Open GIS Consortium, Inc.

OpenGIS® Simple Features Specification

For SQL

Revision 1.1

OpenGIS Project Document 99-049

Release Date: May 5, 1999

***WARNING**: The Open GIS Consortium (OGC) releases this specification to the public without warranty. It is subject to change without notice. This specification is currently under active revision by the OGC Technical Committee*

Requests for clarification and/or revision can be made by contacting the OGC at revisions@opengis.org.

NOTICE

Table of Contents

0 Preface

0.1 Submitting Companies

The following companies submitted this implementation specification in response to the OGC Request 1, Open Geodata Model Working Group, A Request for Proposals: OpenGIS Features (OpenGIS Project Document Number 96-021):

- Environmental Systems Research Institute, Inc.
- IBM Corporation.
- Informix Software, Inc.
- MapInfo Corporation.
- Oracle Corporation.

0.2 Submission Contact Points

All questions about the joint submission should be directed to:

David Beddoe
ESRI–Washington DC.
2070 Chain Bridge Road, Suite 180
Vienna, VA 22182
Phone: (703) 506-9515
Email: dbeddoe@esri.com

Paul Cotton
IBM Corporation
1150 Eglinton Ave.
Toronto, Ontario M3C 1H7
Canada
cotton@vnet.ibm.com

Robert Uleman
Informix Software, Inc.
300 Lakeside Drive, Suite 2700
Oakland, CA 94612
uleman@informix.com

Sandra Johnson
MapInfo Corp.
One Global View
Troy N.Y. 12180-8399
sandra_johnson@mapinfo.com

Dr. John R. Herring
Oracle Corporation
196 VanBuren Street
Herndon, Virginia 22070, USA
phone: 1 703 736 8124
fax: 1 703 708 7233
jrherrin@us.oracle.com

0.3 Document Conventions

The `Courier New` font has been used to indicate SQL or other code segments.

0.4 Revision History

Revision 1.0 includes the following changes from Revision 0:

- Replaced the term 'byte stream' with 'representation'. The source for this change was proposal #1 from Revision Request 97-402.

- Made several minor corrections concerning typographical errors, fixed the definition of the GEOMETRY_COLUMNS table to remove foreign key constraints that accessed INFORMATION_SCHEMA, fixed several functions to replace the Boolean return values with integer returns, and made a clarification on the example in section 3.1.3. The source for these changes was Revision Request 97-403.

Revision 1.1 includes the following changes from Revision 1.0:

- Function name consistency

- Consistent use of UML notation for section 2 (Architecture)

- 18 character function name limits

- Explicit specification of ETYPE codes for SQL numeric representation

- Clarify handling of mixed spatial references in SQL functions

- Fix errors in diagrams

- Misc. typographical errors

- Remove Spatial Reference Data not present in EPSG 1.3 specification

When problems were identified, such as inconsistent function names or function names that exceed 18 characters, the correction was made to conform to the SQL/MM specification.

0.5 Editorial Notes

1 Overview

The purpose of this specification is to define a standard SQL schema that supports storage, retrieval, query and update of simple geospatial feature collections via the ODBC API. A simple feature is defined by the OpenGIS Abstract specification to have both spatial and non-spatial attributes. Spatial attributes are geometry valued, and simple features are based on 2D geometry with linear interpolation between vertices.

1.1 Approach

Simple geospatial feature collections will conceptually be stored as tables with geometry valued columns in a Relational DBMS (RDBMS), each feature will be stored as a row in a table. The non-spatial attributes of features will be mapped onto columns whose types are drawn from the set of standard ODBC/SQL92 data types. The spatial attributes of features will be mapped onto columns whose SQL data types are based on the underlying concept of additional geometric data types for SQL. A table whose rows represent Open GIS features shall be referred to as a **feature table**. Such a table shall contain one or more geometry valued columns. Feature table implementations are described for two target SQL environments: **SQL92** and **SQL92 with Geometry Types**.

In the **SQL92** environment, a geometry-valued column is implemented as a Foreign Key reference into a geometry table. A geometry value is stored using one or more rows in the geometry table. The geometry table may be implemented using either standard SQL numeric types or SQL binary types, schemas for both alternatives are described.

The term **SQL92 with Geometry Types** is used to refer to a SQL92 environment that has been extended with a set of Geometry Types. In this environment a geometry-valued column is implemented as a column whose SQL type is drawn from the set of Geometry Types. *This specification describes a standard set of SQL Geometry Types based on the OpenGIS Geometry Model, together with the SQL functions on those types*. This specification does *not* attempt to standardize any part of the mechanism by which the Geometry Types are added to and maintained in the SQL environment: The standard SQL3 mechanism for extending the type system of a SQL database is through the definition of user defined Abstract Data Types. Commercial implementations of SQL92 environments with user defined type support are available as of mid 1997. The SQL3 standard should be ratified in 1998.

Both the **SQL92** and the **SQL92 with Geometry Types** implementations extend the SQL92 Information Schema in a uniform manner so as to support standard Metadata Queries that return:

1. The list of feature tables in a database.

2. The list of geometry columns for any feature table in the database.

3. The Spatial Reference System for any geometry column in the database.

Both the **SQL92** and the **SQL92 with Geometry Types** implementations are accessed from ODBC using the support already built into ODBC for fetching and storing standard integer, character and binary ODBC SQL types.

In order to be compliant with this OpenGIS ODBC/SQL specification for geospatial feature collections, implementers shall choose to implement **any one** of **three** alternatives **(1a, 1b or 2)** described in this specification:

1. **SQL92** implementation of feature tables

    a) using numeric SQL types for geometry storage and ODBC access.

    b) using binary SQL types for geometry storage and ODBC access.

2. **SQL92 with Geometry Types** implementation of feature tables supporting both textual and binary ODBC access to geometry.

The remainder of this specification is structured as follows:

- Chapter 2 describes the architecture of the system for both the SQL92 environment and for the **SQL92 with Geometry Types** environment. It begins with a Distributed Computing Platform neutral conceptual object model for Geometry. Upon this object model, the detailed specification for geometry values, geometry types and the SQL functions that operate upon geometry types is based.

- Chapter 3 specifies the architectural components of the system for the SQL92 environment and for the **SQL92 with Geometry Types** environment.

- Chapter 4 details supported spatial reference system data for use with this specification.

- Chapter 5 contains the references utilized by the specification.

2 Architecture

2.1 Geometry Object Model

This section describes the object model for geometry. It is Distributed Computing Platform neutral and uses OMT notation. The object model for geometry is shown in Figure 2.1. The base Geometry class has subclasses for Point, Curve, Surface and Geometry Collection. Each geometric object is associated with a Spatial Reference System, which describes the coordinate space in which the geometric object is defined.

Figure 2.1 is based on extending the Geometry Model specified in the OpenGIS Abstract Specification with specialized 0, 1 and two-dimensional collection classes named MultiPoint, MultiLineString and MultiPolygon for modelling geometries corresponding to collections of Points, LineStrings and Polygons respectively. MultiCurve and MultiSurface are introduced as abstract superclasses at this RFP that generalize the collection interfaces to handle Curves and Surfaces. The figure shows aggregation lines between the leaf collection classes and their element classes, the aggregation lines for non-leaf collection classes are described in the text.

The attributes, methods and assertions for each geometry class are described below. In describing methods, *this* is used to refer to the receiver of the method (the object being messaged). The scope of the methods and attributes is based on the scope of RFP1 (SimpleFeatures).

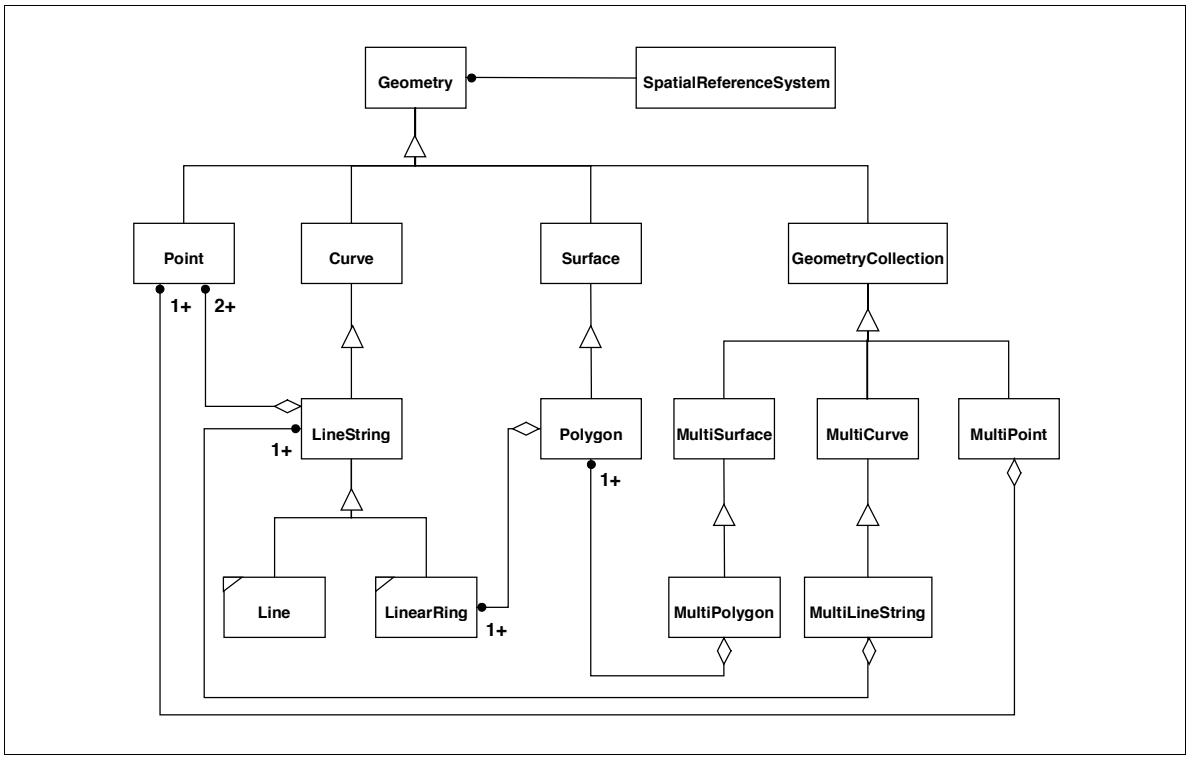


Figure 2.1—Geometry Class Hierarchy

2.1.1 Geometry

Geometry is the root class of the hierarchy. Geometry is an abstract (non-instantiable) class.

The instantiable subclasses of Geometry defined in this specification are restricted to 0, 1 and two-dimensional geometric objects that exist in two-dimensional coordinate space ($\Re^2$).

All instantiable geometry classes described in this specification are defined so that valid instances of a geometry class are topologically closed (i.e. all defined geometries include their boundary).

2.1.1.1 Basic Methods on Geometry

Dimension ( ):Integer—The inherent dimension of *this* Geometry object, which must be less than or equal to the coordinate dimension. This specification is restricted to geometries in two-dimensional coordinate space.

GeometryType ( ):String —Returns the name of the instantiable subtype of Geometry of which *this* Geometry instance is a member. The name of the instantiable subtype of Geometry is returned as a string.

SRID ( ):Integer—Returns the Spatial Reference System ID for *this* Geometry.

Envelope( ):Geometry—The minimum bounding box for *this* Geometry, returned as a Geometry. The polygon is defined by the corner points of the bounding box ((MINX, MINY), (MAXX, MINY), (MAXX, MAXY), (MINX, MAXY), (MINX, MINY)).

AsText( ):String —Exports *this* Geometry to a specific well-known text representation of Geometry.

AsBinary( ):Binary—Exports *this* Geometry to a specific well-known binary representation of Geometry.

IsEmpty( ):Integer —Returns 1 (TRUE) if *this* Geometry is the empty geometry . If true, then *this* Geometry represents the empty point set, ∅, for the coordinate space.

IsSimple( ):Integer —Returns 1 (TRUE) if *this* Geometry has no anomalous geometric points, such as self intersection or self tangency. The description of each instantiable geometric class will include the specific conditions that cause an instance of that class to be classified as not simple.

Boundary( ):Geometry —Returns the closure of the combinatorial boundary of *this* Geometry. The combinatorial boundary is defined as described in section 3.12.3.2 of [1]. Because the result of this function is a closure, and hence topologically closed, the resulting boundary can be represented using representational geometry primitives as discussed in [1], section 3.12.2.

2.1.1.2 Methods for testing Spatial Relations between geometric objects :

The methods in this section are defined and described in more detail following the description of the sub types of Geometry.

Equals(anotherGeometry:Geometry):Integer — Returns 1 (TRUE) if *this* Geometry is 'spatially equal' to anotherGeometry.

Disjoint(anotherGeometry:Geometry):Integer— Returns 1 (TRUE) if *this* Geometry is 'spatially disjoint' from anotherGeometry.

Intersects(anotherGeometry:Geometry):Integer— Returns 1 (TRUE) if *this* Geometry 'spatially intersects' anotherGeometry.

Touches(anotherGeometry:Geometry):Integer— Returns 1 (TRUE) if *this* Geometry 'spatially touches' anotherGeometry.

Crosses(anotherGeometry:Geometry):Integer— Returns 1 (TRUE) if *this* Geometry 'spatially crosses' anotherGeometry.

Within(anotherGeometry:Geometry):Integer — Returns 1 (TRUE) if *this* Geometry is 'spatially within' anotherGeometry.

Contains(anotherGeometry:Geometry):Integer — Returns 1 (TRUE) if *this* Geometry 'spatially contains' anotherGeometry.

Overlaps(anotherGeometry:Geometry):Integer — Returns 1 (TRUE) if *this* Geometry 'spatially overlaps' anotherGeometry.

Relate(anotherGeometry:Geometry, intersectionPatternMatrix:String):Integer— Returns 1 (TRUE) if *this* Geometry is spatially related to anotherGeometry, by testing for intersections between the Interior, Boundary and Exterior of the two geometries as specified by the values in the intersectionPatternMatrix.

2.1.1.3 Methods that support Spatial Analysis

Distance(anotherGeometry:Geometry):Double—Returns the shortest distance between any two points in the two geometries as calculated in the spatial reference system of *this* Geometry.

Buffer(distance:Double):Geometry—Returns a geometry that represents all points whose distance from *this* Geometry is less than or equal to distance. Calculations are in the Spatial Reference System of *this* Geometry.

ConvexHull( ):Geometry—Returns a geometry that represents the convex hull of *this* Geometry.

Intersection(anotherGeometry:Geometry):Geometry—Returns a geometry that represents the point set intersection of *this* Geometry with anotherGeometry.

Union(anotherGeometry:Geometry):Geometry—Returns a geometry that represents the point set union of *this* Geometry with anotherGeometry.

Difference(anotherGeometry:Geometry):Geometry—Returns a geometry that represents the point set difference of *this* Geometry with anotherGeometry.

SymDifference(anotherGeometry:Geometry):Geometry—Returns a geometry that represents the point set symmetric difference of *this* Geometry with anotherGeometry.

2.1.2 Geometry Collection

A GeometryCollection is a geometry that is a collection of 1 or more geometries.

All the elements in a GeometryCollection must be in the same Spatial Reference. This is also the Spatial Reference for the GeometryCollection.

GeometryCollection places no other constraints on its elements. Subclasses of GeometryCollection may restrict membership based on dimension and may also place other constraints on the degree of spatial overlap between elements.

2.1.2.1 Methods

NumGeometries( ):Integer—Returns the number of geometries in *this* GeometryCollection.

GeometryN(N:integer):Geometry—Returns the Nth geometry in *this* GeometryCollection.

2.1.3 Point

A Point is a 0-dimensional geometry and represents a single location in coordinate space. A Point has a x-coordinate value and a y-coordinate value.

The boundary of a Point is the empty set.

2.1.3.1 Methods

X( ):Double —The x-coordinate value for *this* Point.

Y( ):Double —The y-coordinate value for *this* Point.

2.1.4 MultiPoint

A MultiPoint is a 0 dimensional geometric collection. The elements of a MultiPoint are restricted to Points. The points are not connected or ordered.

A MultiPoint is simple if no two Points in the MultiPoint are equal (have identical coordinate values).

The boundary of a MultiPoint is the empty set.

2.1.5 Curve

A Curve is a one-dimensional geometric object usually stored as a sequence of points, with the subtype of Curve specifying the form of the interpolation between points. This specification defines only one subclass of Curve, LineString, which uses linear interpolation between points.

Topologically a Curve is a one-dimensional geometric object that is the homeomorphic image of a real, closed, interval $D = [a, b] = \{x \in R \mid a <= x <= b\}$ under a mapping $f:[a,b] \rightarrow \Re^2$ as defined in [1], section 3.12.7.2.

A Curve is simple if it does not pass through the same point twice ([1], section 3.12.7.3)

$$\forall c \in Curve, [a, b] = c.Domain,$$

$$c.IsSimple \Leftrightarrow (\forall x1, x2 \in (a, b] \; x1 \neq x2 \Rightarrow f(x1) \neq f(x2)) \wedge (\forall x1, x2 \in [a, b) \; x1 \neq x2 \Rightarrow f(x1) \neq f(x2))$$

A Curve is closed if its start point is equal to its end point. ([1], section 3.12.7.3)

The boundary of a closed Curve is empty.

A Curve that is simple and closed is a Ring.

The boundary of a non-closed Curve consists of its two end points. ([1], section 3.12.3.2).

A Curve is defined as topologically closed.

2.1.5.1 Methods

Length( ):Double—The length of *this* Curve in its associated spatial reference.

StartPoint( ):Point—The start point of *this* Curve.

EndPoint( ):Point—The end point of *this* Curve.

IsClosed( ):Integer—Returns 1 (TRUE) if *this* Curve is closed (StartPoint ( ) = EndPoint ( )).

