:dggsLiteral, shall be interpreted as an empty geo:Geometry.

The following ABNF IETF5234 syntax specification formally defines this literal:

```
dggsLiteral ::= iri-and-space dggs-geometry-data  
iri-and-whitespace = "<" IRI ">" LWSP / ""
```

The tokens used above are as per the DGGS ABNF above.

10.8.7.2. Property: geo:asDGGS

The property `geo:asDGGS` is defined to link a Geometry with its DGGS serialization.

REQUIREMENT 42: ASDGGS PROPERTY

IDENTIFIER	/req/geometry-extension-dggs/geometry-as-dggs-literal
STATEMENT	Implementations shall allow the RDF property geo:asDGGS to be used in SPARQL graph patterns.

```
geo:asDGGS  
a rdf:Property, owl:DatatypeProperty ;
```

```

rdfs:subPropertyOf geo:hasSerialization ;
rdfs:isDefinedBy geo: ;
skos:prefLabel "as DGGS"@en ;
skos:definition "A DGGS serialization of a Geometry."@en ;
rdfs:domain geo:Geometry ;
rdfs:range geo:dggsLiteral ;
.
```

10.8.7.3. Function: geof:asDGGS

`geof:asDGGS (geom: ogc:geomLiteral, specificDggsDatatype: xsd:anyURI): geo:DggsLiteral`
`geof:asDGGSResolution (geom: ogc:geomLiteral, specificDggsDatatype: xsd:anyURI, resolution: xsd:string): geo:dggsLiteral`

The function `geof:asDGGS` converts geom to an equivalent DGGS representation, formulated according to the specific DGGS literal indicated by the IRI required to be present in the DGGS literal. This function returns an error if the DGGS needs additional parameters such as a resolution to return a result.

The function `geof:asDGGSResolution` converts geom to an equivalent DGGS representation, formulated according to the specific DGGS literal indicated by the IRI required to be present in the DGGS literal. The parameter resolution describes the resolution in the target DGGS. If the DGGS type does not require a resolution, the parameter resolution will be ignored.

REQUIREMENT 43: ASDGGS FUNCTION

IDENTIFIER /req/geometry-extension-dggs/asDGGS-function

STATEMENT Implementations shall support `geof:asDGGS` and `geof:asDGGSResolution` as a SPARQL extension function.

10.9. Non-topological Query Functions

This Requirements class defines SPARQL functions for performing non-topological spatial operations.

REQUIREMENT 44: NON-TOPOLOGICAL QUERY FUNCTIONS (SIMPLE FEATURES)

IDENTIFIER /req/geometry-extension/query-functions

STATEMENT Implementations shall support the functions `geof:boundary`, `geof:boundingCircle`, `geof:metricBuffer`, `geof:buffer`, `geof:metricWithinDistance`, `geof:withinDistance`, `geof:centroid`, `geof:convexHull`, `geof:concaveHull`, `geof:coordinateDimension`, `geof:difference`, `geof:dimension`, `geof:metricDistance`, `geof:distance`, `geof:envelope`, `geof:geometryType`, `geof:intersection`, `geof:isCollection`,

REQUIREMENT 44: NON-TOPOLOGICAL QUERY FUNCTIONS (SIMPLE FEATURES)

geof:is3D, geof:isEmpty, geof:isClosed, geof:isMeasured, geof:isRing, geof:isSimple, geof:spatialDimension, geof:symDifference, geof:transform, geof:transformCRS84and geof:union as SPARQL extension functions, consistent with definitions of these functions in Simple Features OGCSFAC ISO19125-1, for non-DGGS geometry literals.

REQUIREMENT 45: NON-TOPOLOGICAL QUERY FUNCTIONS (NON SIMPLE FEATURES)

IDENTIFIER	/req/geometry-extension/query-functions-non-sf
STATEMENT	Implementations shall support the functions geof:metricLength, geof:length, geof:metricPerimeter, geof:perimeter, geof:metricArea, geof:area, geof:endPoint, geof:geometryN, geof:easting, geof:northing, geof:maxX, geof:maxY, geof:maxZ, geof:minX, geof:minY, geof:minZ, geof:numGeometries, geof:numInteriorRing, geof:numPatches, geof:numPoints, geof:startPoint, geof:simplify, geof:X, geof:Y, geof:Z, geof:M as SPARQL extension functions which are defined in this standard, for non-DGGS geometry literals.

Functions from this Requirements class are listed below, alphabetically.

10.9.1. Function notes

These notes apply to all of the following functions in this section.

An invocation of any of the following functions with invalid arguments produces an error. An invalid argument includes any of the following:

- An argument of an unexpected type
- An invalid geometry literal value
- A non-fitting geometry type for the given function
- A geometry literal from a spatial reference system that is incompatible with the spatial reference system used for calculations
- An invalid unit IRI

A more detailed description of expected inputs and expected outputs of the given functions is shown in Annex B.

Unless otherwise stated in the function definition, the following behaviors should be followed by all SPARQL extension functions defined in the GeoSPARQL standard:

- Functions returning a new geometry literal should follow the literal format of the first geometry literal input parameter. If no geometry literal input parameter is present, a WKT literal shall be returned.

- Functions returning a new geometry literal should follow the SRS defined in the literal format of the first geometry literal input parameter. If no geometry literal input parameter is present, a geometry result should be returned in the CRS84 SRS.

For further discussion of the effects of errors during FILTER evaluation, consult Section 17¹⁰ of the SPARQL specification SPARQL.

Note that returning values instead of raising an error serves as an extension mechanism of SPARQL.

From Section 17.3.1¹¹ of the SPARQL specification SPARQL:

SPARQL language extensions may provide additional associations between operators and operator functions; ... No additional operator may yield a result that replaces any result other The consequence of this rule is that SPARQL FILTERs will produce at least the same intermediate bindings after applying a FILTER as an unextended implementation.

This extension mechanism enables GeoSPARQL implementations to simultaneously support multiple geometry serializations. For example, a system that supports WKT Literal serializations may also support GML Literal serializations and consequently would not raise an error if it encounters multiple geometry datatypes while processing a given query.

NOTE: Several non-topological query functions use a unit of measure IRI. See the Recommendation for units of measure. Also, the OGC has recommended units of measure vocabularies for use, see the OGC Definitions Server¹².

10.9.2. Function: geof:metricArea

geof:metricArea (geom: ogc:geomLiteral): xsd:double

The function `geof:metricArea` returns the area of geom in square meters. Must return zero for all geometry types other than Polygon. This function is similar to `geof:area` but does not need a specification of measurement unit.

10.9.3. Function: geof:area

geof:area (geom: ogc:geomLiteral, units: xsd:anyURI): rdf:Resource

¹⁰<<https://www.w3.org/TR/sparql11-query/#expressions>>

¹¹<<https://www.w3.org/TR/sparql11-query/#operatorExtensibility>>

¹²<https://www.ogc.org/def-server>

The function `geof:area` returns the area of `geom`. Must return zero for all geometry types other than `Polygon`. This function is similar to `geof:metricArea`, which does not need a specification of measurement unit.

NOTE: See the Recommendation for units of measure.

10.9.4. Function: `geof:boundary`

`geof:boundary (geom: ogc:geomLiteral): ogc:geomLiteral`

The function `geof:boundary` returns the closure of the boundary of `geom`. Calculations are in the spatial reference system of `geom`.

10.9.5. Function: `geof:boundingCircle`

`geof:boundingCircle (geom: ogc:geomLiteral): ogc:geomLiteral`

The function `geof:boundingCircle` returns the minimum bounding circle around `geom`. Calculations are in the spatial reference system of `geom`.

10.9.6. Function: `geof:boundingPolygons`

`geof:boundingPolygons (geom: ogc:geomLiteral, n: xsd:integer): ogc:geomLiteral`

Listing 9

The function `geof:boundingPolygons` returns a collection of polygons which bound the n^{th} polygon of a given `PolyhedralSurface` `geom`.

10.9.7. Function: `geof:metricBuffer`

`geof:metricBuffer (geom: ogc:geomLiteral,
radius: xsd:double): ogc:geomLiteral`

The function `geof:metricBuffer` returns a geometric object that represents all Points whose distance from `geom` is less than or equal to the `radius` measured in meters. Calculations are in the coordinate reference system of `geom`. This function is similar to `geof:buffer`, but does not need a specification of measurement unit.

10.9.8. Function: `geof:buffer`

`geof:buffer (geom: ogc:geomLiteral,
radius: xsd:double,
units: xsd:anyURI): ogc:geomLiteral`

The function `geof:buffer` returns a geometric object that represents all Points whose distance from `geom` is less than or equal to the `radius` measured in `units`. Calculations are in the spatial

reference system of geom. This function is similar to geof:metricBuffer, which does not need a specification of measurement unit.

NOTE: See the Recommendation for units of measure.

10.9.9. Function: geof:centeroid

geof:centeroid (geom: ogc:geomLiteral): ogc:geomLiteral

The function `geof:centeroid` returns the mathematical centroid of geom. The centroid point does not have to be part of the surface it is derived from.

10.9.10. Function: geof:convexHull

geof:convexHull (geom: ogc:geomLiteral): ogc:geomLiteral

The function `geof:convexHull` returns a geometric object that represents all Points in the convex hull of geom. Calculations are in the spatial reference system of geom.

10.9.11. Function: geof:concaveHull

geof:concaveHull (geom: ogc:geomLiteral): ogc:geomLiteral

The function `geof:concaveHull` returns a geometric object that represents all Points in the concave hull of geom. Calculations are in the spatial reference system of geom. Various implementers use parameters to calculate a concave hull. As such, two implementations may return different results from their concave hull functions for the same geometry. Implementers should make clear any default values used to calculate a concave hull in their documentation.

10.9.12. Function: geof:coordinateDimension

geof:coordinateDimension (geom: ogc:geomLiteral): xsd:integer

The function `geof:coordinateDimension` returns the coordinate dimension of geom.

10.9.13. Function: geof:metricWithinDistance

geof:metricWithinDistance (geom1: ogc:geomLiteral, geom2: ogc:geomLiteral,
distance: xsd:double): xsd:boolean

Listing 10

Returns true if geom2 is within a given distance of geom1 in meters. Calculations are according to the units in the spatial reference system of geom1. The triple store implementation needs to take care of a conversion between meter and the unit of the spatial reference system.

10.9.14. Function: geof:withinDistance

```
geof:withinDistance (geom: ogc:geomLiteral, geom2: ogc:geomLiteral,  
                     distance: xsd:double, units: xsd:anyURI): xsd:boolean
```

Listing 11

Returns true if geom2 is within a given distance of geom1. Calculations are in the spatial reference system of geom1. The triple store implementation needs to take care of a conversion between the unit given as a parameter and the unit of the spatial reference system.

10.9.15. Function: geof:difference

```
geof:difference (geom1: ogc:geomLiteral,  
                  geom2: ogc:geomLiteral): ogc:geomLiteral
```

The function geof:difference returns a geometric object that represents all Points in the set difference of geom1 with geom2. Calculations are in the spatial reference system of geom1.

10.9.16. Function: geof:dimension

```
geof:dimension (geom: ogc:geomLiteral): xsd:integer
```

The function geof:dimensions returns the dimension of geom. In non-homogeneous geometry collections, this will return the largest topological dimension of the contained objects.

10.9.17. Function: geof:metricDistance

```
geof:metricDistance (geom1: ogc:geomLiteral,  
                     geom2: ogc:geomLiteral): xsd:double
```

The function geof:metricDistance returns the shortest distance in meters between any two Points in the two geometric objects. Calculations are in the coordinate reference system of geom1. This function is similar to geof:distance, but does not need a specification of measurement unit.

10.9.18. Function: geof:distance

```
geof:distance (geom1: ogc:geomLiteral,  
               geom2: ogc:geomLiteral,  
               units: xsd:anyURI): xsd:double
```

The function geof:distance returns the shortest distance in units between any two Points in the two geometric objects. Calculations are in the spatial reference system of geom1. This function is similar to geof:metricDistance, which does not need a specification of measurement unit.

NOTE: See the Recommendation for units of measure.

10.9.19. Function: `geof:endPoint`

`geof:endPoint (geom: ogc:geomLiteral): ogc:geomLiteral`

Listing 12

The function `geof:endPoint` returns the last point in the given `geom` in the literal format of `geom`.

10.9.20. Function: `geof:envelope`

`geof:envelope (geom: ogc:geomLiteral): ogc:geomLiteral`

The function `geof:envelope` returns the minimum bounding box – a rectangle – of `geom`. Calculations are in the spatial reference system of `geom`.

10.9.21. Function: `geof:exteriorRing`

`geof:exteriorRing (geom: ogc:geomLiteral): ogc:geomLiteral`

Listing 13

The function `geof:exteriorRing` returns the exterior interior ring of `geom` if the geometry represents a Polygon.

10.9.22. Function: `geof:geometryN`

`geof:geometryN (geom: ogc:geomLiteral, geomindex: xsd:integer): ogc:geomLiteral`

The function `geof:geometryN` returns the n^{th} geometry of `geom` if it is a `GeometryCollection` that is defined in a literal type (such as in the case of a `sf:GeometryCollection`) or `geom` if it is a `Geometry`. This function is not applicable to the type `geo:GeometryCollection`, as elements in `geo:GeometryCollection` are not guaranteed to be ordered.

10.9.23. Function: `geof:geometryType`

`geof:geometryType (geom: ogc:geomLiteral): xsd:anyURI`

The function `geof:geometryType` returns the URI of the subtype of `Geometry` of which this geometric object is a member. No attempt to reconcile different geometry subtypes across all support literals need be made.

10.9.24. Function: geof:getSRID

```
geof:getSRID (geom: ogc:geomLiteral): xsd:anyURI
```

Listing 14

The function `geof:getSRID` returns the spatial reference system IRI for geom.

10.9.25. Function: geof:interiorRingN

```
geof:interiorRingN (geom: ogc:geomLiteral, ringindex: xsd:integer): ogc:geomLiteral
```

Listing 15

The function `geof:interiorRingN` returns the n^{th} interior ring of geom if the geometry represents a Polygon.

10.9.26. Function: geof:intersection

```
geof:intersection (geom1: ogc:geomLiteral,  
                   geom2: ogc:geomLiteral): ogc:geomLiteral
```

The function `geof:intersection` returns a geometric object that represents all Points in the intersection of geom1 with geom2. Calculations are in the spatial reference system of geom1.

10.9.27. Function: geof:is3D

```
geof:is3D (geom: ogc:geomLiteral): xsd:boolean
```

The function `geof:is3D` Returns true if geom has z coordinate values.

10.9.28. Function: geof:isCollection

```
geof:isCollection (geom: ogc:geomLiteral): xsd:boolean
```

Listing 16

Returns true if the literal describing geom represents a GeometryCollection.

10.9.29. Function: geof:isClosed

```
geof:isClosed (geom: ogc:geomLiteral): xsd:boolean
```

Listing 17

The function `geof:isClosed` returns true if `geom` is a closed geometry, i.e. its start point equals its end point.

10.9.30. Function: `geof:isEmpty`

`geof:isEmpty (geom: ogc:geomLiteral): xsd:boolean`

The function `geof:isEmpty` returns true if `geom` is an empty geometry, i.e. contains no coordinates.

10.9.31. Function: `geof:isMeasured`

`geof:isMeasured (geom: ogc:geomLiteral): xsd:boolean`

The function `geof:isMeasured` returns true if `geom` has m coordinate values.

10.9.32. Function: `geof:isRing`

`geof:isRing (geom: ogc:geomLiteral): xsd:boolean`

Listing 18

The function `geof:isRing` Returns true if `geom` is a closed geometry (see `geof:isClosed`), and simple (see `geof:isSimple`).

10.9.33. Function: `geof:isSimple`

`geof:isSimple (geom: ogc:geomLiteral): xsd:boolean`

The function `geof:isSimple` returns true if `geom` is a simple geometry, i.e. has no anomalous geometric points, such as self intersection or self tangency.

10.9.34. Function: `geof:metricLength`

`geof:metricLength (geom: ogc:geomLiteral): xsd:double`

The function `geof:metricLength` returns the length of `geom` in meters. The longest length from any one dimension is returned. This is for example the length of a line from its beginning point to its endpoint or the length of the boundary of a polygon. This function is similar to `geof:length` but does not need a specification of measurement unit.

10.9.35. Function: `geof:length`

`geof:length (geom: ogc:geomLiteral, units: xsd:anyURI): xsd:double`

The function `geof:length` returns the length of `geom`. The longest length from any one dimension is returned. This function is similar to `geof:metricLength`, which does not need a specification of measurement unit.

NOTE: See the Recommendation for units of measure.

`geof:easting` (`geom: ogc:geomLiteral`): `xsd:double`

The function `geof:easting` returns the easting, e.g., the latitude of `geom` in the unit that is proposed by the coordinate reference system associated with the geometry. This function is defined only for such `geom` representing Points.

`geof:northing` (`geom: ogc:geomLiteral`): `xsd:double`

The function `geof:northing` returns the northing, e.g., the longitude of `geom` in the unit that is proposed by the coordinate reference system associated with the geometry. This function is defined only for such `geom` representing Points.

10.9.36. Function: `geof:maxX`

`geof:maxX` (`geom: ogc:geomLiteral`): `xsd:double`

The function `geof:maxX` returns the maximum X coordinate for `geom` using the SRS of `geom`.

10.9.37. Function: `geof:maxY`

`geof:maxY` (`geom: ogc:geomLiteral`): `xsd:double`

The function `geof:maxY` returns the maximum Y coordinate for `geom` using the SRS of `geom`.

10.9.38. Function: `geof:maxZ`

`geof:maxZ` (`geom: ogc:geomLiteral`): `xsd:double`

The function `geof:maxZ` returns the maximum Z coordinate for `geom` using the SRS of `geom`.

10.9.39. Function: `geof:minX`

`geof:minX` (`geom: ogc:geomLiteral`): `xsd:double`

The function `geof:minX` returns the minimum X coordinate for `geom` using the SRS of `geom`.

10.9.40. Function: `geof:minY`

`geof:minY` (`geom: ogc:geomLiteral`): `xsd:double`

The function `geof:minY` returns the minimum Y coordinate for `geom` using the SRS of `geom`.

10.9.41. Function: geof:minZ

geof:minZ (geom: ogc:geomLiteral): xsd:double

The function `geof:minZ` returns the minimum Z coordinate for geom using the SRS of geom.

10.9.42. Function: geof:numGeometries

geof:numGeometries (geom: ogc:geomLiteral): xsd:integer

The function `geof:numGeometries` returns the number of geometries of geom.

NOTE: This function returns 1 except in cases when it receives a collection type, such as an `sf:MultiPoint`, a `sf:MultiLineString`, a `sf:MultiPolygon`, or a `sf:GeometryCollection`. The function does not apply to `geo:GeometryCollection` instances, as members of `geo:GeometryCollection` instances are not ordered.

10.9.43. Function: geof:numPatches

geof:numPatches (geom: ogc:geomLiteral): xsd:integer

Listing 19

The function `geof:numPatches` returns the number of including polygons of geom.

10.9.44. Function: geof:numInteriorRing

geof:numInteriorRing (geom: ogc:geomLiteral): xsd:integer

Listing 20

The function `geof:numInteriorRing` Returns the number of interior rings of geom if the geometry represents a Polygon.

10.9.45. Function: geof:numPoints

geof:numPoints (geom: ogc:geomLiteral): xsd:integer

Listing 21

The function `geof:numPoints` returns the number of points of geom.

10.9.46. Function: geof:patchN

geof:patchN (geom: ogc:geomLiteral, index: xsd:integer): ogc:geomLiteral

Listing 22

The function geof:patchN returns the n^{th} polygon of geom, in the order of definition.

10.9.47. Function: geof:perimeter

geof:perimeter (geom: ogc:geomLiteral, unit: xsd:anyURI): xsd:double

The function geof:perimeter returns the perimeter of geom in the unit specified by the unit parameter for areal geometries. For non-areal geometries the result is equivalent to geof:hasLength.

10.9.48. Function: geof:metricPerimeter

geof:metricPerimeter (geom: ogc:geomLiteral): xsd:double

The function geof:metricPerimeter returns the perimeter is similar to the function geof:perimeter, but always returns the result in meter.

10.9.49. Function: geof:pointN

geof:pointN (geom:ogc:geomLiteral, geomindex: xsd:integer): ogc:geomLiteral

Listing 23

The function geof:pointN Returns the n^{th} point in geom.

10.9.50. Function: geof:pointOnSurface

geof:pointOnSurface (geom: ogc:geomLiteral, n: xsd:integer): ogc:geomLiteral

Listing 24

The function geof:pointOnSurface returns a point which is guaranteed to be on the n^{th} surface of geom.

10.9.51. Function: geof:spatialDimension

geof:spatialDimension (geom: ogc:geomLiteral): xsd:integer

The function geof:spatialDimension returns the spatial dimension of geom.

10.9.52. Function: `geof:startPoint`

```
geof:startPoint (geom: ogc:geomLiteral): ogc:geomLiteral
```

Listing 25

The function `geof:startPoint` Returns the first point in the given geom in the literal format of geom.

10.9.53. Function: `geof:symDifference`

```
geof:symDifference (geom1: ogc:geomLiteral,  
                     geom2: ogc:geomLiteral): ogc:geomLiteral
```

The function `geof:symDifference` returns a geometric object that represents all Points in the set symmetric difference of geom1 with geom2. Calculations are in the spatial reference system of geom1.

10.9.54. Function: `geof:simplify`

```
geof:simplify (geom: ogc:geomLiteral, tolerance: xsd:double): ogc:geomLiteral
```

Listing 26

The function `geof:simplify` simplifies geom by applying the Douglas-Peucker algorithm DOUGLASPEUCKER.

10.9.55. Function: `geof:transform`

```
geof:transform (geom: ogc:geomLiteral, srsIRI: xsd:anyURI): ogc:geomLiteral
```

The function `geof:transform` converts geom to a spatial reference system defined by srsIRI. The function raises an error if a transformation is not mathematically possible.

NOTE: We recommend that implementers use the same literal type as a result of this function as the type of the input literal.

10.9.56. Function: `geof:transformCRS84`

```
geof:transformCRS84 (geom: ogc:geomLiteral): ogc:geomLiteral
```

The function `geof:transformCRS84` converts geom to the CRS84 coordinate system. The function raises an error if a transformation is not mathematically possible.

NOTE: We recommend that implementers use the same literal type as a result of this function as the type of the input literal.

10.9.57. Function: geof:union

```
geof:union (geom1: ogc:geomLiteral,  
            geom2: ogc:geomLiteral): ogc:geomLiteral
```

The function `geof:union` returns a geometric object that represents all Points in the union of `geom1` with `geom2`. Calculations are in the spatial reference system of `geom1`.

10.9.58. Function: geof:X

```
geof:X (geom: ogc:geomLiteral): xsd:double
```

Listing 27

The function `geof:X` returns the X coordinate if `geom` is a point geometry. The X coordinate is determined by the X axis definition of its SRS.

10.9.59. Function: geof:Y

```
geof:Y (geom: ogc:geomLiteral): xsd:double
```

Listing 28

The function `geof:Y` returns the Y coordinate if `geom` is a point geometry. The Y coordinate is determined by the Y axis definition of its SRS.

10.9.60. Function: geof:Z

```
geof:Z (geom: ogc:geomLiteral): xsd:double
```

Listing 29

The function `geof:Z` returns the Z coordinate if `geom` is a point geometry. The Z coordinate is determined by the Z axis definition of its SRS.

10.9.61. Function: geof:M

```
geof:M (geom: ogc:geomLiteral): xsd:double
```

Listing 30

The function `geof:M` returns the M coordinate if `geom` is a point geometry. The M coordinate is determined by the M coordinate definition of its SRS.

REQUIREMENT 46: SRID FUNCTION

IDENTIFIER /req/geometry-extension/srid-function

STATEMENT Implementations shall support `geof:getSRID` as a SPARQL extension function.

10.9.62. Function: `geof:getSRID`

`geof:getSRID (geom: ogc:geomLiteral): xsd:anyURI`

The function `geof:getSRID` returns the spatial reference system IRI for geom.

10.10. Non-topological Query Functions – 3D Extension

This Requirements class defines SPARQL functions for performing non-topological spatial operations in 3D.

REQUIREMENT 47: NON-TOPOLOGICAL QUERY FUNCTIONS – 3D

IDENTIFIER /req/geometry-extension/query-functions-3D

STATEMENT Implementations shall support the functions `geof:extrude` `geof:extrudeByLine` `geof:extrudeInTime` as SPARQL extension functions which are defined in this standard.

10.10.1. Function: `geof:extrude`

`geof:extrude (geometry: ogc:geomLiteral,
height: xsd:double): geo:Feature`

The function `geof:extrude` returns a spatial Feature with a 3D geometric object that represents all Points in the extruded form of 2D geometry where the height indicates the number added to Z coordinates of base geometry to arrive at Z coordinates of the top most geometry in the extruded form. In case of no Z coordinates being present in the base geometry, the height is added to 0 and is equal to Z coordinates of the top most geometry in the extruded form. Calculations are in the spatial reference system of geometry.

10.10.2. Function: `geof:extrudeByLine`

`geof:extrudeByLine (geometry: ogc:geomLiteral,
line-segment: ogc:geomLiteral): geo:Feature`

The function `geof:extrudeByLine` returns a spatial Feature with a 3D geometric object that represents all Points in the extruded form of 2D geometry where the line-segment marks

the starting and ending points of the extruded form in space. Calculations are in the spatial reference system of geometry.

10.10.3. Function: `geof:extrudeInTime`

```
geof:extrudeInTime (geometry: ogc:geomLiteral,  
                     line-segment: ogc:geomLiteral,  
                     start: xsd:dateTime,  
                     end: xsd:dateTime): geo:Feature
```

The function `geof:extrudeInTime` returns a spatio-temporal Feature with a 3D geometric object that represents all Points in the extruded form of 2D geometry where the line-segment marks the starting and ending points of the extruded form in space and ProperInterval with start and end in time. Calculations are in the spatial reference system of geometry.

10.11. Spatial Aggregate Functions

This clause defines SPARQL functions for performing spatial aggregations of data.

REQUIREMENT 48: SPATIAL AGGREGATE FUNCTIONS

IDENTIFIER	/req/geometry-extension/sa-functions
STATEMENT	Implementations shall support <code>geof:aggBoundingBox</code> , <code>geof:aggBoundingCircle</code> , <code>geof:aggCentroid</code> , <code>geof:aggCollect</code> , <code>geof:aggConcaveHull</code> , <code>geof:aggConvexHull</code> and <code>geof:aggUnion</code> as a SPARQL extension functions.

NOTE: This spec does not define a deterministic order on geomLiterals which act as inputs of Spatial Aggregate functions, as opposed to functions requiring a single parameter. This means in particular, that the coordinate reference system and the literal type which is to be used in the output of spatial aggregate functions can be derived from the first item in the array of geomLiteral, but GeoSPARQL does not mandate it. Users of GeoSPARQL may use the `geof:transform` function to convert results of spatial aggrgate functions to their intended coordinate reference system.

