



OGC GEOSPARQL - A GEOGRAPHIC QUERY LANGUAGE FOR RDF DATA

STANDARD
Profile

DRAFT

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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 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 8.3.

III

SECURITY CONSIDERATIONS

No security considerations have been made for this document.

IV

SUBMITTERS

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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

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_Coordinate_Reference_Systems_on_geometric_computations].

V. CHANGES TO THE OGC® ABSTRACT SPECIFICATION

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

SUBMITTING ORGANIZATIONS

The following organizations submitted this Document to the Open Geospatial Consortium (OGC):

- CSIRO
- Cubewerx Inc
- Defence Science and Technology Laboratory (DSTL)
- Geonovum
- Geoscape Australia
- Geoscience Australia
- Mainz University Of Applied Sciences
- Oracle America
- OSGeo
- SURROUND Australia Pty Ltd.

1

SCOPE

SCOPE

The OGC GeoSPARQL Standard is comprised of multiple parts. See the Introduction section Clause 8.3 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 specification shall be checked using all the relevant tests specified in [Abstract_Test_Suite_normative_]. 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 Clause 12.2, Definition List 3: [ISO19105].

This document establishes several requirements classes and corresponding conformance classes (a conformance class is a set of tests for each requirement in a requirements class). Any GeoSPARQL implementation claiming conformance with one of the conformance classes shall pass all the tests in the associated abstract test suite.

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

Many Conformance Classes are parameterized. For parameterized conformance classes, the list of parameters is given within parenthesis.

Table 1 – Conformance Classes

CONFORMANCE CLASS	DESCRIPTION	SUBCLAUSE OF THE ABSTRACT TEST SUITE
Core	Defines top-level spatial vocabulary components	Conformance class 1: /conf/core
Topology Vocabulary Extension (relation_family)	Defines topological relation vocabulary	Conformance class 2: /conf/topology-vocab-extension
Geometry Extension (serialization, version)	Defines geometry vocabulary and non-topological query functions	Conformance class 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 4: /conf/geometry-extension-dggs
Geometry Topology Extension (serialization, version, relation_family)	Defines topological query functions for geometry objects	Conformance class 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 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 7: /conf/query-rewrite-extension

Dependencies between each GeoSPARQL requirements class are shown below in Figure 2. To support a requirements class for a given set of parameter values, an implementation must support each dependent requirements 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.

ISO: ISO 19125-1, *Geographic information – Simple feature access – Part 1: Common architecture*. International Organization for Standardization, Geneva <https://www.iso.org/standard/40114.html>.

ISO: ISO 19156, *Geographic information – Observations, measurements and samples*. International Organization for Standardization, Geneva <https://www.iso.org/standard/82463.html>.

[NO INFORMATION AVAILABLE]

M. Duerst, M. Suignard: IETF RFC 3987, *Internationalized Resource Identifiers (IRIs)*. RFC Publisher (2005). <https://www.rfc-editor.org/info/rfc3987>.

World Wide Web Consortium: *OWL 2 Web Ontology Language Document Overview (Second Edition)*, W3C Recommendation (11 December 2012). <https://www.w3.org/TR/owl2-overview/>

World Wide Web Consortium: *RDF 1.1 Concepts and Abstract Syntax*, W3C Recommendation (25 February 2014). <https://www.w3.org/TR/rdf11-concepts/>

World Wide Web Consortium: *RDF Schema 1.1*, W3C Recommendation (25 February 2014). <https://www.w3.org/TR/rdf-schema/>

World Wide Web Consortium: *RIF Core Dialect (Second Edition)*, W3C Recommendation (5 February 2013) <http://www.w3.org/TR/rif-core/>

World Wide Web Consortium: *SPARQL 1.1 Query Language*, W3C Recommendation (21 March 2013). <https://www.w3.org/TR/sparql11-query/>

World Wide Web Consortium: *SPARQL 1.1 Entailment Regimes*, W3C Recommendation (21 March 2013). <https://www.w3.org/TR/sparql11-entailment/>

World Wide Web Consortium: *SPARQL 1.1 Protocol*, W3C Recommendation (21 March 2013) <http://www.w3.org/TR/sparql11-protocol/>

World Wide Web Consortium: *SPARQL Query Results XML Format (Second Edition)*, W3C Recommendation (21 March 2013). <https://www.w3.org/TR/rdf-sparql-XMLres/>

World Wide Web Consortium: *SPARQL 1.1 Query Results JSON Format*, W3C Recommendation (21 March 2013). <http://www.w3.org/TR/sparql11-results-json/>

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

FOREWORD

FOREWORD

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. Open Geospatial Consortium shall not be held responsible for identifying any or all such patent rights. However, to date, no such rights have been claimed or identified.

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 specification set forth in this document, and to provide supporting documentation.

7

CONVENTIONS

7.1. 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 (http://www.w3.org/)
XML	Extensible Markup Language

7.2. Namespaces

The following IRI namespace prefixes are used throughout this document:

ex:	http://example.com/	A non-resolving namespace for examples
geo:	http://www.opengis.net/ont/geosparql#	GeoSPARQL Ontology
geof:	http://www.opengis.net/def/function/geosparql/	GeoSPARQL Functions
geor:	http://www.opengis.net/def/rule/geosparql/	GeoSPARQL Rules
gml:	http://www.opengis.net/ont/gml#	[GML] vocabulary
my:	http://example.org/ApplicationSchema#	Example application schema
ogc:	http://www.opengis.net/	OGC placeholder
owl:	http://www.w3.org/2002/07/owl#	OWL2 ontology
rdf:	http://www.w3.org/1999/02/22-rdf-syntax-ns#	RDF ontology
rdfs:	http://www.w3.org/2000/01/rdf-schema#	RDFS ontology
sf:	http://www.opengis.net/ont/sf#	Simple Features vocabulary
skos:	http://www.w3.org/2004/02/skos/core#	Clause 12.2, Definition List 3: [SKOS] ontology
xsd:	http://www.w3.org/2001/XMLSchema#	Clause 12.2, Definition List 3: [XSD2] datatypes vocabulary

7.3. 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. [<http://www.opengis.net/ont/geosparql#wktLiteral>](http://www.opengis.net/ont/geosparql#wktLiteral).

7.4. RDF Serializations

Three RDF serializations are used in this document. Terse RDF Triple Language (turtle) Clause 12.2, Definition List 3: [TURTLE] is used for RDF snippets placed within the main body of the document, and turtle, JSON-LD Clause 12.2, Definition List 3: [JSON-LD] & RDF/XML Clause 12.2, Definition List 3: [RDFXML] is used for the examples in *Annex B – GeoSPARQL Examples*.

8

INTRODUCTION

INTRODUCTION

The W3C Semantic Web Activity is defining 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 RDF (Resource Description Framework) data model RDF, RDFS, the OWL Web Ontology Language OWL2 and the SPARQL protocol and RDF query language SPARQL.

8.1. RDF

RDF is, among other things, a data model built on edge-node “graphs.” Each link in a graph consists of three things (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)
- 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 a Internationalized Resource Identifier (IRI) [IETF3987], which globally and uniquely identifies the resource referenced. IRIs are an extension to Universal Resource Identifiers (URIs) that allow for non-ASCII characters. In addition to functioning as identifiers, IRIs are usually, but not necessarily, resolvable which means a person or machine can “dereference” them (*click on them* or otherwise action 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 with meaning outside the graph it is defined within). Objects can further be represented with a literal value. Basic literal values in RDF are those used in XML Clause 12.2, Definition List 3: [XSD2] but the basic types can be extended for specialised purposes and in this specification are, for 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, it is similar to the (feature-instance-by-id, attribute, value) tuples of the General Feature Model Clause 12.2, Definition List 3: [ISO19109], and for the relational model as (table primary key, column, value).

8.2. 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.

and, from Wikipedia¹:

SPARQL (pronounced “sparkle” /'spa:kəl/, 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

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

stored in Resource 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. The SPARQL specification SPARQL in section 17.6² 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, and it defines extensions to the SPARQL query language for processing geospatial data.

8.3. GeoSPARQL Standard structure

The GeoSPARQL standard comprises multiple parts, or *profile* resources. The comprehensive listing of them is given not here but in the standard’s *profile definition*, see <http://www.opengis.net/def/geosparql>. Here 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* Clause 12.2, Definition List 3: [PROF]
 - this relates the parts in the standard together, provides access to them, and declares dependencies on other standards
2. *specification document*

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

- <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 Clause 12.2, Definition List 3: [ISO19109], Simple Features ISO 19125-1 and SQL MM Clause 12.2, Definition List 3: [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 Clause 12.2, Definition List 3: [ISO19109], Simple Features Access ISO 19125-1, Feature Geometry Clause 12.2, Definition List 3: [ISO19107] and SQL MM Clause 12.2, Definition List 3: [ISO13249]
 - defined within the specification document and delivered in RDF also
4. Functions & Rules vocabulary
- <http://www.opengis.net/def/geosparql/funcsrules>
 - derived from the ontology
 - presented as a Clause 12.2, Definition List 3: [SKOS] taxonomy
5. Simple Features vocabulary
- <http://www.opengis.net/ont/sf>
 - derived from Simple Features Access ISO 19125-1's class model
 - presented as an [_owl] ontology
6. SPARQL SPARQL extension functions
- defined within this specification document
7. RIF RIFCORE rules
- <http://www.opengis.net/def/geosparql/rifrules>

- templated within the specification document
- also delivered as a RIF document also

8. RDF data validator

- <http://www.opengis.net/def/geosparql/validator>
- defined using SHACL Clause 12.2, Definition List 3: [SHACL]
- presented within a single RDF file

This specification 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 relations between spatial objects
- a *geometry* component defines 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 relation between two features into an equivalent query involving concrete geometries and topological query functions

Each of these specification components forms a *requirements class* (a set of requirements) for GeoSPARQL. Implementations can provide various levels of functionality by choosing which requirements classes to support. For example, a system based purely on qualitative spatial reasoning may support only the core and topological vocabulary components.

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 the Region Connection Calculus Clause 12.2, Definition List 3: [QUAL], Clause 12.2, Definition List 3: [LOGIC]) 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 relations 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 relations 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.

9

CORE

This clause establishes the **Core** requirements class, with IRI /req/core, which has a single corresponding conformance class, **Core**, with IRI /conf/core. This requirements class defines 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.

REQUIREMENTS CLASS 1: CORE EXTENSION

IDENTIFIER	/req/core
TARGET TYPE	Implementation Specification
CONFORMANCE CLASS	Conformance class 1: /conf/core
	/req/core/sparql-protocol
	/req/core/spatial-object-class
	/req/core/feature-class
REQUIREMENT	/req/core/spatial-object-collection-class
	/req/core/feature-collection-class
	/req/core/geometry-collection-class
	/req/core/spatial-object-properties

9.1. 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.

9.2. Classes

Two main classes are defined: geo:SpatialObject and geo:Feature. The class geo:Feature is equivalent to the UML class Feature defined in Clause 12.2, Definition List 3: [ISO19109].

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

9.2.1. 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";
.
```

9.2.2. Class: geo:Feature

The class `geo:Feature` is equivalent to the class GFI_Feature ISO 19156 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
Features
  a river or an apple. While such phenomena (and therefore the
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 geo:Feature to be used in SPARQL graph patterns.

9.2.3. Class: geo:SpatialObjectCollection

The class geo:SpatialObjectCollection 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 geo:SpatialObjectCollection to be used in SPARQL graph patterns.

9.2.4. 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 ;
  rdfs:subClassOf [
    a owl:Restriction ;
```

```

owl:allValuesFrom :Feature ;
owl:onProperty rdfs:member ;
] ;
.

```

Membership of the more general Spatial Object Collection that defines this class is restricted to instances of Feature. geo:FeatureCollection members are to be indicated with the rdfs:member property.

REQUIREMENT 5: FEATURE COLLECTION CLASS

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

9.3. 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.

9.3.1. 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) cannot 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 ;
.

```

9.3.2. 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 cannot 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 ;
.

```

9.3.3. 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 ;
.

```

9.3.4. 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 ;
.
```

9.3.5. 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 ;
.
```

9.3.6. 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)
}
```

9.3.7. 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 ;
.
```

9.3.8. 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)
}

```

9.3.9. 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 ;
.

```

9.3.10. 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)
}

```

9.4. Standard Properties for geo:Feature

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

REQUIREMENT 7: FEATURE PROPERTIES

IDENTIFIER /req/geometry-extension/feature-properties

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

9.4.1. Property: geo:hasGeometry

The property `geo:hasGeometry` is used to link a Feature with a Geometry that represents its spatial extent. A given Feature may have many associated geometries.

```
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 ;
```

9.4.2. 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.