IsRing( ):Integer—Returns 1 (TRUE) if *this* Curve is closed (StartPoint ( ) = EndPoint ( )) and *this* Curve is simple (does not pass through the same point more than once).

2.1.6 LineString, Line, LinearRing

A LineString is a Curve with linear interpolation between points. Each consecutive pair of points defines a line segment.

A Line is a LineString with exactly 2 points.

A LinearRing is a LineString that is both closed and simple. The curve in Figure 2.2—(3) is a closed LineString that is a LinearRing. The curve in Figure 2.2—(4) is a closed LineString that is not a LinearRing.

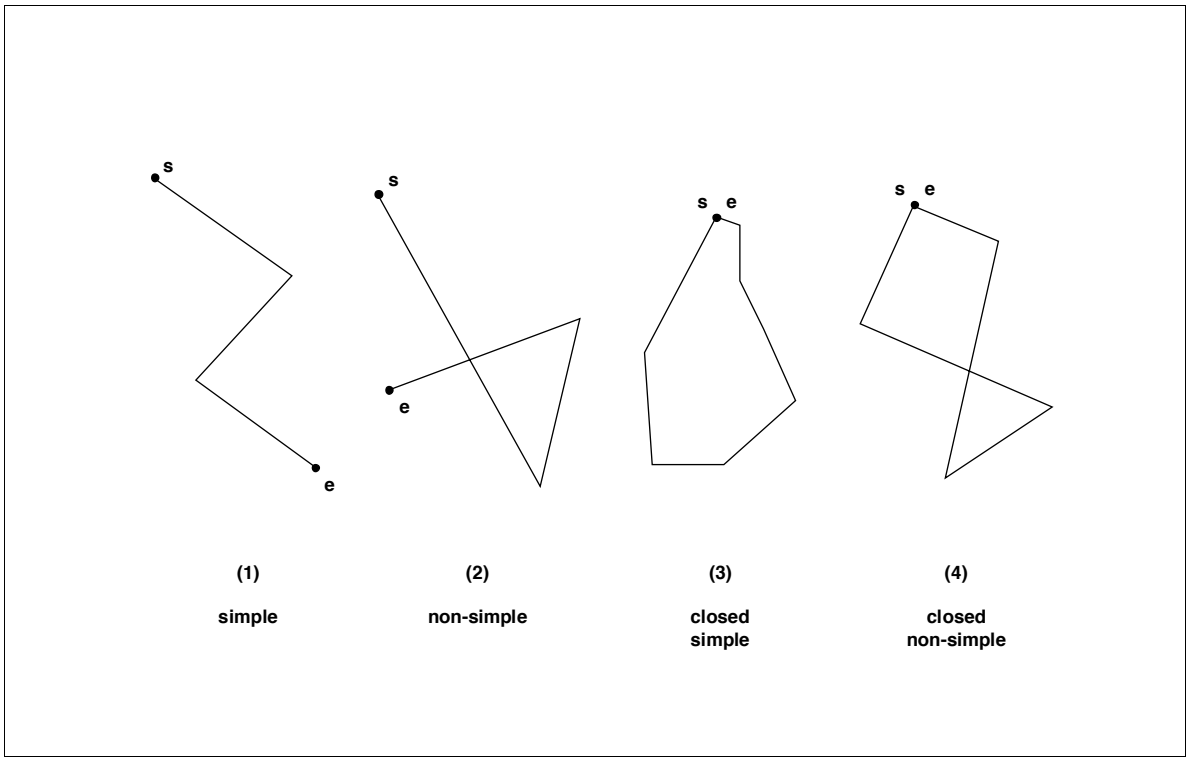


Figure 2.2—(1) a simple LineString, (2) a non-simple LineString, (3) a simple, closed LineString (a LinearRing), (4) a non-simple closed LineString

2.1.6.1 Methods

NumPoints( ):Integer—The number of points in *this* LineString.

PointN(N:Integer):Point—Returns the specified point N in *this* Linestring.

2.1.7 MultiCurve

A MultiCurve is a one-dimensional GeometryCollection whose elements are Curves (Figure 2.3).

MultiCurve is a non-instantiable class in this specification, it defines a set of methods for its subclasses and is included for reasons of extensibility.

A MultiCurve is simple if and only if all of its elements are simple, the only intersections between any two elements occur at points that are on the boundaries of both elements.

The boundary of a MultiCurve is obtained by applying the 'mod 2' union rule: A point is in the boundary of a MultiCurve if it is in the boundaries of an odd number of elements of the MultiCurve. ([1], section 3.12.3.2).

A MultiCurve is closed if all of its elements are closed. The boundary of a closed MultiCurve is always empty.

A MultiCurve is defined as topologically closed.

2.1.7.1 Methods

IsClosed( ):Integer—Returns 1 (TRUE) if *this* MultiCurve is closed (StartPoint ( ) = EndPoint ( ) for each curve in *this* MultiCurve)

Length( ):Double—The Length of *this* MultiCurve which is equal to the sum of the lengths of the element Curves.

2.1.8 MultiLineString

A MultiLineString is a MultiCurve whose elements are LineStrings.

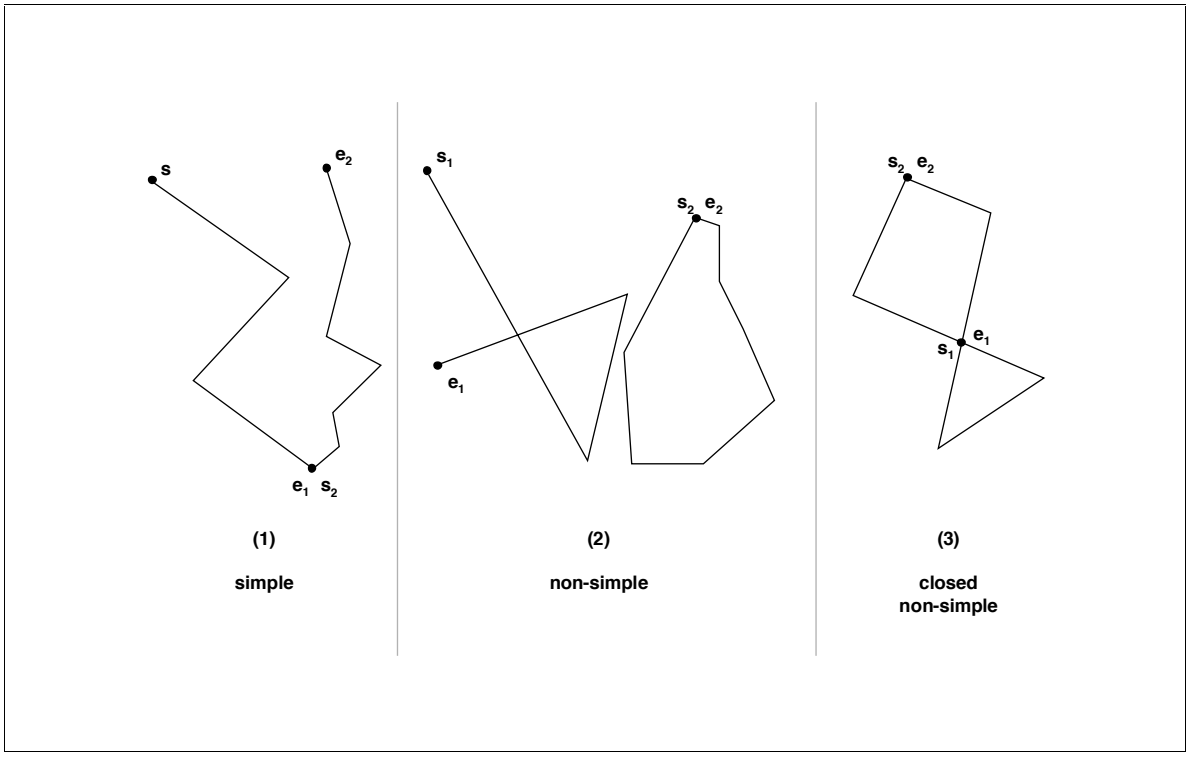


Figure 2.3—(1) a simple MultiLineString, (2) a non-simple MultiLineString with 2 elements, (3) a non-simple, closed MultiLineString with 2 elements

The boundaries for the MultiLineStrings in Figure 2.3 are (1)—{s1, e2}, (2)—{s1, e1}, (3)—∅

2.1.9 Surface

A Surface is a two-dimensional geometric object.

The OpenGIS Abstract Specification defines a simple Surface as consisting of a single 'patch' that is associated with one 'exterior boundary' and 0 or more 'interior' boundaries. Simple surfaces in three-dimensional space are isomorphic to planar surfaces. Polyhedral surfaces are formed by 'stitching' together simple surfaces along their boundaries, polyhedral surfaces in three-dimensional space may not be planar as a whole ([1], sections 3.12.9.1, 3.12.9.3).

The boundary of a simple Surface is the set of closed curves corresponding to its 'exterior' and 'interior boundaries. ([1], section 3.12.9.4).

The only instantiable subclass of Surface defined in this specification, Polygon, is a simple Surface that is planar.

2.1.9.1 Methods

Area( ):Double—The area of *this* Surface, as measured in the spatial reference system of *this* Surface.

Centroid( ):Point—The mathematical centroid for *this* Surface as a Point. The result is not guaranteed to be on *this* Surface.

PointOnSurface( ):Point—A point guaranteed to be on *this* Surface.

2.1.10 Polygon

A Polygon is a planar Surface, defined by 1 exterior boundary and 0 or more interior boundaries. Each interior boundary defines a hole in the Polygon.

The assertions for polygons (the rules that define valid polygons) are:

1. Polygons are topologically closed.

2. The boundary of a Polygon consists of a set of LinearRings that make up its exterior and interior boundaries.

3. No two rings in the boundary cross, the rings in the boundary of a Polygon may intersect at a Point but only as a tangent :

   $\forall P \in Polygon,\ \forall c1, c2 \in P.Boundary(),\ c1 \neq c2,\ \forall p, q \in Point, p, q \in c1, p \neq q, [\ p \in c2 \Rightarrow q \notin c2]$

4. A Polygon may not have cut lines, spikes or punctures:

   $\forall P \in Polygon, P = Closure(Interior(P))$

5. The Interior of every Polygon is a connected point set.

6. The Exterior of a Polygon with 1 or more holes is not connected. Each hole defines a connected component of the Exterior.

In the above assertions, Interior, Closure and Exterior have the standard topological definitions. The combination of 1 and 3 make a Polygon a Regular Closed point set.

Polygons are simple geometries.

Figure 2.4 shows some examples of Polygons. Figure 2.5 shows some examples of geometric objects that violate the above assertions and are not representable as single instances of Polygon. The objects shown in Figure 2.5—(1) and 2.5—(4) can be represented as 2 separate Polygons.

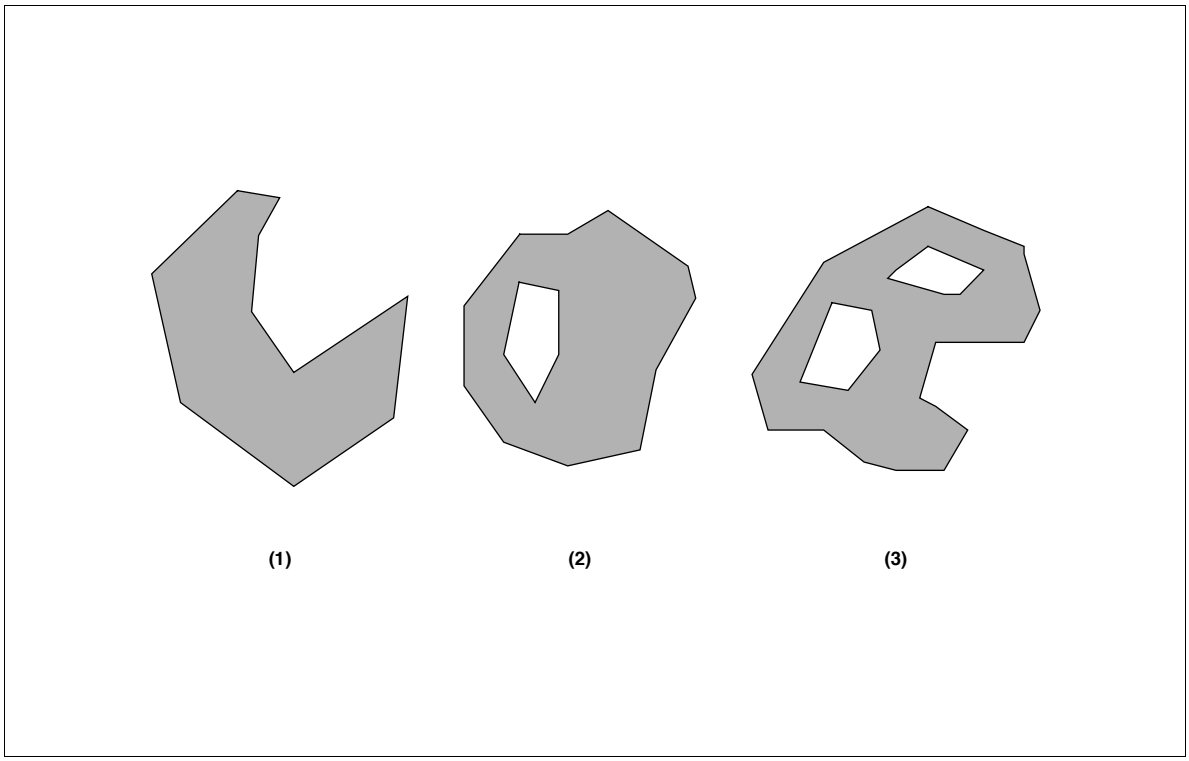


Figure 2.4—Examples of Polygons with 1, 2 and 3 rings respectively.

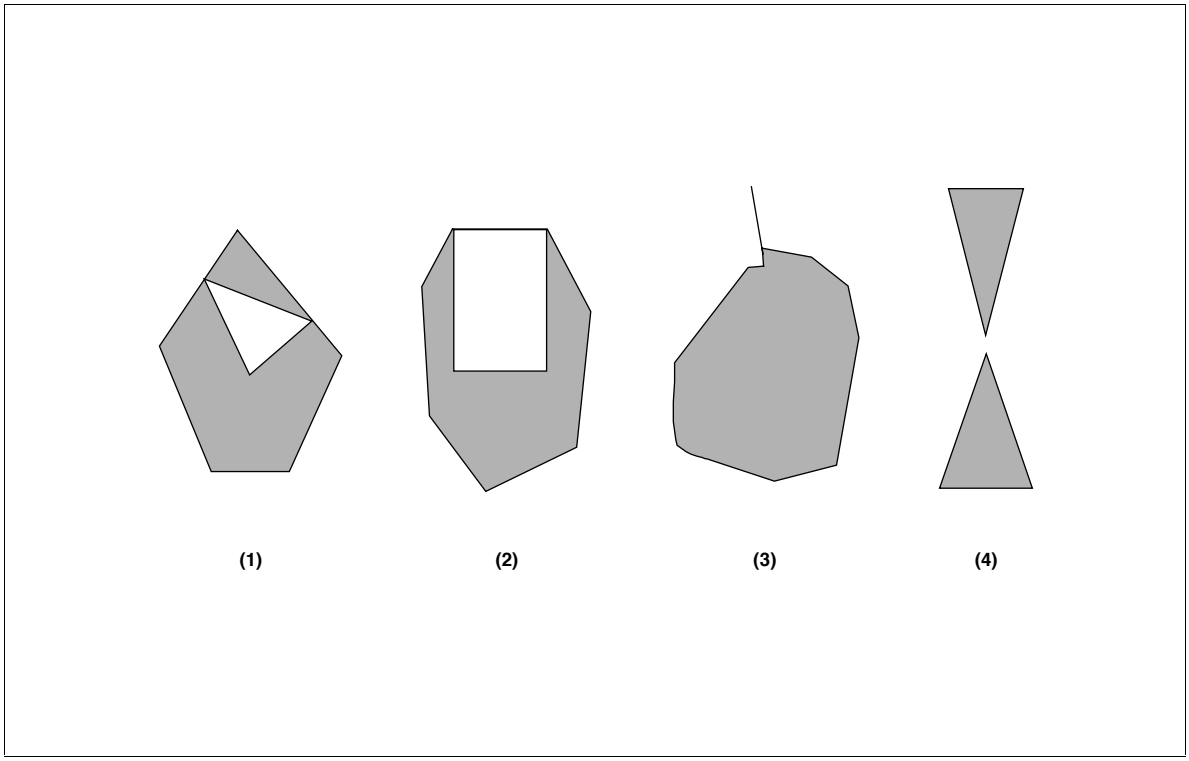


Figure 2.5—Examples of objects not representable as a single instance of Polygon. (1) and (4) can be represented as 2 separate Polygons.

2.1.10.1 Methods

ExteriorRing( ):LineString—Returns the exterior ring of *this* Polygon.

NumInteriorRing( ):Integer—Returns the number of interior rings in *this* Polygon.

InteriorRingN(N:Integer):LineString—Returns the Nth interior ring for *this* Polygon as a LineString.

2.1.11 MultiSurface

A MultiSurface is a two-dimensional geometric collection whose elements are surfaces. The interiors of any two surfaces in a MultiSurface may not intersect. The boundaries of any two elements in a MultiSurface may intersect at most at a finite number of points.

MultiSurface is a non-instantiable class in this specification, it defines a set of methods for its subclasses and is included for reasons of extensibility. The instantiable subclass of MultiSurface is MultiPolygon, corresponding to a collection of Polygons.

2.1.11.1 Methods

Area( ):Double—The area of *this* MultiSurface, as measured in the spatial reference system of *this* MultiSurface.

Centroid( ):Point—The mathematical centroid for *this* MultiSurface. The result is not guaranteed to be on *this* MultiSurface.

PointOnSurface( ):Point—A Point guaranteed to be on *this* MultiSurface.