10.11.1. Function: `geof:aggBoundingBox`

```
geof:aggBoundingBox (geom: ogc:geomLiteral[]): ogc:geomLiteral
```

The function `geof:aggBoundingBox` calculates a minimum bounding box – rectangle – of the set of given geometries.

10.11.2. Function: `geof:aggBoundingCircle`

`geof:aggBoundingCircle (geom: ogc:geomLiteral[]): ogc:geomLiteral`

The function `geof:aggBoundingCircle` calculates a minimum bounding circle of the set of given geometries.

10.11.3. Function: `geof:aggCentroid`

`geof:aggCentroid (geom: ogc:geomLiteral[]): ogc:geomLiteral`

The function `geof:aggCentroid` calculates the centroid of the set of given geometries.

10.11.4. Function: `geof:aggCollect`

`geof:aggCollect (geom: ogc:geomLiteral[]): ogc:geomLiteral`

Listing 31

The function `geof:aggCollect` creates a GeometryCollection literal out of a set of geometries.

10.11.5. Function: `geof:aggConcaveHull`

`geof:aggConcaveHull (geom: ogc:geomLiteral[], targetPercent: xsd:double): ogc:geomLiteral`

The function `geof:aggConcaveHull` calculates the concave hull of the set of given geometries.

10.11.6. Function: `geof:aggConvexHull`

`geof:aggConvexHull (geom: ogc:geomLiteral[]): ogc:geomLiteral`

The function `geof:aggConvexHull` calculates the convex hull of the set of given geometries.

NOTE: This function is similar in name to `geof:convexHull` used to calculate the convex hull of just one geometry.

10.11.7. Function: `geof:aggUnion`

`geof:aggUnion (geom: ogc:geomLiteral[]): ogc:geomLiteral`

The function `geof:aggUnion` calculates the union of the set of given geometries.

NOTE: This function is similar in name to `geof:union` used to calculate the union of just two geometries.

11

GEOMETRY TOPOLOGY EXTENSION

GEOMETRY TOPOLOGY EXTENSION

This clause establishes the *Geometry Topology Extension* parameterized Requirements class with base IRI `/req/geometry-topology-extension`, which defines a collection of topological query functions that operate on geometry literals. These Requirements are parameterized to give implementations flexibility in the topological relation families and geometry serializations that they choose to support. These Requirements have a single corresponding conformance class *Geometry Topology Extension*, with IRI `/conf/geometry-topology-extension`.

The Dimensionally Extended Nine Intersection Model (DE-9IM) [2] has been used to define the relation tested by the query functions introduced in this section. Each query function is associated with a defining DE-9IM intersection pattern. Possible pattern values are:

- -1 (empty)
- 0, 1, 2, T (true) = {0, 1, 2}
- F (false) = {-1}
- * (don't care) = {-1, 0, 1, 2}

In the following descriptions, the notation X/Y is used to denote applying a spatial relation to geometry types X and Y (i.e., $x \text{ relation } y$ where x is of type X and y is of type Y). The symbol P is used for 0-dimensional geometries (e.g., points). The symbol L is used for 1-dimensional geometries (e.g. lines), and the symbol A is used for 2-dimensional geometries (e.g., polygons). Consult the Simple Features specification [OGC06-103r4] ISO19125-1 for a more detailed description of DE-9IM intersection patterns.

REQUIREMENTS CLASS 4: GEOMETRY TOPOLOGY EXTENSION

IDENTIFIER	<code>/req/geometry-topology-extension</code>
TARGET TYPE	Implementation Specification
CONFORMANCE CLASS	Conformance class A.5: <code>/conf/geometry-topology-extension</code> <code>/req/geometry-topology-extension/relate-query-function</code> <code>/req/geometry-topology-extension/sf-query-functions</code>
REQUIREMENT	<code>/req/geometry-topology-extension/eh-query-functions</code> <code>/req/geometry-topology-extension/rcc8-query-functions</code>

11.1. Parameters

- **relation_family:** Specifies the set of topological spatial relations to support.
- **serialization:** Specifies the serialization standard to use for geometry literals.
- **version:** Specifies the version of the serialization format used.

11.2. Common Query Functions

REQUIREMENT 49: RELATE QUERY FUNCTION

IDENTIFIER /req/geometry-topology-extension/relate-query-function

STATEMENT Implementations shall support `geof:relate` as a SPARQL extension function, consistent with the relate operator defined in Simple Features [OGC06-103r4] ISO19125-1.

```
geof:relate (geom1: ogc:geomLiteral,  
             geom2: ogc:geomLiteral,  
             pattern-matrix: xsd:string): xsd:boolean
```

Returns true if the spatial relationship between geom1 and geom2 corresponds to one with acceptable values for the specified pattern-matrix. Otherwise, this function returns false. pattern-matrix represents a DE-9IM intersection pattern consisting of T (true) and F (false) values. The spatial reference system for geom1 is used for spatial calculations.

11.3. Simple Features Relation Family

This clause establishes Requirements for the *Simple Features* relation family.

REQUIREMENT 50: SIMPLE FEATURES QUERY FUNCTIONS

IDENTIFIER /req/geometry-topology-extension/sf-query-functions

STATEMENT Implementations shall support `geof:sfEquals`, `geof:sfDisjoint`, `geof:sfIntersects`, `geof:sfTouches`, `geof:sfCrosses`, `geof:sfWithin`, `geof:sfContains` and `geof:sfOverlaps` as SPARQL extension functions, consistent with their corresponding DE-9IM intersection patterns, as defined by Simple Features [OGC06-103r4] ISO19125-1.

Boolean query functions defined for the Simple Features relation family, along with their associated DE-9IM intersection patterns, are shown in Table 13 below. Multi-row intersection patterns should be interpreted as a logical OR of each row. Each function accepts two arguments (`geom1` and `geom2`) of the geometry literal *serialization type specified by serialization and version*. Each function returns an `xsd:boolean` value of `true` if the specified relation exists between `geom1` and `geom2` and returns false otherwise. In each case, the spatial reference system of `geom1` is used for spatial calculations.

Table 13 – Simple Features Query Functions

QUERY FUNCTION	DEFINING DE-9IM INTERSECTION PATTERN
<code>geof:sfEquals(geom1: ogc:geomLiteral, geom2: ogc:geomLiteral): xsd:boolean</code>	(TFFFFFFFFFF)
<code>geof:sfDisjoint(geom1: ogc:geomLiteral, geom2: ogc:geomLiteral): xsd:boolean</code>	(FF*FF****)
<code>geof:sfIntersects(geom1: ogc:geomLiteral, geom2: ogc:geomLiteral): xsd:boolean</code>	(FT***** F**T***** F***T****)
<code>geof:sfTouches(geom1: ogc:geomLiteral, geom2: ogc:geomLiteral): xsd:boolean</code>	(FT***** F**T***** F***T****)
<code>geof:sfCrosses(geom1: ogc:geomLiteral, geom2: ogc:geomLiteral): xsd:boolean</code>	(T*T***T**) for P/L, P/A, L/A; (0*T***T**) for L/L
<code>geof:sfWithin(geom1: ogc:geomLiteral, geom2: ogc:geomLiteral): xsd:boolean</code>	(T*F**F***)
<code>geof:sfContains(geom1: ogc:geomLiteral, geom2: ogc:geomLiteral): xsd:boolean</code>	(T*****FF*)
<code>geof:sfOverlaps(geom1: ogc:geomLiteral, geom2: ogc:geomLiteral): xsd:boolean</code>	(T*T***T**) for A/A, P/P; (1*T***T**) for L/L

11.4. Egenhofer Relation Family

This clause establishes Requirements for the *Egenhofer* relation family. Consult references [3] and CATEG for a more detailed discussion of *Egenhofer* relations.

REQUIREMENT 51: EGENHOFER QUERY FUNCTIONS

IDENTIFIER /req/geometry-topology-extension/eh-query-functions

STATEMENT Implementations shall support `geof:ehEquals`, `geof:ehDisjoint`, `geof:ehMeet`, `geof:ehOverlap`, `geof:ehCovers`, `geof:ehCoveredBy`, `geof:ehInside` and `geof:ehContains` as

REQUIREMENT 51: EGENHOFER QUERY FUNCTIONS

SPARQL extension functions, consistent with their corresponding DE-9IM intersection patterns, as defined by Simple Features [OGC06-103r4] ISO19125-1.

Boolean query functions defined for the *Egenhofer* relation family, along with their associated DE-9IM intersection patterns, are shown in Table 14 below. Multi-row intersection patterns should be interpreted as a logical OR of each row. Each function accepts two arguments (*geom1* and *geom2*) of the geometry literal serialization type specified by *serialization* and *version*. Each function returns an [xsd:boolean](#) value of *true* if the specified relation exists between *geom1* and *geom2* and returns *false* otherwise. In each case, the spatial reference system of *geom1* is used for spatial calculations.

Table 14 – Egenhofer Query Functions

QUERY FUNCTION	DEFINING DE-9IM INTERSECTION PATTERN
geof:ehEquals(geom1: ogc:geomLiteral, geom2: ogc:geomLiteral): xsd:boolean	(TFFFFFFFFFF)
geof:ehDisjoint(geom1: ogc:geomLiteral, geom2: ogc:geomLiteral): xsd:boolean	(FF*FF****)
geof:ehMeet(geom1: ogc:geomLiteral, geom2: ogc:geomLiteral): xsd:boolean	(FT***** F**T**** F***T****)
geof:ehOverlap(geom1: ogc:geomLiteral, geom2: ogc:geomLiteral): xsd:boolean	(T*T***T**)
geof:ehCovers(geom1: ogc:geomLiteral, geom2: ogc:geomLiteral): xsd:boolean	(T*TFT*FF*)
geof:ehCoveredBy(geom1: ogc:geomLiteral, geom2: ogc:geomLiteral): xsd:boolean	(TFF*TFT**)*)
geof:ehInside(geom1: ogc:geomLiteral, geom2: ogc:geomLiteral): xsd:boolean	(TFF*FFT**)*)
geof:ehContains(geom1: ogc:geomLiteral, geom2: ogc:geomLiteral): xsd:boolean	(T*TFF*FF*)*)

11.5. RCC8 Relation Family

This clause establishes Requirements for the RCC8 relation family. Consult references QUAL and [4] for a more detailed discussion of RCC8 relations.

REQUIREMENT 52: RCC8 QUERY FUNCTIONS

IDENTIFIER	/req/geometry-topology-extension/rcc8-query-functions
STATEMENT	Implementations shall support <code>geof:rcc8eq</code> , <code>geof:rcc8dc</code> , <code>geof:rcc8ec</code> , <code>geof:rcc8po</code> , <code>geof:rcc8tppi</code> , <code>geof:rcc8tpp</code> , <code>geof:rcc8ntpp</code> and <code>geof:rcc8ntppi</code> as SPARQL extension functions, consistent with their corresponding DE-9IM intersection patterns, as defined by Simple Features [OGC06-103r4] ISO19125-1.

Boolean query functions defined for the RCC8 relation family, along with their associated DE-9IM intersection patterns, are shown in Table 15 below. Each function accepts two arguments (`geom1` and `geom2`) of the geometry literal serialization type specified by *serialization* and *version*. Each function returns an `xsd:boolean` value of `true` if the specified relation exists between `geom1` and `geom2` and returns `false` otherwise. In each case, the spatial reference system of `geom1` is used for spatial calculations.

Table 15 – RCC8 Query Functions

QUERY FUNCTION	DEFINING DE-9IM INTERSECTION PATTERN
<code>geof:rcc8eq(geom1: ogc:geomLiteral, geom2: ogc:geomLiteral): xsd:boolean</code>	(TFFFFTFFFF)
<code>geof:rcc8dc(geom1: ogc:geomLiteral, geom2: ogc:geomLiteral): xsd:boolean</code>	(FFTFFFFTTT)
<code>geof:rcc8ec(geom1: ogc:geomLiteral, geom2: ogc:geomLiteral): xsd:boolean</code>	(FFTFTTTTTT)
<code>geof:rcc8po(geom1: ogc:geomLiteral, geom2: ogc:geomLiteral): xsd:boolean</code>	(TTTTTTTTTT)
<code>geof:rcc8tppi(geom1: ogc:geomLiteral, geom2: ogc:geomLiteral): xsd:boolean</code>	(TTTFTTFFFT)
<code>geof:rcc8tpp(geom1: ogc:geomLiteral, geom2: ogc:geomLiteral): xsd:boolean</code>	(TFFFTFTTTT)
<code>geof:rcc8ntpp(geom1: ogc:geomLiteral, geom2: ogc:geomLiteral): xsd:boolean</code>	(TFFFTFFTTT)
<code>geof:rcc8ntppi(geom1: ogc:geomLiteral, geom2: ogc:geomLiteral): xsd:boolean</code>	(TTTFFFTFFT)

11.6. RCC*-9 Relation Family

This clause establishes Requirements for the RCC*-9 relation family. Consult references [5] for a more detailed discussion of RCC*-9 relations.

REQUIREMENT 53: RCC*-9 QUERY FUNCTIONS

IDENTIFIER	/req/geometry-topology-extension/rcc9-query-functions
STATEMENT	Implementations shall support <code>geof:rcc9eq</code> , <code>geof:rcc9dc</code> , <code>geof:rcc9cr</code> , <code>geof:rcc9ec</code> , <code>geof:rcc9po</code> , <code>geof:rcc9tppi</code> , <code>geof:rcc9tpp</code> , <code>geof:rcc9ntpp</code> and <code>geof:rcc9ntppi</code> as SPARQL extension functions, consistent with their corresponding DE-9IM intersection patterns, as defined by Simple Features [OGC06-103r4] ISO19125-1.

Boolean query functions defined for the *RCC*-9* relation family, along with their associated DE-9IM intersection patterns, are shown in Table 16 below. Each function accepts two arguments (*geom1* and *geom2*) of the geometry literal serialization type specified by *serialization* and *version*. Each function returns an `xsd:boolean` value of `true` if the specified relation exists between *geom1* and *geom2* and returns `false` otherwise. In each case, the spatial reference system of *geom1* is used for spatial calculations.

Table 16 – RCC*-9 Query Functions

QUERY FUNCTION	DEFINING DE-9IM INTERSECTION PATTERN
<code>geof:rcc9eq(geom1: ogc:geomLiteral, geom2: ogc:geomLiteral): xsd:boolean</code>	(TFFF*FFFT)
<code>geof:rcc9cr(geom1: ogc:geomLiteral, geom2: ogc:geomLiteral): xsd:boolean</code>	(T*TFFF***) v (TFT*F*TT*) v (TFTFFFFTFT) v (TTTFFFFTTT) v (TFTTFTTTFT)
<code>geof:rcc9dc(geom1: ogc:geomLiteral, geom2: ogc:geomLiteral): xsd:boolean</code>	(FF*FF*****)
<code>geof:rcc9ec(geom1: ogc:geomLiteral, geom2: ogc:geomLiteral): xsd:boolean</code>	(F*TT**T**) v (FTT***T**) v (F*T*T*T**) v (T*T*T*T***)
<code>geof:rcc9po(geom1: ogc:geomLiteral, geom2: ogc:geomLiteral): xsd:boolean</code>	(TTTT**T**) v (T*T*T*T***)
<code>geof:rcc9tppi(geom1: ogc:geomLiteral, geom2: ogc:geomLiteral): xsd:boolean</code>	(***T**FF*) v (****T*FF*) v \neg (TFFFFFFFFFF)
<code>geof:rcc9tpp(geom1: ogc:geomLiteral, geom2: ogc:geomLiteral): xsd:boolean</code>	(*TF**F***) v (**F*TF***) v \neg (TFFFFFFFFFF)
<code>geof:rcc9ntpp(geom1: ogc:geomLiteral, geom2: ogc:geomLiteral): xsd:boolean</code>	(*FF*FFT***)
<code>geof:rcc9ntppi(geom1: ogc:geomLiteral, geom2: ogc:geomLiteral): xsd:boolean</code>	(**TFF*FF*)

12

RDFS ENTAILMENT EXTENSION

This clause establishes the *RDFS Entailment Extension* parameterized Requirements class with base IRI `/req/rdfs-entailment-extension`, which defines a mechanism for matching implicitly-derived RDF triples in GeoSPARQL queries. This class is parameterized to give implementations flexibility in the topological relation families and geometry types that they choose to support. These Requirements have a single corresponding conformance class *RDFS Entailment Extension*, with IRI `/conf/rdfs-entailment-extension`.

12.1. Parameters

- **relation_family**: Specifies the set of topological spatial relations to support.
- **serialization**: Specifies the serialization standard to use for geometry literals.
- **version**: Specifies the version of the serialization format used.

12.2. Common Requirements

The basic mechanism for supporting RDFS entailment has been defined by the W3C SPARQL 1.1 RDFS Entailment Regime SPARQLENT.

REQUIREMENT 54: BASIC GRAPH PATTERN

IDENTIFIER	<code>/req/rdfs-entailment-extension/bgp-rdfs-ent</code>
STATEMENT	Basic graph pattern matching shall use the semantics defined by the RDFS Entailment Regime SPARQLENT.

12.3. WKT Serialization

This section establishes the requirements for representing geometry data in RDF based on WKT as defined by Simple Features OGCSFACA ISO19125-1.

12.3.1. Geometry Class Hierarchy

The Simple Features specification presents a geometry class hierarchy. It is straightforward to represent this class hierarchy in RDFS and OWL by constructing IRIs for geometry classes using the following pattern: <http://www.opengis.net/ont/sf#{geometry class}> and by asserting appropriate `rdfs:subClassOf` statements. The *Simple Features Vocabulary* resource within GeoSPARQL 1.1 (sibling resource to this specification) does this. The following list gives the class hierarchy with each indented item being a subclass of the item in the line above. The class hierarchy starts with GeoSPARQL's `geo:Geometry` class of which `sf:Geometry` is a subclass:

```
geo:Geometry
  sf:Geometry
    sf:Curve
      sf:LineString
        sf:Line
        sf:LinearRing
    sf:GeometryCollection
      sf:MultiCurve
        sf:MultiLineString
      sf:MultiPoint
      sf:MultiSurface
        sf:MultiPolygon
    sf:Point
    sf:Surface
      sf:Polygon
        sf:Envelope
        sf:Triangle
      sf:PolyhedralSurface
        sf:TIN
```

The following example RDF snippet below encodes the *Simple Features vocabulary* Polygon class:

```
sf:Polygon
  a rdfs:Class, owl:Class ;
  rdfs:isDefinedBy <http://www.opengis.net/ont/sf> ;
  skos:prefLabel "Polygon"@en ;
  rdfs:subClassOf sf:Surface ;
  skos:definition "A planar surface defined by 1 exterior boundary and 0 or
  more interior boundaries"@en ;
.
```

REQUIREMENT 55: WKT GEOMETRY TYPES

IDENTIFIER	/req/rdfs-entailment-extension/wkt-geometry-types
------------	---

STATEMENT	Implementations shall support graph patterns involving terms from an RDFS/OWL class hierarchy of geometry types consistent with the one in the specified version of Simple Features OGCSFACA ISO19125-1.
-----------	--

12.4. GML Serialization

This section establishes Requirements for representing geometry data in RDF based on GML as defined by Geography Markup Language Encoding Standard OGC07-036.

12.4.1. Geometry Class Hierarchy

An RDF/OWL class hierarchy can be generated from the GML schema that implements GM_Object by constructing IRIs for geometry classes using the following pattern: http://www.opengis.net/ont/gml#{GML_Element} and by asserting appropriate `rdfs:subClassOf` statements.

The example RDF snippet below encodes the Polygon class from GML 3.2.

```
gml:Polygon
  a rdfs:Class, owl:Class ;
  skos:prefLabel "Polygon"@en ;
  rdfs:subClassOf gml:SurfacePatch ;
  skos:definition "A planar surface defined by 1 exterior boundary and 0 or
                    more interior boundaries."@en ;
.
```

REQUIREMENT 56: GML GEOMETRY TYPES

IDENTIFIER	/req/rdfs-entailment-extension/gml-geometry-types
STATEMENT	Implementations shall support graph patterns involving terms from an RDFS/OWL class hierarchy of geometry types consistent with the GML schema that implements GM_Object using the specified version of GML OGC07-036.

13

QUERY REWRITE EXTENSION

This clause establishes the *Query Rewrite Extension* parameterized Requirements class with base IRI /req/query-rewrite-extension, which has a single corresponding conformance class *Query Rewrite Extension*, with IRI /conf/query-rewrite-extension. These Requirements define a set of RIF rules RIF that use topological extension functions defined in Clause 10 to establish the existence of direct topological predicates defined in [vocabulary_extension]. One possible implementation strategy is to transform a given query by expanding a triple pattern involving a direct spatial predicate into a series of triple patterns and an invocation of the corresponding extension function as specified in the RIF rule.

REQUIREMENTS CLASS 5: QUERY REWRITE EXTENSION

IDENTIFIER	/req/query-rewrite-extension
TARGET TYPE	Implementation Specification
CONFORMANCE CLASS	Conformance class A.7: /conf/query-rewrite-extension
	/req/query-rewrite-extension/sf-query-rewrite
REQUIREMENT	/req/query-rewrite-extension/eh-query-rewrite
	/req/query-rewrite-extension/rcc8-query-rewrite

The following rule specified using the RIF Core Dialect RIFCORE and shown in *Presentation Syntax* is used as a template to describe rules in the remainder of this clause. `ogc:relation` is used as a placeholder for the spatial relation IRIs defined in Clause 7, and `ogc:function` is used as a placeholder for the spatial functions defined in Clause 10. `ogc:asGeomLiteral` is used to indicate one of the properties that link `geo:Geometry` instances to serialisations, such as `geo:asWKT` or `geo:asGeoJSON`. The variables `?so1` & `?so2` represent `geo:SpatialObject` instances (either `geo:Feature` or `geo:Geometry` instances), `?g1` & `?g2` `geo:Geometry` instances only and `?g1Serial` & `?g2Serial` represent `geo:Geometry` instance serializations, e.g., `geo:asWKT` etc. literals.

```
Forall ?so1 ?so2 ?g1 ?g2 ?g1Serial ?g2Serial (
  ?so1[ogc:relation->?so2] :- Or (
    And (
      # feature - feature rule
      ?so1[geo:hasDefaultGeometry->?g1]
      ?so2[geo:hasDefaultGeometry->?g2]
      ?g1[ogc:asGeomLiteral->?g1Serial]
      ?g2[ogc:asGeomLiteral->?g2Serial]
      External(ogc:function(?g1Serial, ?g2Serial))
    )
    And (
      # feature - geometry rule
      ?so1[geo:hasDefaultGeometry->?g1]
```

13.1. Parameters

- **relation_family**: Specifies the set of topological spatial relations to support.
 - **serialization**: Specifies the serialization standard to use for geometry literals.
 - **version**: Specifies the version of the serialization format used.

13.2. Simple Features Relation Family

This clause defines Requirements for the *Simple Features* relation family. Table 17 specifies the function and property substitutions for each rule in the *Simple Features* relation family.

Requirement 57: Simple Features Query Transformation Rules	
Identifier	/req/query-rewrite-extension/sf-query-rewrite
Statement	Basic graph pattern matching shall use the semantics defined by the RIF Core Entailment Regime SPARQLENT for the RIF rules RIFCORE geor:sfEquals , geor:sfDisjoint , geor:sfIntersects , geor:sfTouches , geor:sfCrosses , geor:sfWithin , geor:sfContains and geor:sfOverlaps .

Table 17 – Simple Features Query Transformation Rules

RULE	OGC:RELATION	OGC:FUNCTION
geor:sfEquals	geo:sfEquals	geof:sfEquals
geor:sfDisjoint	geo:sfDisjoint	geof:sfDisjoint
geor:sfIntersects	geo:sfIntersects	geof:sfIntersects
geor:sfTouches	geo:sfTouches	geof:sfTouches
geor:sfCrosses	geo:sfCrosses	geof:sfCrosses
geor:sfWithin	geo:sfWithin	geof:sfWithin
geor:sfContains	geo:sfContains	geof:sfContains
geor:sfOverlaps	geo:sfOverlaps	geof:sfOverlaps

13.3. Egenhofer Relation Family

This clause defines Requirements for the *Egenhofer* relation family. Table 18 specifies the function and property substitutions for each rule in the *Egenhofer* relation family.

REQUIREMENT 58: EGENHOFER QUERY TRANSFORMATION RULES

IDENTIFIER	/req/query-rewrite-extension/eh-query-rewrite
STATEMENT	Basic graph pattern matching shall use the semantics defined by the RIF Core Entailment Regime SPARQLENT for the RIF rules RIFCORE geor:ehEquals , geor:ehDisjoint , geor:ehMeet , geor:ehOverlap , geor:ehCovers , geor:ehCoveredBy , geor:ehInside and geor:ehContains .

Table 18 – Egenhofer Query Transformation Rules

RULE	OGC:RELATION	OGC:FUNCTION
geor:ehEquals	geo:ehEquals	geof:ehEquals
geor:ehDisjoint	geo:ehDisjoint	geof:ehDisjoint

RULE	OGC:RELATION	OGC:FUNCTION
geor:ehMeet	geo:ehMeet	geof:ehMeet
geor:ehOverlap	geo:ehOverlap	geof:ehOverlap
geor:ehCovers	geo:ehCovers	geof:ehCovers
geor:ehCoveredBy	geo:ehCoveredBy	geof:ehCoveredBy
geor:ehInside	geo:ehInside	geof:ehInside
geor:ehContains	geo:ehContains	geof:ehContains

13.4. RCC8 Relation Family

This clause defines Requirements for the RCC8 relation family. Table 19 specifies the function and property substitutions for each rule in the RCC8 relation family.

REQUIREMENT 59: RCC8 QUERY TRANSFORMATION RULES

IDENTIFIER	/req/query-rewrite-extension/rcc8-query-rewrite
STATEMENT	Basic graph pattern matching shall use the semantics defined by the RIF Core Entailment Regime SPARQLENT for the RIF rules RIFCORE geor:rcc8eq , geor:rcc8dc , geor:rcc8ec , geor:rcc8po , geor:rcc8tppi , geor:rcc8tpp , geor:rcc8ntpp and geor:rcc8ntppi .

Table 19 – RCC8 Query Transformation Rules

RULE	OGC:RELATION	OGC:FUNCTION
geor:rcc8eq	geo:rcc8eq	geof:rcc8eq
geor:rcc8dc	geo:rcc8dc	geof:rcc8dc
geor:rcc8ec	geo:rcc8ec	geof:rcc8ec
geor:rcc8po	geo:rcc8po	geof:rcc8po
geor:rcc8tppi	geo:rcc8tppi	geof:rcc8tppi

RULE	OGC:RELATION	OGC:FUNCTION
geor:rcc8tpp	geo:rcc8tpp	geof:rcc8tpp
geor:rcc8ntpp	geo:rcc8ntpp	geof:rcc8ntpp
geor:rcc8ntppi	geo:rcc8ntppi	geof:rcc8ntppi

13.5. Special Considerations

The applicability of GeoSPARQL rules in certain circumstances has intentionally been left undefined.