9.4.3. Property: `geo:hasBoundingBox`

The property `geo:hasBoundingBox` is used to link a Feature with a simplified geometry-representation corresponding to the envelope of its 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.

9.4.4. 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.

10

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 RCC8 and Egenhofer. These relations are generalized so that they may connect features as well as geometries.

REQUIREMENTS CLASS 2: TOPOLOGY VOCABULARY EXTENSION

IDENTIFIER	<code>/req/topology-vocab-extension</code>
TARGET TYPE	Implementation Specification
CONFORMANCE CLASS	Conformance class 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 Clause 12.2, Definition List 3: [DE-9IM] 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 Clause 12.2, Definition List 3: [OGCSFACA] ISO 19125-1 for a more detailed description of DE-9IM intersection patterns.

10.1. Parameters

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

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

10.2. 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: SpatialObject	All	(TFFFFFFFFFF)
disjoint	geo:sfDisjoint	geo: SpatialObject	All	(FF***FF****)
intersects	geo: sfIntersects	geo: SpatialObject	All	(T***** *T***** ***T***** ****T****)
touches	geo:sfTouches	geo: SpatialObject	All except P/P	(FT***** F**T***** F***T****)
within	geo:sfWithin	geo: SpatialObject	All	(T*F**F***)
contains	geo:sfContains	geo: SpatialObject	All	(T*****FF*)
overlaps	geo:sfOverlaps	geo: SpatialObject	A/A, P/P, L/L	(T*T***T**) for A/A, P/P; (1*T***T**) for L/L
crosses	geo:sfCrosses	geo: SpatialObject	P/L, P/A, L/A, L/L	L/A(T*T***T**) for P/L, P/A, L/A; (0******) for L/L

10.3. 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 Clause 12.2, Definition List 3: [FORMAL] and Clause 12.2, Definition List 3: [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: SpatialObject	All	(TFFFFFFFFFF)
disjoint	geo:ehDisjoint	geo: SpatialObject	All	(FF*FF*****)
meet	geo:ehMeet	geo: SpatialObject	All except P/P	(FT***** F**T***** F***T****)
overlap	geo:ehOverlap	geo: SpatialObject	All	(T*T***T**)
covers	geo:ehCovers	geo: SpatialObject	A/A, A/L, L/L	(T*TFT*FF*)
covered by	geo:ehCoveredBy	geo: SpatialObject	A/A, L/A, L/L	(TFF*TFT**)*)
inside	geo:ehInside	geo: SpatialObject	All	(TFF*FFT**)
contains	geo:ehContains	geo: SpatialObject	All	(T*TFF*FF*)

10.4. RCC8 Relation Family

This clause defines Requirements for the region connection calculus basic 8 (RCC8) relation family. The reader should consult references Clause 12.2, Definition List 3: [QUAL] and Clause 12.2, Definition List 3: [LOGIC] for a more detailed discussion of RCC8 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.

Table 4 – RCC8 Topological Relations

RELATION NAME	RELATION IRI	DOMAIN/RANGE	APPLIES TO GEOMETRY TYPES	DE-9IM INTERSECTION PATTERN
equals	geo:rcc8eq	geo: SpatialObject	A/A	(TFFFFFFFFFF)
disconnected	geo:rcc8dc	geo: SpatialObject	A/A	(FFTFFFTTTT)
externally connected	geo:rcc8ec	geo: SpatialObject	A/A	(FFTFTTTTTT)
partially overlapping	geo:rcc8po	geo: SpatialObject	A/A	(TTTTTTTTTT)
tangential proper part inverse	geo:rcc8tppi	geo: SpatialObject	A/A	(TTTFTTTFFT)
tangential proper part	geo:rcc8tpp	geo: SpatialObject	A/A	(TFFTTFTTTT)
non-tangential proper part	geo:rcc8ntpp	geo: SpatialObject	A/A	(TFFTFFTTTT)
non-tangential proper part inverse	geo:rcc8ntppi	geo: SpatialObject	A/A	(TTTFFTFFFT)

10.5. Equivalent RCC8, Egenhofer and Simple Features Topological Relations

Table 5 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 5 – Equivalent Simple Features, RCC8 and Egenhofer relations

SIMPLE FEATURES	RCC8	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 + coveredBy
contains	non-tangential proper part inverse + tangential proper part inverse	contains + covers
overlaps	partially overlapping	overlap

11

GEOMETRY EXTENSION

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 3: GEOMETRY EXTENSION

IDENTIFIER	<code>/req/geometry-extension</code>
TARGET TYPE	Implementation Specification
CONFORMANCE CLASS	Conformance class 3: <code>/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(sa-functions</code>
REQUIREMENT	<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> <code>/req/geometry-extension(gml-literal-empty</code>

REQUIREMENTS CLASS 3: GEOMETRY EXTENSION

```
/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
```

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.

11.1. 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

³<http://www.w3.org/2003/01/geo/>

⁴<http://purl.org/dc/terms/Location>

named place.” and schema.org provides a number of spatial object and geometry classes, such as GeoCoordinates⁵ and GeoShape⁶.

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 Clause 12.2, Definition List 3: [CHARTER] contains references to a number of vocabularies/ontologies that were influential in the generation of this version of GeoSPARQL.

11.2. 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 Clause 12.2, Definition List 3: [OGCSFACA]. Contrary to what the name may imply, SFA-CA is about Geometry and not about Features. SFA-CA describes simple geometry, 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

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>

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 Clause 12.2, Definition List 3: [OGCKML] or the GeoJSON format. For example, neither KML nor GeoJSON support the Triangulated Integrated Network (TIN) or Triangle geometry types.

11.3. 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.

11.4. 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.

⁹<http://www.qudt.org>

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

11.5. 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* Clause 12.2, Definition List 3: [OGCSFACA] ISO 19125-1; the GML serialization aligns the geometry types with *ISO 19107 Spatial Schema* Clause 12.2, Definition List 3: [ISO19107].

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

11.6. 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.

11.6.1. Class: geo:Geometry

The class `geo:Geometry` is conceptually derived from UML class `Geometry` in Clause 12.2, Definition List 3: [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 11: GEOMETRY CLASS

IDENTIFIER	/req/geometry-extension/geometry-class
STATEMENT	Implementations shall allow the RDFS class geo:Geometry to be used in SPARQL graph patterns.

11.6.2. 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 ;
  rdfs:subClassOf [
    a owl:Restriction ;
    owl:allValuesFrom geo:Geometry ;
    owl:onProperty rdfs:member ;
  ] ;
```

Membership of the general Spatial Object Collection that defines this class is restricted to instances of Geometry. geo:GeometryCollection members are to be indicated with the rdfs:member property.

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 12: GEOMETRY COLLECTION CLASS

IDENTIFIER	/req/core/geometry-collection-class
------------	-------------------------------------

REQUIREMENT 12: GEOMETRY COLLECTION CLASS

STATEMENT

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

11.7. Standard Properties for geo:Geometry

Properties are defined for describing geometry metadata.

REQUIREMENT 13: 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:isEmpty, geo:isSimple and geo:hasSerialization to be used in SPARQL graph patterns.

11.7.1. 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 ;
.
```

11.7.2. 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 ;
.
```

11.7.3. 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 ;
.
```

11.7.4. 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 [Recommendation_for_specification_of_units_of_measurement].

11.7.5. 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 ;
.
```

11.7.6. 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 [Recommendation_for_specification_of_units_of_measurement].

11.7.7. 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 ;
.
```

11.7.8. 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 ;
```

11.7.9. 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 ;
```

11.7.10. Property: geo:hasSerialization

The property `geo:hasSerialization` is defined to connect a Geometry with its text-based serialization (e.g., its WKT serialization).

```
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:Literal ;
```

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 serializations of common types with geometries, for example as GeoJSON which can be used for GeoJSON Clause 12.2, Definition List 3: [GEOJSON] literals.

11.8. 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) Clause 12.2, Definition List 3: [OGCSFACA] ISO 19125-1 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.

11.8.1. 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* Clause 12.2, Definition List 3: [OGCSFACA] ISO 19125-1. It defines one RDFS Datatype: WKT Literal and one property, as WKT.

11.8.1.1. 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 14: 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 Clause 12.2, Definition List 3: [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 Clause 12.2, Definition List 3: [ISO13249].

The following ABNF Clause 12.2, Definition List 3: [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 Clause 12.2, Definition List 3: [IETF5234]. geometry-data is the Well-Known Text representation of the Geometry, defined in Clause 12.2, Definition List 3: [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 15: 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 16: 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 17: EMPTY WKT LITERAL

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

REQUIREMENT 17: EMPTY WKT LITERAL

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

11.8.1.2. Property: geo:asWKT

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

REQUIREMENT 18: 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 ;
  .
```

11.8.1.3. 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 19: ASWKT FUNCTION

IDENTIFIER	/req/geometry-extension/asWKT-function
STATEMENT	Implementations shall support geof:asWKT as a SPARQL extension function.

11.8.2. 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.

11.8.2.1. 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 20: 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\"/>
  xmlns:gml=\"http://www.opengis.net/gml/3.2\"
  <gml:pos>-83.38 33.95</gml:pos>
</gml:Point>
"""\^<http://www.opengis.net/ont/geosparql#gmlLiteral>
```

REQUIREMENT 21: EMPTY GML LITERAL

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

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

REQUIREMENT 22: GML PROFILE

IDENTIFIER /req/geometry-extension/gml-profile

REQUIREMENT 22: GML PROFILE

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

11.8.2.2. Property: geo:asGML

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

REQUIREMENT 23: 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 ;
.
```

11.8.2.3. 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 24: ASGML FUNCTION

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

11.8.3. GeoJSON

This section establishes a Requirements class for representing Geometry data in RDF based on Geographic JavaScript Object Notation (GeoJSON) as defined by Clause 11.8.3. It defines one RDFS Datatype: GeoJSON Literal and one property, as GeoJSON.

11.8.3.1. 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 Clause 12.2, Definition List 3: [GEOJSON].

REQUIREMENT 25: 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 Clause 12.2, Definition List 3: [GEOJSON].

REQUIREMENT 26: 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 27: 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 .

11.8.3.2. Property: geo:asGeoJSON

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

REQUIREMENT 28: ASGEOJSON PROPERTY

IDENTIFIER	/req/geometry-extension/geometry-as-geojson-literal
STATEMENT	Implementations shall allow the RDF property <code>geo:asGeoJSON</code> 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 ;
```

.

11.8.3.3. 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 29: ASGEOJSON FUNCTION

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

11.8.4. Keyhole Markup Language

This section establishes the Requirements class for representing Geometry data in RDF based on KML as defined by Clause 12.2, Definition List 3: [OGCKML]. It defines one RDFS Datatype: KML Literal and one property, as KML.

11.8.4.1. 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 Clause 12.2, Definition List 3: [OGCKML].

REQUIREMENT 30: 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 Clause 12.2, Definition List 3: [OGCKML].

REQUIREMENT 31: 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 32: 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 .

11.8.4.2. Property: geo:asKML

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

REQUIREMENT 33: 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 ;
.
```

11.8.4.3. 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 34: ASKML FUNCTION

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

11.8.5. Discrete Global Grid System

REQUIREMENTS CLASS 4: GEOMETRY DGGS EXTENSION

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

REQUIREMENTS CLASS 4: GEOMETRY DGGS EXTENSION

TARGET TYPE	Implementation Specification
CONFORMANCE CLASS	Conformance class 4: /conf/geometry-extension-dggs
	/req/geometry-extension-dggs/query-functions
	/req/geometry-extension-dggs/query-functions-non-sf
	/req/geometry-extension-dggs/srid-function
	/req/geometry-extension-dggs/sa-functions
REQUIREMENT	/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>.

11.8.5.1. 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 35: 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 Clause 12.2, Definition List 3: [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 Clause 12.2, Definition List 3: [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 36: 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 Clause 12.2, Definition List 3: [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.

11.8.5.2. Property: geo:asDGGS

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

REQUIREMENT 37: ASDGGS PROPERTY

IDENTIFIER	/req/geometry-extension-dggs/geometry-as-dggs-literal
STATEMENT	Implementations shall allow the RDF property <code>geo:asDGGS</code> 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 ;
```

.