2.1.12 MultiPolygon

A MultiPolygon is a MultiSurface whose elements are Polygons..

The assertions for MultiPolygons are :

1. The interiors of 2 Polygons that are elements of a MultiPolygon may not intersect.

   $\forall M \in MultiPolygon,\ \forall Pi, Pj \in M.Geometries(), i \neq j, Interior(Pi) \cap Interior(Pj) = \varnothing$

2. The Boundaries of any 2 Polygons that are elements of a MultiPolygon may not ‘cross’ and may touch at only a finite number of points. (Note that crossing is prevented by assertion 1 above).

   $\forall M \in MultiPolygon,\ \forall Pi, Pj \in M.Geometries(),\ \forall ci \in Pi.Boundaries(), cj \in Pj.Boundaries()$
   $ci \cap cj = \{p1, ..., pk \mid pi \in Point, 1 <= i <= k\}$

3. A MultiPolygon is defined as topologically closed.

4. A MultiPolygon may not have cut lines, spikes or punctures, a MultiPolygon is a Regular, Closed point set:

   $\forall M \in MultiPolygon, M = Closure(Interior(M))$

5. The interior of a MultiPolygon with more than 1 Polygon is not connected, the number of connected components of the interior of a MultiPolygon is equal to the number of Polygons in the MultiPolygon.

The boundary of a MultiPolygon is a set of closed curves (LineStrings) corresponding to the boundaries of its element Polygons. Each Curve in the boundary of the MultiPolygon is in the boundary of exactly 1 element Polygon, and every Curve in the boundary of an element Polygon is in the boundary of the MultiPolygon.

The reader is referred to work by Worboys, et. al (7, 8) and Clementini, et. al (5, 6) for work on the definition and specification of MultiPolygons.

Figure 2.6 shows 4 examples of valid MultiPolygons with 1, 3, 2 and 2 polygon elements respectively.

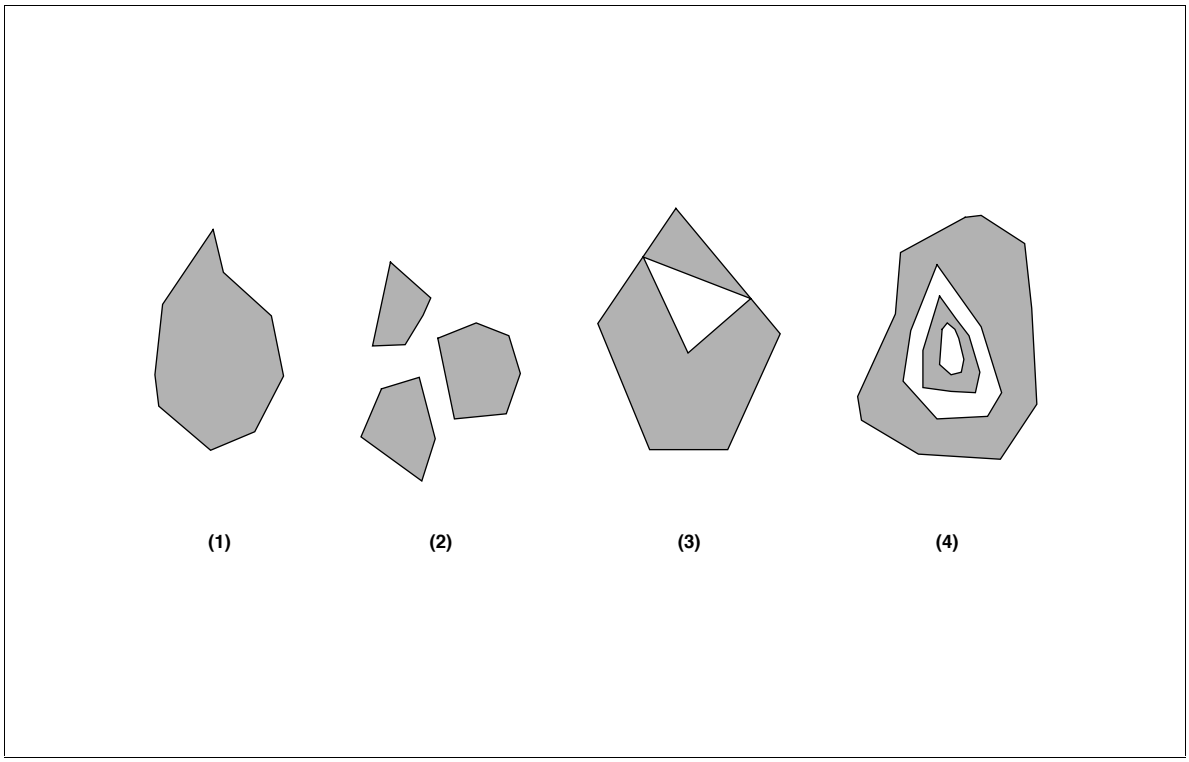


Figure 2.6—Examples of MultiPolygons

Figure 2.7 shows examples of geometric objects not representable as single instances of MultiPolygons.

Note that the subclass of Surface named Polyhedral Surface described in the [1], is a faceted surface whose facets are Polygons. A Polyhedral Surface is not a MultiPolygon because it violates the rule for MultiPolygons that the boundaries of the element Polygons intersect only at a finite number of points.

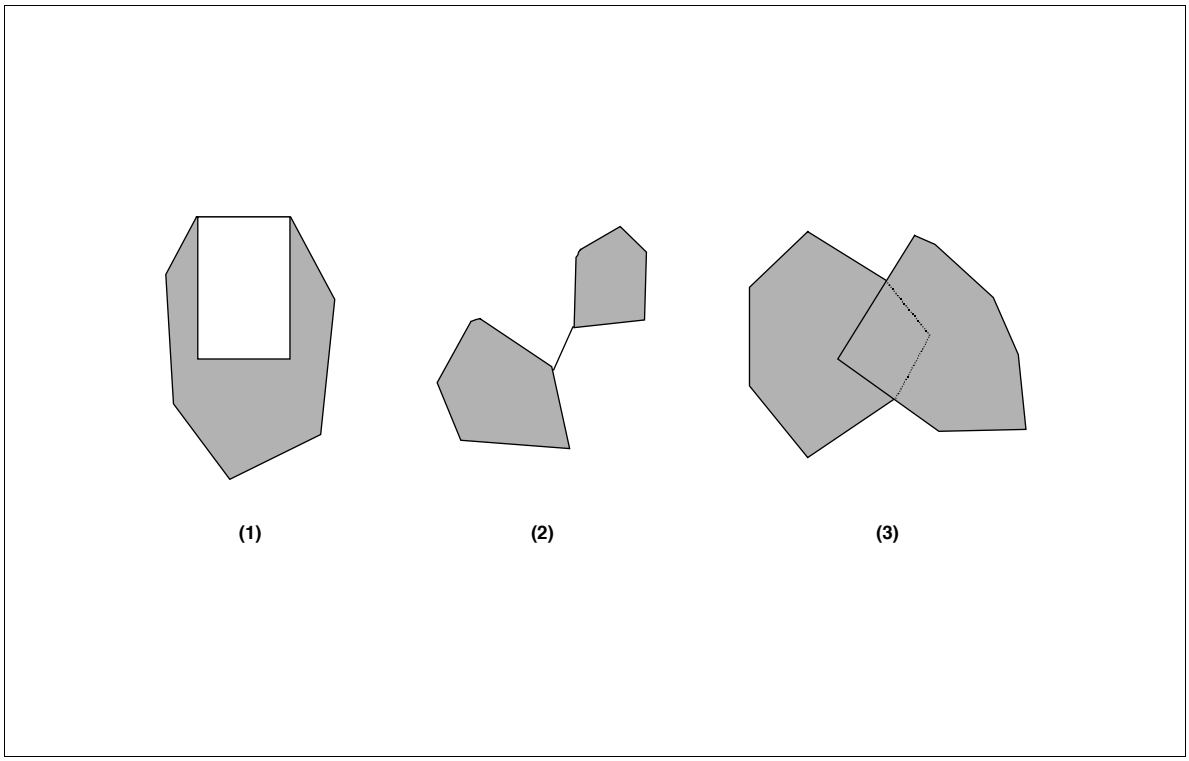


Figure 2.7—Geometric objects not representable as a single instance of a MultiPolygon.

2.1.13 Relational Operators

This section provides a more detailed specification of the relational operators on geometries.

2.1.13.1 Background

The Relational Operators are Boolean methods that are used to test for the existence of a specified topological spatial relationship between two geometries. Topological spatial relationships between two geometric objects have been a topic of extensive study in the literature [4,5,6,7,8,9,10]. The basic approach to comparing two geometries is to make pair-wise tests of the intersections between the Interiors, Boundaries and Exteriors of the two geometries and to classify the relationship between the two geometries based on the entries in the resulting 'intersection' matrix.

The concepts of Interior, Boundary and Exterior are well defined in general topology. For a review of these concepts the user is referred to Egenhofer, et al [4]. These concepts can be applied in defining spatial relationships between two-dimensional objects in two-dimensional space ($\Re^2$). In order to apply the concepts of Interior, Boundary and Exterior to 1 and 0 dimensional objects in $\Re^2$, a combinatorial topology approach must be applied. ([1], section. 3.12.3.2). This approach is based on the accepted definitions of the boundaries, interiors and exteriors for simplicial complexes [12] and yields the following results:

The boundary of a geometry is a set of geometries of the next lower dimension. The boundary of a Point or a MultiPoint is the empty set. The boundary of a non-closed Curve consists of its two end Points, the boundary of a closed Curve is empty. The boundary of a MultiCurve consists of those Points that are in the boundaries of an odd number of its element Curves. The boundary of a Polygon consists of its set of Rings. The boundary of a MultiPolygon consists of the set of Rings of its Polygons. The boundary of an arbitrary collection of geometries whose interiors are disjoint consists of geometries drawn from the boundaries of the element geometries by application of the 'mod 2' union rule ([1], section 3.12.3.2).

The domain of geometric objects considered is those that are topologically closed. The interior of a geometry consists of those points that are left when the boundary points are removed. The exterior of a geometry consists of points not in the interior or boundary.

Studies on the relationships between two geometries both of maximal dimension in $\Re^1$ and $\Re^2$ considered pair-wise intersections between the Interior and Boundary sets and led to the definition of a 4 Intersection Model [8]. The model was extended to consider the exterior of the input geometries, resulting in a nine intersection model [11] and further extended to include information on the dimension of the results of the pair-wise intersections resulting in a dimensionally extended nine intersection model [5]. These extensions allow the model to express spatial relationships between points, lines and areas, including areas with holes and multi component lines and areas [6].

2.1.13.2 The Dimensionally Extended Nine-Intersection Model

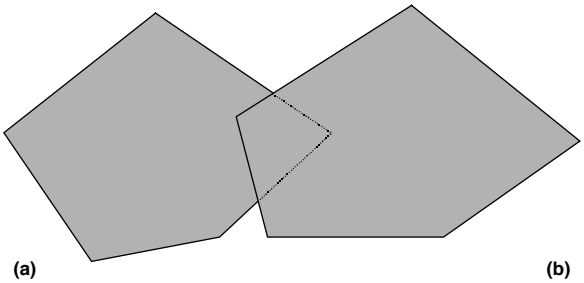
Given a geometry a, let *I(a)*, *B(a)* and *E(a)* represent the Interior, Boundary and Exterior of a respectively. The intersection of any two of *I(a)*, *B(a)* and *E(a)* can result in a set of geometries, *x*, of mixed dimension. For example, the intersection of the boundaries of two polygons may consist of a point and a line. Let *dim(x)* return the maximum dimension (-1, 0, 1, or 2) of the geometries in *x*, with a numeric value of -1 corresponding to *dim(∅)*. A dimensionally extended nine-intersection matrix (DE-9IM) then has the form:

	Interior	Boundary	Exterior
Interior	*dim(I(a)∩I(b))*	*dim(I(a)∩B(b))*	*dim(I(a)∩E(b))*
Boundary	*dim(B(a)∩I(b))*	*dim(B(a)∩B(b))*	*dim(B(a)∩E(b))*
Exterior	*dim(E(a)∩I(b))*	*dim(E(a)∩B(b))*	*dim(E(a)∩E(b))*

Table 2.1—The DE-9IM

For regular, topologically closed input geometries, computing the dimension of the intersection of the Interior, Boundary and Exterior sets does not have as a prerequisite the explicit computation and representation of these sets. For example to compute if the interiors of two regular closed polygons intersect, and to ascertain the dimension of this intersection, it is not necessary to explicitly represent the interior of the two polygons (which are topologically open sets) as separate geometries. In most cases the dimension of the intersection value at a cell is highly constrained given the type of the two geometries. For example, in the Line-Area case the only possible values for the Interior-Interior cell are drawn from {-1, 1} and in the Area-Area case the only possible values for the Interior-Interior cell are drawn from {-1, 2}. In such cases no work beyond detecting the intersection is required.

Figure 2.8 shows an example DE-9IM for the case where *a* and *b* are two polygons that overlap.



	Interior	Boundary	Exterior
Interior	2	1	2
Boundary	1	0	1
Exterior	2	1	2

Figure 2.8—An example instance and its DE-9IM

A spatial relationship predicate can be formulated on two geometries that takes as input a pattern matrix representing the set of acceptable values for the DE-9IM for the two geometries. If the spatial relationship between the two geometries corresponds to one of the acceptable values as represented by the pattern matrix, then the predicate returns TRUE.

The pattern matrix consists of a set of 9 pattern-values, one for each cell in the matrix. The possible pattern-values *p* are {T, F, *, 0, 1, 2} and their meanings for any cell where *x* is the intersection set for the cell are as follows:

$p = T \Rightarrow dim(x) \in \{0, 1, 2\}$, i.e. $x \neq \varnothing$

$p = F \Rightarrow dim(x) = -1$, i.e. $x = \varnothing$

$p = * \Rightarrow dim(x) \in \{-1, 0, 1, 2\}$, i.e. Don't Care

$p = 0 \Rightarrow dim(x) = 0$

$p = 1 \Rightarrow dim(x) = 1$

$p = 2 \Rightarrow dim(x) = 2$

The pattern matrix can be represented as an array or list of nine characters in row major order. As an example the following code fragment could be used to test for 'Overlap' between two areas:

```
char * overlapMatrix = 'T*T***T**';
Geometry* a, b;
Boolean b = a->Relate(b, overlapMatrix);
```

2.1.13.3 Named Spatial Relationship predicates based on the DE-9IM

The Relate predicate based on the pattern matrix has the advantage that clients can test for a large number of spatial relationships and fine tune the particular relationship being tested. It has the disadvantage that it is a lower level building block and does not have a corresponding natural language equivalent. Users of the proposed system include IT developers using the COM API from a language such as Visual Basic, and interactive SQL users who may wish, for example, *to select all features 'spatially within' a query polygon*, in addition to more spatially 'sophisticated' GIS developers.

To address the needs of such users a set of named spatial relationship predicates have been defined in [5,6] for the DE-9IM. The five predicates are named Disjoint, Touches, Crosses, Within and Overlaps. The definition of these predicates [5,6] is given below. In these definitions the term P is used to refer to 0 dimensional geometries (Points and MultiPoints), L is used to refer to one-dimensional geometries (LineStrings and MultiLineStrings) and A is used to refer to two-dimensional geometries (Polygons and MultiPolygons).

Disjoint

Given two (topologically closed) geometries *a* and *b*,

$$a.Disjoint(b) \Leftrightarrow a \cap b = \varnothing$$

Expressed in terms of the DE-9IM:

$$a.Disjoint(b) \Leftrightarrow (I(a) \cap I(b) = \varnothing) \wedge (I(a) \cap B(b) = \varnothing) \wedge (B(a) \cap I(b) = \varnothing) \wedge (B(a) \cap B(b) = \varnothing)$$
$$\Leftrightarrow a.Relate(b, \text{'FF*FF****'})$$

Touches

The Touches relation between two geometries a and b applies to the A/A, L/L, L/A, P/A and P/L groups of relationships but not to the P/P group. It is defined as:

$$a.Touches(b) \Leftrightarrow (I(a) \cap I(b) = \varnothing) \wedge (a \cap b) \neq \varnothing$$

Expressed in terms of the DE-9IM:

$$a.Touches(b) \Leftrightarrow (I(a) \cap I(b) = \varnothing) \wedge ((B(a) \cap I(b) \neq \varnothing) \vee (I(a) \cap B(b) \neq \varnothing) \vee (B(a) \cap B(b) \neq \varnothing))$$
$$\Leftrightarrow a.Relate(b, \text{'FT*******'}) \vee a.Relate(b, \text{'F**T*****'}) \vee a.Relate(b, \text{'F***T****'})$$

Figure 2.9 shows some examples of the Touches relation.