The first situation arises for triple patterns with unbound predicates. Consider the query pattern below:

```
{ my:feature1 ?p my:feature2 }
```

When using a query transformation strategy, this triple pattern could invoke none of the GeoSPARQL rules or all of the rules. Implementations are free to support either of these alternatives.

The second situation arises when supporting GeoSPARQL rules in the presence of RDFS Entailment. The existence of a topological relation (possibly derived from a GeoSPARQL rule) can entail other RDF triples. For example, if geo:sfOverlaps has been defined as an [rdfs:subPropertyOf](#) the property my:overlaps, and the RDF triple my:feature1 geo:sfOverlaps my:feature2 has been derived from a GeoSPARQL rule, then the RDF triple my:feature1 my:overlaps my:feature2 can be entailed. Implementations may support such entailments but are not required to.

14

FUTURE WORK

Many future extensions of this standard are possible and, since the release of GeoSPARQL 1.0, many extensions have been made.

The GeoSPARQL 1.1 release incorporates many additions requested of the GeoSPARQL 1.0 Standard, including the use of particular new serializations: where GeoSPARQL 1.0 supported GML & WKT, GeoSPARQL 1.1 also supports GeoJSON, KML and a generic DGGS literal. GeoSPARQL 1.1 also supports spatial scalar properties.

Plans for future GeoSPARQL releases have been suggested but won't be articulated here. Instead they will be discussed and decided upon by the OGC GeoSPARQL Standards Working Group and related groups. Readers of this document are encouraged to seek out those groups' lists of issues and standards change requests rather than looking for ideas here that will surely age badly.



—



—



—



—



—





—





—





—



A

ANNEX A (NORMATIVE) ABSTRACT TEST SUITE

ANNEX A (NORMATIVE) ABSTRACT TEST SUITE

A.0. Overview

This Annex lists tests for the Conformance Classes defined in the main body sections of this Specification with links to their Requirements and test purpose method and type. Conformance classes may be used to signify the compatibility of a given implementation to parts of the GeoSPARQL standard. They may be stated as part of a SPARQL 1.1 Service Description SPARQLSERVDESC .

A.1. Conformance Class: Core

CONFORMANCE CLASS A.1: CORE

IDENTIFIER	/conf/core
REQUIREMENTS CLASS	/req/core
CONFORMANCE TESTS	<p>Abstract test A.1: /conf/core/sparql-protocol Abstract test A.2: /conf/core/spatial-object-class Abstract test A.3: /conf/core/feature-class Abstract test A.4: /conf/core/spatial-object-collection-class Abstract test A.5: /conf/core/feature-collection-class Abstract test A.6: /conf/core/spatial-object-properties</p>

A.1.1. SPARQL

ABSTRACT TEST A.1

IDENTIFIER	/conf/core/sparql-protocol
REQUIREMENT	Requirement 1: /req/core/sparql-protocol
TEST PURPOSE	Check conformance with this requirement
TEST METHOD	Verify that the implementation accepts SPARQL queries and returns the correct results in the correct format, according to the SPARQL Query Language for RDF, the SPARQL Protocol for RDF and SPARQL Query Results XML Format W3C specifications.
TEST-METHOD-TYPE	Capabilities
REFERENCE	[sparql-protocol]

A.1.2. RDF Classes & Properties

ABSTRACT TEST A.2

IDENTIFIER	/conf/core/spatial-object-class
REQUIREMENT	Requirement 2: /req/core/spatial-object-class
TEST PURPOSE	Check conformance with this requirement
TEST METHOD	Verify that queries involving geo:SpatialObject return the correct result on a test dataset.
TEST-METHOD-TYPE	Capabilities
REFERENCE	Class/ geo

ABSTRACT TEST A.3

IDENTIFIER	/conf/core/feature-class
REQUIREMENT	Requirement 3: /req/core/feature-class
TEST PURPOSE	Check conformance with this requirement
TEST METHOD	Verify that queries involving geo:Feature return the correct result on a test dataset.

ABSTRACT TEST A.3

TEST-METHOD-TYPE Capabilities

REFERENCE Class/ geo

ABSTRACT TEST A.4

IDENTIFIER /conf/core/spatial-object-collection-class

REQUIREMENT Requirement 4: /req/core/spatial-object-collection-class

TEST PURPOSE Check conformance with this requirement

TEST METHOD Verify that queries involving geo:SpatialObjectCollection return the correct result on a test dataset.

TEST-METHOD-TYPE Capabilities

REFERENCE Class/ geo

ABSTRACT TEST A.5

IDENTIFIER /conf/core/feature-collection-class

REQUIREMENT Requirement 5: /req/core/feature-collection-class

TEST PURPOSE Check conformance with this requirement

TEST METHOD Verify that queries involving geo:FeatureCollection return the correct result on a test dataset.

TEST-METHOD-TYPE Capabilities

REFERENCE Class/ geo

ABSTRACT TEST A.6

IDENTIFIER /conf/core/spatial-object-properties

ABSTRACT TEST A.6

REQUIREMENT	Requirement 6: /req/core/spatial-object-properties
TEST PURPOSE	Check conformance with this requirement
TEST METHOD	Verify that queries involving these following properties return the correct result for a test dataset: geo:hasSize, geo:hasMetricSize, geo:hasLength, geo:hasMetricLength, geo:hasPerimeterLength, geo:hasMetricPerimeterLength, geo:hasArea, geo:hasMetricArea, geo:hasVolume and geo:hasMetricVolume
TEST-METHOD-TYPE	Capabilities
REFERENCE	Clause 8.3

A.2. Conformance Class: Topology Vocabulary Extension

CONFORMANCE CLASS A.2: TOPOLOGY VOCABULARY EXTENSION

IDENTIFIER	/conf/topology-vocab-extension
REQUIREMENTS CLASS	Requirements class 1: /req/topology-vocab-extension
CONFORMANCE TESTS	Abstract test A.7: /conf/topology-vocab-extension/sf-spatial-relations Abstract test A.8: /conf/topology-vocab-extension/eh-spatial-relations Abstract test A.9: /conf/topology-vocab-extension/rcc8-spatial-relations

A.2.1. Simple Features Relation Family

ABSTRACT TEST A.7

IDENTIFIER	/conf/topology-vocab-extension/sf-spatial-relations
REQUIREMENT	Requirement 8: /req/topology-vocab-extension/sf-spatial-relations
TEST PURPOSE	Check conformance with this requirement

ABSTRACT TEST A.7

TEST METHOD	Verify that queries involving the following properties return the correct result for a test dataset: geo:sfEquals, geo:sfDisjoint, geo:sfIntersects, geo:sfTouches, geo:sfCrosses, geo:sfWithin, geo:sfContains and geo:sfOverlaps
TEST-METHOD-TYPE	Capabilities
REFERENCE	Table 2

A.2.2. Egenhofer Relation Family

ABSTRACT TEST A.8

IDENTIFIER	/conf/topology-vocab-extension/eh-spatial-relations
REQUIREMENT	Requirement 9: /req/topology-vocab-extension/eh-spatial-relations
TEST PURPOSE	Check conformance with this requirement
TEST METHOD	Verify that queries involving the following properties return the correct result for a test dataset: geo:ehEquals, geo:ehDisjoint, geo:ehMeet, geo:ehOverlap, geo:ehCovers, geo:ehCoveredBy, geo:ehInside and geo:ehContains
TEST-METHOD-TYPE	Capabilities
REFERENCE	Table 3

A.2.3. RCC8 Relation Family

ABSTRACT TEST A.9

IDENTIFIER	/conf/topology-vocab-extension/rcc8-spatial-relations
REQUIREMENT	Requirement 10: /req/topology-vocab-extension/rcc8-spatial-relations
TEST PURPOSE	Check conformance with this requirement
TEST METHOD	Verify that queries involving the following properties return the correct result for a test dataset: geo:rcc8eq, geo:rcc8dc, geo:rcc8ec, geo:rcc8po, geo:rcc8tppi, geo:rcc8tpp, geo:rcc8ntpp, geo:rcc8ntppi

ABSTRACT TEST A.9

TEST-METHOD-
TYPE Capabilities

REFERENCE Table 4

A.3. Conformance Class: Geometry Extension

CONFORMANCE CLASS A.3: GEOMETRY EXTENSION

IDENTIFIER /conf/geometry-extension

SUBJECT Geometry

REQUIREMENTS CLASS Requirements class 2: /req/geometry-extension

Abstract test A.10: /conf/geometry-extension/geometry-class
Abstract test A.11: /conf/geometry-extension/geometry-collection-class
Abstract test A.12: /conf/geometry-extension/feature-properties
Abstract test A.13: /conf/geometry-extension/geometry-properties
Abstract test A.14: /conf/geometry-extension/query-functions
Abstract test A.15: /conf/geometry-extension/srid-function
Abstract test A.16: /conf/geometry-extension/sa-functions
Abstract test A.17: /conf/geometry-extension/wkt-literal
Abstract test A.18: /conf/geometry-extension/wkt-literal-default-srs
Abstract test A.19: /conf/geometry-extension/wkt-axis-order
Abstract test A.20: /conf/geometry-extension/wkt-literal-empty
Abstract test A.21: /conf/geometry-extension/geometry-as-wkt-literal
Abstract test A.22: /conf/geometry-extension/asWKT-function
Abstract test A.23: /conf/geometry-extension/gml-literal
Abstract test A.24: /conf/geometry-extension/gml-literal-empty
Abstract test A.25: /conf/geometry-extension/gml-profile
Abstract test A.26: /conf/geometry-extension/geometry-as-gml-literal
Abstract test A.27: /conf/geometry-extension/asGML-function
Abstract test A.28: /conf/geometry-extension/geojson-literal
Abstract test A.29: /conf/geometry-extension/geojson-literal-srs
Abstract test A.30: /conf/geometry-extension/geojson-literal-empty
Abstract test A.31: /conf/geometry-extension/geometry-as-geojson-literal
Abstract test A.32: /conf/geometry-extension/asGeoJSON-function
Abstract test A.33: /conf/geometry-extension/kml-literal
Abstract test A.34: /conf/geometry-extension/kml-literal-srs
Abstract test A.35: /conf/geometry-extension/kml-literal-empty

CONFORMANCE CLASS A.3: GEOMETRY EXTENSION

Abstract test A.36: /conf/geometry-extension/geometry-as-kml-literal

Abstract test A.37: /conf/geometry-extension/asKML-function

This Conformance Class applies to non-DGGS geometries. See
DGGS Conformance Class/ Geometry Extension – DGGS for DGGS geometries.

A.3.1. Tests for all Serializations except DGGS

ABSTRACT TEST A.10

IDENTIFIER	/conf/geometry-extension/geometry-class
REQUIREMENT	Requirement 12: /req/geometry-extension/geometry-class
TEST PURPOSE	Check conformance with this requirement
TEST METHOD	Verify that queries involving geo:Geometry return the correct result on a test dataset
TEST-METHOD-TYPE	Capabilities
REFERENCE	Class/ geo

ABSTRACT TEST A.11

IDENTIFIER	/conf/geometry-extension/geometry-collection-class
REQUIREMENT	Requirement 13: /req/geometry-extension/geometry-collection-class
TEST PURPOSE	Check conformance with this requirement
TEST METHOD	Verify that queries involving Geometry Collection return the correct result on a test dataset
TEST-METHOD-TYPE	Capabilities
REFERENCE	Class/ geo

ABSTRACT TEST A.12

IDENTIFIER	/conf/geometry-extension/feature-properties
REQUIREMENT	/req/geometry-extension/feature-properties
TEST PURPOSE	Check conformance with this requirement
TEST METHOD	Verify that queries involving the following properties return the correct result for a test dataset: geo:hasGeometry, geo:hasDefaultGeometry, geo:hasLength, geo:hasArea, geo:hasVolume geo: hasCentroid, geo:hasBoundingBox and geo:hasSpatialResolution
TEST-METHOD- TYPE	Capabilities
REFERENCE	Clause 8.4

ABSTRACT TEST A.13

IDENTIFIER	/conf/geometry-extension/geometry-properties
REQUIREMENT	Requirement 14: /req/geometry-extension/geometry-properties
TEST PURPOSE	Check conformance with this requirement
TEST METHOD	Verify that queries involving these properties return the correct result for a test dataset: geo: dimension, geo:coordinateDimension, geo:spatialDimension, geo:hasSpatialResolution, geo:has MetricSpatialResolution, geo:hasSpatialAccuracy, geo:hasMetricSpatialAccuracy, geo:isEmpty, geo:isSimple and geo:hasSerialization
TEST-METHOD- TYPE	Capabilities
REFERENCE	Clause 10.7

ABSTRACT TEST A.14

IDENTIFIER	/conf/geometry-extension/query-functions
REQUIREMENT	Requirement 44: /req/geometry-extension/query-functions
TEST PURPOSE	Check conformance with this requirement
TEST METHOD	Verify that a set of SPARQL queries involving each of the following functions returns the correct result for a test dataset when using the specified serialization and version: geof:boundary geof:

ABSTRACT TEST A.14

boundingCircle, geof:metricBuffer, geof:buffer, geof:centroid, geof:convexHull, geof:concaveHull, geof:coordinateDimension, geof:difference, geof:dimension, geof:metricDistance, geof:distance, geof:envelope, geof:geometryType, geof:intersection, geof:is3D, geof:isEmpty, geof:isMeasured, geof:isSimple, geof:spatialDimension, geof:symDifference, geof:transform and geof:union.

TEST-METHOD-TYPE	Capabilities reference: Clause 10.9
------------------	-------------------------------------

ABSTRACT TEST A.15

IDENTIFIER	/conf/geometry-extension/srid-function
REQUIREMENT	Requirement 46: /req/geometry-extension/srid-function
TEST PURPOSE	Check conformance with this requirement
TEST METHOD	Verify that a SPARQL query involving the get SRID function returns the correct result for a test dataset when using the specified serialization and version.
TEST-METHOD-TYPE	Capabilities
REFERENCE	Function/ geof

ABSTRACT TEST A.16

IDENTIFIER	/conf/geometry-extension/sa-functions
REQUIREMENT	Requirement 48: /req/geometry-extension/sa-functions
TEST PURPOSE	Check conformance with this requirement
TEST METHOD	Verify that a set of SPARQL queries involving each of the following functions returns the correct result for a test dataset: geof:aggBoundingBox, geof:aggBoundingCircle, geof:aggCentroid, geof:aggConcaveHull, geof:aggConvexHull and geof:aggUnion
TEST-METHOD-TYPE	Capabilities
REFERENCE	Clause 10.11

A.3.2. WKT Serialization

ABSTRACT TEST A.17

IDENTIFIER	/conf/geometry-extension/wkt-literal
REQUIREMENT	Requirement 15: /req/geometry-extension/wkt-literal
TEST PURPOSE	Check conformance with this requirement
TEST METHOD	Verify that queries involving WKT Literal values return the correct result for a test dataset.
TEST-METHOD-TYPE	Capabilities
REFERENCE	RDFS Datatype/ geo

ABSTRACT TEST A.18

IDENTIFIER	/conf/geometry-extension/wkt-literal-default-srs
REQUIREMENT	Requirement 16: /req/geometry-extension/wkt-literal-default-srs
TEST PURPOSE	Check conformance with this requirement
TEST METHOD	Verify that queries involving WKT Literal values without an explicit encoded SRS IRI return the correct result for a test dataset.
TEST-METHOD-TYPE	Capabilities
REFERENCE	Requirement 16: /req/geometry-extension/wkt-literal-default-srs

ABSTRACT TEST A.19

IDENTIFIER	/conf/geometry-extension/wkt-axis-order
REQUIREMENT	Requirement 17: /req/geometry-extension/wkt-axis-order
TEST PURPOSE	Check conformance with this requirement

ABSTRACT TEST A.19

TEST METHOD	Verify that queries involving WKT Literal values return the correct result for a test dataset.
TEST-METHOD-TYPE	Capabilities
REFERENCE	Requirement 17: /req/geometry-extension/wkt-axis-order

ABSTRACT TEST A.20

IDENTIFIER	/conf/geometry-extension/wkt-literal-empty
REQUIREMENT	Requirement 18: /req/geometry-extension/wkt-literal-empty
TEST PURPOSE	Check conformance with this requirement
TEST METHOD	Verify that queries involving empty WKT Literal values return the correct result for a test dataset.
TEST-METHOD-TYPE	Capabilities
REFERENCE	Requirement 18: /req/geometry-extension/wkt-literal-empty

ABSTRACT TEST A.21

IDENTIFIER	/conf/geometry-extension/geometry-as-wkt-literal
REQUIREMENT	Requirement 19: /req/geometry-extension/geometry-as-wkt-literal
TEST PURPOSE	Check conformance with this requirement
TEST METHOD	Verify that queries involving the geo:asWKT property return the correct result for a test dataset.
TEST-METHOD-TYPE	Capabilities
REFERENCE	Clause 10.8.1.2

ABSTRACT TEST A.22

IDENTIFIER	/conf/geometry-extension/asWKT-function
REQUIREMENT	Requirement 20: /req/geometry-extension/asWKT-function
TEST PURPOSE	Check conformance with this requirement
TEST METHOD	Verify that a set of SPARQL queries involving the geof:asWKT function returns the correct result for a test dataset when using the specified serialization and version.
TEST-METHOD-TYPE	Capabilities
REFERENCE	Function/ geof

A.3.3. GML Serialization

ABSTRACT TEST A.23

IDENTIFIER	/conf/geometry-extension/gml-literal
REQUIREMENT	Requirement 21: /req/geometry-extension/gml-literal
TEST PURPOSE	Check conformance with this requirement
TEST METHOD	Verify that queries involving geo:gmlLiteral values return the correct result for a test dataset.
TEST-METHOD-TYPE	Capabilities
REFERENCE	RDFS Datatype/ geo

ABSTRACT TEST A.24

IDENTIFIER	/conf/geometry-extension/gml-literal-empty
REQUIREMENT	Requirement 22: /req/geometry-extension/gml-literal-empty
TEST PURPOSE	Check conformance with this requirement
TEST METHOD	Verify that queries involving empty geo:gmlLiteral values return the correct result for a test dataset.

ABSTRACT TEST A.24

TEST-METHOD-TYPE	Capabilities
REFERENCE	Requirement 22: /req/geometry-extension/gml-literal-empty

ABSTRACT TEST A.25

IDENTIFIER	/conf/geometry-extension/gml-profile
REQUIREMENT	Requirement 23: /req/geometry-extension/gml-profile
TEST PURPOSE	Check conformance with this requirement
TEST METHOD	Examine the implementation's documentation to verify that the supported GML profiles are documented.
TEST-METHOD-TYPE	Capabilities
REFERENCE	Requirement 23: /req/geometry-extension/gml-profile

ABSTRACT TEST A.26

IDENTIFIER	/conf/geometry-extension/geometry-as-gml-literal
REQUIREMENT	Requirement 24: /req/geometry-extension/geometry-as-gml-literal
TEST PURPOSE	Check conformance with this requirement
TEST METHOD	Verify that queries involving the geo:asGML property return the correct result for a test dataset.
TEST-METHOD-TYPE	Capabilities
REFERENCE	Requirement 24: /req/geometry-extension/geometry-as-gml-literal

ABSTRACT TEST A.27

IDENTIFIER	/conf/geometry-extension/asGML-function
------------	---

ABSTRACT TEST A.27

REQUIREMENT	Requirement 25: /req/geometry-extension/asGML-function
TEST PURPOSE	Check conformance with this requirement
TEST METHOD	Verify that a set of SPARQL queries involving the geof:asGML function returns the correct result for a test dataset when using the specified serialization and version.
TEST-METHOD-TYPE	Capabilities
REFERENCE	Function/ geof

A.3.4. GeoJSON Serialization

ABSTRACT TEST A.28

IDENTIFIER	/conf/geometry-extension/geojson-literal
REQUIREMENT	Requirement 26: /req/geometry-extension/geojson-literal
TEST PURPOSE	Check conformance with this requirement
TEST METHOD	Verify that queries involving geo:geoJSONLiteral values return the correct result for a test dataset.
TEST-METHOD-TYPE	Capabilities
REFERENCE	RDFS Datatype/ geo

ABSTRACT TEST A.29

IDENTIFIER	/conf/geometry-extension/geojson-literal-srs
REQUIREMENT	Requirement 27: /req/geometry-extension/geojson-literal-srs
TEST PURPOSE	Check conformance with this requirement
TEST METHOD	Verify that queries involving geo:geoJSONLiteral values without an explicit encoded SRS IRI return the correct result for a test dataset.
TEST-METHOD-TYPE	Capabilities

ABSTRACT TEST A.29

REFERENCE	Requirement 27: /req/geometry-extension/geojson-literal-srs
-----------	---

ABSTRACT TEST A.30

IDENTIFIER	/conf/geometry-extension/geojson-literal-empty
REQUIREMENT	Requirement 28: /req/geometry-extension/geojson-literal-empty
TEST PURPOSE	Check conformance with this requirement
TEST METHOD	Verify that queries involving empty geo:geoJSONLiteral values return the correct result for a test dataset.
TEST-METHOD-TYPE	Capabilities
REFERENCE	Requirement 28: /req/geometry-extension/geojson-literal-empty

ABSTRACT TEST A.31

IDENTIFIER	/conf/geometry-extension/geometry-as-geojson-literal
REQUIREMENT	Requirement 29: /req/geometry-extension/geometry-as-geojson-literal
TEST PURPOSE	Check conformance with this requirement
TEST METHOD	Verify that queries involving the geo:asGeoJSON property return the correct result for a test dataset.
TEST-METHOD-TYPE	Capabilities
REFERENCE	Requirement 29: /req/geometry-extension/geometry-as-geojson-literal

ABSTRACT TEST A.32

IDENTIFIER	/conf/geometry-extension/asGeoJSON-function
REQUIREMENT	Requirement 30: /req/geometry-extension/asGeoJSON-function

ABSTRACT TEST A.32

TEST PURPOSE	Check conformance with this requirement
TEST METHOD	Verify that a set of SPARQL queries involving the geof:asGeoJSON function returns the correct result for a test dataset when using the specified serialization and version.
TEST-METHOD-TYPE	Capabilities
REFERENCE	Function/ geof

A.3.5. KML Serialization

ABSTRACT TEST A.33

IDENTIFIER	/conf/geometry-extension/kml-literal
REQUIREMENT	Requirement 31: /req/geometry-extension/kml-literal
TEST PURPOSE	Check conformance with this requirement
TEST METHOD	Verify that queries involving geo:kmlLiteral values return the correct result for a test dataset.
TEST-METHOD-TYPE	Capabilities
REFERENCE	RDFS Datatype/ geo

ABSTRACT TEST A.34

IDENTIFIER	/conf/geometry-extension/kml-literal-srs
REQUIREMENT	Requirement 32: /req/geometry-extension/kml-literal-srs
TEST PURPOSE	Check conformance with this requirement
TEST METHOD	Verify that queries involving geo:kmlLiteral values without an explicit encoded SRS IRI return the correct result for a test dataset.
TEST-METHOD-TYPE	Capabilities
REFERENCE	Requirement 32: /req/geometry-extension/kml-literal-srs

ABSTRACT TEST A.35

IDENTIFIER	/conf/geometry-extension/kml-literal-empty
REQUIREMENT	Requirement 33: /req/geometry-extension/kml-literal-empty
TEST PURPOSE	Check conformance with this requirement
TEST METHOD	Verify that queries involving empty geo:kmlLiteral values return the correct result for a test dataset.
TEST-METHOD-TYPE	Capabilities
REFERENCE	Requirement 33: /req/geometry-extension/kml-literal-empty

ABSTRACT TEST A.36

IDENTIFIER	/conf/geometry-extension/geometry-as-kml-literal
REQUIREMENT	Requirement 34: /req/geometry-extension/geometry-as-kml-literal
TEST PURPOSE	Check conformance with this requirement
TEST METHOD	Verify that queries involving the geo:asKML property return the correct result for a test dataset.
TEST-METHOD-TYPE	Capabilities
REFERENCE	Requirement 34: /req/geometry-extension/geometry-as-kml-literal

ABSTRACT TEST A.37

IDENTIFIER	/conf/geometry-extension/asKML-function
REQUIREMENT	Requirement 35: /req/geometry-extension/asKML-function
TEST PURPOSE	Check conformance with this requirement
TEST METHOD	Verify that a set of SPARQL queries involving the geof:asKML function returns the correct result for a test dataset when using the specified serialization and version.
TEST-METHOD-TYPE	Capabilities

ABSTRACT TEST A.37

REFERENCE Function/ geof

A.4. DGGS Conformance Class: Geometry Extension – DGGS

This conformance Class applies only to DGGS geometries. See Conformance Class/ Geometry Extension for other geometries.

CONFORMANCE CLASS A.4: GEOMETRY EXTENSION DGGS

IDENTIFIER /conf/geometry-extension-dggs

REQUIREMENTS CLASS Requirements class 3: /req/geometry-extension-dggs

Abstract test A.38: /conf/geometry-extension-dggs/query-functions
Abstract test A.39: /conf/geometry-extension-dggs/query-functions-non-sf
Abstract test A.40: /conf/geometry-extension-dggs/srid-function
Abstract test A.41: /conf/geometry-extension-dggs/sa-functions
Abstract test A.42: /conf/geometry-extension-dggs/dggs-literal
Abstract test A.43: /conf/geometry-extension-dggs/dggs-literal-empty
Abstract test A.44: /conf/geometry-extension-dggs/geometry-as-dggs-literal
Abstract test A.45: /conf/geometry-extension-dggs/asDGGS-function

A.4.1. Tests for DGGS Serializations

ABSTRACT TEST A.38

IDENTIFIER /conf/geometry-extension-dggs/query-functions

REQUIREMENT /req/geometry-extension-dggs/query-functions

TEST PURPOSE Check conformance with this requirement

TEST METHOD Verify that implementations support the functions of Requirement <http://www.opengis.net/spec/geosparql/1.1/req/geometry-extension/query-functions> for DGGS geometry literals as

ABSTRACT TEST A.38

SPARQL extension functions, in a manner which is consistent with definitions of these functions in Simple Features OGCSFACA ISO19125-1, for non-DGGS geometry literals.**test-method-type:: Capabilities**

ABSTRACT TEST A.39

IDENTIFIER /conf/geometry-extension-dggs/query-functions-non-sf

REQUIREMENT /req/geometry-extension-dggs/query-functions-non-sf

TEST PURPOSE Check conformance with this requirement

TEST METHOD Verify that implementations support the functions of Requirement <http://www.opengis.net/spec/geosparql/1.1/req/geometry-extension/query-functions-non-sf> for DGGS geometry literals as SPARQL extension functions which are defined in this standard, for non-DGGS geometry literals.

ABSTRACT TEST A.40

IDENTIFIER /conf/geometry-extension-dggs/srid-function

REQUIREMENT /req/geometry-extension-dggs/srid-function

TEST PURPOSE Check conformance with this requirement

TEST METHOD Verify that Implementations shall support geof:getSRID as a SPARQL extension function for DGGS geometry literals.