11.8.5.3. Function: geof:asDGGS

```
geof:asDGGS (geom: ogc:geomLiteral, specificDggsDatatype: xsd:anyURI):
  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.

REQUIREMENT 38: ASDGGS FUNCTION

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

11.9. Non-topological Query Functions

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

REQUIREMENT 39: 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: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 as SPARQL extension functions, consistent with definitions of these functions in Simple Features Clause 12.2, Definition List 3: [OGCSFACA] ISO 19125-1, for non-DGGS geometry literals.

REQUIREMENT 40: 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:geometryN, geof:maxX, geof:maxY, geof:maxZ, geof:minX, geof:minY, geof:minZ and geof:numGeometries as SPARQL extension functions which are defined in this standard, for non-DGGS geometry literals.

NOTE: The Requirements to support non-topological query functions for DGGS geometry literals are separated from the Requirements to support them for traditional geometry literals as it is expected that implementing these functions for DGGS literals will be significantly more difficult. This is due to the novelty of DGGS literals and thus the lack of existing software libraries for their manipulation.

REQUIREMENT 41: DGGS QUERY FUNCTIONS (SIMPLE FEATURES)

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

STATEMENT

Implementations shall support the functions of Requirement 39 for DGGS geometry literals as SPARQL extension functions, in a manner which is consistent with definitions of these functions in Simple Features Clause 12.2, Definition List 3: [OGCSFACA] ISO 19125-1, for non-DGGS geometry literals.

REQUIREMENT 42: DGGS QUERY FUNCTIONS (NON SIMPLE FEATURES)

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

REQUIREMENT 42: DGGS QUERY FUNCTIONS (NON SIMPLE FEATURES)

STATEMENT	Implementations shall support the functions of Requirement 40 for DGGS geometry literals as SPARQL extension functions which are defined in this standard, for non-DGGS geometry literals.
-----------	--

Functions from this Requirements class are listed below, alphabetically.

11.9.1. 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; or
- 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.

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

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 specification of units of measurement. Also, the OGC has recommended units of measure vocabularies for use, see the OGC Definitions Server¹².

11.9.2. 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.

11.9.3. Function: geof:area

`geof:area (geom: ogc:geomLiteral, units: rdfs:Resource): xsd:double`

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 specification of units of measurement.

11.9.4. 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`.

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

¹²<https://www.ogc.org/def-server>

11.9.5. 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`.

11.9.6. 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.

11.9.7. 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 specification of units of measurement.

11.9.8. Function: geof:centroid

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

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

11.9.9. 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`.

11.9.10. 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.

11.9.11. Function: geof:coordinateDimension

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

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

11.9.12. 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`.

11.9.13. 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.

11.9.14. 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.

11.9.15. 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 specification of units of measurement.

11.9.16. 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.

11.9.17. Function: `geof:geometryN`

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

The function `geof:geometryN` returns the nth 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.

11.9.18. 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.

11.9.19. 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.

11.9.20. Function: `geof:is3D`

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

The function `geof:is3D` Returns true if geom has z coordinate values. See [[_GeoSPARQL_and_Simple_Features__SFA-CA_](#)] for a description of GeoSPARQL's limitations: currently it supports 2.5D and geometric functions ignore Z values in calculations.

11.9.21. 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.

11.9.22. Function: geof:isMeasured

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

The function `geof:isMeasured` returns true if `geom` has m coordinate values, as used e.g. in linear referencing. See [[_GeoSPARQL_and_Simple_Features__SFA-CA_](#)] for a description of GeoSPARQL's limitations: at the moment it does not support linear referencing and M values are ignored.

11.9.23. 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.

11.9.24. 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.

11.9.25. Function: geof:length

geof:length (geom: `ogc:geomLiteral`, units: `rdfs:Resource`): `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 specification of units of measurement.

11.9.26. 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`.

11.9.27. 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`.

11.9.28. 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`.

11.9.29. 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`.

11.9.30. 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`.

11.9.31. 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`.

11.9.32. 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.

11.9.33. Function: `geof:perimeter`

`geof:perimeter` (`geom: ogc:geomLiteral`, `unit: rdfs:Resource`): `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`.

11.9.34. Function: `geof:metricPerimeter`

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

The function `geof:metricPerimeter` returns the perimeter of geom. It is similar to the function `geof:perimeter`, but always returns the result in meters.

11.9.35. Function: `geof:spatialDimension`

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

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

11.9.36. 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.

11.9.37. 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.

11.9.38. Function: `geof:union`

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

This 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.

REQUIREMENT 43: SRID FUNCTION

IDENTIFIER /req/geometry-extension/srid-function

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

11.9.39. Function: `geof:getSRID`

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

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

11.10. Spatial Aggregate Functions

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

REQUIREMENT 44: SPATIAL AGGREGATE FUNCTIONS

IDENTIFIER /req/geometry-extension/sa-functions

STATEMENT Implementations shall support `geof:aggBoundingBox`, `geof:aggBoundingCircle`, `geof:aggCentroid`, `geof:aggConcaveHull`, `geof:aggConvexHull` and `geof:aggUnion` as a SPARQL extension functions.

11.10.1. 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.

NOTE: This function is similar in nature to `geof:envelope` used to calculate the bounding box of just one geometry.

11.10.2. 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.

NOTE: This function is similar in name to geof:boundingCircle used to calculate the bounding circle of just one geometry.

11.10.3. Function: **geof:aggCentroid**

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

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

NOTE: This function is similar in name to geof:centeroid used to calculate the centroid of just one geometry.

11.10.4. 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.

NOTE: This function is similar in name to geof:concaveHull used to calculate the concave hull of just one geometry.

11.10.5. 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.

11.10.6. 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.

12

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) Clause 12.2, Definition List 3: [DE-9IM] 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 Clause 12.2, Definition List 3: [OGCSFACA] ISO 19125-1 for a more detailed description of DE-9IM intersection patterns.

REQUIREMENTS CLASS 5: GEOMETRY TOPOLOGY EXTENSION

IDENTIFIER	<code>/req/geometry-topology-extension</code>
TARGET TYPE	Implementation Specification
CONFORMANCE CLASS	Conformance class 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>

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 Query Functions

REQUIREMENT 45: 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 Clause 12.2, Definition List 3: [OGCSFACA] ISO 19125-1.

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

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.

== Simple Features Relation Family

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

REQUIREMENT 46: 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 Clause 12.2, Definition List 3: [OGCSFACA] ISO 19125-1.

Boolean query functions defined for the Simple Features relation family, along with their associated DE-9IM intersection patterns, are shown in `[simple_features_query_functions]` 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.

Simple Features Query Functions

QUERY FUNCTION	DEFINING DE-9IM INTERSECTION PATTERN
<code>`geof:sfEquals(geom1: ogc:geomLiteral, geom2: ogc:geomLiteral): xsd:boolean`</code>	(TFFFFTFFFF)
<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

==== Egenhofer Relation Family

This clause establishes Requirements for the *Egenhofer* relation family. Consult references Clause 12.2, Definition List 3: [FORMAL] and Clause 12.2, Definition List 3: [CATEG] for a more detailed discussion of *Egenhofer* relations.

REQUIREMENT 47: 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 SPARQL extension functions, consistent with their corresponding DE-9IM intersection patterns, as defined by Simple Features Clause 12.2, Definition List 3: [OGCSFACA] ISO 19125-1.

Boolean query functions defined for the *Egenhofer* relation family, along with their associated DE-9IM intersection patterns, are shown in [egenhofer_query_functions] 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.

Egenhofer Query Functions

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

== RCC8 Relation Family

This clause establishes Requirements for the *RCC8* relation family. Consult references Clause 12.2, Definition List 3: [QUAL] and Clause 12.2, Definition List 3: [LOGIC] for a more detailed discussion of *RCC8* relations.

REQUIREMENT 48: RCC8 QUERY FUNCTIONS

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

STATEMENT Implementations shall support `geof:rcc8eq`, `geof:rcc8dc`, `geof:rcc8ec`, `geof:rcc8po`, `geof:rcc8tppi`, `geof:rcc8tpp`, `geof:rcc8ntpp` and `geof:rcc8ntppi` as SPARQL extension functions, consistent with their corresponding DE-9IM intersection patterns, as defined by Simple Features Clause 12.2, Definition List 3: [OGCSFACA] ISO 19125-1.

Boolean query functions defined for the RCC8 relation family, along with their associated DE-9IM intersection patterns, are shown in [rcc8_query_functions] 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.

RCC8 Query Functions

QUERY FUNCTION	DEFINING DE-9IM INTERSECTION PATTERN
<code>`geof:rcc8eq(geom1: ogc:geomLiteral, geom2: ogc:geomLiteral): xsd:boolean`</code>	(TFFFFFFFFFF)
<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>	(TTTFTTTFFT)
<code>`geof:rcc8tpp(geom1: ogc:geomLiteral, geom2: ogc:geomLiteral): xsd:boolean`</code>	(TFFTTFTTTT)
<code>`geof:rcc8ntpp(geom1: ogc:geomLiteral, geom2: ogc:geomLiteral): xsd:boolean`</code>	(TFFTFFFTTF)
<code>`geof:rcc8ntppi(geom1: ogc:geomLiteral, geom2: ogc:geomLiteral): xsd:boolean`</code>	(TTFFFETFFT)

== 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`.

REQUIREMENTS CLASS 6: RDFS ENTAILMENT EXTENSION

IDENTIFIER	<code>/req/rdfs-entailment-extension</code>
TARGET TYPE	Implementation Specification

REQUIREMENTS CLASS 6: RDFS ENTAILMENT EXTENSION

CONFORMANCE CLASS	Conformance class 6: /conf/rdfs-entailment-extension
	/req/rdfs-entailment-extension/bgp-rdfs-ent
REQUIREMENT	/req/rdfs-entailment-extension/wkt-geometry-types
	/req/rdfs-entailment-extension/gml-geometry-types

==== 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.

==== Common Requirements

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

REQUIREMENT 49: BASIC GRAPH PATTERN

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

==== WKT Serialization

This section establishes the requirements for representing geometry data in RDF based on WKT as defined by Simple Features Clause 12.2, Definition List 3: [OGCSFACA] ISO 19125-1.