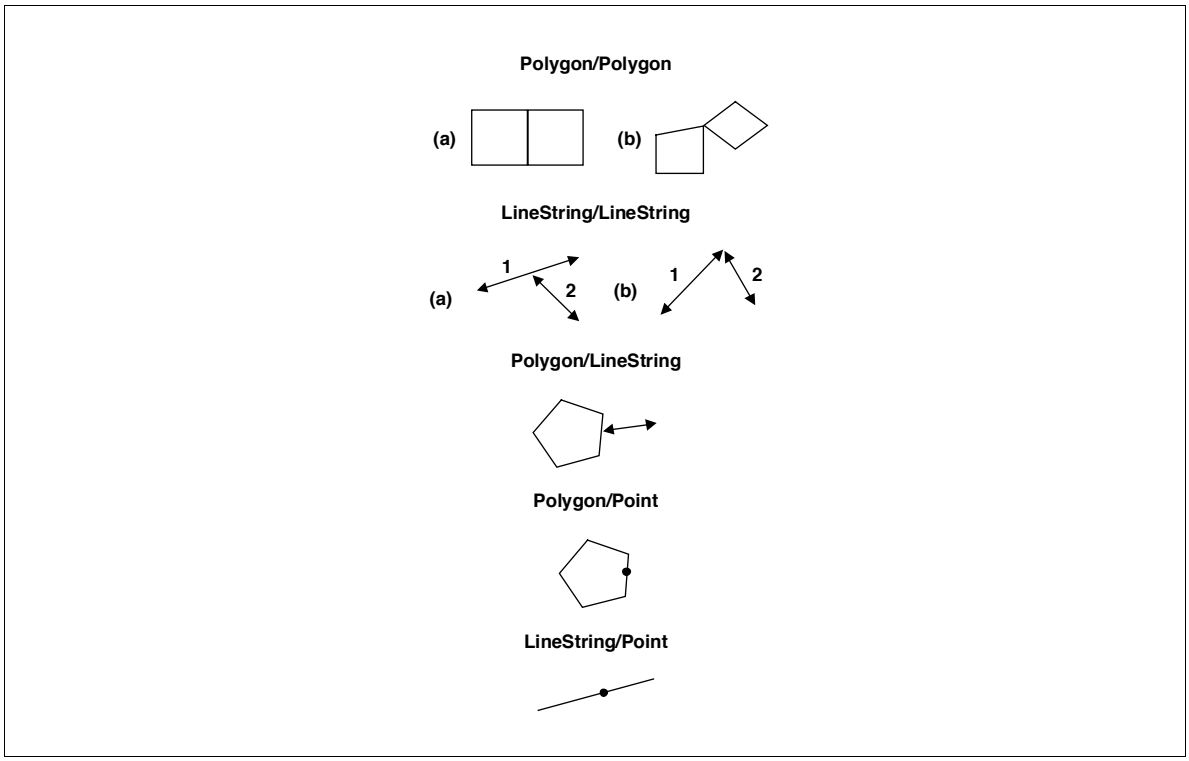


Figure 2.9—Examples of the Touches relationship

Crosses

The Crosses relation applies to P/L, P/A, L/L and L/A situations. It is defined as:

$$a.Crosses(b) \Leftrightarrow (dim(I(a) \cap I(b)) < max(dim(I(a)), dim(I(b)))) \wedge (a \cap b \neq a) \wedge (a \cap b \neq b)$$

Expressed in terms of the DE-9IM:

Case $a \in P$, $b \in L$ or Case $a \in P$, $b \in A$ or Case $a \in L$, $b \in A$:

$$a.Crosses(b) \Leftrightarrow (I(a) \cap I(b) \neq \emptyset) \wedge (I(a) \cap E(b) \neq \emptyset) \Leftrightarrow a.Relate(b, \text{`T*T******'})$$

Case $a \in L$, $b \in L$:

$$a.Crosses(b) \Leftrightarrow dim(I(a) \cap I(b)) = 0 \Leftrightarrow a.Relate(b, \text{`0********'});$$

Figure 2.10 shows some examples of the Crosses relation.

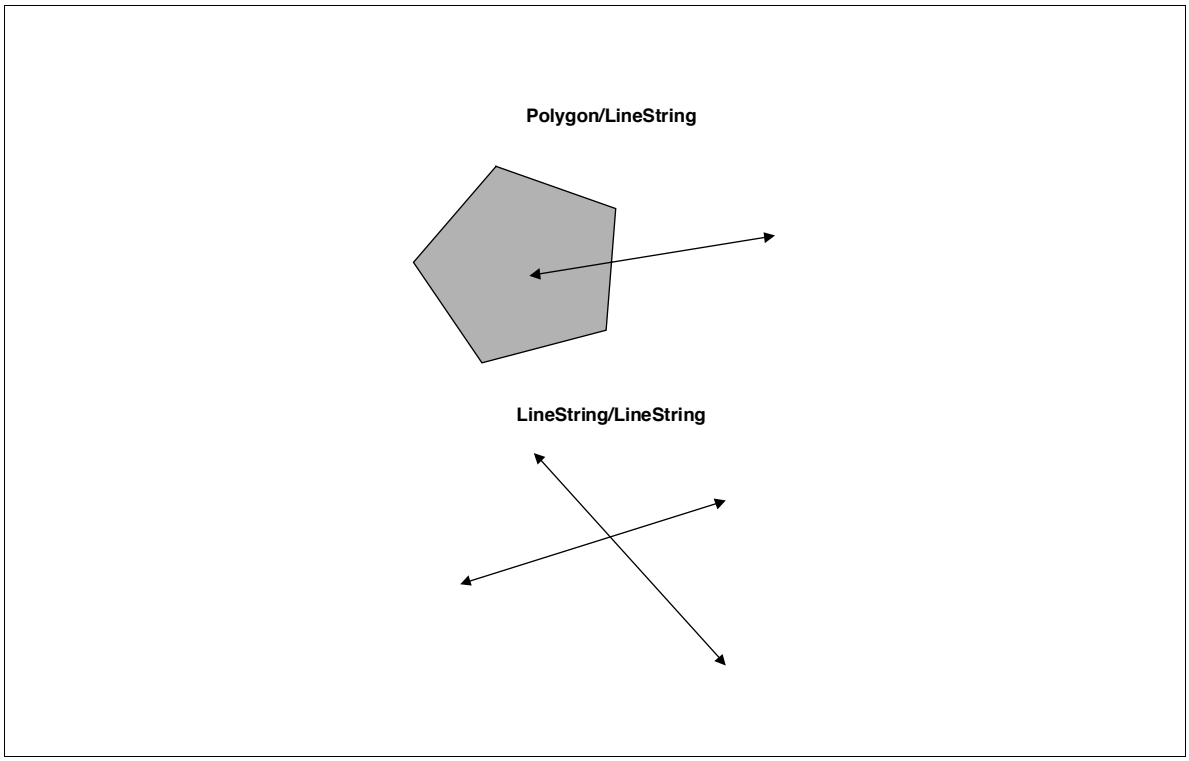


Figure 2.10—Examples of the Crosses relationship

Within

The Within relation is defined as:

$$a.Within(b) \Leftrightarrow (a \cap b = a) \wedge (I(a) \cap I(b) \neq \varnothing)$$

Expressed in terms of the DE-9IM:

$$a.Within(b) \Leftrightarrow (I(a) \cap I(b) \neq \varnothing) \wedge (I(a) \cap E(b) = \varnothing) \wedge (B(a) \cap E(b) = \varnothing)) \Leftrightarrow a.Relate(b, \text{`T*F**F***'})$$

Figure 2.11 shows some examples of the Within relation.

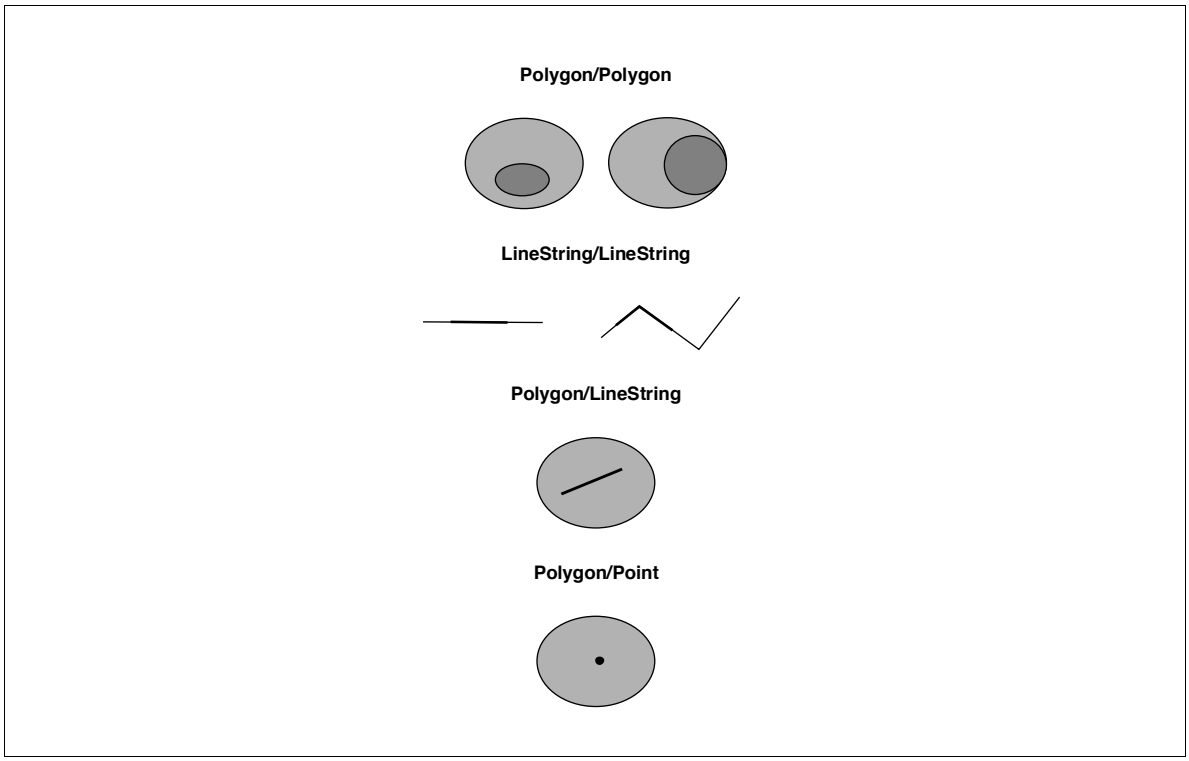


Figure 2.11—Examples of the Within relationship

Overlaps

The Overlaps relation is defined for A/A, L/L and P/P situations.

It is defined as:

$$a.Overlaps(b) \Leftrightarrow (dim(I(a)) = dim(I(b)) = dim(I(a) \cap I(b))) \wedge (a \cap b \neq a) \wedge (a \cap b \neq b)$$

Expressed in terms of the DE-9IM:

Case $a \in P$, $b \in P$ or Case $a \in A$, $b \in A$:

$$a.Overlaps(b) \Leftrightarrow (I(a) \cap I(b) \neq \emptyset) \wedge (I(a) \cap E(b) \neq \emptyset) \wedge (E(a) \cap I(b) \neq \emptyset) \Leftrightarrow a.Relate(b, \text{`T*T***T**'})$$

Case $a \in L$, $b \in L$:

$$a.Overlaps(b) \Leftrightarrow (dim(I(a) \cap I(b) = 1) \wedge (I(a) \cap E(b) \neq \emptyset) \wedge (E(a) \cap I(b) \neq \emptyset) \Leftrightarrow a.Relate(b, \text{`1*T***T**'})$$

Figure 2.12 shows some examples of the Overlaps relation.

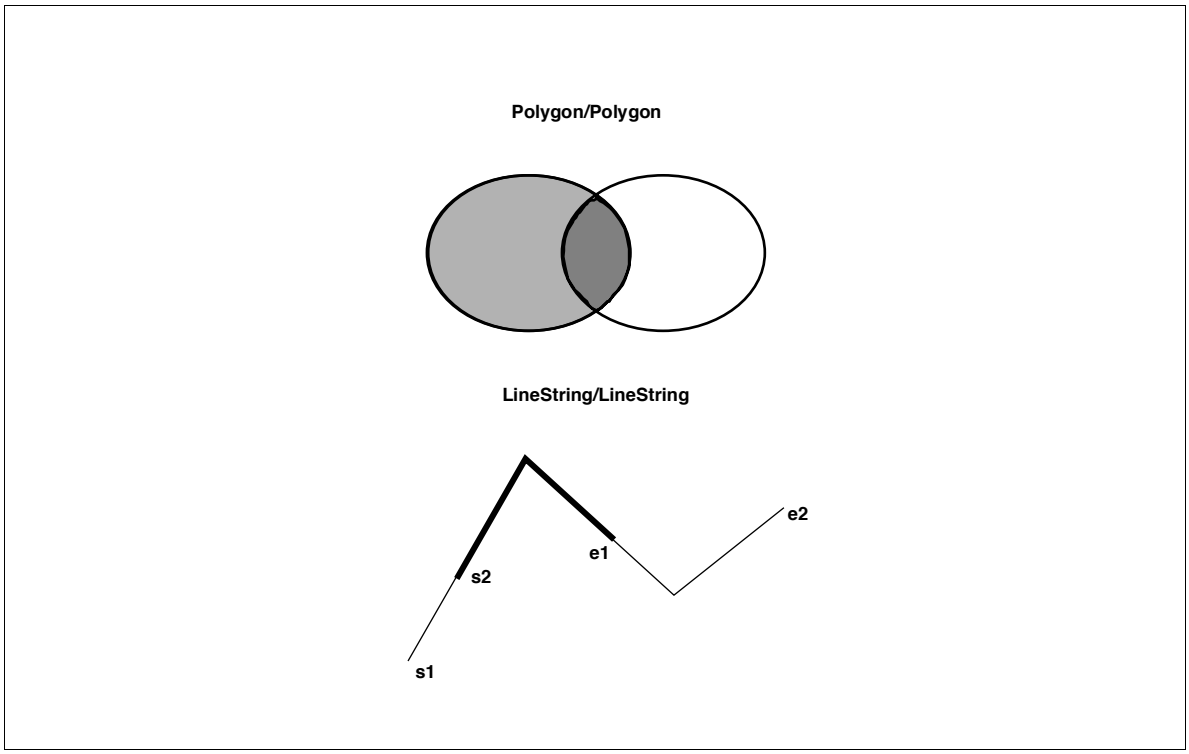


Figure 2.12—Examples of the Overlaps relationship

The following additional named predicates are also defined for user convenience:

Contains

$$a.Contains(b) \Leftrightarrow b.Within(a)$$

Intersects

$$a.Intersects(b) \Leftrightarrow !\, a.Disjoint(b)$$

Based on the above operators the following methods are defined on Geometry:

Equals(anotherGeometry:Geometry):Integer—Returns 1 (TRUE) if *this* Geometry is 'spatially equal' to anotherGeometry.

Disjoint(anotherGeometry:Geometry):Integer— Returns 1 (TRUE) if *this* Geometry is 'spatially disjoint' from anotherGeometry.

Intersects(anotherGeometry:Geometry):Integer— Returns 1 (TRUE) if *this* Geometry 'spatially intersects' anotherGeometry.

Touches(anotherGeometry:Geometry):Integer— Returns 1 (TRUE) if *this* Geometry 'spatially touches' anotherGeometry.

Crosses(anotherGeometry:Geometry):Integer— Returns 1 (TRUE) if *this* Geometry 'spatially crosses' anotherGeometry.

Within(anotherGeometry:Geometry):Integer— Returns 1 (TRUE) if *this* Geometry is 'spatially within' anotherGeometry.

Contains(anotherGeometry:Geometry):Integer— Returns 1 (TRUE) if *this* Geometry 'spatially contains' anotherGeometry.

Overlaps(anotherGeometry:Geometry):Integer— Returns 1 (TRUE) if *this* Geometry 'spatially overlaps' anotherGeometry.

Relate(anotherGeometry:Geometry, intersectionPatternMatrix:String):Integer— Returns 1 (TRUE) if *this* Geometry is spatially related to anotherGeometry, by testing for intersections between the Interior, Boundary and Exterior of the two geometries.

2.2 Architecture—SQL92 Implementation of Feature Tables

A **SQL92** implementation of OpenGIS simple geospatial feature collections defines a schema for storage of feature table, geometry and spatial reference system information. The **SQL92** implementation does **not** define **SQL functions** for access, maintenance, or indexing of geometry, as these functions cannot be uniformly implemented across database systems using the SQL92 standard.

The figure below describes the database schema necessary to support the OpenGIS simple feature data model. A feature table or view corresponds to an OpenGIS feature class. Each feature view contains some number of features represented as rows in the view. Each feature contains some number of geometric attribute values represented as columns in the feature view. Each geometric column in a feature view is associated with a particular geometric view or table that contains geometry instances in a single spatial reference system. The correspondence between the feature instances and the geometry instances shall be accomplished through a foreign key that is stored in the geometry column of the feature table. This foreign key references the GID primary key of the geometry table.

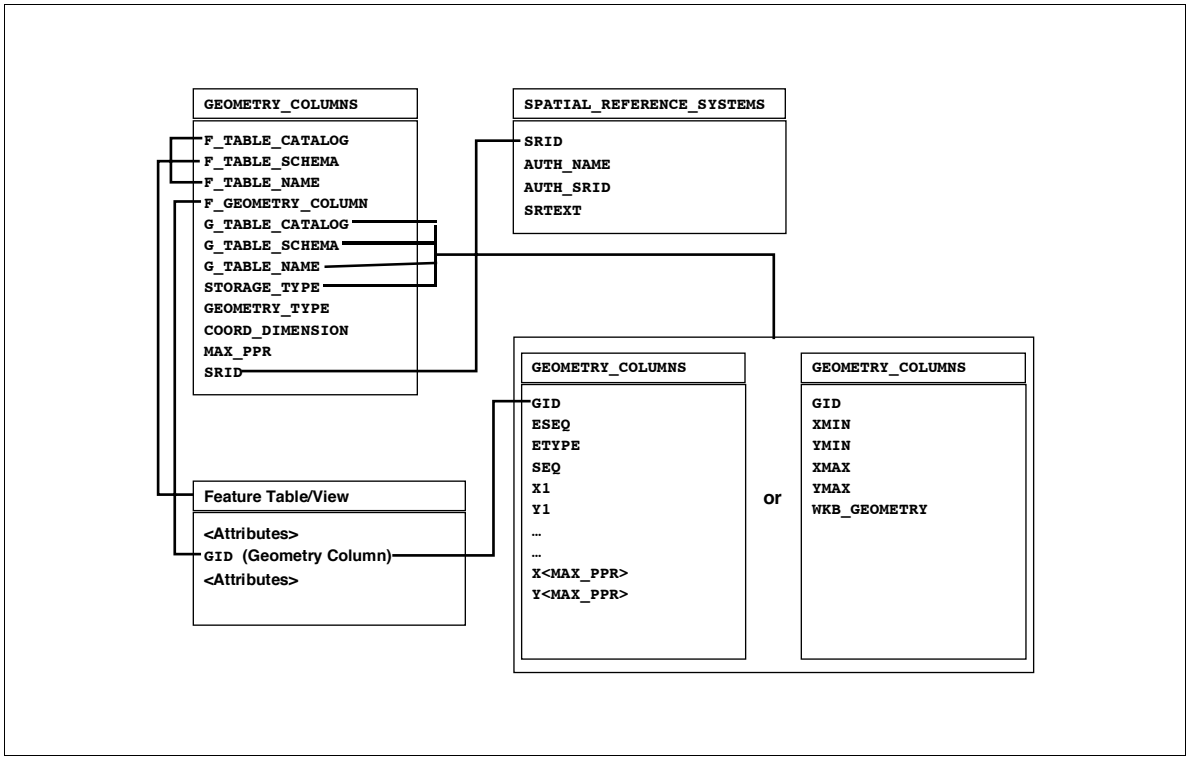


Figure 2.13—Schema for feature tables under SQL92

Depending upon the type of storage specified by the geometry metadata, Geometry instances shall be stored as either arrays of coordinate values or as binary values using an OpenGIS defined Well-Known Binary Representation for Geometry. In the former case, SQL numeric types are used for the coordinates and client side functions are needed to build OpenGIS geometry objects from the retrieved coordinate numeric values. In the latter case clients may feed the retrieved well-known binary representation directly into the Geometry factory of the client side computing environment (e.g., an OLE/COM or CORBA geometry factory) or choose to access the individual coordinate values by unpacking the well-known representation.