REFERENCE [_function_geofgetsrid]

ABSTRACT TEST A.41

IDENTIFIER /conf/geometry-extension-dggs/sa-functions

REQUIREMENT /req/geometry-extension-dggs/sa-functions

TEST PURPOSE Check conformance with this requirement

TEST METHOD Verify that implementations support the functions of Requirement A.3.1.8 /conf/geometry-extension/sa-functions as SPARQL extension functions which are defined in this standard, for DGGS geometry literals, in a manner which is consistent with definitions of these functions in Simple Features OGCSFACA ISO19125-1.

ABSTRACT TEST A.41

TEST-METHOD-TYPE	Capabilities
REFERENCE	[_spatial_aggregate_functions]

A.4.2. DGGS Serialization

ABSTRACT TEST A.42

IDENTIFIER	/conf/geometry-extension-dggs/dggs-literal
REQUIREMENT	Requirement 40: /req/geometry-extension-dggs/dggs-literal
TEST PURPOSE	Check conformance with this requirement
TEST METHOD	Verify that queries involving empty geo:dggsLiteral values return the correct result for a test dataset.
TEST-METHOD-TYPE	Capabilities
REFERENCE	RDFS Datatype/ geo

ABSTRACT TEST A.43

IDENTIFIER	/conf/geometry-extension-dggs/dggs-literal-empty
REQUIREMENT	Requirement 41: /req/geometry-extension-dggs/dggs-literal-empty
TEST PURPOSE	Check conformance with this requirement
TEST METHOD	Verify that queries involving empty geo:dggsLiteral values return the correct result for a test dataset.
TEST-METHOD-TYPE	Capabilities
REFERENCE	Requirement 41: /req/geometry-extension-dggs/dggs-literal-empty

ABSTRACT TEST A.44

IDENTIFIER	/conf/geometry-extension-dggs/geometry-as-dggs-literal
REQUIREMENT	Requirement 42: /req/geometry-extension-dggs/geometry-as-dggs-literal
TEST PURPOSE	Check conformance with this requirement
TEST METHOD	Verify that queries involving the geo:asDGGS property return the correct result for a test dataset.
TEST-METHOD-TYPE	Capabilities
REFERENCE	Requirement 42: /req/geometry-extension-dggs/geometry-as-dggs-literal

ABSTRACT TEST A.45

IDENTIFIER	/conf/geometry-extension-dggs/asDGGS-function
REQUIREMENT	Requirement 43: /req/geometry-extension-dggs/asDGGS-function
TEST PURPOSE	Check conformance with this requirement
TEST METHOD	Verify that a set of SPARQL queries involving the geof:asDGGS function returns the correct result for a test dataset when using the specified serialization and version.
TEST-METHOD-TYPE	Capabilities
REFERENCE	Function/ geof

A.5. Conformance Class: Geometry Topology Extension

CONFORMANCE CLASS A.5: GEOMETRY TOPOLOGY EXTENSION

IDENTIFIER	/conf/geometry-topology-extension
REQUIREMENTS CLASS	Requirements class 4: /req/geometry-topology-extension
CONFORMANCE TESTS	Abstract test A.46: /conf/geometry-topology-extension/relate-query-function

CONFORMANCE CLASS A.5: GEOMETRY TOPOLOGY EXTENSION

Abstract test A.47: /conf/geometry-topology-extension/sf-query-functions
Abstract test A.48: /conf/geometry-topology-extension/eh-query-functions
Abstract test A.49: /conf/geometry-topology-extension/rcc8-query-functions

A.5.1. Tests for all relation families

ABSTRACT TEST A.46

IDENTIFIER	/conf/geometry-topology-extension/relate-query-function
REQUIREMENT	Requirement 49: /req/geometry-topology-extension/relate-query-function
TEST PURPOSE	Check conformance with this requirement
TEST METHOD	Verify that a set of SPARQL queries involving the <code>geof:relate</code> function returns the correct result for a test dataset when using the specified serialization and version.
TEST-METHOD-TYPE	Capabilities
REFERENCE	Function/ geof

A.5.2. Simple Features Relation Family

ABSTRACT TEST A.47

IDENTIFIER	/conf/geometry-topology-extension/sf-query-functions
REQUIREMENT	Requirement 50: /req/geometry-topology-extension/sf-query-functions
TEST PURPOSE	Check conformance with this requirement
TEST METHOD	Verify that a set of SPARQL queries involving each of the following functions returns the correct result for a test dataset when using the specified serialization and version: <code>geof:sfEquals</code> , <code>geof:sfDisjoint</code> , <code>geof:sfIntersects</code> , <code>geof:sfTouches</code> , <code>geof:sfCrosses</code> , <code>geof:sfWithin</code> , <code>geof:sfContains</code> , <code>geof:sfOverlaps</code> .

ABSTRACT TEST A.47

TEST-METHOD-TYPE Capabilities

REFERENCE Clause 11.3

A.5.3. Egenhofer Relation Family

ABSTRACT TEST A.48

IDENTIFIER /conf/geometry-topology-extension/eh-query-functions

REQUIREMENT Requirement 51: /req/geometry-topology-extension/eh-query-functions

TEST PURPOSE Check conformance with this requirement

TEST METHOD Verify that a set of SPARQL queries involving each of the following functions returns the correct result for a test dataset when using the specified serialization and version: [geof:ehEquals](#), [geof:ehDisjoint](#), [geof:ehMeet](#), [geof:ehOverlap](#), [geof:ehCovers](#), [geof:ehCoveredBy](#), [geof:ehInside](#), [geof:ehContains](#).

TEST-METHOD-TYPE Capabilities

REFERENCE Clause 11.4

A.5.4. RCC8 Relation Family

ABSTRACT TEST A.49

IDENTIFIER /conf/geometry-topology-extension/rcc8-query-functions

REQUIREMENT Requirement 52: /req/geometry-topology-extension/rcc8-query-functions

TEST PURPOSE Check conformance with this requirement

TEST METHOD Verify that a set of SPARQL queries involving each of the following functions returns the correct result for a test dataset when using the specified serialization and version: [geof:rcc8eq](#), [geof:rcc8dc](#), [geof:rcc8ec](#), [geof:rcc8po](#), [geof:rcc8tppi](#), [geof:rcc8tpp](#), [geof:rcc8ntp](#), [geof:rcc8ntppi](#).

ABSTRACT TEST A.49

TEST-METHOD-TYPE Capabilities

REFERENCE Clause 11.5

A.6. Conformance Class: RDFS Entailment Extension

CONFORMANCE CLASS A.6: RDFS ENTAILMENT EXTENSION

IDENTIFIER /conf/rdfs-entailment-extension

REQUIREMENTS CLASS /req/rdfs-entailment-extension

CONFORMANCE TESTS Abstract test A.50: /conf/rdfs-entailment-extension/bgp-rdfs-ent
Abstract test A.51: /conf/rdfs-entailment-extension/wkt-geometry-types
Abstract test A.52: /conf/rdfs-entailment-extension/gml-geometry-types

A.6.1. Tests for all implementations

ABSTRACT TEST A.50

IDENTIFIER /conf/rdfs-entailment-extension/bgp-rdfs-ent

REQUIREMENT Requirement 54: /req/rdfs-entailment-extension/bgp-rdfs-ent

TEST PURPOSE Check conformance with this requirement

TEST METHOD Verify that a set of SPARQL queries involving entailed RDF triples returns the correct result for a test dataset using the specified serialization, version and relation_family.

TEST-METHOD-TYPE Capabilities

REFERENCE Clause 12

A.6.2. WKT Serialization

ABSTRACT TEST A.51

IDENTIFIER	/conf/rdfs-entailment-extension/wkt-geometry-types
REQUIREMENT	Requirement 55: /req/rdfs-entailment-extension/wkt-geometry-types
TEST PURPOSE	Check conformance with this requirement
TEST METHOD	Verify that a set of SPARQL queries involving WKT Geometry types returns the correct result for a test dataset using the specified version of Simple Features.
TEST-METHOD-TYPE	Capabilities
REFERENCE	Clause 12.3

A.6.3. GML Serialization

ABSTRACT TEST A.52

IDENTIFIER	/conf/rdfs-entailment-extension/gml-geometry-types
REQUIREMENT	Requirement 56: /req/rdfs-entailment-extension/gml-geometry-types
TEST PURPOSE	Check conformance with this requirement
TEST METHOD	Verify that a set of SPARQL queries involving GML Geometry types returns the correct result for a test dataset using the specified version of GML.
TEST-METHOD-TYPE	Capabilities
REFERENCE	Clause 12.4

A.7. Conformance Class: Query Rewrite Extension

CONFORMANCE CLASS A.7: QUERY REWRITE EXTENSION

IDENTIFIER	/conf/query-rewrite-extension
------------	-------------------------------

CONFORMANCE CLASS A.7: QUERY REWRITE EXTENSION

REQUIREMENTS CLASS	Requirements class 5: /req/query-rewrite-extension
CONFORMANCE TESTS	Abstract test A.53: /conf/query-rewrite-extension/sf-query-rewrite Abstract test A.54: /conf/query-rewrite-extension/eh-query-rewrite Abstract test A.55: /conf/query-rewrite-extension/rcc8-query-rewrite

A.7.1. Simple Features Relation Family

ABSTRACT TEST A.53

IDENTIFIER	/conf/query-rewrite-extension/sf-query-rewrite
REQUIREMENT	Requirement 57: /req/query-rewrite-extension/sf-query-rewrite
TEST PURPOSE	Check conformance with this requirement
TEST METHOD	Verify that queries involving the following query transformation rules return the correct result for a test dataset when using the specified serialization and version: <u>geor:sfEquals</u> , <u>geor:sfDisjoint</u> , <u>geor:sfIntersects</u> , <u>geor:sfTouches</u> , <u>geor:sfCrosses</u> , <u>geor:sfWithin</u> , <u>geor:sfContains</u> and <u>geor:sfOverlaps</u> .
TEST-METHOD-TYPE	Capabilities
REFERENCE	Clause 13.2

A.7.2. Egenhofer Relation Family

ABSTRACT TEST A.54

IDENTIFIER	/conf/query-rewrite-extension/eh-query-rewrite
REQUIREMENT	Requirement 58: /req/query-rewrite-extension/eh-query-rewrite
TEST PURPOSE	Check conformance with this requirement
TEST METHOD	Verify that queries involving the following query transformation rules return the correct result for a test dataset when using the specified serialization and version: <u>geor:ehEquals</u> , <u>geor:ehDisjoint</u> , <u>geor:ehMeet</u> , <u>geor:ehOverlap</u> , <u>geor:ehCovers</u> , <u>geor:ehCoveredBy</u> , <u>geor:ehInside</u> , <u>geor:ehContains</u> .

ABSTRACT TEST A.54

TEST-METHOD-TYPE Capabilities

REFERENCE Clause 13.3

A.7.3. RCC8 Relation Family

ABSTRACT TEST A.55

IDENTIFIER /conf/query-rewrite-extension/rcc8-query-rewrite

REQUIREMENT Requirement 59: /req/query-rewrite-extension/rcc8-query-rewrite

TEST PURPOSE Check conformance with this requirement

TEST METHOD Verify that queries involving the following query transformation rules return the correct result for a test dataset when using the specified serialization and version: [geor:rcc8eq](#), [geor:rcc8dc](#), [geor:rcc8ec](#), [geor:rcc8po](#), [geor:rcc8tppi](#), [geor:rcc8tpp](#), [geor:rcc8ntpp](#), [geor:rcc8ntppi](#).

TEST-METHOD-TYPE Capabilities

REFERENCE Clause 13.4



B

ANNEX B (NORMATIVE) FUNCTIONS SUMMARY

ANNEX B (NORMATIVE) FUNCTIONS SUMMARY

B.0. Overview

This annex summarizes all the functions defined in GeoSPARQL, providing descriptions of their parameters and return types.

The value `ogc:geomLiteral` indicates any one of the specific geometry serializations datatypes defined in this Specification, for example `geo:wktLiteral`.

The geometry subtypes — `Polygon`, `Point`, `CellList` etc. — are the *Simple Features specification* OGCSFACA ISO19125-1 or DGGS types, as implemented by the various geometry serialization specifications referenced here. See Annex C.1.2.4 for the individual specification references.

B.1. Functions Summary Table

Table B.1 – GeoSPARQL Functions Summary

Simple Features Functions				
Function	Input Datatypes	Input Subtypes	Output Datatype	Output Subtype
<code>sfContains</code>	2x <code>ogc:geomLiteral</code>	1x <code>Polygon</code> , 1x <code>Geometry</code>	xsd:boolean	
<code>sfCrosses</code>	2x <code>ogc:geomLiteral</code>	1x <code>Point</code> or <code>LineString</code> , 1 x <code>LineString</code> or <code>Polygon</code>	xsd:boolean	
<code>sfDisjoint</code>	2x <code>ogc:geomLiteral</code>	2x <code>Geometry</code>	xsd:boolean	
<code>sfEquals</code>	2x <code>ogc:geomLiteral</code>	2x <code>Geometry</code>	xsd:boolean	

sfIntersects	2x <code>ogc:geomLiteral</code>	2x <code>Polygon</code>	xsd:boolean
sfOverlaps	2x <code>ogc:geomLiteral</code>	2x <code>Point</code> or 2x <code>LineString</code> or 2x <code>Polygon</code>	xsd:boolean
sfTouches	2x <code>ogc:geomLiteral</code>	2x <code>Geometry</code> but not <code>Point</code>	xsd:boolean
sfWithin	2x <code>ogc:geomLiteral</code>	1x <code>Geometry</code> , 1x <code>Polygon</code>	xsd:boolean

Egenhofer Functions

Function	Input Datatypes	Input Subtypes	Output Datatype	Output Subtype
ehContains	2x <code>ogc:geomLiteral</code>	1x <code>Polygon</code> , 1x <code>Geometry</code>	xsd:boolean	
ehCoveredBy	2x <code>ogc:geomLiteral</code>	1x <code>Polygon</code> , 1x <code>Geometry</code>	xsd:boolean	
ehCovers	2x <code>ogc:geomLiteral</code>	1x <code>Polygon</code> , 1x <code>Geometry</code>	xsd:boolean	
ehDisjoint	2x <code>ogc:geomLiteral</code>	2x <code>Geometry</code>	xsd:boolean	
ehEquals	2x <code>ogc:geomLiteral</code>	2x <code>Geometry</code>	xsd:boolean	
ehMeet	2x <code>ogc:geomLiteral</code>	2x <code>Geometry</code> but not <code>Point</code>	xsd:boolean	
ehOverlap	2x <code>ogc:geomLiteral</code>	2x <code>Geometry</code>	xsd:boolean	
ehInside	2x <code>ogc:geomLiteral</code>	2x <code>Geometry</code>	xsd:boolean	

Region Connection Calculus Functions

Function	Input Datatypes	Input Subtypes	Output Datatype	Output Subtype
rcc8dcc	2x <code>ogc:geomLiteral</code>	2x <code>Polygon</code>	xsd:boolean	
rcc8ecc	2x <code>ogc:geomLiteral</code>	2x <code>Polygon</code>	xsd:boolean	
rcc8eq	2x <code>ogc:geomLiteral</code>	2x <code>Polygon</code>	xsd:boolean	
rcc8ntpp	2x <code>ogc:geomLiteral</code>	2x <code>Polygon</code>	xsd:boolean	
rcc8ntppi	2x <code>ogc:geomLiteral</code>	2x <code>Polygon</code>	xsd:boolean	
rcc8po	2x <code>ogc:geomLiteral</code>	2x <code>Polygon</code>	xsd:boolean	

rcc8tpp	2x <code>ogc:geomLiteral</code>	2x <code>Polygon</code>	<u><code>xsd:boolean</code></u>	
rcc8tpi	2x <code>ogc:geomLiteral</code>	2x <code>Polygon</code>	<u><code>xsd:boolean</code></u>	
Spatial Aggregate Functions				
Function	Input Datatypes	Input Subtypes	Output Datatype	Output Subtype
aggBoundingBox	1 or more <code>ogc:geomLiteral</code>		<code>ogc:geomLiteral</code>	square <code>Polygon</code> (not DGGS), <code>CellList</code> (DGGS)
aggBoundingCircle	1 or more <code>ogc:geomLiteral</code>		<code>ogc:geomLiteral</code>	<code>Polygon</code> (not DGGS), <code>CellList</code> (DGGS)
aggCentroid	1 or more <code>ogc:geomLiteral</code>		<code>ogc:geomLiteral</code>	<code>Point</code> (not DGGS), <code>Cell</code> (DGGS)
aggConcaveHull	1 or more <code>ogc:geomLiteral</code>		<code>ogc:geomLiteral</code>	<code>Polygon</code> (not DGGS), <code>CellList</code> (DGGS)
aggConvexHull	1 or more <code>ogc:geomLiteral</code>		<code>ogc:geomLiteral</code>	<code>Polygon</code> (not DGGS), <code>CellList</code> (DGGS)
aggUnion	1 or more <code>ogc:geomLiteral</code>		<code>ogc:geomLiteral</code>	<code>Polygon</code> (not DGGS), <code>CellList</code> (DGGS)
Non-topological Query Functions				
Function	Input Datatypes	Input Subtypes	Output Datatype	Output Subtype
metricArea	1x <code>ogc:geomLiteral</code>	<code>Polygon</code>	<u><code>xsd:double</code></u>	
area	1x <code>ogc:geomLiteral</code>	<code>Polygon</code>	<u><code>xsd:double</code></u>	
boundary	1x <code>ogc:geomLiteral</code>	<code>Geometry</code>	<code>ogc:geomLiteral</code>	<code>LineString</code> (not DGGS), <code>OrderedCellList</code> (DGGS)
buffer	1x <code>ogc:geomLiteral</code> , 1x <u><code>xsd:double</code></u> , 1x <u><code>xsd:anyURI</code></u>		<code>ogc:geomLiteral</code>	(Multi) <code>Polygon</code> (not DGGS), <code>CellList</code> (DGGS)
convexHull	1x <code>ogc:geomLiteral</code>	<code>Geometry</code>	<code>ogc:geomLiteral</code>	<code>LineString</code> (not DGGS)
coordinateDimension	1x <code>ogc:geomLiteral</code>	<code>Geometry</code>	<u><code>xsd:integer</code></u>	
difference	2x <code>ogc:geomLiteral</code>	2x <code>Geometry</code>	<code>ogc:geomLiteral</code>	(Multi) <code>Polygon</code> (not DGGS), <code>CellList</code> (DGGS)
easting	1x <code>ogc:geomLiteral</code>	<code>Point</code>	<u><code>xsd:double</code></u>	

dimension	1x ogc:geomLiteral	Geometry	xsd:double	
metricDistance	2x ogc:geomLiteral , 1x xsd:anyURI	2x Geometry	xsd:double	
distance	2x ogc:geomLiteral , 1x xsd:anyURI	2x Geometry	rdfs:Resource	
envelope	1x ogc:geomLiteral , 1x xsd:anyURI	Geometry	ogc:geomLiteral	(Multi)Polygon (not DGGS), CellList (DGGS)
geometryN	1x ogc:geomLiteral	GeometryCollection (not DGGS)	xsd:double	
geometryType	1x ogc:geomLiteral	Geometry	xsd:anyURI	
getSRID	1x ogc:geomLiteral	Geometry	xsd:anyURI	
intersection	2x ogc:geomLiteral	2x Geometry	ogc:geomLiteral	Polygon (not DGGS), CellList (DGGS)
is3D	1x ogc:geomLiteral	Geometry	xsd:boolean	
isEmpty	1x ogc:geomLiteral	Geometry	xsd:boolean	
isMeasured	1x ogc:geomLiteral	Geometry	xsd:boolean	
isSimple	1x ogc:geomLiteral	Geometry	xsd:boolean	
metricLength	1x ogc:geomLiteral	Geometry	xsd:double	
length	1x ogc:geomLiteral	Geometry	rdfs:Resource	
numGeometries	1x ogc:geomLiteral	Geometry (not DGGS)	xsd:double	
northing	1x ogc:geomLiteral	Point	xsd:double	
metricPerimeter	1x ogc:geomLiteral	Geometry	xsd:double	
perimeter	1x ogc:geomLiteral	Geometry	rdfs:Resource	
spatialDimension	1x ogc:geomLiteral	Geometry	xsd:integer	
symDifference	2x ogc:geomLiteral	2x Geometry	ogc:geomLiteral	(Multi)Polygon (not DGGS), CellList (DGGS)
transform	1x ogc:geomLiteral , 1x xsd:anyURI	Geometry	ogc:geomLiteral	Geometry

union	2x <code>ogc:geomLiteral</code>	2x <code>Geometry</code>	<code>ogc:geomLiteral</code>	Polygon (not DGGS), CellList (DGGS)
Non-topological Query Functions — 3D Extension				
Function	Input Datatypes	Input Subtypes	Output Datatype	Output Subtype
extrude	2x <code>ogc:geomLiteral</code>	1x <code>Polygon</code> , 1 x <code>LineString</code>	<code>geo:Feature</code>	
extrudeToHeight	1x <code>ogc:geomLiteral</code> , 1x <u><code>xsd:double</code></u>	1x <code>Polygon</code>	<code>geo:Feature</code>	
extrudeInTime	2x <code>ogc:geomLiteral</code> , 2x <u><code>xsd:dateTime</code></u>	1x <code>Polygon</code> , 1 x <code>LineString</code>	<code>geo:Feature</code>	
Serialization Functions				
Function	Input Datatypes	Input Subtypes	Output Datatype	Output Subtype
asDGGS	1x <code>ogc:geomLiteral</code>	<code>Geometry</code>	<code>geo:dggsLiteral</code>	
asGeoJSON	1x <code>ogc:geomLiteral</code>	<code>Geometry</code>	<code>geo:geoJSONLiteral</code>	
asGML	1x <code>ogc:geomLiteral</code> , 1x <u><code>xsd:string</code></u>	<code>Geometry</code>	<code>geo:gmlLiteral</code>	
asGeoCode	1x <code>ogc:geomLiteral</code>	<code>Geometry</code>	<code>geo:geocodeLiteral</code>	
asKML	1x <code>ogc:geomLiteral</code>	<code>Geometry</code>	<code>geo:kmlLiteral</code>	
asWKT	1x <code>ogc:geomLiteral</code>	<code>Geometry</code>	<code>geo:wktLiteral</code>	
Extent Functions				
Function	Input Datatypes	Input Subtypes	Output Datatype	Output Subtype
getSRID	1x <code>ogc:geomLiteral</code>	<code>Geometry</code>	<u><code>xsd:anyURI</code></u>	
maxX	1x <code>ogc:geomLiteral</code>	<code>Geometry</code>	<u><code>xsd:double</code></u>	
maxY	1x <code>ogc:geomLiteral</code>	<code>Geometry</code>	<u><code>xsd:double</code></u>	
maxZ	1x <code>ogc:geomLiteral</code>	<code>Geometry</code>	<u><code>xsd:double</code></u>	
minX	1x <code>ogc:geomLiteral</code>	<code>Geometry</code>	<u><code>xsd:double</code></u>	
minY	1x <code>ogc:geomLiteral</code>	<code>Geometry</code>	<u><code>xsd:double</code></u>	

minZ	1x <code>ogc:geomLiteral</code>	Geometry	<u>xsd:double</u>	
Other Functions				
Function	Input Datatypes	Input Subtypes	Output Datatype	Output Subtype
relate	2x <code>ogc:geomLiteral</code>		<u>xsd:string</u>	

B.2. GeoSPARQL to SFA Functions Mapping

The following table indicates which GeoSPARQL non-topological query functions map to Simple Features Access (OGCSFACA ISO19125-1) functions and in which GeoSPARQL version the functions are defined.

Where the Simple Features Access function has the same name as the GeoSPARQL function, 'x' is recorded.

Table B.2 – GeoSPARQL To SFA Mappings

GEOSPARQL FUNCTION	IN 1.0	IN 1.1	SFA
metricArea		x	Area
area		x	Area
			AsBinary
asWKT*	x	x	AsText
boundary	x	x	Boundary
buffer	x	x	Buffer
			Centroid
convexHull	x	x	ConvexHull
coordinateDimension		x	
difference	x	x	Difference

GEOSPARQL FUNCTION	IN 1.0	IN 1.1	SFA
dimension		x	Dimension
metricDistance		x	Distance
distance	x	x	Distance
			EndPoint
envelope	x	x	Envelope
geometryN		x	GeometryN
geometryType		x	GeometryType
getSRID	x	x	SRID
			InteriorRingN
intersection	x	x	Intersection
is3D		x	
			IsClosed
isEmpty		x	IsEmpty
isMeasured		x	
			IsRing
isSimple		x	IsSimple
metricLength		x	Length
length		x	Length
maxX		x	
maxY		x	
maxZ		x	

GEOSPARQL FUNCTION	IN 1.0	IN 1.1	SFA
minX		x	
minY		x	
minZ		x	
numGeometries		x	NumGeometries
			NumInteriorRing
			NumPoints
perimeterLength		x	
perimeter		x	
			PointN
			PointOnSurface
spatialDimension		x	
			StartPoint
symDifference	x	x	SymDifference
transform		x	
union	x	x	Union
			X
			Y

* GeoSPARQL's asWKT is only a partial implementation of asText since asWKT only returns WKT, not textual geometry literal data in general.

C

ANNEX C (INFORMATIVE) GEOSPARQL EXAMPLES

ANNEX C (INFORMATIVE) GEOSPARQL EXAMPLES

C.0. Overview

This Annex provides examples of the GeoSPARQL ontology and functions. In addition to these, extended examples are provided separately by the GeoSPARQL 1.1 profile. See the Clause 7.3 for the link to those examples.

C.1. RDF Examples

This Section illustrates GeoSPARQL ontology modelling with extended examples.

C.1.1. Classes

C.1.1.1. **SpatialObject**

The SpatialObject class is defined in Class/ geo.

C.1.1.1.1. Basic use

Basic use (as per the example in the class definition)

```
eg:x
  a geo:SpatialObject ;
    skos:prefLabel "Object X";
  .
```

NOTE: It is unlikely that users of GeoSPARQL will create many instances of geo:SpatialObject as its two more concrete subclasses, geo:Feature & geo:Geometry, are more directly relatable to real-world phenomena and use.

C.1.1.2. Size Properties

The “size” properties – geo:hasSize, geo:hasMetricSize, geo:hasLength, geo:hasMetricLength, geo:hasPerimeterLength, geo:hasMetricPerimeterLength, geo:hasArea, geo:hasMetricArea, geo:hasVolume and geo:hasMetricVolume – are all applicable to instances of geo:SpatialObject although, as per the note in the section above, they are likely to be used with geo:Feature & geo:Geometry instances.

```
@prefix qudt: <http://qudt.org/schema/qudt/> .  
@prefix unit: <http://qudt.org/vocab/unit/> .  
  
eg:moreton-island  
    a geo:SpatialObject ;  
  
    skos:prefLabel "Moreton Island" ;  
    rdfs:seeAlso "https://en.wikipedia.org/wiki/Moreton_Island"^^xsd:anyURI ;  
  
    geo:hasPerimeterLength [  
        qudt:numericValue "92.367"^^xsd:float ;  
        qudt:unit unit:KiloM ;  
    ];  
    geo:hasMetricPerimeterLength "92367"^^xsd:double ;  
.
```

Here a spatial object, Moreton Island, has the distance of its coastline given with two properties: geo:hasPerimeterLength & geo:hasMetricPerimeterLength. The object for the first is a Blank Node with a QUDT value property of 92.367 and a QUDT unit property of unit:KiloM (kilometre). The object for the second is the literal 92367 (a double) which is, by the property's definition, a number of metres.