===== 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

<code>sf:MultiCurve</code> <code>sf:MultiSurface</code> <code>sf:Surface</code> <code>sf:Triangle</code>	<code>sf:MultiLineString</code> <code>sf:MultiPolygon</code> <code>sf:Polygon</code> <code>sf:PolyhedralSurface</code>	<code>sf:MultiPoint</code> <code>sf:Point</code> <code>sf:Envelope</code> <code>sf:TIN</code>
---	---	--

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 50: 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 Clause 12.2, Definition List 3: [OGCSFACA] ISO 19125-1.

==== 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.

===== 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 51: 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.

== 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 Clause 12.2, Definition List 3: [RIF] that use topological extension functions defined in [geometry_extension] 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 7: QUERY REWRITE EXTENSION

IDENTIFIER	/req/query-rewrite-extension
TARGET TYPE	Implementation Specification
CONFORMANCE CLASS	Conformance class 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 [geometry_extension]. `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]          )          And (          # feature - geometry rule
          ?so1[geo:hasDefaultGeometry->?g1]          ?g1[ogc:asGeomLiteral-
>?g1Serial]          ?so2[ogc:asGeomLiteral->?g2Serial]
          External(ogc:function(?g1Serial, ?g2Serial))          )          And (
          # geometry - feature rule          ?so1[ogc:asGeomLiteral->?g1Serial]
          ?so2[geo:hasDefaultGeometry->?g2]          ?g2[ogc:asGeomLiteral-
>?g2Serial]          External(ogc:function(?g1Serial, ?g2Serial))
          )          And (          # geometry - geometry rule          ?so1[ogc:
asGeomLiteral->?g1Serial]          ?so2[ogc:asGeomLiteral->?g2Serial]
          External(ogc:function(?g1Serial, ?g2Serial))          )        )
)
==== 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.

==== Simple Features Relation Family

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

REQUIREMENT 52: 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 .

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

==== Egenhofer Relation Family

This clause defines Requirements for the *Egenhofer* relation family.
 [eh_query_transformation_rules] specifies the function and property substitutions for each rule in the *Egenhofer* relation family.

REQUIREMENT 53: 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 .

Egenhofer Query Transformation Rules

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

==== RCC8 Relation Family

This clause defines Requirements for the *RCC8* relation family.
 [rcc8_query_transformation_rules] specifies the function and property substitutions for each rule in the *RCC8* relation family.

REQUIREMENT 54: RCC8 QUERY TRANSFORMATION RULES

IDENTIFIER	/req/query-rewrite-extension/rcc8-query-rewrite
-------------------	---

REQUIREMENT 54: RCC8 QUERY TRANSFORMATION RULES

STATEMENT	Basic graph pattern matching shall use the semantics defined by the RIF Core Entailment Regime SPARQLNT for the RIF rules RIFCORE geor:rcc8eq , geor:rcc8dc , geor:rcc8ec , geor:rcc8po , geor:rcc8tppi , geor:rcc8tpp , geor:rcc8ntpp and geor:rcc8ntppi .
------------------	---

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
geor:rcc8tpp	geo:rcc8tpp	geof:rcc8tpp
geor:rcc8ntpp	geo:rcc8ntpp	geof:rcc8ntpp
geor:rcc8ntppi	geo:rcc8ntppi	geof:rcc8ntppi

==== 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.

== 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 mooted 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.

== 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 Clause 12.2, Definition List 3: [SPARQLSERVDESC].

==== Conformance Class: Core

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

==== SPARQL

ABSTRACT TEST 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]

==== RDF Classes & Properties

ABSTRACT TEST 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	Clause 9.2.1

ABSTRACT TEST 3

IDENTIFIER	/conf/core/feature-class
REQUIREMENT	Requirement 3: /req/core/feature-class
TEST PURPOSE	Check conformance with this requirement

ABSTRACT TEST 3

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

TEST-METHOD-TYPE Capabilities

REFERENCE Clause 9.2.2

ABSTRACT TEST 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 Clause 9.2.3

ABSTRACT TEST 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 Clause 9.2.4

ABSTRACT TEST 6

IDENTIFIER	/conf/core/spatial-object-properties
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 9.3

==== Conformance Class: Topology Vocabulary Extension

CONFORMANCE CLASS 2: TOPOLOGY VOCABULARY EXTENSION

IDENTIFIER	/conf/topology-vocab-extension
REQUIREMENTS CLASS	Requirements class 2: /req/topology-vocab-extension
CONFORMANCE TESTS	Abstract test 7: /conf/topology-vocab-extension/sf-spatial-relations Abstract test 8: /conf/topology-vocab-extension/eh-spatial-relations Abstract test 9: /conf/topology-vocab-extension/rcc8-spatial-relations

===== Simple Features Relation Family

ABSTRACT TEST 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
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

ABSTRACT TEST 7

TEST-METHOD-TYPE Capabilities

REFERENCE Table 2

==== Egenhofer Relation Family

ABSTRACT TEST 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

==== RCC8 Relation Family

ABSTRACT TEST 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:rcc8tpi, geo:rcc8tpp, geo:rcc8ntpp, geo:rcc8ntppi

TEST-METHOD-TYPE Capabilities

REFERENCE Table 4

==== Conformance Class: Geometry Extension

CONFORMANCE CLASS 3: GEOMETRY EXTENSION	
IDENTIFIER	/conf/geometry-extension
SUBJECT	Geometry
REQUIREMENTS CLASS	Requirements class 3: /req/geometry-extension
CONFORMANCE TESTS	<p>Abstract test 10: /conf/geometry-extension/geometry-class Abstract test 11: /conf/geometry-extension/geometry-collection-class Abstract test 12: /conf/geometry-extension/feature-properties Abstract test 13: /conf/geometry-extension/geometry-properties Abstract test 14: /conf/geometry-extension/query-functions Abstract test 15: /conf/geometry-extension/srid-function Abstract test 16: /conf/geometry-extension(sa-functions Abstract test 17: /conf/geometry-extension/wkt-literal Abstract test 18: /conf/geometry-extension/wkt-literal-default-srs Abstract test 19: /conf/geometry-extension/wkt-axis-order Abstract test 20: /conf/geometry-extension/wkt-literal-empty Abstract test 21: /conf/geometry-extension/geometry-as-wkt-literal Abstract test 22: /conf/geometry-extension/asWKT-function Abstract test 23: /conf/geometry-extension/gml-literal Abstract test 24: /conf/geometry-extension/gml-literal-empty Abstract test 25: /conf/geometry-extension/gml-profile Abstract test 26: /conf/geometry-extension/geometry-as-gml-literal Abstract test 27: /conf/geometry-extension/asGML-function Abstract test 28: /conf/geometry-extension/geojson-literal Abstract test 29: /conf/geometry-extension/geojson-literal-srs Abstract test 30: /conf/geometry-extension/geojson-literal-empty Abstract test 31: /conf/geometry-extension/geometry-as-geojson-literal Abstract test 32: /conf/geometry-extension/asGeoJSON-function Abstract test 33: /conf/geometry-extension/kml-literal Abstract test 34: /conf/geometry-extension/kml-literal-srs Abstract test 35: /conf/geometry-extension/kml-literal-empty Abstract test 36: /conf/geometry-extension/geometry-as-kml-literal Abstract test 37: /conf/geometry-extension/asKML-function</p>

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

===== Tests for all Serializations except DGGS

ABSTRACT TEST 10

IDENTIFIER	/conf/geometry-extension/geometry-class
REQUIREMENT	Requirement 11: /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	Clause 11.6.1

ABSTRACT TEST 11

IDENTIFIER	/conf/geometry-extension/geometry-collection-class
REQUIREMENT	/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	Clause 11.6.2

ABSTRACT TEST 12

IDENTIFIER	/conf/geometry-extension/feature-properties
REQUIREMENT	Requirement 7: /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

ABSTRACT TEST 12

REFERENCE Clause 9.4

ABSTRACT TEST 13

IDENTIFIER /conf/geometry-extension/geometry-properties

REQUIREMENT Requirement 13: /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:hasMetricSpatialResolution, geo:hasSpatialAccuracy, geo:hasMetricSpatialAccuracy, geo:isEmpty, geo:isSimple and geo:hasSerialization

TEST-METHOD-TYPE Capabilities

REFERENCE Clause 11.7

ABSTRACT TEST 14

IDENTIFIER /conf/geometry-extension/query-functions

REQUIREMENT Requirement 39: /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: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 11.9

ABSTRACT TEST 15

IDENTIFIER	/conf/geometry-extension/srid-function
REQUIREMENT	Requirement 43: /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	Clause 11.9.39

ABSTRACT TEST 16

IDENTIFIER	/conf/geometry-extension/sa-functions
REQUIREMENT	Requirement 44: /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 11.10

==== WKT Serialization

ABSTRACT TEST 17

IDENTIFIER	/conf/geometry-extension/wkt-literal
REQUIREMENT	Requirement 14: /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.

ABSTRACT TEST 17

TEST-METHOD-TYPE Capabilities

REFERENCE Clause 11.8.1.1

ABSTRACT TEST 18

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

REQUIREMENT Requirement 15: /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 15: /req/geometry-extension/wkt-literal-default-srs

ABSTRACT TEST 19

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

REQUIREMENT Requirement 16: /req/geometry-extension/wkt-axis-order

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 Requirement 16: /req/geometry-extension/wkt-axis-order

ABSTRACT TEST 20

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

REQUIREMENT Requirement 17: /req/geometry-extension/wkt-literal-empty

ABSTRACT TEST 20

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 17: /req/geometry-extension/wkt-literal-empty

ABSTRACT TEST 21

IDENTIFIER	/conf/geometry-extension/geometry-as-wkt-literal
REQUIREMENT	Requirement 18: /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 11.8.1.2

ABSTRACT TEST 22

IDENTIFIER	/conf/geometry-extension/asWKT-function
REQUIREMENT	Requirement 19: /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	Clause 11.8.1.3

===== GML Serialization

ABSTRACT TEST 23

IDENTIFIER	/conf/geometry-extension/gml-literal
REQUIREMENT	Requirement 20: /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	Clause 11.8.2.1

ABSTRACT TEST 24

IDENTIFIER	/conf/geometry-extension/gml-literal-empty
REQUIREMENT	Requirement 21: /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.
TEST-METHOD-TYPE	Capabilities
REFERENCE	Requirement 21: /req/geometry-extension/gml-literal-empty

ABSTRACT TEST 25

IDENTIFIER	/conf/geometry-extension/gml-profile
REQUIREMENT	Requirement 22: /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

ABSTRACT TEST 25

REFERENCE	Requirement 22: /req/geometry-extension/gml-profile
-----------	---

ABSTRACT TEST 26

IDENTIFIER	/conf/geometry-extension/geometry-as-gml-literal
REQUIREMENT	Requirement 23: /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 23: /req/geometry-extension/geometry-as-gml-literal

ABSTRACT TEST 27

IDENTIFIER	/conf/geometry-extension/asGML-function
REQUIREMENT	Requirement 24: /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	Clause 11.8.2.3

==== GeoJSON Serialization

ABSTRACT TEST 28

IDENTIFIER	/conf/geometry-extension/geojson-literal
------------	--

ABSTRACT TEST 28

REQUIREMENT	Requirement 25: /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	Clause 11.8.3.1

ABSTRACT TEST 29

IDENTIFIER	/conf/geometry-extension/geojson-literal-srs
REQUIREMENT	Requirement 26: /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
REFERENCE	Requirement 26: /req/geometry-extension/geojson-literal-srs

ABSTRACT TEST 30

IDENTIFIER	/conf/geometry-extension/geojson-literal-empty
REQUIREMENT	Requirement 27: /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 27: /req/geometry-extension/geojson-literal-empty

ABSTRACT TEST 31

IDENTIFIER	/conf/geometry-extension/geometry-as-geojson-literal
REQUIREMENT	Requirement 28: /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 28: /req/geometry-extension/geometry-as-geojson-literal

ABSTRACT TEST 32

IDENTIFIER	/conf/geometry-extension/asGeoJSON-function
REQUIREMENT	Requirement 29: /req/geometry-extension/asGeoJSON-function
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	Clause 11.8.3.3

==== KML Serialization

ABSTRACT TEST 33

IDENTIFIER	/conf/geometry-extension/kml-literal
REQUIREMENT	Requirement 30: /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.

ABSTRACT TEST 33

TEST-METHOD-TYPE Capabilities

REFERENCE Clause 11.8.4.1

ABSTRACT TEST 34

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

REQUIREMENT Requirement 31: /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 31: /req/geometry-extension/kml-literal-srs

ABSTRACT TEST 35