2.2.1 Feature Table Metadata Views

A feature table is any table having 1 or more foreign key reference to a geometry table or view. The set of feature tables in a database can be determined using the above rule from the TABLES, REFERENTIAL_CONSTRAINTS and COLUMNS metadata views in the SQL92 INFORMATION_SCHEMA. The set of feature tables can also be determined by issuing a query over the GEOMETRY_COLUMNS metadata view described below.

2.2.2 Geometry Columns Metadata Views

Each geometry column will be represented as a row in the standard COLUMNS metadata view in the SQL92 INFORMATION_SCHEMA. Spatial Reference System Identity is however not a standard part of the SQL92 INFORMATION_SCHEMA. To represent this information we introduce an additional metadata view named GEOMETRY_COLUMNS.

The GEOMETRY_COLUMNS table or view consists of a row for each geometry column in the database. The data stored for each geometry column includes:

- the identity of the feature table of which it is a member,
- the spatial reference system ID,
- the type of geometry for the column,
- the coordinate dimension for the column,
- the identity of the geometry table that stores its instances, and
- the information necessary to navigate the geometry tables in the case of normalized geometry storage.

2.2.3 Spatial Reference System Information Views

Every geometry column is associated with a Spatial Reference System. The Spatial Reference System identifies the coordinate system for all geometries stored in the column, and gives meaning to the numeric coordinate values for any geometry instance stored in the column. Examples of commonly used Spatial Reference Systems include ‘Latitude Longitude’, and ‘UTM Zone 10’.

The SPATIAL_REFERENCE_SYSTEMS table stores information on each Spatial Reference System in the database. The columns of this table are the Spatial Reference System Identifier (SRID), the Spatial Reference System Authority Name (AUTH_NAME) , the Authority Specific Spatial Reference System Identifier (AUTH_SRID) and the Well-known Text description of the Spatial Reference System (SRTEXT). The Spatial Reference System Identifier (SRID) constitutes a unique integer key for a Spatial Reference System within a database.

Interoperability between clients is achieved via the SRTEXT column which stores the Well-known Text representation for a Spatial Reference System as described in Section 3.4.

2.2.4 Feature Tables and Views

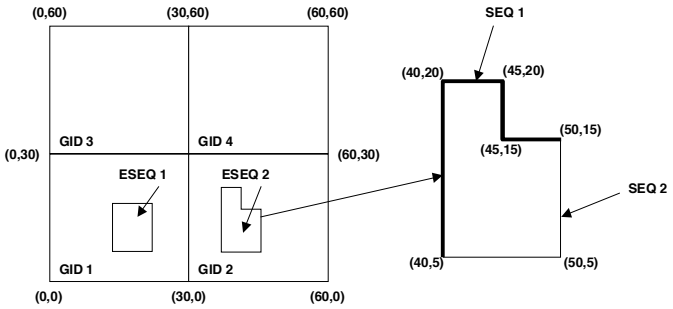
A Feature is an object with geometric attributes [1]. Features are stored as rows in tables, each geometric attribute is a foreign key reference to a geometry table or view. Relationships between Features are defined as FOREIGN KEY references between feature tables.

2.2.5 Geometry and Geometric Element Views

There are two implementations for storing geometries in SQL92: using a normalized geometry SQL92 schema, and using a binary geometry SQL92 schema. The binary geometry schema uses the Well-known Binary Representation for Geometry (WKBGeometry) described in section 3.3. The normalized geometry implementation defines fixed width SQL92 tables such as the example in Figure 2.14. Each primitive element in the geometry is distributed over some number of adjacent rows in the table ordered by a sequence number (SEQ), and identified by a primitive type (ETYPE). Each geometry identified by a key (GID), consists of a collection of elements numbered by an element sequence (ESEQ).

The rules for geometric entity representation in the normalized SQL92 schema are defined as follows:

- ETYPE designates the geometry type.
- Geometries may have multiple elements. The ESEQ value identifies the individual elements.
- An element may be built up from multiple parts (rows). The rows and their proper sequence are identified by the SEQ value.
- Polygons may contain holes, as described in the geometry object model.
- Polygon rings must close when assembled from an ordered list of parts. The SEQ value designates the part order.
- Coordinate pairs that are not used must be set to Nil in complete sets (both X and Y). This is the only way to identify the end of list of coordinates.
- For geometries that continue onto an additional row (as defined by an constant element sequence number or ESEQ) the last point of one row is equal to the first point of the next.
- There is no limit on the number of elements in the geometry, or the number of rows in a element.



GID	ESEQ	ETYPE	SEQ	X0	Y0	X1	Y1	X2	Y2	X3	Y3	X4	Y4
1	1	3	1	0	0	0	30	30	30	30	0	0	0
1	2	3	1	10	10	10	20	20	20	20	10	10	10
2	1	3	1	30	0	30	30	60	30	60	0	30	0
2	2	3	1	40	5	40	20	45	20	45	15	50	15
2	2	3	2	50	15	50	5	40	5	Nil	Nil	Nil	Nil
3	1	3	1	0	30	0	60	30	60	30	30	0	30
4	1	3	1	30	30	30	60	60	60	60	30	30	30

Figure 2.14—Example of geometry table for Polygon Geometry using SQL

The binary geometry implementation is illustrated in Table 2.2, and uses the same GID as a key, but stores the geometry using the Well-known Binary Representation for Geometry (WKBGeometry) described in section 3.3. The geometry table includes the minimum bounding rectangle for the geometry as well as the WKBGeometry for the geometry. This permits construction of spatial indexes without accessing the actual geometry structure, if desired.

GID	XMIN	YMIN	XMAX	YMAX	GEOMETRY
1	0	0	30	30	< WKBGeometry>
2	30	0	60	30	< WKBGeometry >
3	0	30	30	60	< WKBGeometry >
4	30	30	60	60	< WKBGeometry >

Table 2.2—Example of geometry table for above Polygon Geometry using the Well-known Binary Representation for Geometry.

2.2.6 Notes on SQL92 data types

There are various ways to store the same values in a relational database. For example, there are usually several ways to store numbers. In this specification, the use of a storage alternative is not meant to be binding. Since the storage type of any column is available in the data dictionary, and such casting operators between similar types are available, any particular implementation may use alternative storage formats as long as casting operations would not lead to difficulties.

2.2.7 Notes on ODBC Access to Geometry Values stored in Binary form.

ODBC provides standard mechanisms to bind character, numeric and binary data values.

This section describes the process of retrieving geometry values for the case where the binary storage alternative is chosen.

The WKB_GEOMETRY column in the geometry table for a geometry column surfaces in ODBC as one of the ODBC binary SQL data types (SQL_BINARY, SQL_VARBINARY, or SQL_LONGVARBINARY). An application binds to this column using the ODBC 2.0 C datatype SQL_C_BINARY.

For example, the application would use the SQL_C_BINARY value for the fCType parameter of SQLBindCol (or SQLGetData) in order to describe the application data buffer that will receive the fetched Geometry data value. Similarly, a dynamic parameter whose value is a Geometry would be described using the SQL_C_BINARY value for the fCType parameter of SQLBindParameter.

This allows binary values to be both retrieved from and inserted into the geometry tables.

2.3 Architecture—SQL92 with Geometry Types Implementation of Feature Tables

2.3.1 Feature Table Metadata Views

A feature table is any table having one or more columns whose SQL Type is drawn from the set of Geometry SQL Types defined in section 3.2.3. The set of feature tables in a database can be determined from the TABLES and COLUMNS metadata views in the SQL92 INFORMATION_SCHEMA. The set of feature tables can also be determined by querying the GEOMETRY_COLUMNS metadata view as described below.

2.3.2 Geometry Columns Metadata Views

Each geometry column will be represented as a row in the standard COLUMNS metadata view in the SQL92 INFORMATION_SCHEMA. Spatial Reference System Identity is however not a standard part of the SQL92 INFORMATION_SCHEMA. To represent this information we introduce an additional metadata view named GEOMETRY_COLUMNS.

The GEOMETRY_COLUMNS table or view consists of a row for each geometry column in the database. The data stored for each geometry column includes the identity of the feature table of which it is a member, the spatial reference system ID, the type of geometry for the column, and the coordinate dimension.

The columns in the GEOMETRY_COLUMNS metadata view for the **SQL92 with Geometry Types** environment are a subset of the columns in the GEOMETRY_COLUMNS view defined for the **SQL92** environment.

2.3.3 Spatial Reference System Information Views

Every geometry column is associated with a Spatial Reference System. The Spatial Reference System identifies the coordinate system for all geometries stored in the column, and gives meaning to the numeric coordinate values for any geometry instance stored in the column. Examples of commonly used Spatial Reference Systems include ‘Latitude Longitude’, and ‘UTM Zone 10’.

The SPATIAL_REFERENCE_SYSTEMS table stores information on each Spatial Reference System in the database. The columns of this table are the Spatial Reference System Identifier (SRID), the Spatial

Reference System Authority Name (AUTH_NAME) , the Authority Specific Spatial Reference System Identifier (AUTH_SRID) and the Well-known Text description of the Spatial Reference System (SRTEXT). The Spatial Reference System Identifier (SRID) constitutes a unique integer key for a Spatial Reference System within a database.

Interoperability between clients is achieved via the SRTEXT column which stores the Well-known Text representation for a Spatial Reference System as described in section 3.4.

The Spatial Reference System Information View for the **SQL92 with Geometry Types** implementation is identical to the Spatial Reference System Information View for the **SQL92** implementation.

2.3.4 Feature Tables and Views

A Feature is an object with geometric attributes [1]. Feature are stored in tables, each geometric attribute is stored in a geometric column whose type is drawn from the set of SQL Geometry Types described in section 3.2.3. Relationships between Features are defined as FOREIGN KEY references between feature tables.

2.3.5 Background Information on SQL Abstract Data Types

The term Abstract Data Type (ADT) refers to a data type that extends the SQL type system.

ADT types can be used to define the column types for tables, this allows values stored in the columns of a table to be instances of ADTs.

SQL functions may be declared to take ADT values as arguments, and return ADT values as results.

An ADT may be defined as a subtype of another ADT, referred to as its supertype. This allows an instance of the subtype to be stored in any column where an instance of the supertype is expected and allows an instance of the subtype to be used as an argument or return value in any SQL function that is declared to use the super type as an argument or return value.

The above definition of ADTs is value based, and value based ADTs with the above properties are defined as part of the current draft SQL3 standard.

SQL implementations that support Abstract Data Types may also support the concept of References to Abstract Data Type instances that are stored as rows in a table whose type corresponds to the type of the Abstract Data Type. The terms RowType and Reference to RowType are also used to describe such types. The above concepts of Types that support tables whose rows are instances of the Type and that support References to Type instances are also part of the current draft SQL3 standard.

This specification allows Geometry Types to be implemented as either pure value based Types or as Types that support persistent References.

2.3.6 Scope of this OpenGIS Geometry Types specification

This specification ***does not*** attempt to standardize ***and does not depend upon*** any part of the mechanism by which Types are added and maintained in the SQL environment including

- The syntax and functionality provided for defining types
- The syntax and functionality provided for defining SQL functions
- The physical storage of type instances in the database

- The specific terminology used to refer to types, for example, ADT.

This specification ***does*** standardize:

- The names and geometric definitions of the OpenGIS SQL Types for Geometry.

- The names, signatures and geometric definitions of the OpenGIS SQL Functions for Geometry.

The types for geometry are defined in *black box* terms, i.e. all access to information about a geometry type instance is through SQL functions. No attempt is made to distinguish functions that may access type instance attributes (such as the *dimension* of a geometry instance) from functions that may compute values given a type instance (such as the *centroid* of a polygon). In particular, a SQL3 implementation of this specification would be free to nominate any set of functions as observer methods on attributes of an Abstract Data Type in SQL3 as long as the signatures of the SQL functions described in this specification are preserved.

This specification does not place any requirements on when or how or who defines the Geometry Types. In particular, a compliant system may be shipped to the database user with the set of Geometry Types and Functions already built into the RDBMS server, or with the set of Geometry Types and Functions supplied to the database user as a dynamically loaded extension to the RDBMS server or in any other manner not mentioned in this specification.

2.3.7 SQL Geometry Type Hierarchy

The SQL Geometry Types are organized into a type hierarchy based on the Open GIS Geometry Model and are shown in the figure below.

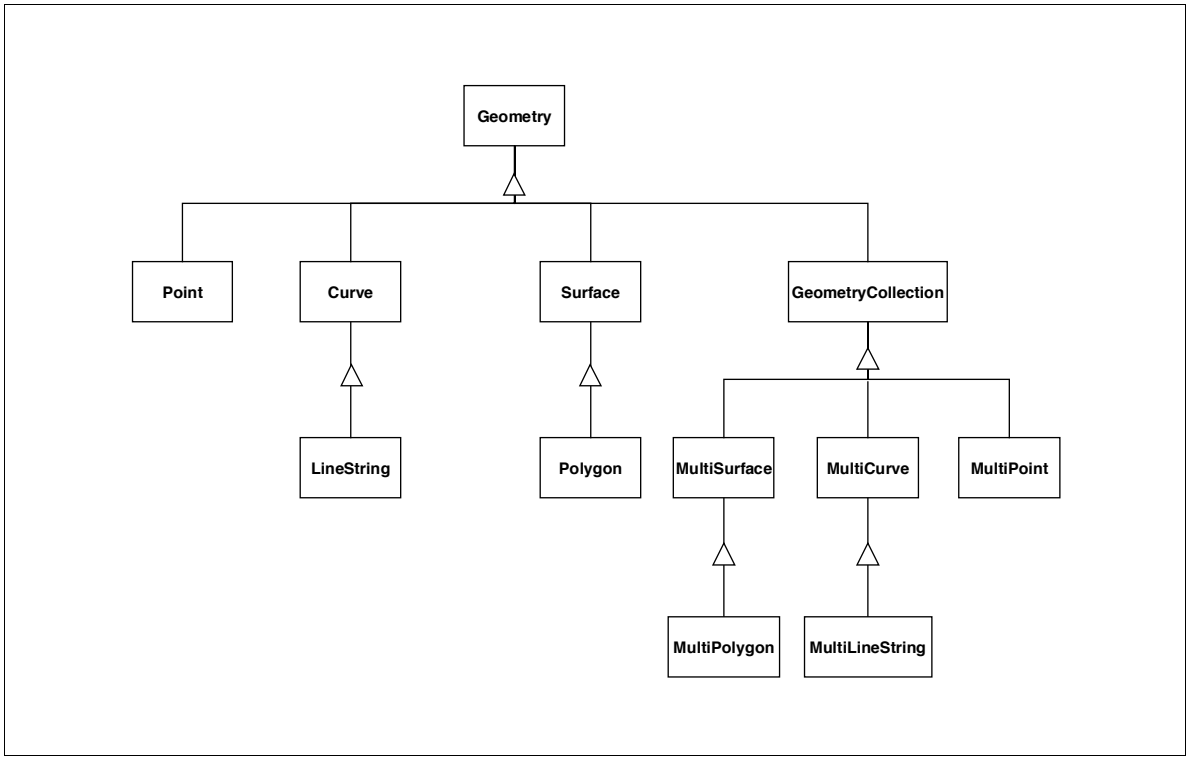


Figure 2.15—SQL Geometry Type Hierarchy

The root type, named Geometry, has subtypes for Point, Curve, Area and GeometryCollection. A GeometryCollection is a Geometry that is a collection of possibly heterogeneous Geometries. MultiPoint, MultiCurve and MultiSurface are specific subtypes of GeometryCollection used to manage homogenous collections of Points, Curves and Surfaces. The 0 dimensional geometric Types are Point and MultiPoint. The one-dimensional geometric Types are Curve and MultiCurve together with their subclasses. The two-dimensional geometric Types are Surface and MultiSurface together with their subclasses.

SQL functions are defined to construct instances of the above types given well-known textual or binary representations of the types. SQL functions defined on the types implement the methods described in the Geometry Model of section 2.1.

2.3.8 Geometry Values and Spatial Reference Systems

In order to model Spatial Reference System information each geometry value in the **SQL92 with Geometry Types** implementation is associated with a Spatial Reference System. Capturing this association at the level of the individual geometry value allows literal geometry values that are not yet part of a column in the database, to be associated with a Spatial Reference System. Examples of such geometry values are geometry values that are used as a parameter to a spatial query or a geometry value that is part of an insert statement. Capturing this association at the level of the individual geometry value also allows functions that take two geometry values to check for compatible spatial reference systems.