The use of the *Quantities, Units, Dimensions and Types (QUDT)* ontology⁹ and its qudt:numericValue & qudt:unit is just one of many possible ways to convey the value of geo:hasPerimeterLength and any subproperty of geo:hasSize.

C.1.1.2. Feature

The Feature class is defined in Class/ geo.

C.1.1.2.1. Basic use

```
eg:x  
    a geo:Feature ;  
    skos:prefLabel "Feature X" ;  
.
```

Here a Feature is declared and given a preferred label.

C.1.1.2.2. A Feature related to a Geometry and a GeometryCollection

```
eg:x
```

```

a geo:Feature ;
skos:prefLabel "Feature X" ;
geo:hasGeometry [
    geo:asWKT "MULTIPOLYGON (((149.06016 -35.23610, 149.06062 -35.23604, ...
, 149.06016 -35.23610)))"^^geo:wktLiteral ;
] ;
.
```

Here a geo:Feature is declared, given a preferred label and a Geometry for that geo:Feature is indicated with the use of geo:hasGeometry. The Geometry indicated is described using a *Well-Known Text* literal value, indicated by the property geo:asWKT and the literal type geo:wktLiteral.

```

eg:x
a geo:Feature ;
skos:prefLabel "Feature X" ;
geo:hasGeometry [
    a geo:GeometryCollection ;
    rdfs:member [
        geo:asWKT "POLYGON ((149.06016 -35.23610, 149.06062 -35.23604, ... ,
149.06016 -35.23610))"^^geo:wktLiteral ;
    ] ,
    [
        geo:asWKT "POINT (149.061 -35.23607)"^^geo:wktLiteral ;
    ] ;
]
```

Here a geo:Feature is declared and linked to a geo:GeometryCollection in order to bundle multiple `geo:Geometry instances together. Using this mechanism, you could add additional properties to the geo:GeometryCollection to detail useful things about the set of Geometries. This is an alternative to the pattern given in `Feature example below.

C.1.1.2.3. Feature with Geometry and size (area)

```

eg:x
a geo:Feature ;
skos:prefLabel "Feature X" ;
geo:hasGeometry [
    geo:asWKT "MULTIPOLYGON (((149.06016 -35.23610, 149.06062 -35.23604,
... , 149.06016 -35.23610)))"^^geo:wktLiteral ;
] ;
geo:hasMetricArea "8.9E4"^^xsd:double ;
.
```

This example and the example below (B 1.1.2.4) show the same geo:Feature, but with a different specification of its area. This example shows the recommended way to express size: by using a subproperty of geo:hasMetricSize (in this case, Property/ geo). These subproperties have fixed units based on meter (the unit of distance in the International System of Units).

C.1.1.2.4. Feature with Geometry and non-metric size

```
@prefix qudt: <http://qudt.org/schema/qudt/> .
```

```

eg:x
a geo:Feature ;
skos:prefLabel "Feature X";
```

```

    geo:hasGeometry [
        geo:asWKT "MULTIPOLYGON (((149.06016 -35.23610, 149.06062 -35.23604,
... , 149.06016 -35.23610)))"^^geo:wktLiteral ;
    ] ;
    geo:hasArea [
        qudt:numericValue "2.2E5"^^xsd:double ;
        qudt:unit <http://qudt.org/vocab/unit/AC> ; # international acre
    ] ;
.

```

Here a geo:Feature is described as per the previous example but its area is expressed in non-metric units: the acre.

C.1.1.2.5. Feature with two different Geometry instances indicated

```

eg:x
  a geo:Feature ;
  skos:prefLabel "Feature X";
  geo:hasGeometry [
      rdfs:label "Official boundary" ;
      rdfs:comment "Official boundary from the Department of Xxx" ;
      geo:asWKT "MULTIPOLYGON (((149.06016 -35.23610, 149.06062 -35.23604, ...
, 149.06016 -35.23610)))"^^geo:wktLiteral ;
  ] ,
  [
      rdfs:label "Unofficial boundary" ;
      rdfs:comment "Unofficial boundary as actually used by everyone" ;
      geo:asWKT "MULTIPOLYGON (((149.06016 -35.23610, 149.06062 -35.23604, ...
, 149.06016 -35.23610)))"^^geo:wktLiteral ;
  ] ;
.

```

In this example, Feature X has two different Geometry instances indicated with their difference explained in annotation properties. No GeoSPARQL ontology properties are used to indicate a difference in these Geometry instances thus machine use of this Feature would not be easily able to differentiate them.

C.1.1.2.6. Feature with two different Geometry instances with different property values

```

eg:x
  a geo:Feature ;
  skos:prefLabel "Feature X";
  geo:hasGeometry [
      geo:hasMetricSpatialResolution "100"^^xsd:double ;
      geo:asWKT "MULTIPOLYGON (((149.0601 -35.2361, 149.0606 -35.2360, ...
, 149.0601 -35.2361)))"^^geo:wktLiteral ;
  ] ,
  [
      geo:hasMetricSpatialResolution "5"^^xsd:double ;
      geo:asWKT "MULTIPOLYGON (((149.06016 -35.23610, 149.06062 -35.23604, ...
, 149.06016 -35.23610)))"^^geo:wktLiteral ;
  ] ;
.

```

In this example, Feature X has two different Geometry instances indicated with different spatial resolutions. Machine use of this Feature would be able to differentiate the two Geometry instances based on this use of geo:hasMetricSpatialResolution.

C.1.1.2.7. Feature with non-metric size

```
@prefix dbp: <http://dbpedia.org/resource/> .  
@prefix qudt: <http://qudt.org/schema/qudt/> .  
  
ex:Seleucia_Artemita  
    a geo:Feature ;  
    skos:prefLabel "The route from Seleucia to Artemita"@en ;  
    geo:hasLength [  
        qudt:unit ex:Schoenus ;  
        qudt:value "15"^^xsd:integer ;  
    ]  
.  
ex:Schoenus  
    a qudt:Unit ;  
    skos:exactMatch dbp:Schoenus ;  
.
```

In this example it is not possible to convert the length of the feature to meters, because the historical length unit does not have a known precise conversion factor.

C.1.1.2.8. Feature with two different types of Geometry instances

```
eg:x  
    a geo:Feature ;  
    skos:prefLabel "Feature X" ;  
    geo:hasGeometry [  
        geo:asWKT "POLYGON ((149.06016 -35.23610, 149.060620 -35.236043, ... ,  
        149.06016 -35.23610))"^^geo:wktLiteral ;  
    ] ;  
    geo:hasCentroid [  
        geo:asWKT "POINT (149.06017784 -35.23612321)"^^geo:WktLiteral ;  
    ] ;  
.
```

Here a Feature instance has two geometries, one indicated with the general property hasGeometry and a second indicated with the specialized property hasCentroid which suggests the role that the indicated geometry plays. Note that while hasGeometry may indicate any type of Geometry, hasCentroid should only be used to indicate a point geometry. It may be informally inferred that the polygonal geometry is the Feature instance's boundary.

C.1.1.2.9. Feature with multiple sizes

```
ex:lake-x  
    a geo:Feature ;  
    skos:prefLabel "Lake X" ;  
    eg:hasFeatureCategory <http://example.com/cat/lake> ;  
    geo:hasMetricArea "9.26E4"^^xsd:double ;  
    geo:hasMetricVolume "6E5"^^xsd:double ;  
.
```

This example shows a Feature instance with area and volume declared. A categorization of the Feature is given through the use of the eg:hasFeatureCategory dummy property which, along

with the Feature's preferred label, indicate that this Feature is a lake. Having both an area and a volume makes sense for a lake.

C.1.1.3. Geometry

The Geometry class is defined in Class/ geo.

C.1.1.3.1. Basic Use

```
eg:y a geo:Geometry ;
    skos:prefLabel "Geometry Y";
```

Here a Geometry is declared and given a preferred label.

From GeoSPARQL 1.0 use, the most commonly observed use of a Geometry is in relation to a Feature as per the first example in Annex C.1.1.1.1 and often the Geometry instance's class type is indirectly declared by the use of hasGeometry on the Feature instance indicating a Blank Node, given the range value for hasGeometry. However, it is entirely possible to declare Geometry instances without any Feature instances. The next basic example declares a Geometry instance with an absolute URI and data.

```
<https://example.com/geometry/y>
  a geo:Geometry ;
  skos:prefLabel "Geometry Y";
  geo:asWKT "MULTIPOLYGON (((149.06016 -35.23610, 149.060620 -35.236043, ... ,
149.06016 -35.23610)))"^^geo:wktLiteral ;
```

Here the Geometry instance has data in WKT form and, since no CRS is declared, WGS84 is the assumed, default, CRS. This Geometry might have been declared with a named nod, i.e. not with a Blank Node, so that it can be referred to from multiple Features.

C.1.1.3.2. A Geometry with multiple serializations

```
eg:x
  a geo:Feature ;
  skos:prefLabel "Feature X";
  geo:hasGeometry [
    geo:asWKT "<http://www.opengis.net/def/crs/EPSG/0/4326>
MULTIPOLYGON (((-35.23610 149.06016, -35.236043 149.060620, ... , -35.23610
149.06016)))"^^geo:wktLiteral ;
    geo:asDGGS "<https://w3id.org/dggs/auspix> CELLLIST ((R1234 R1235 R1236 .
... R1256))"^^geo:dggsLiteral ;
  ] ;
```

Here a single Geometry, linked to a Feature instance, is expressed using two different serializations: Well-known Text and the DGGS with the AusPIX DGGS indicated by its IRI.

C.1.1.3.3. Geometry with scalar spatial property

```
eg:x
  a geo:Feature ;
  skos:prefLabel "Feature X";
  geo:hasGeometry eg:x-geo ;
.

eg:x-geo
  a geo:Geometry ;
  geo:asWKT "MULTIPOLYGON (((149.06016 -35.23610, 149.060620 -35.236043, ... ,
149.06016 -35.23610)))"^^geo:wktLiteral ;
  geo:hasMetricArea "8.7E4"^^xsd:double;
.
```

This example shows a Feature, eg:x, with a Geometry, eg:x-geo, which has both a serialization (WKT) indicated with the predicate geo:asWKT and a scalar area indicated with the predicate geo:hasMetricArea. While it is entirely possible that scalar areas can be calculated from polygons, it may be efficient to store a pre-calculated scalar area in addition to the polygon. Perhaps the polygon is large and detailed and a one-time calculation with results stored is efficient for repeated use.

This use of a scalar spatial measurement property with a Geometry, here geo:hasMetricArea, is possible since the domain of such properties is geo:SpatialObject, the superclass of both geo:Feature and geo:Geometry.

C.1.1.4. SpatialObjectCollection

geo:SpatialObjectCollection isn't really intended to be implemented — it's essentially an abstract class — therefore no examples of its use are given. See the following two sections for examples of the concrete geo:FeatureCollection & geo:GeometryCollection classes.

C.1.1.5. FeatureCollection

This example shows a FeatureCollection instance containing 3 Feature instances and a hasBoundingBox predicate instance indicating a Geometry — the bounding box of all the Features within the Feature Collection.

```
ex:fc-x
  a geo:FeatureCollection ;
  dcterms:title "Feature Collection X" ;
  rdfs:member
    ex:feature-something ,
    ex:feature-other ,
    ex:feature-another ;
  geo:hasBoundingBox [
    geo:asWKT "<http://www.opengis.net/def/crs/EPSG/0/4326> POLYGON ((-
35.236 149.060, ... , -35.236 149.060))"^^geo:wktLiteral ;
  ] ;
.
```

All the GeoSPARQL collection classes are unordered since they are subclasses of the generic [rdfs:Container](#), however implementers should consider that there are many ways to order the members of a FeatureCollection such as the Feature instance labels, their areas, geometries or any other property.

C.1.1.6. GeometryCollection

This example shows a GeometryCollection instance containing 3 Geometry instances.

```
ex:gc-x
  a geo:GeometryCollection ;
  dcterms:title "Geometry Collection X" ;
  rdfs:member
    ex:geometry-shape ,
    ex:geometry-othershape ,
    ex:geometry-anothershape ;
.
```

As per FeatureCollection, the GeometryCollection itself doesn't impose any ordering on its member Geometry instances, however there are many ways to order them, based on their own properties.

C.1.1.7. Simple Features classes

Most of the geometry serializations used in GeoSPARQL define the geometry type – point, polygon etc. *within* the literal, e.g. WKT can encode POLYGON(()) or 'POINT()', however the *Simple Features Vocabulary* resource within GeoSPARQL 1.1 contains specialised Geometry RDF classes such as [sf:Polygon](#), [sf:PolyhedralSurface](#) and others.

It may be appropriate to use these specialized forms of Geometry in circumstances when geometry type differentiation is required within RDF and not withing specialized literal handling. This is the case when type differentiation must occur within plain SPARQL, not GeoSPARQL.

The following example shows a Feature instance with two Geometry instances where the *Simple Features Vocabulary* classes are used to indicate the Geometry type:

```
ex:x
  a geo:Feature ;
  rdfs:label "Feature X" ;
  geo:hasGeometry [
    a sf:Point ;
    geo:asWKT "POINT(...)" ;
    rdfs:comment "A point geometry for Feature X, possibly a centroid though
not declared one" ;
  ] ;
  geo:hasGeometry [
    a sf:Polygon ;
    geo:asWKT "POLYGON((...))" ;
    rdfs:comment "A polygon geometry for Feature X" ;
  ] ;
```

There are several GeoSPARQL properties that suggest they could be used with particular *Simple Features Vocabulary* geometry types, for instance, geo:hasCentroid indicates it could be used with a `sf:Point` and geo:hasBoundingBox indicates use with an `sf:Envelope`.

C.1.2. Properties

C.1.2.1. Spatial Object Properties

See the section Annex C.1.1.1.1 above.

C.1.2.2. Feature Properties

This example shows a geo:Feature instance with each of the properties defined in Clause 8.4 used, except for the properties geo:hasMetricSize and geo:hasSize, that are intended to be used through their subproperties and geo:hasMetricPerimeterLength and geo:hasPerimeterLength which are exemplified in Annex C.1.1.1.2.

```
@prefix qudt: <http://qudt.org/schema/qudt/> .  
  
eg:x  
  a geo:Feature ;  
  skos:preferredLabel "Feature X" ;  
  geo:hasGeometry [  
    geo:asWKT "<http://www.opengis.net/def/crs/EPSG/0/4326> POLYGON ((-35.23610 149.06016, ... , -35.23610 149.06016))"^^geo:wktLiteral ;  
  ] ;  
  geo:hasDefaultGeometry [  
    geo:asWKT "<http://www.opengis.net/def/crs/EPSG/0/4326> POLYGON ((-35.2361 149.0601, ... , -35.2361 149.0601))"^^geo:wktLiteral ;  
  ] ;  
  geo:hasMetricLength "355"^^xsd:double ;  
  geo:hasLength [  
    qudt:numericValue 355 ;  
    qudt:unit <http://qudt.org/vocab/unit/M> ; # meter  
  ] ;  
  geo:hasMetricArea "8.7E4"^^xsd:double ;  
  geo:hasArea [  
    qudt:numericValue 8.7 ;  
    qudt:unit <http://qudt.org/vocab/unit/HA> ; # hectare  
  ] ;  
  geo:hasMetricVolume "624432"^^xsd:double ;  
  geo:hasVolume [  
    qudt:numericValue 624432 ;  
    qudt:unit <http://qudt.org/vocab/unit/M3> ; # cubic meter  
  ] ;  
  geo:hasCentroid [  
    geo:asWKT "POINT (149.06017 -35.23612)"^^geo:wktLiteral ;  
  ] ;  
  geo:hasBoundingBox [  
    geo:asWKT "<http://www.opengis.net/def/crs/EPSG/0/4326> POLYGON ((149.060 -35.236, ... , 149.060 -35.236))"^^geo:wktLiteral ;  
  ] ;  
  geo:hasMetricSpatialResolution "5"^^xsd:double ;  
  geo:hasSpatialResolution [
```

```

    qudt:numericValue 5 ;
    qudt:unit <http://qudt.org/vocab/unit/M> ; # meter
] ;
.
```

The properties defined for this example's Feature instance are vaguely aligned in that the values are not real but are not unrealistic either. It is outside the scope of GeoSPARQL to validate Feature instances' property values.

Note that this Feature has a 2D Geometry and yet a property indicating a scalar volume: geo:hasVolume. Used in this way, the scalar property is indicating information that cannot be calculated from other information about the Feature such as its geometry. Perhaps a volume for the feature has been estimated or measured in such a way that a 3D geometry was not created.

C.1.2.3. Geometry Properties

This example shows a Geometry instance, a Blank Node, declared in relation to a Feature instance, with each of the properties defined in Clause 10.7 used.

```

@prefix qudt: <http://qudt.org/schema/qudt/> .
@prefix unit: <http://qudt.org/vocab/unit/> .

eg:x
  a geo:Feature ;
  geo:hasGeometry [
    skos:prefLabel "Geometry Y" ;
    geo:dimension 2 ;
    geo:coordinateDimension 2 ;
    geo:spatialDimension 2 ;
    geo:isEmpty false ;
    geo:isSimple true ;
    geo:hasSerialization "<http://www.opengis.net/def/crs/EPSG/0/4326>
POLYGON ((-35.236 149.060, ... , -35.236 149.060))"^^geo:wktLiteral ;
    geo:hasSpatialAccuracy [
      qudt:numericValue "30"^^xsd:float ;
      qudt:unit unit:CentiM ; # centimetres
    ] ;
    geo:hasMetricSpatialAccuracy "0.3"^^xsd:double ;
  ] ;
.
```

In this example, each of the properties defined for a Geometry instance has realistic values. For example, the isEmpty property is set to false since the Geometry contains information.

C.1.2.4. Geometry Serializations

C.1.2.5. Literals

This example shows a Geometry instance for a Feature instance which is represented in all supported literal GeoSPARQL serializations. The geometry values given are real geometry values and approximate Moreton Island in Queensland, Australia.

Note that the concrete DGGS serialization used is for example purposes only as it is not formally defined in GeoSPARQL.

```
eg:x
  a geo:Feature ;
  geo:hasGeometry [
    geo:asWKT """<http://www.opengis.net/def/crs/EPSG/0/4326>
      POLYGON (( -27.0621757 153.3610112,
                  -27.1990606 153.3658177,
                  -27.3406573 153.421436,
                  -27.3607835 153.4269292,
                  -27.3315078 153.4434087,
                  -27.2913403 153.4183848,
                  -27.2039578 153.4189391,
                  -27.0267166 153.4673476,
                  -27.0621757 153.3610112
                ))""""^^geo:wktLiteral ;

    geo:asGML """<gml:Polygon
      srsName="http://www.opengis.net/def/crs/EPSG/0/4326">
        <gml:exterior>
          <gml:LinearRing>
            <gml:posList>
              -27.0621757 153.3610112
              -27.1990606 153.3658177
              -27.3406573 153.421436
              -27.3607835 153.4269292
              -27.3315078 153.4434087
              -27.2913403 153.4183848
              -27.2039578 153.4189391
              -27.0267166 153.4673476
              -27.0621757 153.3610112
            </gml:posList>
          </gml:LinearRing>
        </gml:exterior>
      </gml:Polygon>""""^^go:gmlLiteral ;

    geo:asKML """<Polygon>
      <outerBoundaryIs>
        <LinearRing>
          <coordinates>
            153.3610112,-27.0621757
            153.3658177,-27.1990606
            153.421436,-27.3406573
            153.4269292,-27.3607835
            153.4434087,-27.3315078
            153.4183848,-27.2913403
            153.4189391,-27.2039578
            153.4673476,-27.0267166
            153.3610112,-27.0621757
          </coordinates>
        </LinearRing>
      </outerBoundaryIs>
    </Polygon>""""^^go:kmlLiteral ;

    geo:asGeoJSON """
      "type": "Polygon",
      "coordinates": [
        [153.3610112, -27.0621757],
        [153.3658177, -27.1990606],
        [153.421436, -27.3406573],
        [153.4269292, -27.3607835],
```

```

        [153.4434087, -27.3315078],
        [153.4183848, -27.2913403],
        [153.4189391, -27.2039578],
        [153.4673476, -27.0267166],
        [153.3610112, -27.0621757]
    ]
}""^geo:geoJSONLiteral ;

geo:asDGGS """<https://w3id.org/dggs/auspix> CELLLIST ((R8346031
R8346034 R8346037
R83460058 R83460065 R83460068 R83460072 R83460073 R83460074
R83460075 R83460076
R83460077 R83460078 R83460080 R83460081 R83460082 R83460083
R83460084 R83460085
R83460086 R83460087 R83460088 R83460302 R83460305 R83460308
R83460320 R83460321
R83460323 R83460324 R83460326 R83460327 R83460332 R83460335
R83460338 R83460350
R83460353 R83460356 R83460362 R83460365 R83460380 R83460610
R83460611 R83460612
R83460613 R83460614 R83460615 R83460617 R83460618 R83460641
R83460642 R83460644
R83460645 R83460648 R83460672 R83460686 R83463020 R83463021
R834600487 R834600488
R834600557 R834600558 R834600564 R834600565 R834600566 R834600567
R834600568
R834600571 R834600572 R834600573 R834600574 R834600575 R834600576
R834600577
R834600578 R834600628 R834600705 R834600706 R834600707 R834600708
R834600712
R834600713 R834600714 R834600715 R834600716 R834600717 R834600718
R834601334
R834601335 R834601336 R834601337 R834601338 R834601360 R834601361
R834601363
R834601364 R834601366 R834601367 R834601600 R834601601 R834601603
R834601606
R834601630 R834601633 R834603220 R834603221 R834603223 R834603224
R834603226
R834603227 R834603250 R834603251 R834603253 R834603256 R834603280
R834603283
R834603510 R834603511 R834603512 R834603513 R834603514 R834603515
R834603516
R834603517 R834603540 R834603541 R834603543 R834603544 R834603546
R834603547
R834603570 R834603573 R834603576 R834603681 R834603682 R834603684
R834603685
R834603687 R834603688 R834603810 R834603830 R834603831 R834603832
R834603833
R834603834 R834603835 R834603836 R834603837 R834603860 R834603861
R834603863
R834603864 R834603866 R834603867 R834606021 R834606022 R834606024
R834606025
R834606028 R834606052 R834606055 R834606160 R834606161 R834606162
R834606164
R834606165 R834606167 R834606168 R834606200 R834606203 R834606206
R834606230
R834606233 R834606236 R834606260 R834606263 R834606266 R834606401
R834606402
R834606405 R834606408 R834606432 R834606471 R834606472 R834606474
R834606475
R834606477 R834606478 R834606500 R834606503 R834606506 R834606530
R834606533

```

```

R834606536 R834606560 R834606563 R834606566 R834606712 R834606715
R834606718 R834606750 R834606751 R834606752 R834606753 R834606754 R834606755
R834606757 R834606758 R834606781 R834606782 R834606784 R834606785 R834606788
R834606800 R834606803 R834606806 R834606807 R834606830 R834606831 R834606833
R834606834 R834606835 R834606836 R834606837 R834606838 R834606870 R834606873
R834606874 R834606876 R834606877 R834630122 R834630125 R834630226 R834630230
R834630231 R834630232 R834630234 R834630235 R834630237 R834630238 R834630240
R834630241 R834630242 R834630243 R834630244 R834630245 R834630246 R834630247
R834630261 R834630262 R834630264 R834630265 R834630268 R834630270 R834630271
R834630273 R834630276 R834630502))""^^geo:dggsLiteral ;
]
.

```

C.1.2.6. Distributions

This example shows a Geometry instance linked to a serialization of it in the [Industry Foundation Classes](#) according to ISO 10303-21 (not a format directly supported with a GeoSPARQL predicate) stored in a local file:

```

ex:mygeom
  a geo:Geometry ;
  geo:hasSerialization [
    a dcat:Distribution ;
    dcterms:conformsTo "https://www.iso.org/standard/63141.html"^^xsd:anyURI
  ;
    dcat:byteSize 714356 ;
    dcat:accessURL "file:///some/local/path/mygeom.ifc"^^xsd:anyURI .
  ]
.

```

C.2. Example SPARQL Queries & Rules

This Section provides example data and then illustrates the use of GeoSPARQL functions and the application of rules with that data.

C.2.1. Example Data

The following RDF data (Turtle format) encodes application-specific spatial data. The resulting spatial data is illustrated in the figure below. The RDF statements define the feature class `my:PlaceOfInterest`, and two properties are created for associating geometries with features:

`my:hasExactGeometry` and `my:hasPointGeometry`. `my:hasExactGeometry` is designated as the default geometry for the `my:PlaceOfInterest` feature class.

All the following examples use the parameter values `relation_family = Simple Features`, `serialization = WKT`, and `version = 1.0`.