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

REQUIREMENT Requirement 32: /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 32: /req/geometry-extension/kml-literal-empty

ABSTRACT TEST 36

IDENTIFIER /conf/geometry-extension/geometry-as-kml-literal

ABSTRACT TEST 36

REQUIREMENT	Requirement 33: /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 33: /req/geometry-extension/geometry-as-kml-literal

ABSTRACT TEST 37

IDENTIFIER	/conf/geometry-extension/asKML-function
REQUIREMENT	Requirement 34: /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
REFERENCE	Clause 11.8.4.3

==== DGGS Conformance Class: Geometry Extension – DGGS

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

CONFORMANCE CLASS 4: GEOMETRY EXTENSION DGGS

IDENTIFIER	/conf/geometry-extension-dggs
REQUIREMENTS CLASS	Requirements class 4: /req/geometry-extension-dggs
CONFORMANCE TESTS	Abstract test 38: /conf/geometry-extension-dggs/query-functions Abstract test 39: /conf/geometry-extension-dggs/query-functions-non-sf Abstract test 40: /conf/geometry-extension-dggs/srid-function Abstract test 41: /conf/geometry-extension-dggs/sa-functions

CONFORMANCE CLASS 4: GEOMETRY EXTENSION DGGS

Abstract test 42: /conf/geometry-extension-dggs/dggs-literal
Abstract test 43: /conf/geometry-extension-dggs/dggs-literal-empty
Abstract test 44: /conf/geometry-extension-dggs/geometry-as-dggs-literal
Abstract test 45: /conf/geometry-extension-dggs/asDGGS-function

===== Tests for DGGS Serializations

ABSTRACT TEST 38

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

REQUIREMENT Requirement 41: /req/geometry-extension-dggs/query-functions

TEST PURPOSE Check conformance with this requirement

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

TEST METHOD 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 39

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

REQUIREMENT Requirement 42: /req/geometry-extension-dggs/query-functions-non-sf

TEST PURPOSE Check conformance with this requirement

Verify that implementations support the functions of Requirement <http://www.opengis.net/spec/>

TEST METHOD [geosparql/1.1/req/geometry-extension/query-functions-non-sf](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 40

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

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

TEST PURPOSE Check conformance with this requirement

ABSTRACT TEST 40

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

REFERENCE Clause 11.9.39

ABSTRACT TEST 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 Clause 12.2, Definition List 3: [OGCSFACA] ISO 19125-1.

TEST-METHOD-TYPE Capabilities

REFERENCE [_spatial_aggregate_functions]

==== DGGS Serialization

ABSTRACT TEST 42

IDENTIFIER /conf/geometry-extension-dggs/dggs-literal

REQUIREMENT Requirement 35: /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 Clause 11.8.5.1

ABSTRACT TEST 43

IDENTIFIER	/conf/geometry-extension-dggs/dggs-literal-empty
REQUIREMENT	Requirement 36: /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 36: /req/geometry-extension-dggs/dggs-literal-empty

ABSTRACT TEST 44

IDENTIFIER	/conf/geometry-extension-dggs/geometry-as-dggs-literal
REQUIREMENT	Requirement 37: /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 37: /req/geometry-extension-dggs/geometry-as-dggs-literal

ABSTRACT TEST 45

IDENTIFIER	/conf/geometry-extension-dggs/asDGGS-function
REQUIREMENT	Requirement 38: /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

ABSTRACT TEST 45

REFERENCE Clause 11.8.5.3

==== Conformance Class: Geometry Topology Extension

CONFORMANCE CLASS 5: GEOMETRY TOPOLOGY EXTENSION

IDENTIFIER /conf/geometry-topology-extension

REQUIREMENTS CLASS Requirements class 5: /req/geometry-topology-extension

CONFORMANCE TESTS Abstract test 46: /conf/geometry-topology-extension/relate-query-function
Abstract test 47: /conf/geometry-topology-extension/sf-query-functions
Abstract test 48: /conf/geometry-topology-extension/eh-query-functions
Abstract test 49: /conf/geometry-topology-extension/rcc8-query-functions

===== Tests for all relation families

ABSTRACT TEST 46

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

REQUIREMENT Requirement 45: /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 `geof:relate` function returns the correct result for a test dataset when using the specified serialization and version.

TEST-METHOD-TYPE Capabilities

REFERENCE Function/ geof

===== Simple Features Relation Family

ABSTRACT TEST 47

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

REQUIREMENT Requirement 46: /req/geometry-topology-extension/sf-query-functions

ABSTRACT TEST 47

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:sfEquals , geof:sfDisjoint , geof:sfIntersects , geof:sfTouches , geof:sfCrosses , geof:sfWithin , geof:sfContains , geof:sfOverlaps .
TEST-METHOD-TYPE	Capabilities
REFERENCE	[sf-query-functions]

==== Egenhofer Relation Family

ABSTRACT TEST 48

IDENTIFIER	/conf/geometry-topology-extension/eh-query-functions
REQUIREMENT	Requirement 47: /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	[eh-query-functions]

==== RCC8 Relation Family

ABSTRACT TEST 49

IDENTIFIER	/conf/geometry-topology-extension/rcc8-query-functions
REQUIREMENT	Requirement 48: /req/geometry-topology-extension/rcc8-query-functions
TEST PURPOSE	Check conformance with this requirement

ABSTRACT TEST 49

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 .
TEST-METHOD-TYPE	Capabilities
REFERENCE	[rcc8-query-functions]

==== Conformance Class: RDFS Entailment Extension

CONFORMANCE CLASS 6: RDFS ENTAILMENT EXTENSION

IDENTIFIER	/conf/rdfs-entailment-extension
REQUIREMENTS CLASS	Requirements class 6: /req/rdfs-entailment-extension
CONFORMANCE TESTS	Abstract test 50: /conf/rdfs-entailment-extension/bgp-rdfs-ent Abstract test 51: /conf/rdfs-entailment-extension/wkt-geometry-types Abstract test 52: /conf/rdfs-entailment-extension/gml-geometry-types

===== Tests for all implementations

ABSTRACT TEST 50

IDENTIFIER	/conf/rdfs-entailment-extension/bgp-rdfs-ent
REQUIREMENT	Requirement 49: /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	[rdfse_common_reqs]

===== WKT Serialization

ABSTRACT TEST 51

IDENTIFIER	/conf/rdfs-entailment-extension/wkt-geometry-types
REQUIREMENT	Requirement 50: /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	[rdfse_wkt]

==== GML Serialization

ABSTRACT TEST 52

IDENTIFIER	/conf/rdfs-entailment-extension/gml-geometry-types
REQUIREMENT	Requirement 51: /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	[rdfse_gml]

== Conformance Class: Query Rewrite Extension

CONFORMANCE CLASS 7: QUERY REWRITE EXTENSION

IDENTIFIER	/conf/query-rewrite-extension
REQUIREMENTS CLASS	Requirements class 7: /req/query-rewrite-extension
CONFORMANCE TESTS	Abstract test 53: /conf/query-rewrite-extension/sf-query-rewrite Abstract test 54: /conf/query-rewrite-extension/eh-query-rewrite Abstract test 55: /conf/query-rewrite-extension/rcc8-query-rewrite

==== Simple Features Relation Family

ABSTRACT TEST 53

IDENTIFIER	/conf/query-rewrite-extension/sf-query-rewrite
REQUIREMENT	Requirement 52: /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: geor:sfEquals , geor:sfDisjoint , geor:sfIntersects , geor:sfTouches , geor:sfCrosses , geor:sfWithin , geor:sfContains and geor:sfOverlaps .
TEST-METHOD-TYPE	Capabilities
REFERENCE	[query_rewrite_sf]

==== Egenhofer Relation Family

ABSTRACT TEST 54

IDENTIFIER	/conf/query-rewrite-extension/eh-query-rewrite
REQUIREMENT	Requirement 53: /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: geor:ehEquals , geor:ehDisjoint , geor:ehMeet , geor:ehOverlap , geor:ehCovers , geor:ehCoveredBy , geor:ehInside , geor:ehContains .
TEST-METHOD-TYPE	Capabilities
REFERENCE	[query_rewrite_eh]

==== RCC8 Relation Family

ABSTRACT TEST 55

IDENTIFIER	/conf/query-rewrite-extension/rcc8-query-rewrite
REQUIREMENT	Requirement 54: /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	[query_rewrite_rcc8]

== 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* Clause 12.2, Definition List 3: [OGCSFACA] ISO 19125-1 or DGGS types, as implemented by the various geometry serialization specifications referenced here. See Clause 11.8 for the individual specification references.

== Functions Summary Table

GeoSPARQL Functions Summary

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

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

Egenhofer Functions

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

Region Connection Calculus Functions

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

rcc8eq	2x ogc:geomLiteral	2x Polygon	xsd:boolean
rcc8ntpp	2x ogc:geomLiteral	2x Polygon	xsd:boolean
rcc8ntppi	2x ogc:geomLiteral	2x Polygon	xsd:boolean
rcc8po	2x ogc:geomLiteral	2x Polygon	xsd:boolean
rcc8tpp	2x ogc:geomLiteral	2x Polygon	xsd:boolean
rcc8tpi	2x ogc:geomLiteral	2x Polygon	xsd:boolean

Spatial Aggregate Functions

Function	Input Datatypes	Input Subtypes	Output Datatype	Output Subtype
aggBoundingBox	1 or more ogc:geomLiteral		ogc:geomLiteral	square Polygon (not DGGS), CellList (DGGS)
aggBoundingCircle	1 or more ogc:geomLiteral		ogc:geomLiteral	Polygon (not DGGS), CellList (DGGS)
aggCentroid	1 or more ogc:geomLiteral		ogc:geomLiteral	Point (not DGGS), Cell (DGGS)
aggConcaveHull	1 or more ogc:geomLiteral		ogc:geomLiteral	Polygon (not DGGS), CellList (DGGS)
aggConvexHull	1 or more ogc:geomLiteral		ogc:geomLiteral	Polygon (not DGGS), CellList (DGGS)
aggUnion	1 or more ogc:geomLiteral		ogc:geomLiteral	Polygon (not DGGS), CellList (DGGS)

Non-topological Query Functions

Function	Input Datatypes	Input Subtypes	Output Datatype	Output Subtype
metricArea	1x ogc:geomLiteral	Polygon	xsd:double	
area	1x ogc:geomLiteral	Polygon	xsd:double	
boundary	1x ogc:geomLiteral	Geometry	ogc:geomLiteral	LineString (not DGGS), OrderedCellList (DGGS)
buffer	1x ogc:geomLiteral , 1x xsd:double , 1x xsd:anyURI		ogc:geomLiteral	(Multi) Polygon (not DGGS), CellList (DGGS)

convexHull	1x ogc:geomLiteral	Geometry	ogc:geomLiteral	LineString (not DGGS)
coordinateDimension	1x ogc:geomLiteral	Geometry	xsd:integer	
difference	2x ogc:geomLiteral	2x Geometry	ogc:geomLiteral	(Multi)Polygon (not DGGS), CellList (DGGS)
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	
metricPerimeter	1x ogc:geomLiteral	Geometry	xsd:double	
perimeter	1x ogc:geomLiteral	Geometry	rdfs:Resource	
spatialDimension	1x ogc:geomLiteral	Geometry	xsd:integer	

symDifference	2x <code>ogc:geomLiteral</code>	2x <code>Geometry</code>	<code>ogc:geomLiteral</code>	(Multi)Polygon (not DGGS), CellList DGGS)
transform	1x <code>ogc:geomLiteral</code> , 1x <u>xsd:anyURI</u>	<code>Geometry</code>	<code>ogc:geomLiteral</code>	<code>Geometry</code>
union	2x <code>ogc:geomLiteral</code>	2x <code>Geometry</code>	<code>ogc:geomLiteral</code>	Polygon (not DGGS), CellList (DGGS)
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>xsd:string</u>	<code>Geometry</code>	<code>geo:gmlLiteral</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>xsd:anyURI</u>	
maxX	1x <code>ogc:geomLiteral</code>	<code>Geometry</code>	<u>xsd:double</u>	
maxY	1x <code>ogc:geomLiteral</code>	<code>Geometry</code>	<u>xsd:double</u>	
maxZ	1x <code>ogc:geomLiteral</code>	<code>Geometry</code>	<u>xsd:double</u>	
minX	1x <code>ogc:geomLiteral</code>	<code>Geometry</code>	<u>xsd:double</u>	
minY	1x <code>ogc:geomLiteral</code>	<code>Geometry</code>	<u>xsd:double</u>	
minZ	1x <code>ogc:geomLiteral</code>	<code>Geometry</code>	<u>xsd:double</u>	
Other Functions				
Function	Input Datatypes	Input Subtypes	Output Datatype	Output Subtype

relate

2x `ogc:geomLiteral``xsd:string`

==== GeoSPARQL to SFA Functions Mapping

The following table indicates which GeoSPARQL non-topological query functions map to Simple Features Access (Clause 12.2, Definition List 3: [OGCSFACA] ISO 19125-1) 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.

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
dimension		x	Dimension
metricDistance		x	Distance
distance	x	x	Distance
			EndPoint
envelope	x	x	Envelope

GEOSPARQL FUNCTION	IN 1.0	IN 1.1	SFA
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	
minX		x	
minY		x	
minZ		x	
numGeometries		x	NumGeometries
			NumInteriorRing

GEOSPARQL FUNCTION	IN 1.0	IN 1.1	SFA
			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.

== 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 8.3 for the link to those examples.

==== RDF Examples

This Section illustrates GeoSPARQL ontology modelling with extended examples.

===== Classes

Example 1: ===== SpatialObject The SpatialObject class is defined in Clause 9.2.1.

===== Basic use

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

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

NOTE 1: 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.

Example 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.

Example 3: ===== Feature The Feature class is defined in Clause 9.2.2.

===== Basic use

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

Here a Feature is declared and given a preferred label.

Example 4: ===== A Feature related to a Geometry