A geometry value is associated with a Spatial Reference System by storing the Spatial Reference System Identity (SRID) for the Spatial Reference System as a part of the geometry value. As explained in the Spatial Reference System Metadata views, each Spatial Reference System in the database is identified by a unique value of SRID.

The SRID for a geometry is assigned to it at construction time. This allows the **SQL92 with Geometry Types** implementation to ensure that

1. the geometry values being inserted into a geometry column match the Spatial Reference System declared for the geometry column

2. queries that spatially join columns from different tables operate on geometry columns with compatible Spatial Reference Systems.

If either of these conditions are violated, a run time SQL error is generated. These compatible spatial reference system checks are not possible in the **SQL92** implementation.

The SRID function, defined on the Geometry type, returns the integer SRID of a geometry value.

In all operations on the Geometry type, geometric calculations shall be done in the spatial reference system of the first geometric object. Returned objects shall be in the spatial reference system of the first geometric object unless explicitly stated otherwise.

Before a geometry can be constructed and inserted into a table, the corresponding row for its SRID must exist in the SPATIAL_REFERENCE_SYSTEMS table, else construction of the geometry will fail. When defining a table, a SQL check constraint can be used to enforce the rule that all geometries in a geometry column have the same SRID as that defined for the column in the GEOMETRY_COLUMNS table. The following example shows the definition of a table, named Countries, with two columns named Name and Geometry of type VARCHAR and POLYGON respectively.

```
CREATE TABLE Countries (
           Name       VARCHAR(200) NOT NULL PRIMARY KEY,
           Location   Polygon NOT NULL,
```

```
            CONSTRAINT spatial_reference
            CHECK (SRID(Geometry) in (SELECT SRID from GEOMETRY_COLUMNS where
            F_TABLE_CATALOG = <catalog> and F_TABLE_SCHEMA = <schema> and
            F_TABLE_NAME = 'Countries' and F_GEOMETRY_COLUMN = 'Location'))
)
```

We expect that most implementations will use Stored Procedures similar to those shown below for the purpose of adding and dropping geometry columns to and from a feature table.

The **AddGeometryColumn**(FEATURE_TABLE_CATALOG, FEATURE_TABLE_SCHEMA, FEATURE_TABLE_NAME, GEOMETRY_COLUMN_NAME, SRID) procedure will :

1. ensure that an entry for the SRID exists in the SPATIAL_REFERENCE_SYSTEMS table.

2. add an entry to the GEOMETRY_COLUMNS table that stores the SRID for the geometry column.

3. add the geometry column to the feature table using a SQL `ALTER TABLE` statement

4. add the Spatial Reference Check Constraint to the feature table

The **DropGeometryColumn**(FEATURE_TABLE_CATALOG, FEATURE_TABLE_SCHEMA, FEATURE_TABLE_NAME, GEOMETRY_COLUMN_NAME) stored procedure will :

1. drop the spatial reference Check Constraint on the feature table

2. drop the entry from the GEOMETRY_COLUMNS table

3. drop the geometry column from the feature table

2.3.9 ODBC Access to Geometry Values in the SQL with Geometry Types case

Spatial data are accessed using the SQL query language extended with SQL functions on Geometry Types as described in section 3.2.3. The SQL pass through capabilities of ODBC allow a client to pass these or any extended SQL statements containing RDBMS specific SQL extensions to a server. (Applications are free to send any SQL statements to an RDBMS even if the statement is not described within the ODBC conformance levels).

Geometry columns are implemented using the Geometry data types described above.

GIS applications will be able to determine the existence of a Geometry column based on the Geometry data type or one of its subtypes using one or more of the following ODBC programming techniques:

The SQLTypeInfo function can be used to determine both the TYPE_NAME and the underlying SQL_DATA_TYPE of an ODBC SQL Type.

The SQLColumns catalog function can be used to determine the TYPE_NAME and the underlying SQL_DATA_TYPE of a column in a table.

The SQLDescribeCol and SQLColAttributes functions can be used to determine a column's data type and description.

An ODBC client application uses either one of two SQL functions

GeomFromText ([in] String, [in] Integer) : Geometry, or

GeomFromWKB([in] Binary,[in] Integer) : Geometry

or their type specific versions (for example, PolygonFromText and PolygonFromWKB) to pass geometry values into the database from a client application that represents them using either the well-known text or the well-known binary representations.

The **input arguments** to the above functions are **ODBC standard** character, binary and integer data types (SQL_C_CHAR, SQL_C_BINARY, SQL_C_INTEGER) and clients bind to these parameters using standard ODBC binding methods.

An ODBC client application uses either one of two SQL functions

AsText([in]Geometry) : **String,** or

AsBinary([in]Geometry) : Binary

to extract geometry values from the database as either text or well-known binary values.

The **output arguments** to the above functions are **ODBC standard** character and binary data types (SQL_C_CHAR, SQL_C_BINARY) and clients bind to these parameters using standard ODBC binding methods.

The above SQL functions are described in sections 3.2.8 and 3.2.9.

3 Component Specifications

In order to be compliant with this OpenGIS ODBC/SQL specification for geospatial feature collections an implementer shall choose to implement the components described in this section for **any one** of **three** alternatives (1a, 1b or 2) listed below and described in this specification:

1. **SQL92** implementation of feature tables

   a) using numeric SQL types for geometry storage and ODBC access.

   b) using binary SQL types for geometry storage and ODBC access.

2. **SQL92 with Geometry Types** implementation of feature tables supporting both textual and binary ODBC access to geometry.

The components for the **SQL92** implementation of feature tables are described in section 3.1. Alternatives 1a) and 1b) listed above differ only in the implementation of the geometry table component as described in section 3.1.4.

The components for the **SQL92 with Geometry Types** implementation of feature tables are described in section 3.2.

3.1 Components—SQL92 Implementation of Feature Tables

The components of the ODBC OpenGIS specification for feature table implementation in a SQL92 environment consists of the tables or views discussed in this section. Since the existence of some unknown table is prerequisite for a view, most of the definitions below are stated as `CREATE TABLE` statements. Views that create the same logical structure are equally compliant. *Table names and column names have been restricted to 18 characters in length to allow for the widest possible implementation.*

3.1.1 Spatial Reference System Information

3.1.1.1 Component Overview

The Spatial Reference Systems table, which is named `SPATIAL_REF_SYS`, stores information on each spatial reference system used in the database.

3.1.1.2 Table or View Constructs

The following CREATE TABLE statement creates an appropriately structured Spatial Reference Systems table.

```
CREATE TABLE SPATIAL_REF_SYS
           (
           SRID               INTEGER NOT NULL PRIMARY KEY,
           AUTH_NAME          VARCHAR (256),
           AUTH_SRID          INTEGER,
           SRTEXT             VARCHAR (2048)
           )
```

3.1.1.3 Field Description

The meanings of the attributes in the view are as follows:

- SRID—an integer value that uniquely identifies each Spatial Reference System within a database.
- AUTH_NAME—the name of the standard or standards body that is being cited for this reference system. EPSG would be a valid AUTH_NAME
- AUTH_SRID–the ID of the Spatial Reference System as defined by the Authority cited in AUTH_NAME.
- SRTEXT—The Well-known Text representation of the Spatial Reference System.

3.1.1.4 Exceptions, Errors, and Error Codes

Error handling will be accomplished by using the standard SQL status returns.

3.1.2 Geometry Columns Metadata View

3.1.2.1 Component Overview

The Geometric Columns Metadata view provides metadata information on the spatial reference for each geometry column in the database.

3.1.2.2 Table or View Constructs

The following CREATE TABLE statement creates an appropriately structured table. This should be either an actual table or an updateable view so that insertion of reference system information can be done directly with SQL.

```
CREATE TABLE GEOMETRY_COLUMNS (
           F_TABLE_CATALOG           VARCHAR(256)   NOT NULL,
           F_TABLE_SCHEMA            VARCHAR(256)   NOT NULL,
           F_TABLE_NAME              VARCHAR(256)   NOT NULL,
           F_GEOMETRY_COLUMN         VARCHAR(256)   NOT NULL,
           G_TABLE_CATALOG           VARCHAR(256)   NOT NULL,
           G_TABLE_SCHEMA            VARCHAR(256)   NOT NULL,
           G_TABLE_NAME              VARCHAR(256)   NOT NULL,
           STORAGE_TYPE              INTEGER,
```

```
GEOMETRY_TYPE             INTEGER,
COORD_DIMENSION           INTEGER,
MAX_PPR                   INTEGER,
SRID                      INTEGER REFERENCES  SPATIAL_REF_SYS,
CONSTRAINT GC_PK PRIMARY KEY
     (F_TABLE_CATALOG, F_TABLE_SCHEMA, F_TABLE_NAME, F_GEOMETRY_COLUMN)
)
```

3.1.2.3 Field Description

The fields in the Geometric Complex Information view are:

- F_TABLE_CATALOG, F_TABLE_SCHEMA, F_TABLE_NAME—the fully qualified name of the feature table containing the geometry column.

- F_GEOMETRY_COLUMN—the name of the column in the feature table that is the geometry column. This column will contain a foreign key reference into the geometry table for a **SQL92** implementation.

- G_TABLE_CATALOG, G_TABLE_SCHEMA, G_TABLE_NAME—the name of the geometry table and its schema and catalog. The geometry table implements the geometry column.

- STORAGE_TYPE—the type of storage being used for this geometry column.

  0 = normalized geometry **SQL92** implementation.
  1 = binary geometry **SQL92** implementation (Well-known Binary Representation for Geometry).

- GEOMETRY_TYPE—the type of geometry values stored in this column. The use of a non-leaf geometry class name from the Geometry Object Model described in section 3.1 for a geometry column implies that domain of the column corresponds to instances of the class and all of its subclasses.

  ```
  0 = GEOMETRY
  1 = POINT
  2 = CURVE
  3 = LINESTRING
  4 = SURFACE
  5 = POLYGON
  6 = COLLECTION
  7 = MULTIPOINT
  8 = MULTICURVE
  9 = MULTILINESTRING
  10 = MULTISURFACE
  11 = MULTIPOLYGON
  ```

- COORD_DIMENSION—the number of ordinates used in the complex, usually corresponds to the number of dimensions in the spatial reference system.

- MAX_PPR—(This value contains data for the normalized SQL92 geometry implementation only) points per row, the number of points stored as ordinate columns in the geometry table.

- SRID—the ID of the spatial reference system used for the coordinate geometry in this table. It is a foreign key reference to the SPATIAL_REF_SYS table.

3.1.2.4 Exceptions, Errors, and Error Codes

Error handling will be accomplished by using the standard SQL status returns for ODBC.

3.1.3 Feature Tables and Views

The basic restriction in this specification for feature tables is that for each geometric attribute they include geometry via a `FOREIGN KEY` reference to a geometry table. Feature-to-feature relations would similarly be defined as `FOREIGN KEY` references**.** By [1], features are simply objects that have geometric attributes. In SQL92, these geometric attributes are stored in the geometry tables.

The general format of a feature table would be as follows:

```
CREATE TABLE <feature-name>    (
           <FID name>             <FID type>,
           <feature attributes>   <other FID type> REFERENCES <other feature view>,
           …   (other FID based attributes for feature relations)
           …   (other attributes for feature)
           <geometry attribute 1> <GID type>,
           …   (other geometric attributes for feature)
           PRIMARY KEY <FID name>,
           …   (other geometric attributes foreign key statements)
           FOREIGN KEY <geometric attribute 1>   REFERENCES <geometry-table-name-1>,
           FOREIGN KEY <FID relation name>   REFERENCES <FEATURE table> <other FID name>,
           …   (other geometric attributes foreign key statements)
           )
```

The geometric attribute Foreign Key reference applies only for the case where the geometry table stores geometry in binary form. In the case where geometry is stored in normalized form there may be multiple rows in the geometry table corresponding to a single geometry value. In this case the geometry attribute reference may be captured by a constraint that checks that the geometry column value stored in the Feature Table corresponds to the GID value for some row in the Geometry Table.

The foreign key reference to the geometry table name creates an entry in the data dictionary that ties this table to that geometry table. This is sufficient to identify this table as a feature table. Foreign keys also define feature-to-feature relations. Alternatively, applications may check the `GEOMETRY_COLUMNS` view, where all geometry columns and their associated feature tables and geometry tables are listed.

3.1.4 Geometry Tables or Views

3.1.4.1 Component Overview

Each Geometry View stores geometry instances corresponding to a geometry column in a feature table. Geometries may be stored as individual ordinate values, using SQL types, or as binary objects, using the OpenGIS Well-known Binary Representation for Geometry. Table schemas for both implementations are provided.

3.1.4.2 Geometry stored using ODBC/SQL numeric types

3.1.4.3 Table or View Constructs

The following `CREATE TABLE` statement creates an appropriately structured table for geometry stored as individual ordinate values using SQL types. Implementations should either use this table format or provide stored procedures to create, populate and maintain this table.

```
CREATE TABLE <table name> (
          GID                   NUMBER     NOT NULL,
          ESEQ                  INTEGER NOT NULL,
          ETYPE                 INTEGER NOT NULL,
          SEQ                   INTEGER NOT NULL,
          X1                    <ordinate type>,
          Y1                    <ordinate type>,
          ... <repeated for each ordinate, repeated for each point>
          X<max_ppr>            <ordinate type>,
          Y<max_ppr>            <ordinate type>,
          ...,
          <attribute name>      <attribute type>

          CONSTRAINT GID_PK PRIMARY KEY (GID, ESEQ, SEQ)
          )
```

3.1.4.4 Field Descriptions :

The fields of a geometric view are:

- `GID`—identity of this geometry
- `ESEQ`—identifies multiple components within a geometry
- `ETYPE`—element type of this primitive element for the geometry. The following values are defined for ETYPE:

  1 = Point
  2 = LineString
  3 = Polygon

- `SEQ`—identifies the sequence of rows to define a geometry component
- `X1`—first ordinate of first point
- `Y1`—second ordinate of first point
- ...—(repeated for each ordinate, for this point)
- ...—(repeated for each coordinate, for this row)

- X<MAX_PPR>—first ordinate of last point,. The maximum number of points per row 'MAX_PPR' is consistent with the information in the GEOMETRY_COLUMNS table.
- Y<MAX_PPR>—second ordinate of last point
- ...—(repeated for each ordinate, for this last point)
- <ATTRIBUTE>—other attributes can be carried in the geometry view for specific feature schema

3.1.4.5 Geometry stored using ODBC/SQL binary types

3.1.4.6 Table or View Constructs

The following CREATE TABLE statement creates an appropriately defined table for geometry stored using the OpenGIS Well-known Binary Representation for Geometry defined in section 4.3. Implementations should either use this table format or provide stored procedures to create, populate and maintain this table.

```
CREATE TABLE <table name> (
          GID                   NUMBER     NOT NULL PRIMARY KEY,
          XMIN                  <ordinate type>,
          YMIN                  <ordinate type>,
          XMAX                  <ordinate type>,
          YMAX                  <ordinate type>,
          WKB_GEOMETRY          VARBINARY,
          <attribute name>      <attribute type>
          )
```

3.1.4.7 Field Descriptions

The fields of a geometric view are:

- GID—identity of this geometry
- XMIN—the minimum x-coordinate of the geometry bounding box
- YMIN—the minimum y-coordinate of the geometry bounding box
- XMAX—the maximum x-coordinate of the geometry bounding box
- YMAX—the maximum y-coordinate of the geometry bounding box
- WKB_GEOMETRY—the well-known binary representation of the geometry
- <ATTRIBUTE>—other attributes can be carried in the geometry view for specific feature schema

3.1.4.8 Exceptions, Errors, and Error Codes

Error handling will use the standard SQL status returns for ODBC.

3.1.5 Operators

No SQL92 spatial operators are defined as part of this specification.

3.2 Components—SQL92 with Geometry Types Implementation of Feature Tables

The components of the ODBC OpenGIS specification for feature table implementation in a **SQL92 with Geometry Types** environment consists of the tables or views, SQL types and SQL functions discussed in this section.

Since the existence of some unknown table is prerequisite for a view, most of the definitions below are stated as `CREATE TABLE` statements. Views that create the same logical structure are equally compliant.

3.2.1 Spatial Reference System Information View

3.2.1.1 Component Overview

This component is identical to the corresponding Component described for the **SQL92** implementation:

3.2.1.2 Table or View Constructs

The following `CREATE TABLE` statement creates an appropriately structured Spatial Reference Systems table.

```
CREATE TABLE SPATIAL_REF_SYS
           (
           SRID               INTEGER NOT NULL PRIMARY KEY,
           AUTH_NAME          VARCHAR (256),
           AUTH_SRID          INTEGER,
           SRTEXT             VARCHAR (2048)
           )
```

3.2.1.3 Field Description

The meanings of the attributes in the view are as follows:

- `SRID`—an integer value that uniquely identifies each Spatial Reference System within a database.
- `AUTH_NAME`—the name of the standard or standards body that is being cited for this reference system. EPSG would be a valid `AUTH_NAME`
- `AUTH_SRID`—the ID of the Spatial Reference System as defined by the Authority cited in `AUTH_NAME`.
- `SRTEXT`—The Well-known Text representation of the Spatial Reference System.

3.2.1.4 Exceptions, Errors, and Error Codes

Error handling will be accomplished by using the standard SQL status returns.

3.2.2 Geometry Columns Metadata View

3.2.2.1 Component Overview

The Geometric Columns Information view provides metadata information on the spatial reference for each geometry column in the database. The columns for this view in the **SQL92 with Geometry Types** implementation are a subset of the columns in the **SQL92** implementation.