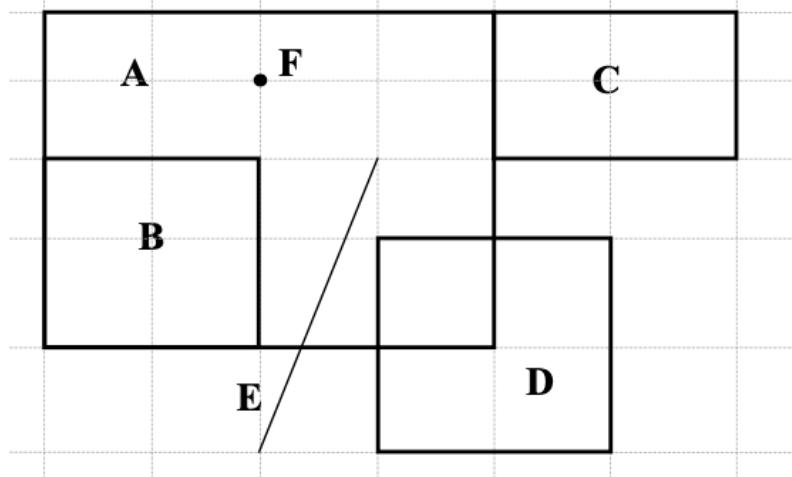


Figure C.1 – Illustration of spatial data

```
@prefix geo: <http://www.opengis.net/ont/geosparql#> .
@prefix my: <http://example.org/ApplicationSchema#> .
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#> .
@prefix sf: <http://www.opengis.net/ont/sf#> .

my:PlaceOfInterest a rdfs:Class ;
    rdfs:subClassOf geo:Feature .

my:A a my:PlaceOfInterest ;
    my:hasExactGeometry my:AExactGeom ;
    my:hasPointGeometry my:APointGeom .

my:B a my:PlaceOfInterest ;
    my:hasExactGeometry my:BExactGeom ;
    my:hasPointGeometry my:BPointGeom .

my:C a my:PlaceOfInterest ;
    my:hasExactGeometry my:CExactGeom ;
    my:hasPointGeometry my:CPointGeom .

my:D a my:PlaceOfInterest ;
    my:hasExactGeometry my:DExactGeom ;
    my:hasPointGeometry my:DPointGeom .

my:E a my:PlaceOfInterest ;
    my:hasExactGeometry my:EExactGeom .

my:F a my:PlaceOfInterest ;
    my:hasExactGeometry my:FExactGeom .

my:hasExactGeometry a rdf:Property ;
    rdfs:subPropertyOf geo:hasDefaultGeometry,
        geo:hasGeometry .
```

```

my:hasPointGeometry a rdf:Property ;
    rdfs:subPropertyOf geo:hasGeometry .

my:AExactGeom a sf:Polygon ;
    geo:asWKT """<http://www.opengis.net/def/crs/OGC/1.3/CRS84>
        Polygon((-83.6 34.1, -83.2 34.1, -83.2 34.5,
        -83.6 34.5, -83.6 34.1))""""^^geo:wktLiteral.

my:APointGeom a sf:Point ;
    geo:asWKT """<http://www.opengis.net/def/crs/OGC/1.3/CRS84>
        Point(-83.4 34.3)""""^^geo:wktLiteral.

my:BExactGeom a sf:Polygon ;
    geo:asWKT """<http://www.opengis.net/def/crs/OGC/1.3/CRS84>
        Polygon((-83.6 34.1, -83.4 34.1, -83.4 34.3,
        -83.6 34.3, -83.6 34.1))""""^^geo:wktLiteral.

my:BPointGeom a sf:Point ;
    geo:asWKT """<http://www.opengis.net/def/crs/OGC/1.3/CRS84>
        Point(-83.5 34.2)""""^^geo:wktLiteral.

my:CExactGeom a sf:Polygon ;
    geo:asWKT """<http://www.opengis.net/def/crs/OGC/1.3/CRS84>
        Polygon((-83.2 34.3, -83.0 34.3, -83.0 34.5,
        -83.2 34.5, -83.2 34.3))""""^^geo:wktLiteral.

my:CPointGeom a sf:Point ;
    geo:asWKT """<http://www.opengis.net/def/crs/OGC/1.3/CRS84>
        Point(-83.1 34.4)""""^^geo:wktLiteral.

my:DExactGeom a sf:Polygon ;
    geo:asWKT """<http://www.opengis.net/def/crs/OGC/1.3/CRS84>
        Polygon((-83.3 34.0, -83.1 34.0, -83.1 34.2,
        -83.3 34.2, -83.3 34.0))""""^^geo:wktLiteral.

my:DPointGeom a sf:Point ;
    geo:asWKT """<http://www.opengis.net/def/crs/OGC/1.3/CRS84>
        Point(-83.2 34.1)""""^^geo:wktLiteral.

my:EExactGeom a sf:LineString ;
    geo:asWKT """<http://www.opengis.net/def/crs/OGC/1.3/CRS84>
        LineString(-83.4 34.0, -83.3 34.3)""""^^geo:wktLiteral.

my:FExactGeom a sf:Point ;
    geo:asWKT """<http://www.opengis.net/def/crs/OGC/1.3/CRS84>
        Point(-83.4 34.4)""""^^geo:wktLiteral.

```

C.2.2. Example Queries

This Section illustrates the use of GeoSPARQL functions through a series of example queries.

C.2.2.1. All features that a given feature contains

Find all features that feature `my:A` contains, where spatial calculations are based on `my:hasExactGeometry`.

```

PREFIX my: <http://example.org/ApplicationSchema#>
PREFIX geo: <http://www.opengis.net/ont/geosparql#>

```

```

PREFIX geof: <http://www.opengis.net/def/function/geosparql/>

SELECT ?f
WHERE {
    my:A my:hasExactGeometry ?aGeom .
    ?aGeom geo:asWKT ?aWKT .
    ?f my:hasExactGeometry ?fGeom .
    ?fGeom geo:asWKT ?fWKT .

    FILTER (
        geof:sfContains(?aWKT, ?fWKT) &&
        !sameTerm(?aGeom, ?fGeom)
    )
}

```

Result:

?F
my:B
my:F

C.2.2.2. All features within bounding box

Find all features that are within a transient bounding box geometry, where spatial calculations are based on my:hasPointGeometry.

```

PREFIX my: <http://example.org/ApplicationSchema#>
PREFIX geo: <http://www.opengis.net/ont/geosparql#>
PREFIX geof: <http://www.opengis.net/def/function/geosparql/>

SELECT ?f
WHERE {
    ?f my:hasPointGeometry ?fGeom .
    ?fGeom geo:asWKT ?fWKT .
    FILTER (
        geof:sfWithin(
            ?fWKT,
            "<http://www.opengis.net/def/crs/OGC/1.3/CRS84>
            Polygon ((-83.4 34.0, -83.1 34.0,
                      -83.1 34.2, -83.4 34.2,
                      -83.4 34.0))"^^geo:wktLiteral
        )
    )
}

```

Result:

?F
my:D

C.2.2.3. All features touching the union of two features

Find all features that touch the union of feature *my:A* and feature *my:D*, where computations are based on *my:hasExactGeometry*.

```
PREFIX my: <http://example.org/ApplicationSchema#>
PREFIX geo: <http://www.opengis.net/ont/geosparql#>
PREFIX geof: <http://www.opengis.net/def/function/geosparql/>

SELECT ?f
WHERE {
  ?f my:hasExactGeometry ?fGeom .
  ?fGeom geo:asWKT ?fWKT .
  my:A my:hasExactGeometry ?aGeom .
  ?aGeom geo:asWKT ?aWKT .
  my:D my:hasExactGeometry ?dGeom .
  ?dGeom geo:asWKT ?dWKT .
  FILTER (
    geof:sfTouches(
      ?fWKT,
      geof:union(?aWKT, ?dWKT)
    )
  )
}
```

Result:

?F
my:C

C.2.2.4. Three closest features to a feature

Find the 3 closest features to feature *my:C*, where computations are based on *my:hasExactGeometry*.

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

SELECT ?f
WHERE {
  my:C my:hasExactGeometry ?cGeom .
  ?cGeom geo:asWKT ?cWKT .
  ?f my:hasExactGeometry ?fGeom .
  ?fGeom geo:asWKT ?fWKT .
  FILTER (?fGeom != ?cGeom)
}
ORDER BY ASC (geof:distance(?cWKT, ?fWKT, uom:metre))
LIMIT 3
```

Result:

?F
my:A
my:D
my:E

C.2.2.5. Maximum and minimum coordinates of a set of geometries

Find the maximum and minimum coordinates of a given set of geometries.

```
PREFIX geo: <http://www.opengis.net/ont/geosparql#>
PREFIX geof: <http://www.opengis.net/def/function/geosparql/>

SELECT ?minX ?minY ?minZ ?maxX ?maxY ?maxZ
WHERE {
    BIND ("<http://www.opengis.net/def/crs/OGC/1.3/CRS84>
          Polygon Z((-83.4 34.0 0, -83.1 34.0 1,
                     -83.1 34.2 1, -83.4 34.2 1,
                     -83.4 34.0 0))"^^geo:wktLiteral) AS ?testgeom)
    BIND(geof:minX(?testgeom) AS ?minX)
    BIND(geof:maxX(?testgeom) AS ?maxX)
    BIND(geof:minY(?testgeom) AS ?minY)
    BIND(geof:maxY(?testgeom) AS ?maxY)
    BIND(geof:maxZ(?testgeom) AS ?maxZ)
    BIND(geof:minZ(?testgeom) AS ?minZ)
}
```

Result:

?MINX	?MINY	?MINZ	?MAXX	?MAXY	?MAXZ
-83.4	34.0	0	-83.1	34.2	1

C.2.3. Example Easting and Northing Functions

Find the easting and northing values of the given geometries.

```
PREFIX geo: <http://www.opengis.net/ont/geosparql#>
PREFIX geof: <http://www.opengis.net/def/function/geosparql/>

SELECT ?easting_geom1 ?easting_geom2 ?easting_geom3 ?northing_geom1 ?northing_geom2 ?northing_geom3
WHERE {
    BIND ("<http://www.opengis.net/def/crs/OGC/1.3/CRS84>
          Point (33.95 -83.38)"^^geo:wktLiteral) AS ?testgeom1)
```

```

    BIND ("<http://www.opengis.net/def/crs/EPSG/0/4326>
          Point (33.95 -83.38)"^^geo:wktLiteral) AS ?testgeom2)
    BIND ("<http://www.opengis.net/def/crs/EPSG/0/3857>
          POINT (3779296.71243164 -18178745.6206012)"^^geo:wktLiteral) AS ?
  testgeom2)
    BIND(geof:easting(?testgeom1) AS ?easting_geom1)
    BIND(geof:easting(?testgeom2) AS ?easting_geom2)
    BIND(geof:easting(?testgeom3) AS ?easting_geom3)
    BIND(geof:northing(?testgeom1) AS ?northing_geom1)
    BIND(geof:northing(?testgeom2) AS ?northing_geom2)
    BIND(geof:northing(?testgeom3) AS ?northing_geom3)
}

```

Result:

?EASTING_GEOM1	?EASTING_GEOM2	?EASTING_GEOM3	?NORTHING_GEOM1	?NORTHING_GEOM2	?NORTHING_GEOM3
33.95	-83.38	3779296.71243164	-83.38	33.95	-18178745.6206012

C.2.4. Example Rule Application

This section illustrates the query transformation strategy for implementing GeoSPARQL rules.

C.2.4.1. All features or geometries overlapping with another feature

Find all features or geometries that overlap feature my:A.

Original Query:

```

PREFIX geo: <http://www.opengis.net/ont/geosparql#>

SELECT ?f
WHERE { ?f geo:sfOverlaps my:A }

```

Transformed Query (application of transformation rule geor:sfOverlaps):

```

PREFIX my: <http://example.org/ApplicationSchema#>
PREFIX geo: <http://www.opengis.net/ont/geosparql#>
PREFIX geof: <http://www.opengis.net/def/function/geosparql/>

SELECT ?f
WHERE {
  # check for asserted statement
  ?f geo:sfOverlaps my:A
  UNION
  # feature - feature
  { ?f geo:hasDefaultGeometry ?fGeom .
    ?fGeom geo:asWKT ?fSerial .
    my:A geo:hasDefaultGeometry ?aGeom .
    ?aGeom geo:asWKT ?aSerial .
    FILTER (geof:sfOverlaps(?fSerial, ?aSerial))
  }
  UNION
  # feature - geometry
}

```

```

?f geo:hasDefaultGeometry ?fGeom .
?fGeom geo:asWKT ?fSerial .
my:A geo:asWKT ?aSerial .
FILTER (geof:sfOverlaps(?fSerial, ?aSerial))
}
UNION
{ # geometry - feature
?f geo:asWKT ?fSerial .
my:A geo:hasDefaultGeometry ?aGeom .
?aGeom geo:asWKT ?aSerial .
FILTER (geof:sfOverlaps(?fSerial, ?aSerial))
}
UNION
{ # geometry - geometry
?f geo:asWKT ?fSerial .
my:A geo:asWKT ?aSerial .
FILTER (geof:sfOverlaps(?fSerial, ?aSerial))
}

```

Result:

?F
my:D
my:DExactGeom
my:E
my:EExactGeom

C.2.5. Example Geometry Serialization Conversion Functions

For the geometry literal values in C.1.2.4 Geometry Serializations:

Application of the function `geof:asWKT` to the GML, KML, GeoJSON, GeoCode, and DGGS literals should return WKT literal and similarly for each of the other conversion methods, `geof:asGML`, `geof:asKML`, `geof:asGeoJSON` & `geof:asDGGS`.



D

ANNEX D (INFORMATIVE) USAGE OF SHACL SHAPES

ANNEX D (INFORMATIVE) USAGE OF SHACL SHAPES

D.0. Overview

This Annex provides guidance on the usage of the SHACL shapes included with GeoSPARQL 1.1.

The Shapes Constraint Language [SHACL](#) allows the specification of constraints on RDF data, phrased as a set of conditions modeled in “Shape” graphs.

In GeoSPARQL 1.1, SHACL Shapes area defined in such a way that they validate anticipated graph structures expected by Requirements defined in the standard. Users may validate a given RDF document claiming conformance to GeoSPARQL 1.1 by using these Shapes and use the validation results to correct any mistakes.

D.1. Tools

[SHACL Shapes provided with GeoSPARQL](#) are used to verify the graph structure of GeoSPARQL graphs. There are several SHACL tools that one can use to validate data using this Shapes information:

- [PySHACL](#): A Python implementation based on the RDF library [RDFlib](#)
- [Apache Jena SHACL](#): a Java implementation, based on [Apache Jena](#)
- [SHACL Playground](#): An online, JavaScript-based implementation that allows validation without local tools
- Triple Stores: SHACL validation is part of many triple store implementations:
 - [GraphDB](#)
 - [RDF4J](#)
 - [Apache Jena Fuseki](#)

Validators produce error messages and warnings based on the SHACL standard's defined reporting structure.

D.2. Scope of SHACL Shapes provided with GeoSPARQL

The SHACL Shapes defined in the GeoSPARQL 1.1 standard all target the verification of specific graph structures, but only in very few cases validate the content of literal types. In particular, the following attributes of the graph are validated:

- **Proper usage of GeoSPARQL classes:** These Shapes check for a proper usage of instances of GeoSPARQL classes. For example, we check that instances of collection classes should at least have one element and that instances of Geometry classes should at least have one serialization to avoid creating graphs which contain nodes without necessary information.
- **Geometry property consistency:** Certain checks are applied for properties describing geometries. For example we check dimensionality properties for corresponding values.
- **Rudimentary checks of literal contents:** The SHACL Shapes defined in this standard do not substitute a verification of literal contents by validators of the respective data formats. However, they define checks using regular expressions to detect a falsely formatted geospatial literal. For example, if a GeoJSON literal is declared using its literal type, a SHACL shape will check for curly brackets to be present (as they are part of the JSON specification).

D.3. Table of SHACL Shapes

Table D.1 – Alignment: GeoSPARQL SHACL Shapes

SHACL SHAPE ID	SEVERITY	TEST PURPOSE	REQUIREMENTS TESTED
<u>Shape 1a</u>	Violation	Each node with an incoming geo:hasGeometry, or a specialization of it, should have at minimum one outgoing relation that is either geo:hasSerialization, or a specialization of it.	[_req_geometry-extension_feature-properties], Requirement 14: /req/geometry-extension/geometry-properties
<u>Shape 1b</u>	Violation	Each node with an incoming geo:hasGeometry, or a specialization of it, can have a maximum of	Requirement 14: /req/geometry-extension/geometry-properties Requirement 19: /req/

SHACL SHAPE ID	SEVERITY	TEST PURPOSE	REQUIREMENTS TESTED
Shape 1c	Violation	one outgoing geo:asWKT relation.	geometry-extension/ geometry-as-wkt-literal
Shape 1d	Violation	Each node with an incoming geo:hasGeometry, or a specialization of it, can have a maximum of one outgoing geo:asGML relation.	Requirement 14: /req/geometry-extension/geometry-properties Requirement 24: /req/geometry-extension/geometry-as-gml-literal
Shape 1e	Violation	Each node with an incoming geo:hasGeometry, or a specialization of it, can have a maximum of one outgoing geo:asGeoJSON relation.	Requirement 14: /req/geometry-extension/geometry-properties Requirement 29: /req/geometry-extension/geometry-as-geojson-literal
Shape 2	Violation	Each node with an incoming geo:hasGeometry, or a specialization of it, can have a maximum of one outgoing geo:asKML relation.	Requirement 14: /req/geometry-extension/geometry-properties Requirement 34: /req/geometry-extension/geometry-as-kml-literal
Shape 3a-c	Violation	Each node with one or more outgoing relations that are either geo:hasSerialization, or a specialization of it, should have at least one incoming geo:hasGeometry relation or a specialization of it.	Requirement 14: /req/geometry-extension/geometry-properties
		A node that has an incoming geo:hasGeometry property, or specialization of it, cannot have an outgoing geo:hasGeometry property, or a specialization of it, at the same time (a geo:Feature cannot be a geo:Geometry at the same time)	[_req_geometry-extension_feature-properties]

SHACL SHAPE ID	SEVERITY	TEST PURPOSE	REQUIREMENTS TESTED
Shape 4	Violation	The target of a geo:hasSerialization property, or a specialization of, it should be an RDF literal	Requirement 14: /req/geometry-extension/geometry-properties
Shape 5	Violation	The target of a geo:asWKT property should be an RDF literal with datatype geo:wktLiteral	Requirement 15: /req/geometry-extension/wkt-literal
Shape 6	Violation	The target of a geo:asGML property should be an RDF literal with datatype geo:gmlLiteral	Requirement 21: /req/geometry-extension/gml-literal
Shape 7	Violation	The target of a geo:asGeoJSON property should be an RDF literal with datatype geo:geoJSONLiteral	Requirement 26: /req/geometry-extension/geojson-literal
Shape 8	Violation	The target of a geo:askML property should be an RDF literal with datatype geo:kmlLiteral	Requirement 31: /req/geometry-extension/kml-literal
Shape 9	Violation	A geo:Geometry node should have a maximum of one outgoing geo:coordinateDimension property	Requirement 14: /req/geometry-extension/geometry-properties
Shape 10	Violation	A geo:Geometry node should have a maximum of one outgoing geo:dimension property	Requirement 14: /req/geometry-extension/geometry-properties
Shape 11	Violation	A geo:Geometry node should have a maximum of one outgoing geo:isEmpty property	Requirement 14: /req/geometry-extension/geometry-properties
Shape 12	Violation	A geo:Geometry node should have a maximum of one outgoing geo:isSimple property	Requirement 14: /req/geometry-extension/geometry-properties
Shape 13	Violation	A geo:Geometry node should have a maximum of one outgoing geo:spatialDimension property	Requirement 14: /req/geometry-extension/geometry-properties

SHACL SHAPE ID	SEVERITY	TEST PURPOSE	REQUIREMENTS TESTED
Shape 14a	Violation	A geo:Geometry node should have maximum of one outgoing <code>geo:hasSpatialResolution</code> property	Requirement 14: /req/geometry-extension/geometry-properties
Shape 14b	Violation	A geo:Geometry node should have maximum of one outgoing <code>geo:hasSpatialAccuracy</code> property	Requirement 14: /req/geometry-extension/geometry-properties
Shape 14c	Violation	A geo:Geometry node should have maximum of one outgoing <code>geo:hasMetricSpatialAccuracy</code> property	Requirement 14: /req/geometry-extension/geometry-properties
Shape 14d	Violation	A geo:Geometry node should have maximum of one outgoing <code>geo:hasMetricSpatialResolution</code> property	Requirement 14: /req/geometry-extension/geometry-properties
Shape 15	Violation	The content of an RDF literal with an incoming <code>geo:asWKT</code> relation must conform to a well-formed WKT string, as defined by its official specification (Simple Features Access)	Requirement 15: /req/geometry-extension/wkt-literal
Shape 16	Violation	The content of an RDF literal with an incoming <code>geo:asWKT</code> relation must conform to a well-formed WKT string, as defined by its official specification (Simple Features Access)	Requirement 21: /req/geometry-extension/gml-literal
Shape 17	Violation	The content of an RDF literal with an incoming <code>geo:asGeoJSON</code> relation must conform to a well-formed GeoJSON geometry string, as defined by its official specification	Requirement 26: /req/geometry-extension/geojson-literal
Shape 18	Violation	The content of an RDF literal with an incoming <code>geo:asKML</code> relation must conform to a well-formed KML geometry XML string, as defined by its official specification	Requirement 31: /req/geometry-extension/kml-literal

SHACL SHAPE ID	SEVERITY	TEST PURPOSE	REQUIREMENTS TESTED
Shape 20	Violation	If both geo:dimension and geo:coordinateDimension properties are asserted, the value of geo:dimension should be less than or equal to the value of geo: coordinateDimension	Requirement 14: /req/geometry-extension/geometry-properties
Shape 21a	Violation	An instance of geo:Feature Collection should have at least one outgoing <u>rdfs:member</u> relation	Requirement 5: /req/core/feature-collection-class
Shape 21b	Violation	An instance of geo:Feature Collection should only have outgoing <u>rdfs:member</u> going to geo:Feature instances	Requirement 5: /req/core/feature-collection-class
Shape 22a	Violation	An instance of geo: GeometryCollection should have at least one outgoing <u>rdfs:member</u> relation	[_req_core_geometry-collection-class]
Shape 22b	Violation	An instance of geo: GeometryCollection should only have outgoing <u>rdfs:member</u> relations to geo: Geometry instances	[_req_core_geometry-collection-class]
Shape 23a	Violation	An instance of geo:Spatial ObjectCollection should have at least one outgoing <u>rdfs:member</u> relation	Requirement 4: /req/core/spatial-object-collection-class
Shape 23b	Violation	An instance of geo:Spatial ObjectCollection should only have outgoing <u>rdfs:member</u> relations going to geo:SpatialObject instances, or subclasses of them	Requirement 4: /req/core/spatial-object-collection-class



E

ANNEX E (INFORMATIVE) ALIGNMENTS

ANNEX E (INFORMATIVE) ALIGNMENTS

E.0. Overview

This Annex provides alignments of GeoSPARQL to other well known ontologies that are either commonly used with GeoSPARQL or could be.

The prefixes used for the ontologies mapped to in all following sections are given in the following table.

Table E.1 – Alignment: Namespaces

as:	https://www.w3.org/ns/activitystreams#
dcterms:	http://purl.org/dc/terms/
geo:	http://www.opengis.net/ont/geosparql#
geom:	http://geovocab.org/geometry#
gn:	https://www.geonames.org/ontology#
juso:	http://rdfs.co/juso/
lgd:	http://linkedgeodata.org/ontology/
locn:	https://www.w3.org/ns/locn
obo:	http://purl.obolibrary.org/obo/
osm:	https://w3id.org/openstreetmap/terms#
osmm:	https://www.openstreetmap.org/meta/

osmt:	https://wiki.openstreetmap.org/wiki/Key:
pos:	http://www.w3.org/2003/01/geo/wgs84_pos#
prov:	http://www.w3.org/ns/prov#
rdf:	http://www.w3.org/1999/02/22-rdf-syntax-ns#
rdfs:	http://www.w3.org/2000/01/rdf-schema#
sdo:	https://schema.org
sosa:	http://www.w3.org/ns/sosa/
spatialuk:	http://data.ordnancesurvey.co.uk/ontology/spatialrelations/
spatialukgeom:	http://data.ordnancesurvey.co.uk/ontology/geometry/
spatial:	http://geovocab.org/spatial#
ssn:	http://www.w3.org/ns/ssn/
time:	http://www.w3.org/2006/time#
wdt:	http://www.wikidata.org/entity/

E.1. ISA Programme Location Core Vocabulary (LOCN)

LOCN Source: <https://www.w3.org/ns/locn>

The LOCN specification provides notes on the use of GeoSPARQL literals (see <https://www.w3.org/ns/locn#changes>).

Table E.2 – Alignment: ISA Programme Location Core Vocabulary (LOCN)

FROM ELEMENT	MAPPING RELATION	TO ELEMENT	NOTES
geo:Feature	rdfs:subClassOf	dcterms:Location	LOCN states that dcterms:Location “represents any location, irrespective of size or other restriction”. As such, it can be considered as a superclass of geo:Feature.

FROM ELEMENT	MAPPING RELATION	TO ELEMENT	NOTES
<u>locn:</u> <u>Address</u>	<u>rdfs:subClassOf</u>	geo:Feature	Although LOCN does not explicitly indicate spatial or geometry properties for locn:Address, this class can be considered as a specialized form of a geo:Feature.
geo: Geometry	<u>rdfs:subClassOf</u>	<u>locn:</u> <u>Geometry</u>	In LOCN, class <u>locn:Geometry</u> “[...] defines the notion of geometry at the conceptual level, and it shall be encoded by using different formats”. More precisely, its instances can be either literals or individuals. The GeoSPARQL’s class geo:Geometry is more narrowly defined, as its instances can only be individuals, and not literals.
geo:has Geometry	<u>rdfs:</u> <u>subPropertyOf</u>	<u>locn:</u> <u>geometry</u>	In LOCN, the usage note to property <u>locn:geometry</u> states that “Depending on how a geometry is encoded, the range of this property may be one of the following: a literal [...], an instance of a geometry class [...], geocoded URIs [...].” The Geo SPARQL’s property geo:hasGeometry is more narrowly defined, as it can only be used with instances of geo:Geometry, and not with literals.

E.2. WGS84 Geo Positioning: an RDF vocabulary (POS)

POS Source: <http://www.w3.org/2003/01/geo/>

Table E.3 – Alignment: WGS84 Geo Positioning Vocabulary (POS)

FROM ELEMENT	MAPPING RELATION	TO ELEMENT	NOTES
geo:Spatial Object	<u>owl:</u> <u>equivalentClass</u>	<u>pos:</u> <u>SpatialThing</u>	Both classes are unrestricted, essentially abstract classes
<u>pos:Point</u>	<u>rdfs:subClassOf</u>	geo:Geometry	Via pos:Point rdfs:subClassOf pos: SpatialThing but since pos:Point usage notes indicates direct positioning, it is a form of geometry
<u>pos:Point</u>	<u>owl:</u> <u>equivalentClass</u>	<u>sf:Point</u>	
<u>pos:lat</u> <u>long</u>	<u>rdfs:subPropertyOf</u>	geo:has Serialization	A special datatype is not indicated for use with this property by POS, unlike GeoSPARQL’s geo:has Serialization object literals
<u>pos:</u> <u>location</u>	<u>rdfs:subPropertyOf</u>	geo:hasGeometry	

E.3. W3C Activity Streams Vocabulary

AS Source: <https://www.w3.org/TR/activitystreams-vocabulary/>

Table E.4 – Alignment: W3C Activity Streams Vocabulary

FROM ELEMENT	MAPPING RELATION	TO ELEMENT	NOTES
as:Place	owl:equivalentClass	geo:Feature	AS places are only defined for point geometries
as:accuracy	rdfs:subPropertyOf	geo:hasSpatial Accuracy	AS expresses the accuracy in percent
as:altitude			The altitude property can be expressed as a Z coordinate in GeoSPARQL-compatible literals
as:latitude	rdfs:subPropertyOf	geo:hasSerialization	AS defines the range of this property as xsd:float
as:longitude	rdfs:subPropertyOf	geo:hasSerialization	AS defines the range of this property as xsd:float

E.4. Geonames Ontology (GN)

Geonames source: <http://www.geonames.org/ontology/documentation.html>

Table E.5 – Alignment: Geonames Vocabulary (GN)

FROM ELEMENT	MAPPING RELATION	TO ELEMENT	NOTES
gn:Feature	owl:equivalentClass	geo:Feature	
gn:GeonamesFeature	rdfs:subClassOf	geo:Feature	The GN class is defined as “A feature described in geonames database...”
geo:Feature	rdfs:subClassOf	gn:Class	The GN class’ definition reads “A class of features”
gn:locatedIn	owl:equivalentProperty	geo:sfWithin	
gn:nearby	rdfs:subPropertyOf	geo:sfDisjoint	A gn:nearby B means A is not within or touching B. The only close SF property is disjoint

FROM ELEMENT	MAPPING RELATION	TO ELEMENT	NOTES
gn:neighbour	owl: equivalentProperty	geo: sfTouches	

E.5. NeoGeo Vocabulary

NeoGeo Source: <http://geovocab.org/> / <http://geovocab.org/doc/neogeo/>

Table E.6 – Alignment: NeoGeo Vocabulary

FROM ELEMENT	MAPPING RELATION	TO ELEMENT	NOTES
spatial:Feature	owl: equivalentClass	geo:Feature	
spatial:C	rdfs: subPropertyOf	geo:rcc8ec	Sub property not equivalent property since the NeoGeo property has more restrictive domain & range
spatial:DR	rdfs: subPropertyOf	geo:rcc8dc	
spatial:EC	rdfs: subPropertyOf	geo:rcc8ec	
spatial:EQ	rdfs: subPropertyOf	geo:rcc8eq	
spatial:NTPP	rdfs: subPropertyOf	geo:rcc8ntp	
spatial:NTPPi	rdfs: subPropertyOf	geo:rcc8ntppi	
spatial:O	rdfs: subPropertyOf	geo:sfOverlaps	
spatial:P	rdfs: subPropertyOf	geo:sfWithin	
spatial:PO	rdfs: subPropertyOf	geo:rcc8po	
spatial:PP	rdfs: subPropertyOf	geo:sfWithin	
spatial:PPi	rdfs: subPropertyOf	geo:sfContains	
spatial:Pi	rdfs: subPropertyOf	geo:sfContains	

FROM ELEMENT	MAPPING RELATION	TO ELEMENT	NOTES
spatial:TPP	rdfs: subPropertyOf	geo:rcc8tpp	
spatial:TPPi	rdfs: subPropertyOf	geo::rcc8tppi	
geom:Geometry	owl: equivalentClass	geo:Geometry	
geom:BoundingBox	rdfs:subClassOf	geo:Geometry	GeoSPARQL doesn't have a Bounding Box class but has a generic Geometry class that is the range of the geo:hasBoundingBox property
geom:GeometryCollection	owl: equivalentClass	geo:Geometry Collection	
geom:LineString	owl: equivalentClass	sf:LineString	
geom:LinearRing	owl: equivalentClass	sf:LinearRing	
geom:MultiLineString	owl: equivalentClass	sf: MultiLineString	
geom:MultiPoint	owl: equivalentClass	sf:MultiPoint	
geom:MultiPolygon	owl: equivalentClass	sf:MultiPolygon	
geom:Polygon	owl: equivalentClass	sf:Polygon	
geom:Point	owl: equivalentClass	sf:Point	
geo:hasGeometry	rdfs: subPropertyOf	geom:geometry	geo:hasGeometry has more restrictive domain

- The geom:bbox property relates a Geometry to another Geometry and is thus not equivalent to GeoSPARQL's Feature-to-Geometry geo:hasBoundingBox.
 - An equivalent to geo:bbox could be made using a geo:Feature with a geo:Geometry, indicated by geo:hasGeometry and a second, specialised Bounding Box geo:Geometry indicated with geo:hasBoundingBox

E.6. Juso Ontology

Juso Source: <http://rdfs.co/juso/>

Juso contains mappings to GeoSPARQL but uses `owl:sameAs` which it should instead use `owl:equivalentClass`.

Table E.7 – Alignment: Juso Ontology

FROM ELEMENT	MAPPING RELATION	TO ELEMENT
<code>juso:SpatialThing</code>	<code>owl:equivalentClass</code>	<code>geo:SpatialObject</code>
<code>juso:Feature</code>	<code>owl:equivalentClass</code>	<code>geo:Feature</code>
<code>juso:Geometry</code>	<code>owl:equivalentClass</code>	<code>geo:Geometry</code>
<code>juso:Point</code>	<code>owl:equivalentClass</code>	<code>sf:Point</code>
<code>juso:geometry</code>	<code>owl:equivalentProperty</code>	<code>geo:hasGeometry</code>
<code>juso:parent</code>	<code>rdfs:subPropertyOf</code>	<code>geo:sfWithin</code>
<code>juso:political_division</code>	<code>rdfs:subPropertyOf</code>	<code>geo:sfContains</code>
<code>juso:within</code>	<code>owl:equivalentProperty</code>	<code>geo:sfWithin</code>

E.7. Time Ontology in OWL (TIME)

TIME Source: <https://www.w3.org/TR/owl-time/>

There are no direct class or property correspondences between GeoSPARQL and TIME however class patterning is similar:

- TIME uses `time:hasTime` to indicate that something has a temporal projection
- GeoSPARQL uses `geo:hasGeometry` to indicate that a `geo:Feature` has a spatial projection

and

- TIME uses properties such as `time:inXSDate` to indicate the position of temporal entities on a temporal reference system
- GeoSPARQL uses properties such as `geo:asWKT` to indicate the position of spatial entities (Geometries) on spatial reference systems

OWL TIME sets no domain for `time:hasTime` thus this property may be used with anything, including a GeoSPARQL `geo:Feature` so that a spatio-temporal Feature may be indicated like this:

```
:flooded-area-x
  a geo:Feature ;
  geo:hasGeometry [
    a geo:Geometry ;
    geo:asWKT "POLYGON (((...)))"^^geo:wktLiteral ;
  ] ;
  time:hasTime [
    a time:ProperInterval ;
    time:hasBeginning [
      time:inXSDate "...""^^xsd:date ;
    ] ;
    time:hasEnd [
      time:inXSDate "...""^^xsd:date ;
    ] ;
  ] ;
.
```

In the above example, `:flooded-area-x` is a spatio-temporal Feature that has both a GeoSPARQL spatial projection – a `geo:Geometry` – and a temporal projection – a `time:ProperInterval` which is a specialized form of `time:TemporalEntity`.

Another possible use of TIME with GeoSPARQL is to assign temporality to individual `geo:Geometry` instances. This is allowed given `time:hasTime`'s open domain:

```
:flooded-area-x
  a geo:Feature ;
  geo:hasGeometry [
    a geo:Geometry ;
    geo:asWKT "POLYGON (((...)))"^^geo:wktLiteral ;
    time:hasTime [ ... ] ;
  ] ;
.
```

In contrast to the first example, `:flooded-area-x` is inferred to be a spatio-temporal Feature but since it is the Geometry of `:flooded-area-x` that has a temporality, it is possible to describe other Geometries of `:flooded-area-x` with other temporalities.

E.8. schema.org

schema.org Source: <https://schema.org>

Table E.8 – Alignment: schema.org

FROM ELEMENT	MAPPING RELATION	TO ELEMENT	NOTES
geo:Geometry	rdfs:subClassOf	sdo:GeoShape	A GeoShape can various literal geometry representation
sdo:GeospatialGeometry	owl:equivalentClass	geo:SpatialObject	Since sdo:GeospatialGeometry is the domain of SimpleFeature-like properties and a superclass of GeoShape
sdo:GeoCoordinates	rdfs:subClassOf	geo:Geometry	GoCoordinates uses direct lat, long, elevation etc properties to indicate position, not a while geometry serialization but it is nevertheless a form of a Geometry
sdo:geo	rdfs:subPropertyOf	geo:hasGeometry	
sdo:geoCoveredBy	owl:equivalentProperty	geo: ehCoveredBy	
sdo:geoCovers	owl:equivalentProperty	geo:ehCovers	
sdo:geoCrosses	owl:equivalentProperty	geo:sfCrosses	
sdo:geoDisjoint	owl:equivalentProperty	geo: sfDisjoint	
sdo:geoEquals	owl:equivalentProperty	geo:sfEquals	
sdo:geoIntersects	owl:equivalentProperty	geo: sfIntersects	
sdo:geoOverlaps	owl:equivalentProperty	geo: sfOverlaps	
sdo:geoTouches	owl:equivalentProperty	geo:sfTouches	
sdo:geoWithin	owl:equivalentProperty	geo:sfWithin	
sdo:geoMidpoint	owl:equivalentProperty	geo:hasCentroid	
sdo:Landform	rdfs:subClassOf	geo:Feature	

E.9. Semantic Sensor Network Ontology (SSN)

SSN Source: <https://www.w3.org/TR/vocab-ssn/>

SSN and GeoSPARQL do not cover overlapping concerns directly and therefore there are no direct class or property correspondences between them, however SSN provides advice on the use of GeoSPARQL for location, see Section 7.1 (<https://www.w3.org/TR/vocab-ssn/#x7-1-location>):

GeoSPARQL ... provides a flexible and relatively complete platform for geospatial objects, that fosters interoperability between geo-datasets. To do so, these entities can be declared as instances of geo:Feature and geometries can be assigned to them via the geo:hasGeometry property. In case of classes, e.g., specific features of interests such as rivers, these can be defined as subclasses of geo:Feature.

E.10. DCMI Metadata Terms (DCTERMS)

DCTERMS Source: <https://www.dublincore.org/specifications/dublin-core/dcmi-terms/>

Table E.9 – Alignment: DCMI Metadata Terms (DCTERMS)

FROM ELEMENT	MAPPING RELATION	TO ELEMENT	NOTES
geo:Feature	rdfs:subClassOf	dcterms:Location	A Location is a “A spatial region or named place.”
geo:hasGeometry	rdfs:subPropertyOf	dcterms:spatial	dcterms:spatial indicates the “Spatial characteristics of the resource”, thus it is a more general form of Geo SPARQL’s geo:hasGeometry which indicates geometry spatial information

- [dcterms:spatial](#): “Spatial characteristics of the resource”. The range of this property includes a [dcterms:Location](#), so it is a property for indicating a geo:Feature, for which GeoSPARQL has no equivalent, but perhaps also for indicating a geo:Geometry, thus the subPropertyOf mapping above.
- [dcterms:coverage](#): “The spatial or temporal topic of the resource, spatial applicability of the resource, or jurisdiction under which the resource is relevant”. This is a more generic form of [dcterms:spatial](#) but, since there is no direct GeoSPARQL mapping for [dcterms:spatial](#), there is no direct mapping for this property either.

DCTERMS-related geometry literals, such as the *DCMI Box Encoding Scheme*¹³ and the *DCMI Point Encoding Scheme*¹⁴ could be indicated as GeoSPARQL geometry literals if a literal datatype were created for each. For example, the *DCMI Point Encoding Scheme* example of “The highest point in Australia” with the literal value `east=148.26218; north=-36.45746; elevation=2228; name=Mt. Kosciusko` might be encoded in GeoSPARQL like this:

```
:mt-kosciusko
  a geo:Feature ;
  geo:hasGeometry [
    a geo:Geometry ;
    geo:hasSerialization "east=148.26218; north=-36.45746; elevation=2228;
  name=Mt. Kosciusko"^^ex:dcmiPoint ;
  ] ;
.
```

E.11. The Provenance Ontology (PROV)

PROV Source: <https://www.w3.org/TR/prov-o/>

From GeoSPARQL’s point of view, PROV is an “upper” ontology – one dealing with more abstract concepts – and only one of PROV’s three main classes of object – Entity, Activity & Agent – has direct relations to GeoSPARQL classes and that is Entity. This is because GeoSPARQL characterizes things – spatial objects – which are a kind of Entity but does not deal with events (Activity) or things with agency (Agent).

Table E.10 – Alignment: The Provenance Ontology (PROV)

FROM ELEMENT	MAPPING RELATION	TO ELEMENT	NOTES
geo: SpatialObjectCollection	<u>rdflib:</u> <u>subClassOf</u>	<u>prov:</u> <u>Collection</u>	PROV’s class is a generic collection class and GeoSPARQL’s property is clearly a specialized form of it that may only consist of certain class instances (geo:SpatialObject)
geo:SpatialObject	<u>rdflib:</u> <u>subClassOf</u>	<u>prov:Entity</u>	All SpatialObjects fit within PROV’s Entity’s definition: “An entity is a physical, digital, conceptual, or other kind of thing with some fixed aspects; entities may be real or imaginary.”
geo:Feature	<u>rdflib:</u> <u>subClassOf</u>	<u>prov:</u> <u>Location</u>	A Location “...can be an identifiable geographic place (ISO 19112), but it can also be a non-geographic place such as a directory, row, or column” so seem to be wider in scope than

¹³<https://www.dublincore.org/specifications/dublin-core/dcmi-box/>

¹⁴<https://www.dublincore.org/specifications/dublin-core/dcmi-point/>

FROM ELEMENT	MAPPING RELATION	TO ELEMENT	NOTES
			GeoSPARQL's Feature although a Feature could indeed be something such as a "directory, row, or column"

- The PROV property `prov:atLocation` indicates `prov:Location` instances, which may be geo:Feature instances, but GeoSPARQL has no property to indicate a geo:Feature, so no mapping is possible. Indicating features is commonly done in ontologies which use GeoSPARQL but not within GeoSPARQL.
- Derivative relations between GeoSPARQL objects could be modelled using PROV, for instance a BoundingBox may be indicated as having been derived from a Polygon like this:

```
:bounding-box-y prov:wasDerivedFrom :polygon-x .
```

E.12. WikiData

Table E.11 – Alignment: WikiData

FROM ELEMENT	MAPPING RELATION	TO ELEMENT	NOTES
<code>wdt:P625</code>	<code>owl:</code> <code>equivalentProperty</code>	<code>geo:asWKT</code>	The Wikidata description of this property labeled "coordinate location" note that "For Earth, please note that only WGS84 coordinating system is supported at the moment" but that is a system limit, not an ontological one
<code>wdt:P3896</code>	<code>owl:</code> <code>propertyChainAxiom</code>	(<code>geo:has</code> <code>Geometry</code> <code>geo:</code> <code>asGeoJSON</code>)	This Wikidata property labeled "geoshape" indicated GeoJSON geometry literal content for a Feature, but it allows information other than just Geometry in the GeoJSON whereas GeoSPARQL does not.
<code>wdt:P3096</code>	<code>owl:</code> <code>propertyChainAxiom</code>	(<code>geo:has</code> <code>Geometry</code> <code>geo:</code> <code>askML</code>)	This Wikidata property labeled "KML File" links to a KML file which is related to the respective instance. This may not be the same representation as in GeoSPARQL, as GeoSPARQL KML literals only encode the geometry part of a KML.
<code>wd:Q82794</code>	<code>rdfs:subClassOf</code>	<code>geo:Feature</code>	The Wikidata class is labeled "geographic region" and thus is a subclass of the more general geo: Feature. There are likely many other classes in Wikidata that could be interpreted as subclasses of geo:Feature

FROM ELEMENT	MAPPING RELATION	TO ELEMENT	NOTES
wd:Q618123	owl:equivalentClass	geo:Feature	The Wikidata class is labeled “geographical feature” and thus corresponds to geo:Feature.
wd:Q25404640	owl:equivalentClass	geo:SpatialObject	The Wikidata class is labeled “spatial object” and thus corresponds to geo:SpatialObject.
wdt:P150	rdfs:subPropertyOf	geo:sfContains	The Wikidata property is labeled “contains administrative territorial entity” but also alternatively labeled “contains”, “has districts” and others. There are likely many other specialized forms of geo:sfContains and geo:sfWithin in Wikidata
geo: sfWithin	rdfs:subPropertyOf	wdt:P361	The Wikidata property is labeled “part of” and is sometimes used to indicate Feature parthood. There are likely other parthood properties like this in Wikipedia that may also be used as superproperties of GeoSPARQL feature relations properties. The Wikidata inverse is wdt:Q65964571 “has part”
geo: sfContains	rdfs:subPropertyOf	wd:Q65964571	The property labeled “has part” is the inverse of wdt:P361 (see above)
wdt:P131	rdfs:subPropertyOf	geo:sfContains	The Wikidata property is labeled “located in the administrative territorial entity” and is essentially the inverse of wdt:P150 (described above)
wdt:P706	rdfs:subPropertyOf	geo:sfWithin	The Wikidata property is labeled “located in/on physical feature” and is indicated for use with a “(geo)physical feature” and not to be used for administrative features where wdt:P131 (see above) should be
wdt:P4688	rdfs:subClassOf	geo:Feature	The Wikidata class is labeled “geomorphological unit” and is one of many Wikidata feature classes that could be expressed as a subclass of geo:Feature. More specialized geological unit examples are wd:Q5107 “continent” and wdt:P4552 “mountain range”.
wdt:P2046	owl: equivalentProperty	geo:hasArea	The Wikidata property is labeled “area”. It indicates a microformat – NUMBER + SPACE + ALLOWED_UNIT_LABEL – with a fixed set of ALLOWED_UNIT_LABELs to present values and units of measure.

E.13. OpenStreetMap Ontologies

There are several approaches to make OpenStreetMap data accessible in the Linked Open Data cloud.

E.13.1. LinkedGeoData

LinkedGeoData emerged from a research project connecting OpenStreetMap representations to an ontology model. In this model, specific values of OpenStreetMap tags, e.g. the values of amenity tags are converted to `owl:Class` representations using an automated process. Every class defined in this way represented a `geo:Feature` and is linked to either a Geometry or a latitude longitude representation. Hence, every linked geodata class can be considered a `geo:Feature` in the sense of GeoSPARQL.

Table E.12 – Alignment: LinkedGeoData

From Element	Mapping relation	To Element	Notes
Any LGD Class	<code>rdfs:subClassOf</code>	<code>geo:Feature</code>	Any class defined in the LinkedGeoData ontology is a subclass of <code>geo:Feature</code>

E.13.2. OpenStreetMap RDF (Sophox)

https://wiki.openstreetmap.org/wiki/Sophox#How_OSM_data_is_stored

Table E.13 – Alignment: OpenStreetMap RDF (Sophox)

FROM ELEMENT	MAPPING RELATION	TO ELEMENT	NOTES
<code>osmm:loc</code>	<code>owl:equivalentProperty</code>	<code>geo:asWKT</code>	The OpenStreetMap property <code>osmm:loc</code> includes WKT literals which depending on the type of the subject instance describe an OSM node or the centroid of a way or OSM relation
<code>osmm:type</code> 'n'	<code>owl:equivalentClass</code>	<code>sf:Point</code>	The OpenStreetMap RDF property <code>osmm:type</code> with value 'n' describes an OSM Node which is equivalent to a <code>sf:Point</code>
<code>osmm:type</code> 'w'	<code>owl:equivalentClass</code>	<code>sf:LineString</code>	The OpenStreetMap RDF property <code>osmm:type</code> with value 'w' describes an OSM Way which is equivalent to a <code>sf:LineString</code>

FROM ELEMENT	MAPPING RELATION	TO ELEMENT	NOTES
<u>osmm:type</u> 'r'	<u>owl:equivalentClass</u>	<u>sf:GeometryCollection</u>	The OpenStreetMap RDF property <u>osmm:type</u> with value 'r' describes an OSM relation Way which is equivalent to a <u>sf:GeometryCollection</u>
<u>osmm:has</u>	<u>owl:equivalentProperty</u>	<u>geo:sfContains</u> , <u>geo:ehContains</u> , <u>geo:rcc8ntpp</u>	The OpenStreetMap RDF property <u>osmm:has</u> describes that a relation contains a way or that a way contains a node
<u>osmm:isClosed</u> true	<u>owl:equivalentClass</u>	<u>sf:Polygon</u>	The OpenStreetMap RDF property <u>osmm:isClosed</u> indicates whether a Way is closed, i.e. if it constitutes a Polygon
<u>osmm:isClosed</u> false	<u>owl:equivalentClass</u>	<u>sf:LineString</u>	The OpenStreetMap RDF property <u>osmm:isClosed</u> indicates whether a Way is closed, i.e. if it constitutes a Polygon

E.13.3. Routable Tiles Ontology

<https://github.com/openplannerteam/routable-tiles-ontology>

Table E.14 – Alignment: Routable Tiles Ontology

FROM ELEMENT	MAPPING RELATION	TO ELEMENT	NOTES
<u>osm:Element</u>	<u>owl:equivalentClass</u>	<u>geo:Geometry</u>	The class <u>osm:Element</u> is equivalent to a <u>geo:Geometry</u>
<u>osm:Node</u>	<u>owl:equivalentClass</u>	<u>sf:Point</u>	The class <u>osm:Node</u> is equivalent to a <u>sf:Point</u>
<u>osm:Way</u>	<u>owl:equivalentClass</u>	<u>sf:LineString</u>	The class <u>osm:Way</u> is equivalent to a <u>sf:LineString</u>
<u>osm:Relation</u>	<u>owl:equivalentClass</u>	<u>sf:GeometryCollection</u>	The class <u>osm:Relation</u> is equivalent to a <u>sf:GeometryCollection</u>

E.14. Ordnance Survey UK Spatial Ontology

<http://www.ordnancesurvey.co.uk/legacy/ontologies/spatialrelations.owl> & <http://www.ordnancesurvey.co.uk/legacy/ontologies/geometry.owl>

NOTE: These two ontologies will be withdrawn during 2022.

The ontology authors note: "We are pleased to have contributed to the discussion some ten years ago but recognize that the subject area has moved on. We would not recommend people starting to relate to our ontology now, and we look forward to migrating to some more authoritative one in due course."

Table E.15 – Alignment: Ordnance Survey UK Spatial Ontology

FROM ELEMENT	MAPPING RELATION	TO ELEMENT	NOTES
spatialuk:contains	owl:equivalentProperty	geo:sfContains	
spatialuk:disjoint	owl:equivalentProperty	geo:sfDisjoint	
spatialuk:easting	owl:equivalentProperty	-	Distance in metres east of National Grid origin
spatialuk>equals	owl:equivalentProperty	geo:sfEquals	
spatialuk:northing	owl:equivalentProperty	-	Distance in metres north of National Grid origin
spatialuk.touches	owl:equivalentProperty	geo:sfTouches	
spatialuk:within	owl:equivalentProperty	geo:sfWithin	
spatialukgeom:AbstractGeometry	owl:equivalentProperty	geo:Geometry	
spatialukgeom:extent	owl:equivalentProperty	geo:has Geometry	The range of spatialukgeom:extent is constrained to 2D geometries
spatialukgeom:asGML	owl:equivalentProperty	geo:asGML	The properties are equivalent, but the range of `spatialukgeom:asGML` is more general: An rdf:XMLLiteral

- [spatialuk:easting](#) describes a latitude coordinate east of the national UK grid and GeoSPARQL does not contain modelling of individual coordinate reference system elements
- [spatialuk:northing](#) describes a longitude coordinate north of the national UK grid so, as above, has not GeoSPARQL equivalent

E.15. CIDOC CRM Geo

CRMGeo Source: https://www.cidoc-crm.org/crmgeo/sites/default/files/CRMgeo1_2.pdf

Table E.16 – Alignment: CIDOC CRM Geo

FROM ELEMENT	MAPPING RELATION	TO ELEMENT	NOTES
<u>cidoc:SP1_PhenoenmalSpaceTimeVolume</u>	<u>rdfs:subClassOf</u>	geo:Feature	The CIDOC CRMGeo class SP1_PhenoenmalSpaceTimeVolume is a subclass of geo:Feature as described in the CRMGeo 1.2 specification document.
<u>cidoc:SP2_PhenoenmalPlace</u>	<u>rdfs:subClassOf</u>	geo:Feature	The CIDOC CRMGeo class SP2_PhenoenmalPlace is a subclass of geo:Feature as described in the CRMGeo 1.2 specification document.
<u>cidoc:SP5_GeometricPlaceExpression</u>	<u>rdfs:subClassOf</u>	geo:Geometry	The CIDOC CRMGeo class SP5_GeometricPlaceExpression is a subclass of geo:Geometry as described in the CRMGeo 1.2 specification document.
<u>cidoc:SP6_DeclarativePlace</u>	<u>rdfs:subClassOf</u>	geo:Geometry	The CIDOC CRMGeo class SP6_DeclarativePlace is a subclass of geo:Geometry as described in the CRMGeo 1.2 specification document.
<u>cidoc:SP7_DelcarativePlace</u>	<u>rdfs:subClassOf</u>	geo:Geometry	The CIDOC CRMGeo class SP7_DeclarativePlace is a subclass of geo:Geometry as described in the CRMGeo 1.2 specification document.
<u>cidoc:SP10_DeclarativeTimeSpan</u>	<u>rdfs:subClassOf</u>	geo:Geometry	The CIDOC CRMGeo class SP10_DeclarativeTimeSpan is a subclass of geo:Geometry as described in the CRMGeo 1.2 specification document.
<u>cidoc:SP14_TimeExpression</u>	<u>rdfs:subClassOf</u>	geo:Geometry	The CIDOC CRMGeo class SP14_TimeExpression is a subclass of geo:Geometry as described in the CRMGeo 1.2 specification document.
<u>cidoc:SP15_Geometry</u>	<u>rdfs:subClassOf</u>	geo:Geometry	The CIDOC CRMGeo class SP15_Geometry is a subclass of geo:Geometry as described in the CRMGeo 1.2 specification document.

E.16. Basic Formal Ontology (BFO)

BFO Source: <https://basic-formal-ontology.org/bfo-2020.html>, and from there, an OWL ontology of BFO2020 at <https://github.com/BFO-ontology/BFO-2020>

Table E.17 – Alignment: Basic Formal Ontology (BFO)

FROM ELEMENT	MAPPING RELATION	TO ELEMENT	NOTES
geo:SpatialObject	<u>rdfs:</u> <u>subClassOf</u>	<u>obo:BFO_0000004</u> “independent continuant”	BFO’s “independent continuant” is the superclass of “material entity” & “immaterial entity” which are mapped to Feature & Geometry respectively, so at least some independent continuants must be Spatial Objects
geo:Geometry	<u>rdfs:</u> <u>subClassOf</u>	<u>obo:BFO_0000006</u> “spatial region”	BFO’s “spatial region” class is described as a “spatial projection of a portion of spacetime” so Geometry appears to be a subclass of this as it’s “A coherent set of direct positions in space”
geo:Geometry	<u>rdfs:</u> <u>subClassOf</u>	<u>obo:IAO_0000030</u> “information content entity”	BFO’s “information content entity” class is described as “an entity that represents information about some other entity”, so Geometry appears to be subclass of this as well as “spatial region” since in GeoSPARQL, Geometry gives the details of the spatial projection of a Feature.
<u>obo:BFO_0000040</u> “material entity”	<u>rdfs:</u> <u>subClassOf</u>	geo:Feature	A BFO “material entity” is something that “has some portion of matter as continuant part” and some Features are such, however Features may be imaginary too
<u>obo:BFO_0000029</u> “site”	<u>rdfs:</u> <u>subClassOf</u>	geo:Feature	BFO’s sites either cover the same areas as, or have locations determined in relation to, material entities, so sites are Features but not necessarily the other way around
geo:hasGeometry	<u>rdfs:</u> <u>subPropertyOf</u>	<u>obo:BFO_0000211</u> “occupies spatial region at all times”	The BFO property links a thing that is not a spatial region to a spatial region, so it can be used as geo:hasGeometry is used when the thing is taken to be a geo:Feature and the spatial region a geo:Geometry. No GeoSPARQL temporality indicators mean mappings are eternal.
geo:hasGeometry	<u>rdfs:</u> <u>subPropertyOf</u>	<u>obo:BFO_0000210</u> “occupies spatial region at some time”	A transitive mapping from the mapping above. Temporal qualification can be used with GeoSPARQL, see the OWL TIME alignment.
geo:sfWithin	<u>rdfs:</u> <u>subPropertyOf</u>	<u>obo:BFO_0000082</u> “located in at all times”	The BFO property “located in at all times” is a super property of geo:sfWithin when the thing located in the spatial region are defined to both be instances of geo: Feature. Since GeoSPARQL natively supplies no temporal

FROM ELEMENT	MAPPING RELATION	TO ELEMENT	NOTES
			qualifiers, pure GeoSPARQL assertions are assumed to be eternal: "...at all times"
geo:sfWithin	<u>rdfs:subPropertyOf</u>	<u>obo:BFO_0000171</u> "located in at some time"	A transitive mapping from the mapping above. Temporal qualification can be used with GeoSPARQL, see the OWL TIME alignment.
<u>obo:BFO_0000066</u> "occurs in"	<u>rdfs:range</u>	geo:SpatialObject	The BFO property relates a temporal activity to a spatial region but since GeoSPARQL has no notion of events, no mapping to this property can be made. However, BFO indicates this property should be used with a BFO "spatial region" (geo:Geometry) range value but from GeoSPARQL's point of view, it could also be used with a geo:Feature where the "in" would be taken to be within the feature's geometry, so the superclass of feature and geometry is given as the range
<u>obo:BFO_0000216</u> "spatially projects onto at some time"	<u>rdfs:range</u>	geo:SpatialObject	The reasoning is the same as for "occurs in"

- BFO distinguishes between *continuants* & *occurrents*, which *spatial region* & *spatiotemporal region* are subclasses of, respectively. GeoSPARQL has no handling of temporality, so cannot yet map to any *continuants*
 - a future version of GeoSPARQL that handled spatio-temporal Features could perhaps claim that geo:Feature is a rdfs:subClassOf obo:BFO_000011 "spatiotemporal region", however inconsistencies from this mapping will occur due to the current Feature/"spatial region" mapping above and this will need to be handled



F

ANNEX F (INFORMATIVE) CQL / GEOSPARQL MAPPING

ANNEX F (INFORMATIVE)

CQL / GEOSPARQL MAPPING

F.0. Overview

This annex presents a mapping between the Common Query Language(CQL) CQLDEF and GeoSPARQL as well as generic SPARQL SPARQL. This is likely of relevance to the delivery of GeoSPARQL data via systems such as the OGC's Web Feature Service WFS and OGC API Features OGCSFACA which implement CQL.

F.1. Accessing spatial Features in a SPARQL endpoint

Spatial *Features* accessed via SPARQL endpoints SPARQLPROT are, as defined in the GeoSPARQL standard, instances of the OWL class geo:Feature or of subclasses of it. They may have one or more geo:hasGeometry properties indicating geo:Geometry instances and other properties related to the Feature. They may also be grouped into geo:FeatureCollection instances where geo:FeatureCollection is a new class in GeoSPARQL 1.1, specifically for the description of collections of geo:Feature instances.

The following example SPARQL query retrieves all Features within the Feature Collection with the IRI ex:x within a given SPARQL endpoint.