```
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.

Example 5: ===== 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).

Example 6: ===== 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.

Example 7: ===== 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.

Example 8: ===== 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.

Example 9: ===== 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.

Example 10: ===== 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.

Example 11: ===== 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.

Example 12: ===== Geometry The Geometry class is defined in Clause 11.6.1.

===== 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 example in [B_1.1.2.2_A_lt_tt_gt_Feature_lt_tt_gt_related_to_a_lt_tt_gt_Geometry_lt_tt_gt_] and often the Geometry is indirectly declared by the use of hasGeometry on the Feature instance indicating a Blank Node. 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.

Example 13: ===== 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 (((149.06016 -35.23610, 149.060620 -35.236043, ... , 149.06016
-35.23610)))"^^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.

Example 14: ===== 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.

Example 15: ===== 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.

Example 16: ===== FeatureCollection

This example shows a FeatureCollection instance containing 3 Feature instances.

```

ex:fc-x      a geo:FeatureCollection ;      dcterms:title "Feature Collection X" ;
      rdfs:member      ex:feature-something ,      ex:feature-other ,
      ex:feature-another ; .

```

All of 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.

Example 17: ===== 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.

Example 18: ===== 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 is could be used with a `sf:Point` and `geo:hasBoundingBox` indicates use with an `sf:Envelope`.

===== Properties

===== Spatial Object Properties

See the section [C.1.1.2_Size_Properties] above.

Example 19: ===== Feature Properties

This example shows a `geo:Feature` instance with each of the properties defined in Clause 9.4 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 [C.1.1.2_Size_Properties].

```
@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 ((149.06016 -35.23610, ...
```

```

, 149.06016 -35.23610)))"^^geo:wktLiteral ;      ] ;      geo:hasDefaultGeometry
[           geo:asWKT "<http://www.opengis.net/def/crs/EPSG/0/4326> POLYGON
((149.0601 -35.2361, ... , 149.0601 -35.2361))"^^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.

Example 20: ===== 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 11.7 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 ((149.060 -35.236, ... ,
149.060 -35.236))"^^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.

Example 21: ===== Geometry Serializations

This section shows a Geometry instance for a Feature instance which is represented in all supported 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 ((

```

```

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:wktLiteral ;
geo:asGML """<gml:Polygon srsName="http://www.opengis.net/
def/crs/EPSG/0/4326">
<LinearRing> <gml:exterior> <gml:posList>
-27.0621757 153.3610112 -27.3406573 153.421436
-27.3607835 153.4269292 -27.2913403 153.4183848
-27.2039578 153.4189391 -27.0621757 153.3610112
-</gml:posList> </gml:LinearRing> </gml:
exterior> </gml:Polygon>""^go:gmlLiteral ; geo:asKML """
<Polygon> <outerBoundaryIs> <coordinates>
<coordinates> 153.3658177,-27.1990606
27.0621757 153.421436,-27.3406573 153.4269292,-27.3607835
-27.2913403 153.4434087,-27.3315078 153.4189391,-27.2039578
153.4673476,-27.0267166 153.3610112,-27.0621757
-</coordinates> </outerBoundaryIs> </Polygon>""^go:kmlLiteral ;
geo:asGeoJSON """{
"coordinates": [
[ [153.3610112, -27.0621757],
[153.3658177, -27.1990606], [153.421436, -27.3406573],
[153.4269292, -27.3607835], [153.4434087, -27.3315078],
[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 ; ] ; .

```

Example 22: === 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.

==== 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`.

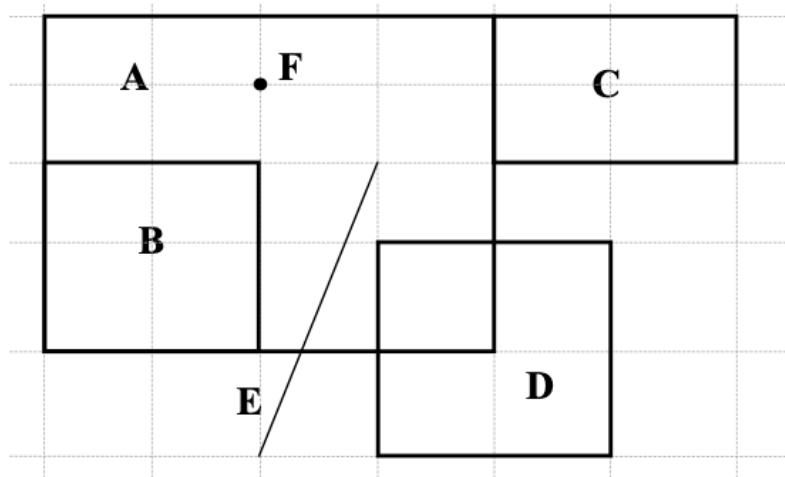


Figure 4 – Illustration of spatial data

```

@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 34.0))""^^geo:wktLiteral.  my:DPointGeom a sf:Point ;
<http://www.opengis.net/def/crs/OGC/1.3/CRS84>           Point(-83.2
34.1)""^^geo:wktLiteral.  my:EExactGeom a sf:LineString ;
<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.

```

===== Example Queries

This Section illustrates the use of GeoSPARQL functions through a series of example queries.

Example 23: ===== 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

Example 24: ===== 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
```

Example 25: ===== 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, ?dWKT ) ) }
```

Result:

```
?F
```

```
my:C
```

Example 26: ===== 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

Example 27: ===== 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

===== Example Rule Application

This section illustrates the query transformation strategy for implementing GeoSPARQL rules.

Example 28: ===== 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 { ?f # 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

Example 29: ===== 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 and DGGS literals should return WKT literal and similarly for each of the other conversion methods, `geof:asGML`, `geof:asKML`, `geof:asGeoJSON` & `geof:asDGGS`.

== 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.

==== 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.

==== 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).

==== Table of SHACL Shapes

Alignment: GeoSPARQL SHACL Shapes

SHACL SHAPE ID	SEVERITY	TEST PURPOSE	REQUIREMENTS TESTED
Shape 1a	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.	Requirement 7: /req/geometry-extension/feature-properties, Requirement 13: /req/geometry-extension/geometry-properties
Shape 1b	Violation	Each node with an incoming geo:hasGeometry, or a specialization of it, can have a maximum of one outgoing geo:asWKT relation.	Requirement 13: /req/geometry-extension/geometry-properties, Requirement 18: /req/geometry-extension/geometry-as-wkt-literal
Shape 1c	Violation	Each node with an incoming geo:hasGeometry, or a specialization of it, can have a maximum of one outgoing geo:asGML relation.	Requirement 13: /req/geometry-extension/geometry-properties, Requirement 23: /req/geometry-extension/geometry-as-gml-literal
Shape 1d	Violation	Each node with an incoming geo:hasGeometry, or a specialization of it, can have a maximum of one outgoing geo:asGeoJSON relation.	Requirement 13: /req/geometry-extension/geometry-properties, Requirement 28: /req/geometry-extension/geometry-as-geojson-literal
Shape 1e	Violation	Each node with an incoming geo:hasGeometry, or a specialization of it, can have a maximum of one outgoing geo:asKML relation.	Requirement 13: /req/geometry-extension/geometry-properties, Requirement 33: /req/geometry-extension/geometry-as-kml-literal
Shape 2	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	Requirement 13: /req/geometry-extension/geometry-properties

SHACL SHAPE ID	SEVERITY	TEST PURPOSE	REQUIREMENTS TESTED
		geo:hasGeometry relation or a specialization of it.	
<u>Shape 3a-c</u>	Violation	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)	Requirement 7: /req/geometry-extension/feature-properties
<u>Shape 4</u>	Violation	The target of a geo:hasSerialization property, or a specialization of, it should be an RDF literal	Requirement 13: /req/geometry-extension/geometry-properties
<u>Shape 5</u>	Violation	The target of a geo:asWKT property should be an RDF literal with datatype <u>geo:wktLiteral</u>	Requirement 14: /req/geometry-extension/wkt-literal
<u>Shape 6</u>	Violation	The target of a geo:asGML property should be an RDF literal with datatype <u>geo:gmlLiteral</u>	Requirement 20: /req/geometry-extension/gml-literal
<u>Shape 7</u>	Violation	The target of a geo:asGeoJSON property should be an RDF literal with datatype <u>geo:geoJSONLiteral</u>	Requirement 25: /req/geometry-extension/geojson-literal
<u>Shape 8</u>	Violation	The target of a geo:asKML property should be an RDF literal with datatype <u>geo:kmlLiteral</u>	Requirement 30: /req/geometry-extension/kml-literal
<u>Shape 9</u>	Violation	A geo:Geometry node should have a maximum of one outgoing <u>geo:coordinateDimension</u> property	Requirement 13: /req/geometry-extension/geometry-properties
<u>Shape 10</u>	Violation	A geo:Geometry node should have a maximum of one outgoing <u>geo:dimension</u> property	Requirement 13: /req/geometry-extension/geometry-properties

SHACL SHAPE ID	SEVERITY	TEST PURPOSE	REQUIREMENTS TESTED
Shape 11	Violation	A geo:Geometry node should have a maximum of one outgoing <code>geo:isEmpty</code> property	Requirement 13: /req/geometry-extension/geometry-properties
Shape 12	Violation	A geo:Geometry node should have a maximum of one outgoing <code>geo:isSimple</code> property	Requirement 13: /req/geometry-extension/geometry-properties
Shape 13	Violation	A geo:Geometry node should have maximum of one outgoing <code>geo:spatialDimension</code> property	Requirement 13: /req/geometry-extension/geometry-properties
Shape 14a	Violation	A geo:Geometry node should have maximum of one outgoing <code>geo:hasSpatialResolution</code> property	Requirement 13: /req/geometry-extension/geometry-properties
Shape 14b	Violation	A geo:Geometry node should have maximum of one outgoing <code>geo:hasSpatialAccuracy</code> property	Requirement 13: /req/geometry-extension/geometry-properties
Shape 14c	Violation	A geo:Geometry node should have maximum of one outgoing <code>geo:hasMetricSpatialAccuracy</code> property	Requirement 13: /req/geometry-extension/geometry-properties
Shape 14d	Violation	A geo:Geometry node should have maximum of one outgoing <code>geo:hasMetricSpatialResolution</code> property	Requirement 13: /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 14: /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 20: /req/geometry-extension/gml-literal

SHACL SHAPE ID	SEVERITY	TEST PURPOSE	REQUIREMENTS TESTED
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 25: /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 30: /req/geometry-extension/kml-literal
Shape 20	Violation	If both <code>geo:dimension</code> and <code>geo:coordinateDimension</code> properties are asserted, the value of <code>geo:dimension</code> should be less than or equal to the value of <code>geo:coordinateDimension</code>	Requirement 13: /req/geometry-extension/geometry-properties
Shape 21a	Violation	An instance of <code>geo:FeatureCollection</code> should have at least one outgoing <code>rdfs:member</code> relation	Requirement 5: /req/core/feature-collection-class
Shape 21b	Violation	An instance of <code>geo:FeatureCollection</code> should only have outgoing <code>rdfs:member</code> going to <code>geo:Feature</code> instances	Requirement 5: /req/core/feature-collection-class
Shape 22a	Violation	An instance of <code>geo:GeometryCollection</code> should have at least one outgoing <code>rdfs:member</code> relation	Requirement 12: /req/core/geometry-collection-class
Shape 22b	Violation	An instance of <code>geo:GeometryCollection</code> should only have outgoing <code>rdfs:member</code> relations to <code>geo:Geometry</code> instances	Requirement 12: /req/core/geometry-collection-class
Shape 23a	Violation	An instance of <code>geo:SpatialObjectCollection</code> should have at least one outgoing <code>rdfs:member</code> relation	Requirement 4: /req/core/spatial-object-collection-class

SHACL SHAPE ID	SEVERITY	TEST PURPOSE	REQUIREMENTS TESTED
Shape 23b	Violation	An instance of geo:SpatialObjectCollection should only have outgoing <code>rdfs:member</code> relations going to geo:SpatialObject instances, or subclasses of them	Requirement 4: /req/core/spatial-object-collection-class

== 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.

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/

==== 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>).