3.2.2.2 Table or View Constructs

The following `CREATE TABLE` statement creates an appropriately structured table. This should be either an actual table or an updateable view so that insertion of reference system information can be done directly with SQL.

```
CREATE TABLE GEOMETRY_COLUMNS (
            F_TABLE_CATALOG        VARCHAR(256)   NOT NULL,
            F_TABLE_SCHEMA         VARCHAR(256)   NOT NULL,
            F_TABLE_NAME           VARCHAR(256)   NOT NULL,
            F_GEOMETRY_COLUMN      VARCHAR(256)   NOT NULL,
            COORD_DIMENSION            INTEGER,
            SRID                       INTEGER REFERENCES SPATIAL_REF_SYS,
            CONSTRAINT GC_PK PRIMARY KEY
                  (F_TABLE_CATALOG, F_TABLE_SCHEMA, F_TABLE_NAME, F_GEOMETRY_COLUMN)
            )
```

3.2.2.3 Field Description

The fields in the Geometric Complex Information view are:

- `F_TABLE_CATALOG`, `F_TABLE_SCHEMA`, `F_TABLE_NAME`—the fully qualified name of the feature table containing the geometry column.
- `F_GEOMETRY_COLUMN`—the name of the geometry column in the feature table.
- `COORD_DIMENSION`—the coordinate dimension for the geometry values in this column, which will be equal to the number of dimensions in the spatial reference system.
- `SRID`—the ID of the spatial reference system used for the coordinate geometry in this table. It is a foreign key reference to the `SPATIAL_REFERENCES` table.

3.2.2.4 Exceptions, Errors, and Error Codes

Error handling will be accomplished by using the standard SQL status returns for ODBC.

3.2.3 SQL Geometry Types

3.2.3.1 Component Overview

The SQL Geometry Types extend the set of available SQL92 types to include Geometry Types.

3.2.3.2 Language Constructs

The SQL language will support a subset of the following set of SQL Geometry Types: {`Geometry`, `Point`, `Curve`, `LineString`, `Surface`, `Polygon`, `GeometryCollection`, `MultiCurve`, `MultiLineString`, `MultiSurface`, `MultiPolygon`, `MultiPoint`}. The permissible type subsets that an implementer may choose to implement are described in Table 3.1 below.

An implementation must preserve the subtype relationships between geometry types shown in Figure 3.1 below for the types that are implemented. An implementation that implements 2 types A and B where B is an immediate subtype of A in Figure 3.1 is free to introduce additional types C, outside the scope of this specification, between A and B as long as A continues to be a supertype of B.

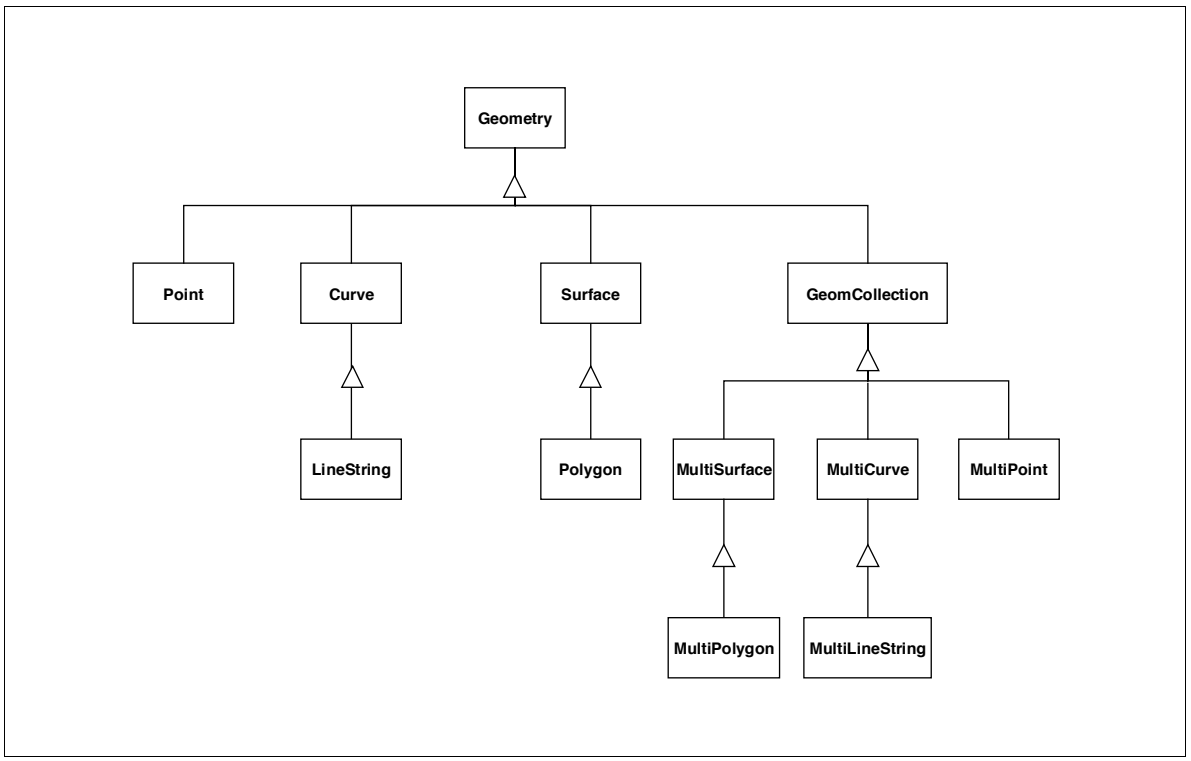


Figure 3.1—Subtype relationships between Types

`Geometry`, `Curve`, `Surface`, `MultiCurve` and `MultiSurface` are defined to be non-instantiable types. No constructors are defined for these types.

The remaining seven types are defined to be instantiable. An implementation may support only a subset of these seven types as instantiable as defined in the table below

Type Level	Available Types	Instantiable Types
1	`Geometry, Point, Curve, LineString, Surface, Polygon, GeomCollection`	`Point, LineString, Polygon, GeomCollection`
2	`Geometry, Point, Curve, LineString, Surface, Polygon, GeomCollection, MultiPoint, MultiCurve, MultiLineString, MultiSurface, MultiPolygon`	`Point, LineString, Polygon, MultiPoint, MultiLineString,MultiPolygon`

3	Geometry, Point, Curve, LineString, Surface, Polygon, GeomCollection, MultiPoint , MultiCurve, MultiLineString, MultiSurface, MultiPolygon	Point, LineString, Polygon, GeomCollection, MultiPoint, MultiLineString, MultiPolygon

Table 3.1—Available and instantiable types by implementation type level

Any implemented SQL geometry type may be used as the type for a column. Declaring a column to be of a particular type implies that any instance of the type or of any of its subtypes may be stored in the column.

3.2.4 Feature Tables and Views

3.2.4.1 Component Overview

The basic restriction in this specification for feature tables is that each geometric attribute is modeled using a column whose type corresponds to a SQL Geometry Type as defined in section 3.2.3. Feature-to-feature relations are defined as `FOREIGN KEY` references**.**

3.2.4.2 Table or View Constructs

The general format of a feature table in the **SQL92 with Geometry Types** implementation shall be as follows:

```
CREATE TABLE <feature-name>    (
            <FID name>     <FID type>,
            <feature attributes>  <other FID type> REFERENCES <other feature view>,
            …   (other FID based attributes for feature relations)
            …   (other attributes for feature)
            <geometry attribute 1> <Geometry type>,
            …   (other geometric attributes for feature)
            PRIMARY KEY <FID name>,
            FOREIGN KEY <FID relation name>   REFERENCES <FEATURE table> <other FID name>
            CONSTRAINT SRS_1 CHECK (SRID(<geometry attribute 1>) in (SELECT SRID from
            GEOMETRY_COLUMNS where F_TABLE_CATALOG = <catalog> and
            F_TABLE_SCHEMA = <schema> and     F_TABLE_NAME = <feature-name> and
            F_GEOMETRY_COLUMN = <geometry attribute 1>))
            ... (spatial reference constraints for other geometric attributes)
            )
```

The use of a SQL Geometry Type for one of the columns in the table identifies this table as a feature table. Alternatively, applications may check the `GEOMETRY_COLUMNS` view, where all geometry columns and their associated feature tables and geometry tables are listed.

3.2.4.3 Exceptions, Errors, and Error Codes

Error handling will be accomplished by using the standard SQL status returns.

3.2.5 SQL Textual Representation of Geometry

3.2.5.1 Component Overview

Each Geometry Type has a Well-known Text representation that may be used both to construct new instances of the type and to convert existing instances to textual form for alphanumeric display.

3.2.5.2 Language Constructs

The Well-known Text representation of Geometry is defined below; the notation `{}*` denotes 0 or more repetitions of the tokens within the braces, the braces do not appear in the output token list. The text representation of the instantiable geometric types implemented shall conform to this grammar.

```
<Geometry Tagged Text> :=
                <Point Tagged Text>
              | <LineString Tagged Text>
              | <Polygon Tagged Text>
              | <MultiPoint Tagged Text>
              | <MultiLineString Tagged Text>
              | <MultiPolygon Tagged Text>
              | <GeometryCollection Tagged Text>
<Point Tagged Text> :=
            POINT <Point Text>
<LineString Tagged Text> :=
            LINESTRING <LineString Text>
<Polygon Tagged Text> :=
            POLYGON <Polygon Text>
<MultiPoint Tagged Text> :=
            MULTIPOINT <Multipoint Text>
<MultiLineString Tagged Text> :=
            MULTILINESTRING <MultiLineString Text>
<MultiPolygon Tagged Text> :=
            MULTIPOLYGON <MultiPolygon Text>
<GeometryCollection Tagged Text> :=
            GEOMETRYCOLLECTION <GeometryCollection Text>
<Point Text> := EMPTY | ( <Point> )
<Point> := <x> <y>
<x> := double precision literal
<y> := double precision literal
<LineString Text> := EMPTY
              | ( <Point >  {, <Point > }* )
<Polygon Text> := EMPTY
              | ( <LineString Text >  {, < LineString Text > }*)
<Multipoint Text> := EMPTY
              | ( <Point Text >  {, <Point Text > }* )
<MultiLineString Text> := EMPTY
```

```
            | ( <LineString Text >  {, < LineString Text > }* )
<MultiPolygon Text> := EMPTY
            | ( < Polygon Text >  {, < Polygon Text > }* )
<GeometryCollection Text> := EMPTY
            | ( <Geometry Tagged Text> {, <Geometry Tagged Text> }* )
```

The above grammar has been designed to support a compact and readable textual representation of geometric instances. The representation of a geometry that consists of a set of *homogeneous* components does not include the tags for each embedded component.

3.2.5.3 Examples

Examples of SQL textual representations of Geometry Types are shown below. The coordinates are shown as integer values; coordinates may be any double precision value.

Geometry Type	SQL Text Literal Representation	Comment
Point	`'POINT (10 10)'`	a `Point`
LineString	`'LINESTRING ( 10 10, 20 20, 30 40)'`	a `LineString` with 3 points
Polygon	`'POLYGON ((10 10, 10 20, 20 20, 20 15, 10 10))'`	a `Polygon` with 1 exterior ring and 0 interior rings
Multipoint	`'MULTIPOINT (10 10,  20 20)'`	a `MultiPoint` with 2 point
MultiLineString	`'MULTILINESTRING ((10 10, 20 20), (15 15, 30 15))'`	a `MultiLineString` with 2 linestrings
MultiPolygon	`'MULTIPOLYGON ( ((10 10, 10 20, 20 20, 20 15, 10 10)), ((60 60, 70 70, 80 60, 60 60 ) ))'`	a `MultiPolygon` with 2 polygons
GeomCollection	`'GEOMETRYCOLLECTION (POINT (10 10), POINT (30 30), LINESTRING (15 15, 20 20))'`	a `GeometryCollection` consisting of 2 `Point` values and a `LineString` value

3.2.6 SQL Functions for Constructing a Geometry Value given its Well-known Text Representation

3.2.6.1 Component Overview

The functions are used to construct `Geometry` instances from their text representations.

3.2.6.2 Language Constructs

The `GeomFromText` function, takes a geometry textual representation (a `<Geometry Tagged Text>` as described in the grammar above), and a Spatial Reference System ID (`SRID`) and creates an instance of the appropriate geometry type. This function plays the role of the `Geometry` factory in SQL.

An implementation shall substitute an SQL type suitable for representing text data (e.g., `VARCHAR`) for the type `String` below.

`GeomFromText( geometryTaggedText String, SRID Integer) : Geometry`	Construct a `Geometry` value given its well-known textual representation.

The return type of the `Geometry` function is the `Geometry` supertype. For construction of `Geometry` values to be stored in columns restricted to a particular subtype, an implementation shall also provide a type specific construction function for each instantiable subtype as described in the table below.

`PointFromText ( pointTaggedText String, SRID Integer): Point`	Construct a `Point`
`LineFromText( lineStringTaggedText String, SRID Integer) : LineString`	Construct a `LineString`
`PolyFromText( polygonTaggedText String, SRID Integer): Polygon`	Construct a `Polygon`
`MPointFromText (multiPointTaggedText String, SRID Integer): MultiPoint`	Construct a `MultiPoint`
`MLineFromText ( multiLineStringTaggedText String, SRID Integer): MultiLineString`	Construct a `MultiLineString`
`MPolyFromText( multiPolygonTaggedText String, SRID Integer): MultiPolygon`	Construct a `MultiPolygon`
`GeomCollFromTxt( geometryCollectionTaggedText String, SRID Integer): GeomCollection`	Construct a `GeometryCollection`

As an optional feature, an implementation may also support 'building' of `Polygon` or `MultiPolygon` values given an arbitrary collection of possibly intersecting rings or closed `LineString` values. Implementations that support this feature should include the following functions:

`BdPolyFromText( multiLineStringTaggedText String, SRID Integer): Polygon`	Construct a `Polygon` given an arbitrary collection of closed linestrings as a `MultiLineString` text representation.
`BdMPolyFromText( multiLineStringTaggedText String, SRID Integer): MultiPolygon`	Construct a `MultiPolygon` given an arbitrary collection of closed linestrings as a `MultiLineString` text representation.

3.2.6.3 Exceptions, Errors, and Error Codes

Error handling will be accomplished by using the standard SQL status returns.

3.2.6.4 Example

The following example shows the use of the `Polygon` type specific constructor:

```
INSERT INTO Countries (Name, Location)
           VALUES ('Kenya', PolygonFromText('POLYGON ((x y, x y, x y, ...,  x y))', 14))
```

3.2.7 SQL Functions for Constructing a Geometry Value given its Well-known Binary Representation

3.2.7.1 Component Overview

The functions are used to construct geometry instances from their well-known binary representations.

3.2.7.2 Language Constructs

The `GeomFromWKB` function, takes a well-known binary representation of geometry (`WKBGeometry` as described in section 3.3) and a Spatial Reference System ID (`SRID`) and creates an instance of the appropriate geometry type. This function plays the role of the Geometry Factory in SQL. An implementation shall substitute an SQL type used to represent binary values for the type `Binary` in the definitions below.

`GeomFromWKB`
`(WKBGeometry Binary,`
`  SRID Integer) : Geometry`
	Construct a `Geometry` value given its well-known binary representation.

The return type of the `Geometry` function is the `Geometry` supertype. For construction of `Geometry` values to be stored in columns restricted to a particular subtype, an implementation shall also provide a type specific construction function for each instantiable subtype as described in the table below (the well-known binary representations for each `Geometry` type are as described in section 3.3).

`PointFromWKB (WKBPoint Binary, SRID Integer): Point`	Construct a `Point`
`LineFromWKB(WKBLineString Binary,` `  SRID Integer) : LineString`	Construct a `LineString`
`PolyFromWKB(WKBPolygon Binary, SRID Integer): Polygon`	Construct a `Polygon`
`MPointFromWKB (WKBMultiPoint Binary,` `  SRID Integer): MultiPoint`	Construct a `MultiPoint`
`MLineFromWKB (WKBMultiLineString Binary,` `  SRID Integer): MultiLineString`	Construct a `MultiLineString`
`MPolyFromWKB (WKBMultiPolygon Binary,` `  SRID Integer): MultiPolygon`	Construct a `MultiPolygon`

`GeomCollFromWKB`
`(WKBGeometryCollection Binary,`
`  SRID Integer): GeomCollection`
	Construct a `GeometryCollection`

As an optional feature, an implementation may also support the 'building' of `Polygon` or `MultiPolygon` values given an arbitrary collection of possibly intersecting rings or closed `LineString` values. Implementations that support this feature should include the following functions:

`BdPolyFromWKB`
`(WKBMultiLineString Binary,`
`  SRID Integer): Polygon`
	Construct a `Polygon` given an arbitrary collection of closed linestrings as a `MultiLineString` binary representation.

BdMPolyFromWKB (WKBMultiLineString Binary, SRID Integer): MultiPolygon	Construct a MultiPolygon given an arbitrary collection of closed linestrings as a MultiLineString binary representation.

3.2.7.3 Exceptions, Errors, and Error Codes

Error handling will be accomplished by using the standard SQL status returns.

3.2.7.4 Examples

The following example shows the use of the binary Polygon type specific constructor in Dynamic SQL, the :wkb and :srid parameters are bound to application program variables containing the binary representation of a Polygon and of the SRID respectively :

```
INSERT INTO Countries (Name, Location)
          VALUES ('Kenya', PolygonFromWKB(:wkb, :srid))
```

3.2.8 SQL functions for obtaining the Well-known Text Representation of a Geometry

3.2.8.1 Component Overview

This function returns the well-known textual representation for a Geometry.

3.2.8.2 Language Constructs

The AsText function takes a single argument of type Geometry and returns its well-known textual representation. This function applies to all subtypes of Geometry.

AsText (g Geometry) : String	Returns the well-known textual representation

3.2.8.3 Exceptions, Errors, and Error Codes

Error handling will be accomplished by using the standard SQL status returns.