```
PREFIX ex: <http://example.com/>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>

SELECT ?fcollection ?item ?rel ?val ?geom
WHERE {
  ex:x rdfs:member ?item .
  ?item rdfs:subClassOf* geo:Feature .
}
```

GeoSPARQL's geo:FeatureCollection definition requires that geo:Feature instances are to be linked to the Collection by use of the rdf:member property. No inverse property is defined.

NOTE: Some CQL-implementing systems, such as OGC API, have fixed notions of Feature Collections and require that Features be members of exactly one Feature Collection. There is no such restriction in GeoSPARQL: Features may be members of one or more Feature Collections.

An extension to the above can retrieve any Geometry serializations for the Features within Feature Collection ex:x:

```
PREFIX ex: <http://example.com/>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>

SELECT ?fcollection ?item ?rel ?val ?geom
WHERE {
  ex:x rdfs:member ?item .
  ?item rdfs:subClassOf* geo:Feature .

  OPTIONAL {
    ?item geo:hasGeometry/geo:hasSerialization ?geom
  }
}
```

Some additional concerns for GeoSPARQL / CQL or OGC API Features Feature Collections mappings are:

- APIs may need more information about the geo:FeatureCollection instance for correct handling, in particular, an identifier and perhaps a label. If the back-end data store also contains information for the geo:FeatureCollection instance then this may be queried for. If not, the API might need to create such data
 - One particular scenario observed is that OGC APIs require token-like identifiers for Feature Collections and GeoSPARQL IRIs, or their parts, may not be able to be used for such. In these cases, the RDF property `dcterms:identifier` may be used to store appropriate token-like identifiers
- Perhaps only data in a certain namespace is of interest. The solution is to apply FILTER expressions to the SPARQL query

F.2. Mappings from CQL2 statements to GeoSPARQL queries

This section presents lists of equivalences between Common Query Language (CQL2) CQLDEF statements and GeoSPARQL statements.

F.2.1. Query Parameters

Several query parameters may be given as parameters to the HTTP request of CD-implementing systems, such as the OGC API Features service. These parameters have an influence on the SPARQL query to be executed for the retrieval of a FeatureCollection to be exposed using an OGC API Features service.

Table F.1 – CQL To GeoSPARQL Mappings: Query Parameters

QUERY PARAMETER	EXAMPLE	SPARQL EXPRESSION	EXAMPLE	COMMENT
limit	limit=5	LIMIT	LIMIT 5	
offset	offset=10	OFFSET	OFFSET 10	
bbox	bbox= 160.6,-55.95,-170,-25.89	FILTER(geo:sfIntersects(geom, "POLYGON((160.6 -25.95, 160.6 -25.89, -170 -25.89, -170 -55.95, 160.6 -55.95))"^^geo:wktLiteral)		WKT does not define a type boundingbox, therefore a bbox is converted to a Polygon
datetime	datetime= 2018-02-12T23:3A20:3A52	-	-	GeoSPARQL doesn't detail temporal aspects of data. Filtering data using RDF temporal properties may be achieved using basic SPARQL queries and also OWL TIME TIME

F.2.2. Literal Values

CQL2 defines literal values for a variety of datatypes. The following table shows the equivalences of these values in RDF which may be used in any GeoSPARQL query.

Table F.2 – CQL To GeoSPARQL Mappings: Literal Values

CQL2 LITERAL	EXAMPLES	(GEO)SPARQL LITERAL	EXAMPLES
String	"This is a string"	<code>xsd:string</code>	"This is a string"^^xsd:string
Number	-100 3.14159	<code>xsd:int</code> , <code>xsd:integer</code> , <code>xsd:double</code>	"-100"^^xsd:integer "3.14159"^^xsd:double
Boolean	true false	<code>xsd:boolean</code>	"true"^^xsd:boolean "false"^^xsd:boolean
Spatial Geometry (WKT)	POINT(1 1)	WKT Literal	"POINT(1 1)"^^geo:wktLiteral

CQL2 LITERAL EXAMPLES	(GEO)SPARQL LITERAL	EXAMPLES
Spatial Geometry (JSON) {"type": "Point", "coordinates": [1,1]}	GeoJSON Literal	{"type": "Point", "coordinates": [1,1]}^^geo:geoJSONLiteral
Temporal Literal 1969-07-20T20:17:40Z	xsd:date, xsd:dateTime, xsd:dateTimeStamp	"1969-07-20"^^xsd:date "1969-07-20T20:17:40Z"^^xsd:dateTime

F.2.3. Property references

CQL2 allows the referencing of properties in a Feature Collection it is targeting for filtering. A property reference is converted to a triple pattern as shown in the following example. A SPARQL variable ?item is assumed to represent the Feature Collection.

Table F.3 – CQL To GeoSPARQL Mappings: Property references

PROPERTY REFERENCE	TRIPLE PATTERN
name="OGC"	?item my:name "OGC"^^xsd:string
number=5	?item my:number "5"^^xsd:integer
number>5	?item my:number ?number . FILTER(?number>5)

F.2.4. Comparison Predicates

CQL2 defines comparison predicates to compare two scalar expressions. A comparison predicate is converted to a triple pattern as shown in the following example. A SPARQL variable ?item is assumed to represent the Feature Collection.

Table F.4 – CQL To GeoSPARQL Mappings: Comparison Predicates

COMPARISON PREDICATE	TRIPLE PATTERN	COMMENT
name="OGC"	?item my:name "OGC"^^xsd:string	Equality statements can be converted to a triple pattern
number=5	?item my:number "5"^^xsd:integer	
number>5	?item my:number ?number . FILTER(?number>5)	Arithmetic comparisons (<,>, >=, <=) are converted to filter expressions

COMPARISON PREDICATE	TRIPLE PATTERN	COMMENT
number BETWEEN 5 AND 10	?item my:number ?number . FILTER(?number>=5 && ?number <= 10)	BETWEEN statements are converted to arithmetic expressions
name IN ("OGC","W3C")	?item my:name IN ("OGC", "W3C")	IN statements may also be expressed using SPARQL VALUES statements
name IS NOT NULL	EXISTS {?item my:name ?name }	NOT NULL statements are converted to EXIST statements
name LIKE "OGC."	?item my:name ?name . FILTER(regex(?name, "OGC.", "i"))	LIKE statements are converted to SPARQL regex filters
INTERSECTS(geometry1, geometry2)	FILTER(geof:sfIntersects(?geometry1,?geometry2))	The INTERSECTS filter statement is converted to a GeoSPARQL FILTER statement

There is no direct GeoSPARQL equivalent to a CRS-based CQL filter, however certain GeoSPARQL geometry literals have explicit CRS/SRS information that may be filtered using SPARQL REGEX operators.

F.2.5. Spatial Operators

GeoSPARQL includes equivalents of many CQL2 filter functions as can be seen in the table below.

Table F.5 – CQL To GeoSPARQL Mappings: Spatial Operators

CQL2 FILTER EXPRESSION	GEOSPARQL FILTER FUNCTION
CONTAINS(geometry1,geometry2)	FILTER(geof:sfContains(?geometry1,?geometry2))
CROSSES(geometry1,geometry2)	FILTER(geof:sfCrosses(?geometry1,?geometry2))
DISJOINT(geometry1,geometry2)	FILTER(geof:sfDisjoint(?geometry1,?geometry2))
EQUALS(geometry1,geometry2)	FILTER(geof:sfEquals(?geometry1,?geometry2))
INTERSECTS(geometry1,geometry2)	FILTER(geof:sfIntersects(?geometry1,?geometry2))
OVERLAPS(geometry1,geometry2)	FILTER(geof:sfOverlaps(?geometry1,?geometry2))
TOUCHES(geometry1,geometry2)	FILTER(geof:sfTouches(?geometry1,?geometry2))

CQL2 FILTER EXPRESSION	GEOSPARQL FILTER FUNCTION
WITHIN(geometry1,geometry2)	FILTER(geof:sfWithin(?geometry1,?geometry2))

F.2.6. Temporal Operators

Temporal operators are not part of the GeoSPARQL standard.

Table F.6 – CQL To GeoSPARQL Mappings: Temporal Operators

CQL2 FILTER EXPRESSION	GEOSPARQL FILTER FUNCTION
beginTime AFTER 1969-07-16T13:32:00Z	N/A
beginTime BEFORE 1969-07-16T13:32:00Z	N/A
beginTime BEGINS 1969-07-16T13:32:00Z	N/A
beginTime BEGUNBY 1969-07-16T13:32:00Z	N/A
beginTime DURING 1969-07-16T13:32:00Z	N/A
beginTime ENDEDBY 1969-07-16T13:32:00Z	N/A
beginTime ENDS 1969-07-16T13:32:00Z	N/A
beginTime MEETS 1969-07-16T13:32:00Z	N/A
beginTime METBY 1969-07-16T13:32:00Z	N/A
beginTime OVERLAPPEDBY 1969-07-16T13:32:00Z	N/A
beginTime TCONTAINS 1969-07-16T13:32:00Z	N/A
beginTime TEQUALS 1969-07-16T13:32:00Z	N/A
beginTime TOVERLAPS 1969-07-16T13:32:00Z	N/A

As noted above in Section F.2.1 Query Parameters, temporal filtering of RDF data via SPARQL queries is possible with standard SPARQL functions to compare date values ([xsd:date](#), [xsd:dateTime](#) and [xsd:dateTimeStamp](#) literals) and OWL TIME TIME may be used to assert temporal relations between objects.

F.3. Mappings from Simple Features for SQL

The following table maps the functions and properties from Simple Features for SQL OGCSFACA ISO19125-1 to GeoSPARQL.

Table F.7 – CQL To GeoSPARQL Mappings: Simple Features for SQL

SIMPLE FEATURES FOR SQL	GEOSPARQL EQUIVALENT	SINCE GEOSPARQL	RELATED PROPERTY AVAILABLE	SINCE GEOSPARQL
2.1.1.1 Basic Methods on Geometry				
Dimension(): Double	geof:dimension	-	geo:dimension	1.0
GeometryType(): Integer	Class of geometry instance	1.0	N/A	-
SRID(): Integer	geof:getSRID	1.0	N/A	-
Envelope(): Geometry	geof:envelope	1.0	geo:hasBoundingBox	1.1
AsText(): String	geof:asWKT	1.1	geo:asWKT	1.0
AsBinary(): Binary	N/A	-	N/A	-
IsEmpty(): Integer	geof:isEmpty	-	geo:isEmpty	1.0
IsSimple(): Integer	geof:isEmpty	-	geo:isSimple	1.0
Boundary(): Geometry	geof:boundary	1.0	N/A	-
2.1.1.2 Spatial Relations				
Equals(another Geometry: Geometry): Integer	geof:sfEquals	1.0	geo:sfEquals	1.0
Disjoint(another Geometry: Geometry): Integer	geof:sfDisjoint	1.0	geo:sfDisjoint	1.0
Intersects(another Geometry: Geometry): Integer	geof:sfIntersects	1.0	geo:sfIntersects	1.0

SIMPLE FEATURES FOR SQL	GEOSPARQL EQUIVALENT	SINCE GEOSPARQL	RELATED PROPERTY AVAILABLE	SINCE GEOSPARQL
Touches(another Geometry: Geometry): Integer	geof:sfTouches	1.0	geo:sfTouches	1.0
Crosses(another Geometry: Geometry): Integer	geof:sfCrosses	1.0	geo:sfCrosses	1.0
Within(another Geometry: Geometry): Integer	geof:sfWithin	1.0	geo:sfWithin	1.0
Contains(another Geometry: Geometry): Integer	geof:sfContains	1.0	geo:sfContains	1.0
Overlaps(another Geometry: Geometry): Integer	geof:sfOverlaps	1.0	geo:sfOverlaps	1.0
Relate(another Geometry: Geometry, IntersectionPattern Matrix: String): Integer	geof:relate	1.0	N/A	-
2.1.1.3 Spatial Analysis				
Buffer(distance: Double): Geometry	geof:buffer	1.0	N/A	-
ConvexHull(): Geometry	geof:convexHull	1.0	N/A	-
Intersection (anotherGeometry: Geometry): Geometry	geof:intersection	1.0	N/A	-
Union(another Geometry: Geometry): Geometry	geof:union	1.0	N/A	-
Difference(another Geometry: Geometry): Geometry	geof:difference	1.0	N/A	-
SymDifference (anotherGeometry: Geometry): Geometry	geof:symDifference	1.0	N/A	-
2.1.2.1 GeometryCollection				

SIMPLE FEATURES FOR SQL	GEOSPARQL EQUIVALENT	SINCE GEOSPARQL	RELATED PROPERTY AVAILABLE	SINCE GEOSPARQL
NumGeometries(): Integer	geof:numGeometries	-	N/A	-
GeometryN(N: Integer): Geometry	geof:geometryN	-	N/A	-
2.1.3.1 Point				
X(): Double	N/A	-	N/A	-
Y(): Double	N/A	-	N/A	-
Z(): Double (not in the SQL spec, but a logical extension)	N/A	-	N/A	-
M(): Double (not in the SQL spec, but a logical extension)	N/A	-	N/A	-
2.1.5.1 Curve				
Length(): Double	geof:length	-	geo:hasLength	1.1
StartPoint(): Point	N/A	-	N/A	-
EndPoint(): Point	N/A	-	N/A	-
IsClosed(): Integer	N/A	-	N/A	-
IsRing(): Integer	N/A	-	N/A	-
2.1.6.1 LineString				
NumPoints(): Integer	N/A	-	N/A	-
PointN(N: Integer): Point	N/A	-	N/A	-
2.1.7.1 MultiCurve				
IsClosed(): Integer	N/A	-	N/A	-
Length(): Double	geof:length	-	geo:hasLength	1.1

SIMPLE FEATURES FOR SQL	GEOSPARQL EQUIVALENT	SINCE GEOSPARQL	RELATED PROPERTY AVAILABLE	SINCE GEOSPARQL
2.1.9.1 Surface				
Area(): Double	geof:area	-	geo:hasArea	1.1
Centroid(): Point	geof:centeroid	1.1	geo:hasCentroid	1.1
PointOnSurface(): Point	N/A	-	N/A	-
2.1.10.1 Polygon				
ExteriorRing(): LineString	N/A	-	N/A	-
NumInteriorRing(): Integer	N/A	-	N/A	-
InteriorRingN(N: Integer): LineString	N/A	-	N/A	-
2.1.11.1 MultiSurface				
Area(): Double	geof:area	-	geo:hasArea	1.1
Centroid(): Point	geof:centeroid	1.1	geo:hasCentroid	1.1
PointOnSurface(): Point	N/A	-	N/A	-



G

ANNEX G (INFORMATIVE) REVISION HISTORY

ANNEX G (INFORMATIVE) REVISION HISTORY

Table G.1 – Revision History

DATE	RELEASE	AUTHOR	PARAGRAPH MODIFIED	DESCRIPTION
27 Oct. 2009	Draft	Matthew Perry	Clause 6	Technical Draft
11 Nov. 2009	Draft	John R. Herring	All	Creation
06 Jan. 2010	Draft	John R. Herring	All	Comment responses
30 March 2010	Draft	Matthew Perry	All	Comment responses
26 Oct. 2010	Draft	Matthew Perry	All	Revision based on working group discussion
28 Jan. 2011	Draft	Matthew Perry	All	Revision based on working group discussion
18 April 2011	Draft	Matthew Perry	All	Restructure with multiple conformance classes
02 May 2011	Draft	Matthew Perry	Clause 6 and Clause 8	Move Geometry Class from core to geometryExtension
05 May 2011	Draft	Matthew Perry	All	Update URIs
13 Jan. 2012	Draft	Matthew Perry	All	Revision based on Public RFC
16 April 2012	Draft	Matthew Perry	All	Revision based on adoption vote comments
19 July 2012	1.0	Matthew Perry	All	Revision of URIs based on OGC Naming Authority recommendations
09 Oct. 2020	1.1 Draft	Joseph Abhayaratna	All	Establishment of the 1.1 Specification
10 Oct. 2020 to 02 June. 2022	1.1 Draft	GeoSPARQL 1.1 SWG	All	Addition of GeoSPARQL 1.1 elements

DATE	RELEASE	AUTHOR	PARAGRAPH MODIFIED	DESCRIPTION
23 Oct. 2022	1.1 For Public Comment	Carl Reed, Joseph Abhayaratna	All	Final review prior to public comment



BIBLIOGRAPHY



BIBLIOGRAPHY

- [1] Car NJ, Homburg T: GeoSPARQL 1.1: Motivations, Details and Applications of the Decadal Update to the Most Important Geospatial LOD Standard. *ISPRS International Journal of Geo-Information* vol. 11 (2022).
- [2] Clementini E, Di Felice P, van Oosterom P: A small set of formal topological relationships suitable for end-user interaction. In: p. 277. Springer Berlin Heidelberg, Berlin, Heidelberg. (1993).
- [3] Egenhofer MJ: A Formal Definition of Binary Topological Relationships. In: p. 457–472. Springer-Verlag, Berlin, Heidelberg. (1989).
- [4] Randell DA, Cui Z, Cohn AG: A spatial logic based on regions and connection. In: p. 165–176. Morgan Kaufmann Publishers Inc., San Francisco, CA, USA. (1992).
- [5] Clementini E, Cohn AG: Extension of RCC*-9 to Complex and Three-Dimensional Features and Its Reasoning System. *ISPRS International Journal of Geo-Information* vol. 13 (2024).
- [6] AusPIX: An Australian Government implementation of the rHEALPix DGGS in Python. Geoscience Australia, n.p. (2020).
- [7] Egenhofer M, Herring J: Categorizing binary topological relations between regions, lines and points in geographic databases, the 9-intersection: Formalism and its Use for Naturallanguage Spatial Predicates. *Santa Barbara CA National Center for Geographic Information and Analysis Technical Report* vol. 94, p. 1 (1990).
- [8] Open Geospatial Consortium: CHARTER, OGC GeoSPARQL SWG Charter. (2020). https://github.com/opengeospatial/ogc-geosparql/blob/master/charter/swg_charter.pdf.
- [9] Open Geospatial Consortium: CQLDEF, OGC API – Features – Part 3: Filtering and the Common Query Language (CQL2). (2021a). <https://docs.ogc.org/DRAFTS/19-079r1.html>.
- [10] Douglas DH, Peucker TK: ALGORITHMS FOR THE REDUCTION OF THE NUMBER OF POINTS REQUIRED TO REPRESENT A DIGITIZED LINE OR ITS CARICATURE. *Cartographica: The International Journal for Geographic Information and Geovisualization* vol. 10, p. 112 (1973).
- [11] Butler H, Daly M, Doyle A, Gillies S, Schaub T, Hagen S: GEOJSON, The GeoJSON Format. RFC Editor (2016). <https://www.rfc-editor.org/info/rfc7946>.
- [12] Crocker D, Overell P: IETF5234, Augmented BNF for Syntax Specifications: ABNF. RFC Editor (2008). <https://www.rfc-editor.org/info/rfc5234>.

- [13] International Organization for Standardization: ISO13249, *Information technology – Database languages – SQL multimedia and application packages – Part 3: Spatial*. Geneva, CH (2000a). <https://www.iso.org/standard/31369.html>.
- [14] International Organization for Standardization: ISO19105, *Geographic information – Conformance and testing*. Geneva, CH (2000b). <https://www.iso.org/standard/26010.html>.
- [15] International Organization for Standardization: ISO19107, *Geographic information – Spatial schema*. Geneva, CH (2018). <https://www.iso.org/standard/66175.html>.
- [16] International Organization for Standardization: ISO19109, *Geographic information – Rules for application schemas*. Geneva, CH (2005b). <https://www.iso.org/standard/39891.html>.
- [17] Kellogg G, Longley D, Champin P: JSON-LD, JSON-LD 1.1. (2020). <https://www.w3.org/TR/2020/REC-json-ld11-20200716/>.
- [18] Open Geospatial Consortium: OGCSFACA, *OpenGIS Implementation Specification for Geographic information – Simple feature access – Part 1: Common architecture*. (2011). https://portal.ogc.org/files/?artifact_id=25355.
- [19] Car N: PROF, *The Profiles Vocabulary*. (2019). <https://www.w3.org/TR/2019/NOTE-dx-prof-20191218/>.
- [20] Cohn AG, Brandon B, Gooday J, Mark Gotts N: A small set of formal topological relationships suitable for end-user interaction. In: vol. 1, p. 275. *GeoInformatica*, Berlin, Heidelberg. (1997).
- [21] Patel-Schneider P, Hayes P: RDFSEM, *RDF 1.1 Semantics*. (2014). <https://www.w3.org/TR/2014/REC-rdf11-mt-20140225/>.
- [22] Gandon F, Schreiber G: RDFXML, *RDF 1.1 XML Syntax*. (2014). <https://www.w3.org/TR/2014/REC-rdf-syntax-grammar-20140225/>.
- [23] Boley H, Kifer M: RIF, *RIF Overview (Second Edition)*. (2013). <https://www.w3.org/TR/2013/NOTE-rif-overview-20130205/>.
- [24] Knublauch H, Kontokostas D: SHACL, *Shapes Constraint Language (SHACL)*. (2017). <https://www.w3.org/TR/2017/REC-shacl-20170720/>.
- [25] Miles A, Bechhofer S: SKOS, *SKOS Simple Knowledge Organization System Reference*. (2009). <https://www.w3.org/TR/2009/REC-skos-reference-20090818/>.
- [26] Williams G: SPARQLSERVDESC, *SPARQL 1.1 Service Description*. (2013). <https://www.w3.org/TR/2013/REC-sparql11-service-description-20130321/>.
- [27] Cox S, Little C: TIME, *Time Ontology in OWL*. (2022). <https://www.w3.org/TR/2022/CRD-owl-time-20221115/>.
- [28] Carothers G, Prud'hommeaux E: TURTLE, *RDF 1.1 Turtle*. (2014). <https://www.w3.org/TR/2014/REC-turtle-20140225/>.

- [29] International Organization for Standardization: WFS, *Geographic information – Spatial schema*. Geneva, CH (2010). <https://www.iso.org/standard/42136.html>.
- [30] Bray T, Yergeau F, Sperberg-McQueen M, Paoli J, Maler E: XML, Extensible Markup Language (XML) 1.0 (Fifth Edition). (2008). <https://www.w3.org/TR/2008/REC-xml-20081126/>.
- [31] Layman A, Thompson H, Hollander D, Bray T, Tobin R: XMLNS, Namespaces in XML 1.0 (Third Edition). (2009). <https://www.w3.org/TR/2009/REC-xml-names-20091208/>.
- [32] Thompson H, Beech D, Mendelsohn N, Maloney M: XSD1, XML Schema Part 1: Structures Second Edition. (2004). <https://www.w3.org/TR/2004/REC-xmlschema-1-20041028/>.
- [33] Malhotra A, Biron PV: XSD2, XML Schema Part 2: Datatypes Second Edition. (2004). <https://www.w3.org/TR/2004/REC-xmlschema-2-20041028/>.
- [34] Open Geospatial Consortium: OGC12-007r2, OGC KML 2.3. (2013). <http://www.opengis.net/doc/IS/kml/2.3>.
- [35] International Organization for Standardization: ISO10303-21, *Industrial automation systems and integration – Product data representation and exchangePart 21: Implementation methods: Clear text encoding of the exchange structure*. Geneva, CH (2000c). <https://www.iso.org/standard/33713.html>.
- [36] Open Geospatial Consortium: OGC07-036, *OpenGIS Geography Markup Language (GML) Encoding Standard*. (2007b). https://portal.ogc.org/files/?artifact_id=20509.
- [37] Open Geospatial Consortium: OGC20-040r3, *Abstract Standard Topic 21 – Discrete Global Grid Systems – Part 1 Core Reference system and Operations and Equal Area Earth Reference System*. (2021b). <https://docs.ogc.org/as/20-040r3/20-040r3.html>.
- [38] Open Geospatial Consortium: OGC17-069r3, *OGC API – Features – Part 1: Core*. (2019). <http://www.opengis.net/doc/IS/ogcapi-features-1/1.0>.