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
<code>locn:Address</code>	<code>rdfs:subClassOf</code>	<code>geo:Feature</code>	Although LOCN does not explicitly indicate spatial or geometry properties for <code>locn:Address</code> , this class can be considered as a specialized form of a <code>geo:Feature</code> .
<code>geo:Geometry</code>	<code>rdfs:subClassOf</code>	<code>locn:Geometry</code>	In LOCN, class <code>locn:Geometry</code> [...] 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 <code>geo:Geometry</code> is more narrowly defined, as its instances can only be individuals, and not literals.
<code>geo:hasGeometry</code>	<code>rdfs:subPropertyOf</code>	<code>locn:geometry</code>	In LOCN, the usage note to property <code>locn:geometry</code> 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 URLs [...]" . The GeoSPARQL's property <code>geo:hasGeometry</code> is more narrowly defined, as it can only be used with instances of <code>geo:Geometry</code> , and not with literals.

==== WGS84 Geo Positioning: an RDF vocabulary (POS)

POS Source: <http://www.w3.org/2003/01/geo/>

Alignment: WGS84 Geo Positioning Vocabulary (POS)

FROM ELEMENT	MAPPING RELATION	TO ELEMENT	NOTES
<code>geo:SpatialObject</code>	<code>owl:equivalentClass</code>	<code>pos:SpatialThing</code>	Both classes are unrestricted, essentially abstract classes
<code>pos:Point</code>	<code>rdfs:subClassOf</code>	<code>geo:Geometry</code>	Via <code>pos:Point rdfs:subClassOf pos:SpatialThing</code> but since <code>pos:Point</code> usage notes indicates direct positioning, it is a form of geometry
<code>pos:Point</code>	<code>owl:equivalentClass</code>	<code>sf:Point</code>	
<code>pos:lat_long</code>	<code>rdfs:subPropertyOf</code>	<code>geo:hasSerialization</code>	A special datatype is not indicated for use with this property by POS, unlike Geo SPARQL's <code>geo:hasSerialization</code> object literals
<code>pos:location</code>	<code>rdfs:subPropertyOf</code>	<code>geo:hasGeometry</code>	

==== W3C Activity Streams Vocabulary

AS Source: <https://www.w3.org/TR/activitystreams-vocabulary/>

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:hasSpatialAccuracy	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

==== Geonames Ontology (GN)

Geonames source: <http://www.geonames.org/ontology/documentation.html>

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
gn:neighbour	owl:equivalentProperty	geo:sfTouches	

==== NeoGeo Vocabulary

NeoGeo Source: <http://geovocab.org/> / <http://geovocab.org/doc/neogeo/>

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:rcc8n TPP	
spatial:NTPPi	rdfs:subPropertyOf	geo:rcc8n TPPi	
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	
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 BoundingBox class but has a generic Geometry class that is the range of the geo:hasBoundingBox property
geom:GeometryCollection	owl:equivalentClass	geo:GeometryCollection	

FROM ELEMENT	MAPPING RELATION TO ELEMENT	NOTES
<code>geom:LineString</code>	<code>owl:equivalentClass sf:LineString</code>	
<code>geom:LinearRing</code>	<code>owl:equivalentClass sf:LinearRing</code>	
<code>geom:MultiLineString</code>	<code>owl:equivalentClass sf:MultiLineString</code>	
<code>geom:MultiPoint</code>	<code>owl:equivalentClass sf:MultiPoint</code>	
<code>geom:MultiPolygon</code>	<code>owl:equivalentClass sf:MultiPolygon</code>	
<code>geom:Polygon</code>	<code>owl:equivalentClass sf:Polygon</code>	
<code>geom:Point</code>	<code>owl:equivalentClass sf:Point</code>	
<code>geo:hasGeometry</code>	<code>rdfs:subPropertyOf geom:geometry</code>	<code>geo:hasGeometry</code> 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`

==== Juso Ontology

Juso Source: <http://rdfs.co/juso/>

Juso contains mappings to GeoSPARQL but uses `owl:sameAs` which it should instead use `owl:equivalentClass`.

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>

FROM ELEMENT	MAPPING RELATION	TO ELEMENT
juso:geometry	owl:equivalentProperty	geo:hasGeometry
juso:parent	rdfs:subPropertyOf	geo:sfWithin
juso:political_division	rdfs:subPropertyOf	geo:sfContains
juso:within	owl:equivalentProperty	geo:sfWithin

== 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:inXSDDate](#) 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:inXSDDate "...""^xsd:date ; ] ; time:hasEnd [
        time:inXSDDate "...""^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.

==== schema.org

schema.org Source: <https://schema.org>

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 Geo Shape
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		

FROM ELEMENT	MAPPING RELATION	TO ELEMENT	NOTES
sdo:geoMidpoint	owl:equivalentProperty	geo:hasCentroid	
sdo:Landform	rdfs:subClassOf	geo:Feature	

==== 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.

==== DCMI Metadata Terms (DCTERMS)

DCTERMS Source: <https://www.dublincore.org/specifications/dublin-core/dcmi-terms/>

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 ;      ] ; .
```

==== 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).

Alignment: The Provenance Ontology (PROV)

FROM ELEMENT	MAPPING RELATION	TO ELEMENT	NOTES
geo:SpatialObjectCollection	<u>rdfs:</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>rdfs:</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>rdfs:</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 Geo SPARQL’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

¹³<https://www.dublincore.org/specifications/dublin-core/dcmi-box/>

¹⁴<https://www.dublincore.org/specifications/dublin-core/dcmi-point/>

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 .
```

==== WikiData

Alignment: WikiData

FROM ELEMENT	MAPPING RELATION	TO ELEMENT	NOTES
wdt:P625	owl:equivalentProperty	geo:asWKT	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
wdt:P3896	owl:propertyChainAxiom	(geo:hasGeometry geo:asGeoJSON)	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 Geo SPARQL does not.
wdt:P3096	owl:propertyChainAxiom	(geo:hasGeometry geo:asKML)	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 Geo SPARQL KML literals only encode the geometry part of a KML.
wd:Q82794	rdfs:subClassOf	geo:Feature	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
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

FROM ELEMENT	MAPPING RELATION	TO ELEMENT	NOTES
			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.

==== OpenStreetMap Ontologies There are several approaches to make OpenStreetMap data accessible in the Linked Open Data cloud.

===== 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.

Alignment: LinkedGeoData

From Element	Mapping relation	To Element	Notes
Any LGD Class	rdfs:subClassOf	geo:Feature	Any class defined in the LinkedGeoData ontology is a subclass of geo:Feature

==== OpenStreetMap RDF (Sophox) https://wiki.openstreetmap.org/wiki/Sophox#How_OSM_data_is_stored

Alignment: OpenStreetMap RDF (Sophox)

FROM ELEMENT	MAPPING RELATION	TO ELEMENT	NOTES
osmm:loc	owl:equivalentProperty	geo:asWKT	The OpenStreetMap property osmm:loc 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
osmm:type 'n'	owl:equivalentClass	sf:Point	The OpenStreetMap property osmm:type with value 'n' describes an OSM Node which is equivalent to a sf:Point
osmm:type 'w'	owl:equivalentClass	sf:LineString	The OpenStreetMap property osmm:type with value 'w' describes an OSM Way which is equivalent to a sf:LineString
osmm:type 'r'	owl:equivalentClass	sf:GeometryCollection	The OpenStreetMap property osmm:type with value 'r' describes an OSM relation Way which is equivalent to a sf:GeometryCollection
osmm:has	owl:equivalentProperty	geo:sfContains, geo:ehContains, geo:rcc8ntpp	The OpenStreetMap RDF property osmm:has describes that a relation contains a way or that a way contains a node
osmm:isClosed true	owl:equivalentClass	sf:Polygon	The OpenStreetMap RDF property osmm:isClosed indicates whether a Way is closed, i.e. if it constitutes a Polygon
osmm:isClosed false	owl:equivalentClass	sf:LineString	The OpenStreetMap RDF property osmm:isClosed indicates whether a Way is closed, i.e. if it constitutes a Polygon

==== Routable Tiles Ontology <https://github.com/openplannerteam/routable-tiles-ontology>

Alignment: Routable Tiles Ontology

FROM ELEMENT	MAPPING RELATION	TO ELEMENT	NOTES
osm:Element	owl:equivalentClass	geo:Geometry	The class osm:Element is equivalent to a geo:Geometry
osm:Node	owl:equivalentClass	sf:Point	The class osm:Node is equivalent to a sf:Point
osm:Way	owl:equivalentClass	sf:LineString	The class osm:Way is equivalent to a sf:LineString
osm:Relation	owl:equivalentClass	sf:GeometryCollection	The class osm:Relation is equivalent to a sf:GeometryCollection

==== Ordnance Survey UK Spatial Ontology <http://www.ordnancesurvey.co.uk/legacy/ontologies/spatialrelations.owl> & <http://www.ordnancesurvey.co.uk/legacy/ontologies/geometry.owl>

NOTE 2: 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."

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	

FROM ELEMENT	MAPPING RELATION	TO ELEMENT	NOTES
spatialukgeom:extent	owl:equivalentProperty	geo: hasGeometry	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

==== CIDOC CRM Geo

CRMGeo Source: https://www.cidoc-crm.org/crmgeo/sites/default/files/CRMgeo1_2.pdf

Alignment: CIDOC CRM Geo

FROM ELEMENT	MAPPING RELATION	TO ELEMENT	NOTES
cidoc:SP1_PhenoenmalSpaceTimeVolume	rdfs:subClassOf	geo: Feature	The CIDOC CRMgeo class SP1_Phenoenmal SpaceTimeVolume is a subclass of geo:Feature as described in the CRMgeo 1.2 specification document.
cidoc:SP2_PhenoenmalPlace	rdfs:subClassOf	geo: Feature	The CIDOC CRMgeo class SP2_Phenoenmal Place is a subclass of geo:Feature as described in the CRMgeo 1.2 specification document.
cidoc:SP5_GeometricPlaceExpression	rdfs:subClassOf	geo: Geometry	The CIDOC CRMgeo class SP5_Geometric PlaceExpression is a subclass of geo:Geometry as described in the CRMgeo 1.2 specification document.
cidoc:SP6_DeclarativePlace	rdfs:subClassOf	geo: Geometry	The CIDOC CRMgeo class SP6_Declarative Place is a subclass of geo:Geometry as described in the CRMgeo 1.2 specification document.
cidoc:SP7_DelcarativePlace	rdfs:subClassOf	geo: Geometry	The CIDOC CRMgeo class SP7_Declarative Place is a subclass of geo:Geometry as described in the CRMgeo 1.2 specification document.
cidoc:SP10_DeclarativeTimeSpan	rdfs:subClassOf	geo: Geometry	The CIDOC CRMgeo class SP10_Declarative TimeSpan is a subclass of geo:Geometry as

FROM ELEMENT	MAPPING RELATION	TO ELEMENT	NOTES
			described in the CRMgeo 1.2 specification document.
cidoc:SP14_TimeExpression	rdfs:subClassOf	geo:Geometry	The CIDOC CRMgeo class SP14_Time Expression is a subclass of geo:Geometry as described in the CRMgeo 1.2 specification document.
cidoc:SP15_Geometry	rdfs:subClassOf	geo:Geometry	The CIDOC CRMgeo class SP15_Geometry is a subclass of geo:Geometry as described in the CRMgeo 1.2 specification document.

==== 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>

Alignment: Basic Formal Ontology (BFO)

FROM ELEMENT	MAPPING RELATION	TO ELEMENT	NOTES
geo: SpatialObject	rdfs:subClassOf	obo:BFO_0000004 “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	rdfs:subClassOf	obo:BFO_0000006 “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	rdfs:subClassOf	obo:IAO_0000030 “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.
obo:BFO_0000040 “material entity”	rdfs:subClassOf	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
obo:BFO_0000029 “site”	rdfs:subClassOf	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	rdfs: subPropertyOf	obo:BFO_0000211 “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

FROM ELEMENT	MAPPING RELATION	TO ELEMENT	NOTES
			and the spatial region a geo:Geometry. No GeoSPARQL temporality indicators mean mappings are eternal.
geo:hasGeometry	<u>rdfs:</u> <u>subPropertyOf</u>	obo:BFO_0000210 “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>	obo:BFO_000082 “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 qualifiers, pure GeoSPARQL assertions are assumed to be eternal: “...at all times”
geo:sfWithin	<u>rdfs:</u> <u>subPropertyOf</u>	obo:BFO_0000171 “located in at some time”	A transitive mapping from the mapping above. Temporal qualification can be used with GeoSPARQL, see the OWL TIME alignment.
obo:BFO_0000066 “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
obo:BFO_000216 “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

== CQL / GeoSPARQL Mapping

F.0. Overview

This annex presents a mapping between the Common Query Language(CQL) Clause 12.2, Definition List 3: [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 Clause 12.2, Definition List 3: [WFS] and OGC API Features Clause 12.2, Definition List 3: [OGCAPIF] which implement CQL.

==== 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.

```
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 3: 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:

```
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

==== Mappings from CQL2 statements to GeoSPARQL queries

This section presents lists of equivalences between Common Query Language (CQL2) Clause 12.2, Definition List 3: [CQLDEF] statements and GeoSPARQL statements.

===== 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.

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 -55.95,160.6 -25.89, -170 -25.89, 160.6 -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= 2018-02-12 -T23%3A20%3A52Z	-	-	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 Clause 12.2, Definition List 3: [TIME]

===== 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.

CQL To GeoSPARQL Mappings: Literal Values

CQL2 LITERAL	EXAMPLES	(GEO)SPARQL LITERAL	EXAMPLES
String	"This is a string"	<u>xsd:string</u>	"This is a string"^^xsd:string
Number	-100 3.14159	<u>xsd:int</u> , <u>xsd:integer</u> , <u>xsd:double</u>	"-100"^^xsd:integer "3.14159"^^xsd:double
Boolean	true false	<u>xsd:boolean</u>	"true"^^xsd:boolean "false"^^xsd:boolean
Spatial Geometry (WKT)	POINT(1 1)	WKT Literal	"POINT(1 1)"^^geo:wktLiteral
Spatial Geometry (JSON)	{"type": "Point", "coordinates": [1,1]}	GeoJSON Literal	{"type": "Point", "coordinates": [1,1]}^^geo:geoJSONLiteral
Temporal Literal	1969-07-20 1969-07-20T20:17:40Z	<u>xsd:date</u> , <u>xsd:dateTime</u> , <u>xsd:dateTimeStamp</u>	"1969-07-20"^^xsd:date "1969-07-20T20:17:40Z"^^xsd:dateTime

==== 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.

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)

==== 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.

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
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 explicitly CRS/SRS information that may be filtered using SPARQL REGEX operators.

==== Spatial Operators

GeoSPARQL includes equivalents of many CQL2 filter functions as can be seen in the table below.

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))

CQL2 FILTER EXPRESSION	GEOSPARQL FILTER FUNCTION
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))
WITHIN(geometry1,geometry2)	FILTER(geof:sfWithin(?geometry1,?geometry2))

===== Temporal Operators

Temporal operators are not part of the GeoSPARQL standard.

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

CQL2 FILTER EXPRESSION	GEOSPARQL FILTER FUNCTION
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 Clause 12.2, Definition List 3: [TIME] may be used to assert temporal relations between objects.

==== Mappings from Simple Features for SQL

The following table maps the functions and properties from Simple Features for SQL Clause 12.2, Definition List 3: [OGCSFACA] ISO 19125-1 to GeoSPARQL.

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): Integer	geof:sfEquals	1.0	geo:sfEquals	1.0

SIMPLE FEATURES FOR SQL	GEOSPARQL EQUIVALENT	SINCE GEOSPARQL	RELATED PROPERTY AVAILABLE	SINCE GEOSPARQL
Disjoint(another Geometry: Integer)	geof:sfDisjoint	1.0	geo:sfDisjoint	1.0
Intersects(another Geometry: Integer)	geof:sfIntersects	1.0	geo:sfIntersects	1.0
Touches(another Geometry: Integer)	geof:sfTouches	1.0	geo:sfTouches	1.0
Crosses(another Geometry: Integer)	geof:sfCrosses	1.0	geo:sfCrosses	1.0
Within(another Geometry: Integer)	geof:sfWithin	1.0	geo:sfWithin	1.0
Contains(another Geometry: Integer)	geof:sfContains	1.0	geo:sfContains	1.0
Overlaps(another 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)	geof:union	1.0	N/A	-

SIMPLE FEATURES FOR SQL	GEOSPARQL EQUIVALENT	SINCE GEOSPARQL	RELATED PROPERTY AVAILABLE	SINCE GEOSPARQL
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				
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	-

SIMPLE FEATURES FOR SQL	GEOSPARQL EQUIVALENT	SINCE GEOSPARQL	RELATED PROPERTY AVAILABLE	SINCE GEOSPARQL
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
2.1.9.1 Surface				
Area(): Double	geof:area	-	geo:hasArea	1.1
Centroid(): Point	geof:centroid	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:centroid	1.1	geo:hasCentroid	1.1
PointOnSurface(): Point	N/A	-	N/A	-

= Revision History

Revision History

DATE	RELEASE	AUTHOR	PARAGRAPH MODIFIED	DESCRIPTION
27 Oct. 2009	Draft	Matthew Perry	Clause 6	Technical Draft

DATE	RELEASE	AUTHOR	PARAGRAPH MODIFIED	DESCRIPTION
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 URLs 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
23 Oct. 2022	1.1 For Public Comment	Carl Reed, Joseph Abhayaratna	All	Final review prior to public comment

= Bibliography

[DE-9IM] Clementini, Eliseo; Di Felice, Paolino and van Oosterom, Peter: *A small set of formal topological relationships suitable for end-user interaction* (1993). In Abel, David; Ooi, Beng Chin (eds.). Advances in Spatial Databases: Third International Symposium, SSD '93 Singapore, June 23–25, 1993 Proceedings. Lecture Notes in Computer Science. 692/1993. Springer. pp. 277–295. doi:10.1007/3-540-56869-7_16

[QUAL] Cohn, Anthony G.; Brandon Bennett; John Gooday; Nicholas Mark Gotts: *Qualitative Spatial Representation and Reasoning with the Region Connection Calculus*, GeoInformatica, 1, 275–316 (1997) <https://doi.org/10.1023/A:1009712514511>

[FORMAL]	Egenhofer Max: <i>A Formal Definition of Binary Topological Relationships</i> (1989). In: Litwin, W. and Schek, H.J., Eds., <i>Proceedings of the 3rd International Conference on Foundations of Data Organization and Algorithms (FODO)</i> , Paris, France, <i>Lecture Notes in Computer Science</i> , 367, (Springer-Verlag, New York, 1989) 457-472. (1989)
[CATEG]	Egenhofer, Max and J. Herring: <i>Categorizing Binary Topological Relations Between Regions, Lines, and Points</i> (1990). <i>Geographic Databases</i> , Technical Report, Department of Surveying Engineering, University of Maine
[AUSPIX]	Geoscience Australia: <i>AusPIX: An Australian Government implementation of the rHEALPix DGGS in Python</i> (2020). https://github.com/GeoscienceAustralia/AusPIX_DGGS
[ISO13249]	International Organization for Standardization/International Electrotechnical Commission 13249-3: ISO/IEC 13249-3: <i>Information technology – Database languages – SQL multimedia and application packages – Part 3: Spatial</i> (2000)
[ISO19105]	International Organization for Standardization: <i>ISO 19105: Geographic information – Conformance and testing</i> (2000)
[ISO19107]	International Organization for Standardization: <i>ISO 19107: Geographic information – Spatial schema</i> (2018)
[ISO19109]	International Organization for Standardization: <i>ISO 19109: Geographic information – Rules for application schemas</i> (2005)
[IETF5234]	Internet Engineering Task Force: <i>RFC 5234: Internet Standard 68: Augmented BNF for Syntax Specifications: ABNF</i> . IETF Request for Comment (2008) https://tools.ietf.org/html/std68
[GEOJSON]	Internet Engineering Task Force: <i>RFC 7946: The GeoJSON Format</i> . IETF Request for Comment (August 2016). https://tools.ietf.org/html/rfc7946
[OGCKML]	Open Geospatial Consortium: <i>OGC KML 2.3. OGC Implementation Standard</i> (04 August 2015). http://www.opengis.net/doc/IS/kml/2.3
[OGCOM]	Open Geospatial Consortium: <i>OGC Observations and Measurements 2.0. OGC Abstract Specification</i> (17 September 2013). http://www.opengis.net/doc/as/om/2.0
[OGCSFACA]	Open Geospatial Consortium: <i>OGC 06-103r4 OpenGIS® Implementation Standard for Geographic information – Simple feature access – Part 1: Common architecture</i> . http://www.opengis.net/doc/is/sfa/1.2.1
[CHARTER]	Open Geospatial Consortium: <i>OGC GeoSPARQL SWG Charter</i> , OGC Working Group Charter (25 August 2020). https://github.com/opengeospatial/ogc-geosparql/blob/master/charter/swg_charter.pdf

[OGC API]	Open Geospatial Consortium: OGC API – Features – Part 1: Core. OGC Implementation Standard (14 October 2019). http://www.opengis.net/doc/IS/ogcapi-features-1/1.0
[DGGSAS]	Open Geospatial Consortium: Abstract Standard Topic 21 – Discrete Global Grid Systems – Part 1 Core Reference system and Operations and Equal Area Earth Reference System, Open Geospatial Consortium Standard (2021) https://docs.ogc.org/as/20-040r3/20-040r3.html
[CQLDEF]	Open Geospatial Consortium: OGC API – Features – Part 3: Filtering and the Common Query Language (CQL2) (2021) https://docs.ogc.org/DRAFTS/19-079r1.html
[WFS]	Open Geospatial Consortium: OpenGIS Web Feature Service 2.0 Interface Standard (2010). OGC Implementation Standard (2 November 2010). http://www.opengeospatial.org/standards/wfs
[LOGIC]	Randell, D. A., Cui, Z. and Cohn, A. G.: A spatial logic based on regions and connection, Proc. 3rd Int. Conf. on Knowledge Representation and Reasoning, Morgan Kaufmann, San Mateo, pp. 165–176 (1992)
[XSD1]	World Wide Web Consortium: XML Schema Part 1: Structures (Second Edition), W3C Recommendation (28 October 2004). https://www.w3.org/TR/xmlschema-1/
[XSD2]	World Wide Web Consortium: XML Schema Part 2: Datatypes (Second Edition), W3C Recommendation (28 October 2004). https://www.w3.org/TR/xmlschema-2/
[XML]	World Wide Web Consortium: Extensible Markup Language (XML) 1.0 (Fifth Edition), W3C Recommendation (26 November 2008). http://www.w3.org/TR/xml/
[SKOS]	World Wide Web Consortium: SKOS Simple Knowledge Organization System Reference, W3C Recommendation (18 August 2009). https://www.w3.org/TR/skos-reference/
[XMLNS]	World Wide Web Consortium: Namespaces in XML 1.0 (Third Edition), W3C Recommendation (8 December 2009). https://www.w3.org/TR/xml-names/
[TIME]	World Wide Web Consortium: Time Ontology in OWL, W3C Candidate Recommendation (26 March 2020). https://www.w3.org/TR/owl-time/
[RIF]	World Wide Web Consortium: RIF Overview (Second Edition), W3C Working Group Note (5 February 2013). https://www.w3.org/TR/rif-overview/
[TURTLE]	World Wide Web Consortium: RDF 1.1 Turtle – Terse RDF Triple Language, W3C Recommendation (25 February 2014). https://www.w3.org/TR/turtle/

[RDFXML]	World Wide Web Consortium: <i>RDF 1.1 XML Syntax</i> , W3C Recommendation (25 February 2014). https://www.w3.org/TR/rdf-syntax-grammar/
[RDFSEM]	World Wide Web Consortium: <i>RDF 1.1 Semantics</i> , W3C Recommendation (25 February 2014). https://www.w3.org/TR/rdf11-mt/
[SHACL]	World Wide Web Consortium: <i>Shapes Constraint Language (SHACL)</i> , W3C Recommendation (20 July 2017). https://www.w3.org/TR/shacl/
[PROF]	World Wide Web Consortium: <i>The Profiles Vocabulary</i> , W3C Working Group Note (18 December 2019). https://www.w3.org/TR/dx-prof/
[JSON-LD]	World Wide Web Consortium: <i>JSON-LD 1.1: A JSON-based Serialization for Linked Data</i> , W3C Recommendation (16 July 2020). https://www.w3.org/TR/json-ld11/
[SPARQLSERVDESC]	Word Wide Web Consortium: <i>SPARQL 1.1 Service Description</i> , W3C Recommendation (21 March 2013). https://www.w3.org/TR/sparql11-service-description/



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