3.2.8.4 Examples

The following example shows the use of the AsText function to extract the name and textual representation of geometry of all countries whose names begin with the letter K.

```
SELECT Name, AsText(Location) FROM Countries WHERE Name LIKE 'K%'
```

3.2.9 SQL functions for obtaining the Well-known Binary Representation of a Geometry

3.2.9.1 Component Overview

This function returns the well-known binary representation for a Geometry

3.2.9.2 Language Constructs

The `AsBinary` function takes a single argument of type `Geometry` and returns its well-known binary representation. This function applies to all subtypes of `Geometry`.

`AsBinary (g Geometry) : Binary`	Returns the well-known binary representation

3.2.9.3 Exceptions, Errors, and Error Codes

Error handling will be accomplished by using the standard SQL status returns.

3.2.9.4 Example

The following example shows the use of the `AsBinary` function to extract the name and well-known binary representation of geometry for all countries whose names begin with the letter K.

```
SELECT Name, AsBinary(Location) FROM Countries WHERE Name LIKE 'K%'
```

3.2.10 SQL Functions on Type Geometry

3.2.10.1 Component Description

In all operations on the Geometry type, geometric calculations shall be done in the spatial reference system of the first geometric object. Returned objects shall be in the spatial reference system of the first geometric object unless explicitly stated otherwise.

The following SQL functions apply to all subtypes of `Geometry`.

3.2.10.2 Language Constructs

`Dimension(g Geometry) : Integer`	Returns the dimension of the `Geometry`, which is less than or equal to the dimension of the coordinate space.
`GeometryType(g Geometry) : String`	Returns the name of the instantiable subtype of `Geometry` of which this instance is a member, as a `String`.
`AsText(g Geometry) : String`	Returns the well-known textual representation
`AsBinary(g Geometry) : Binary`	Returns the well-known binary representation
`SRID(g Geometry) : Integer`	Returns the Spatial Reference System ID for this `Geometry`.
`IsEmpty(g Geometry) : Integer`	The return type is `Integer`, with a return value of 1 for `TRUE`, 0 for `FALSE`, and –1 for `UNKNOWN` corresponding to a function invocation on `NULL` arguments. `TRUE` if this `Geometry` corresponds to the empty set.

`IsSimple(g Geometry): Integer`	The return type is `Integer`, with a return value of 1 for `TRUE`, 0 for `FALSE`, and –1 for `UNKNOWN` corresponding to a function invocation on `NULL` arguments. `TRUE` if this `Geometry` is simple, as defined in the Geometry Model.
`Boundary(g Geometry) : Geometry`	Returns a `Geometry` that is the combinatorial boundary of `g` as defined in the Geometry Model.
`Envelope(g Geometry) : Geometry`	Returns the rectangle bounding `g` as a `Polygon`. The polygon is defined by the corner points of the bounding box ((MINX, MINY),(MAXX, MINY), (MAXX, MAXY), (MINX, MAXY), (MINX, MINY)).

3.2.10.3 Exceptions, Errors, and Error Codes

Error handling will be accomplished by using the standard SQL status returns.

3.2.11 SQL Functions on Type Point

3.2.11.1 Component Description

The following SQL functions are defined on `Point`.

3.2.11.2 Language Constructs

`X(p Point) : Double Precision`	Return the x-coordinate of `Point p` as a `Double Precision` number
`Y(p Point) : Double Precision`	Return the y-coordinate of `Point p` as a `Double Precision` number

3.2.11.3 Exceptions, Errors, and Error Codes

Error handling will be accomplished by using the standard SQL status returns.

3.2.12 SQL Functions on Type Curve

3.2.12.1 Component Overview

The following SQL functions apply to all subtypes of `Curve`.

3.2.12.2 Language Constructs

`StartPoint(c Curve) : Point`	Return a `Point` containing the first point of `c`
`EndPoint(c Curve) : Point`	Return a `Point` containing the last point of `c`

`IsClosed(c Curve) : Integer`	The return type is `Integer`, with a return value of 1 for `TRUE`, 0 for `FALSE`, and –1 for `UNKNOWN` corresponding to a function invocation on `NULL` arguments. Return `TRUE` if `c` is closed, i.e., if `StartPoint(c) = EndPoint(c)`
`IsRing(c Curve) : Integer`	The return type is `Integer`, with a return value of 1 for `TRUE`, 0 for `FALSE`, and –1 for `UNKNOWN` corresponding to a function invocation on `NULL` arguments. Return `TRUE` if `c` is a `Ring`, i.e., if `c` is closed and simple. A simple curve does not pass through the same point more than once.
`Length(c Curve) : Double Precision`	Return the length of `c`

3.2.12.3 Exceptions, Errors, and Error Codes

Error handling will be accomplished by using the standard SQL status returns.

3.2.13 SQL Functions on Type LineString

3.2.13.1 Component Overview :

The following SQL functions apply to `LineString`.

3.2.13.2 Language Constructs :

`NumPoints(l LineString) : Integer`	Return the number of points in the `LineString`.
`PointN(l LineString, n Integer) : Point`	Return a `Point` containing point `n` of `l`

3.2.13.3 Exceptions, Errors, and Error Codes

Error handling will be accomplished by using the standard SQL status returns.

3.2.14 SQL Functions on Type Surface

3.2.14.1 Component Overview

The following SQL functions apply to all subtypes of `Surface`.

3.2.14.2 Language Constructs

`Centroid(s Surface) : Point`	Return the centroid of `s`, which may lie outside `s`
`PointOnSurface(s Surface) : Point`	Return a `Point` guaranteed to lie on the surface
`Area(s Surface) : Double Precision`	Return the area of `s`

3.2.14.3 Exceptions, Errors, and Error Codes

Error handling will be accomplished by using the standard SQL status returns.

3.2.15 SQL Functions on Type Polygon

3.2.15.1 Component Overview

The following SQL functions apply to `Polygon`.

3.2.15.2 Language Constructs

`ExteriorRing(p Polygon) : LineString`	Return the exterior ring of `p`.
`NumInteriorRing(p Polygon) : Integer`	Return the number of interior rings.
`InteriorRingN(p Polygon, n Integer) : LineString`	Return the nth interior ring. The order of rings is not geometrically significant.

3.2.15.3 Exceptions, Errors, and Error Codes

Error handling will be accomplished by using the standard SQL status returns.

3.2.16 SQL Functions on Type GeomCollection

3.2.16.1 Component Overview

The following SQL functions apply to `GeomCollection` and all of its subtypes.

3.2.16.2 Language Constructs

`NumGeometries(g GeomCollection) : Integer`	Return the number of geometries in the collection.
`GeometryN(g GeomCollection, n Integer) : Geometry`	Return the nth geometry in the collection. The order of the elements in the collection is not geometrically significant.

3.2.16.3 Exceptions, Errors, and Error Codes

Error handling will be accomplished by using the standard SQL status returns.

3.2.17 SQL Functions on Type MultiCurve

3.2.17.1 Component Overview

The following SQL functions apply to all subtypes of `MultiCurve`.

3.2.17.2 Language Constructs

`IsClosed(mc MultiCurve) : Integer`	The return type is `Integer`, with a return value of 1 for `TRUE`, 0 for `FALSE`, and –1 for `UNKNOWN` corresponding to a function invocation on `NULL` arguments. Return `TRUE` if `mc` is closed.
`Length(mc MultiCurve) : Double Precision`	Return the length of `mc`.

3.2.17.3 Exceptions, Errors, and Error Codes

Error handling will be accomplished by using the standard SQL status returns.

3.2.18 SQL Functions on Type MultiSurface

3.2.18.1 Component Overview

The following SQL functions apply to all subtypes of `MultiSurface`.

3.2.18.2 Language Constructs

`Centroid(ms MultiSurface) : Point`	Return the centroid of `ms`, which may lie outside `ms`
`PointOnSurface(ms MultiSurface) : Point`	Return a Point guaranteed to lie on the multi surface
`Area(ms MultiSurface) : Double Precision`	Return the area of `ms`

3.2.18.3 Exceptions, Errors, and Error Codes

Error handling will be accomplished by using the standard SQL status returns.

3.2.19 SQL functions that test Spatial Relationships

3.2.19.1 Component Overview

The following functions test named spatial relationships between two geometries. The specific definitions of these spatial relationships in terms of the DE-9IM may be found in section 2.1.13.2.

3.2.19.2 Language Constructs:

`Equals(g1 Geometry,g2 Geometry) : Integer`	The return type is `Integer`, with a return value of 1 for `TRUE`, 0 for `FALSE`, and –1 for `UNKNOWN` corresponding to a function invocation on `NULL` arguments. `TRUE` if `g1` and `g2` are equal.

`Disjoint(g1 Geometry, g2 Geometry) : Integer`	The return type is `Integer`, with a return value of 1 for `TRUE`, 0 for `FALSE`, and –1 for `UNKNOWN` corresponding to a function invocation on `NULL` arguments. `TRUE` if the intersection of `g1` and `g2` is the empty set.
`Touches(g1 Geometry, g2 Geometry) : Integer`	The return type is `Integer`, with a return value of 1 for `TRUE`, 0 for `FALSE`, and –1 for `UNKNOWN` corresponding to a function invocation on `NULL` arguments. `TRUE` if the only points in common between `g1` and `g2` lie in the union of the boundaries of `g1` and `g2`.
`Within(g1 Geometry, g2 Geometry) : Integer`	The return type is `Integer`, with a return value of 1 for `TRUE`, 0 for `FALSE`, and –1 for `UNKNOWN` corresponding to a function invocation on `NULL` arguments. `TRUE` if `g1` is completely contained in `g2`.
`Overlaps(g1 Geometry, g2 Geometry) : Integer`	The return type is `Integer`, with a return value of 1 for `TRUE`, 0 for `FALSE`, and –1 for `UNKNOWN` corresponding to a function invocation on `NULL` arguments. `TRUE` if the intersection of `g1` and `g2` results in a value of the same dimension as `g1` and `g2` that is different from both `g1` and `g2`.
`Crosses(g1 Geometry, g2 Geometry) : Integer`	The return type is `Integer`, with a return value of 1 for `TRUE`, 0 for `FALSE`, and –1 for `UNKNOWN` corresponding to a function invocation on `NULL` arguments. `TRUE` if the intersection of `g1` and `g2` results in a value whose dimension is less than the maximum dimension of `g1` and `g2` and the intersection value includes points interior to both `g1` and `g2`, and the intersection value is not equal to either `g1` or `g2`.
`Intersects(g1 Geometry, g2 Geometry) : Integer`	The return type is `Integer`, with a return value of 1 for `TRUE`, 0 for `FALSE`, and –1 for `UNKNOWN` corresponding to a function invocation on `NULL` arguments. Convenience predicate: `TRUE` if the intersection of `g1` and `g2` is not empty. *Intersects(g1, g2) ⇔ Not (Disjoint(g1, g2))*

`Contains(g1 Geometry, g2 Geometry) : Integer`	The return type is `Integer`, with a return value of 1 for `TRUE`, 0 for `FALSE`, and –1 for `UNKNOWN` corresponding to a function invocation on `NULL` arguments. Convenience predicate: `TRUE` if `g2` is completely contained in `g1`. *Contains(g1, g2) ⇔ Within(g2 , g1)*

The following function tests if the specified spatial relationship between two geometry values exists, where the spatial relationship is expressed as a string encoding the acceptable values for the DE-9IM between the two geometries, as described in the Geometry Object Model.

`Relate(g1 Geometry, g2 Geometry,` `  patternMatrix String) : Integer`	The return type is `Integer`, with a return value of 1 for `TRUE`, 0 for `FALSE`, and –1 for `UNKNOWN` corresponding to a function invocation on `NULL` arguments. Returns `TRUE` if the spatial relationship specified by the `patternMatrix` holds.

3.2.19.3 Exceptions, Errors, and Error Codes

Error handling will be accomplished by using the standard SQL status returns.

3.2.19.4 Example Queries

The functions and predicates in this section allow the expression of detailed spatial relationship queries.

Return all parcels that intersect a specified polygon:

```
SELECT Parcel.Name, Parcel.Id FROM Parcels
          WHERE Intersects(Parcels.Location, PolygonFromWKB(:wkb, : srid)) = 1
```

Return all parcels completely contained in a specified polygon:

```
SELECT Parcel.Name, Parcel.Id FROM Parcels
          WHERE Within(Parcels. Location, PolygonFromWKB(:wkb, :srid)) = 1
```

The following adjacency query may be used to select all parcels that are ‘adjacent’ to a query parcel and share one or more boundary lines with a query parcel while excluding parcels that share only corner points.

```
SELECT Parcel.Name, Parcel.Id FROM Parcels
          WHERE Touches(Parcels. Location, PolygonFromWKB(:wkb, :srid)) = 1 and
              Overlaps(Boundary(Parcels. Location), Boundary(PolygonFromWKB(:wkb,
:srid))) = 1
```

3.2.20 SQL Functions for Distance Relationships

3.2.20.1 Component Overview

The distance function can be used to calculate the distance between two values of type `Geometry`.

3.2.20.2 Language Constructs

`Distance(g1 Geometry, g2 Geometry) : Double Precision`	Return the distance between `g1` and `g2`.

3.2.20.3 Exceptions, Errors, and Error Codes

Error handling will be accomplished by using the standard SQL status returns.

3.2.20.4 Example Query

```
SELECT Airport.Name FROM Airports
WHERE Distance(PointFromText(:pointTaggedText, :srid), Airport.Location) < 2000
```

3.2.21 SQL Functions that implement Spatial Operators

3.2.21.1 Component Overview

These functions implement set-theoretic and constructive geometry operations on geometry values. These operations are defined for all types of `Geometry`.

3.2.21.2 Language Constructs

`Intersection (g1 Geometry, g2 Geometry) : Geometry`	Return a `Geometry` that is the set intersection of geometries g1 and g2.
`Difference (g1 Geometry, g2 Geometry) : Geometry`	Return a `Geometry` that is the closure of the set difference of g1 and g2.
`Union (g1 Geometry, g2 Geometry) : Geometry`	Return a `Geometry` that is the set union of `g1` and `g2`.
`SymDifference(g1 Geometry, g2 Geometry) : Geometry`	Return a `Geometry` that is the closure of the set symmetric difference of `g1` and `g2` (logical XOR of space).
`Buffer (g1 Geometry, d Double Precision) : Geometry`	Return as `Geometry` defined by buffering a distance `d` around `g1`, where `d` is in the distance units for the Spatial Reference of `g1`.
`ConvexHull(g1 Geometry) : Geometry`	Return a `Geometry` that is the convex hull of `g1`.

3.2.21.3 Exceptions, Errors, and Error Codes

Error handling will be accomplished by using the standard SQL status returns.

3.2.21.4 Example Query

The following query returns the name of the state and the fragment(s) of the state that fall within the query polygon for each state that intersects the query polygon.

```
SELECT States.Name, Intersection(PolygonFromWKB(:wkb, :srid), States.Location)
FROM States
```

```
WHERE Intersects(PolygonFromWKB(:wkb, :srid), States.Location)
```

3.2.22 SQL Function usage and References to Geometry

The SQL Functions that operate on Geometry Types have been defined above to take geometry values as arguments. This conforms to the model for value based ADTs under SQL3.

As described in section 2.3.5, a SQL Type may also support the concept of persistent references to instances of the Type. To support the latter type of implementation, a reference to a geometry type instance, `REF(Geometry)`, may be used in place of a Geometry value in the SQL functions defined in this section.

3.3 The Well-known Binary Representation for Geometry (WKBGeometry)

3.3.1 Component Overview

The Well-known Binary Representation for Geometry (`WKBGeometry`), provides a portable representation of a `Geometry` value as a contiguous stream of bytes. It permits `Geometry` values to be exchanged between an ODBC client and an SQL database in binary form.

3.3.2 Component Description

The Well-known Binary Representation for Geometry is obtained by serializing a geometry instance as a sequence of numeric types drawn from the set {`Unsigned Integer`, `Double`} and then serializing each numeric type as a sequence of bytes using one of two well defined, standard, binary representations for numeric types (NDR, XDR). The specific binary encoding (NDR or XDR) used for a geometry representation is described by a one byte tag that precedes the serialized bytes. The only difference between the two encodings of geometry is one of byte order, the XDR encoding is Big Endian, the NDR encoding is Little Endian.

3.3.2.1 Numeric Type Definitions

An `Unsigned Integer` is a 32-bit (4-byte) data type that encodes a nonnegative integer in the range [0, 4294967295].

A `Double` is a 64-bit (8-byte) double precision data type that encodes a double precision number using the IEEE 754 double precision format

The above definitions are common to both XDR and NDR.

3.3.2.2 XDR (Big Endian) Encoding of Numeric Types

The XDR representation of an `Unsigned Integer` is Big Endian (most significant byte first).

The XDR representation of a `Double` is Big Endian (sign bit is first byte).

3.3.2.3 NDR (Little Endian) Encoding of Numeric Types

The NDR representation of an `Unsigned Integer` is Little Endian (least significant byte first).

The NDR representation of a `Double` is Little Endian (sign bit is last byte).

3.3.2.4 Conversion between the NDR and XDR representations of WKBGeometry

Conversion between the NDR and XDR data types for `Unsigned Integer` and `Double` numbers is a simple operation involving reversing the order of bytes within each `Unsigned Integer` or `Double` number in the representation.

3.3.2.5 Relationship to other COM and CORBA data transfer protocols

The XDR representation for `Unsigned Integer` and `Double` numbers described above is also the standard representation for `Unsigned Integer` and for `Double` number in the CORBA Standard Stream Format for Externalized Object Data that is described as part of the CORBA Externalization Service Specification [15].

The NDR representation for `Unsigned Integer` and `Double` number described above is also the standard representation for `Unsigned Integer` and for `Double` number in the DCOM protocols that is based on DCE RPC and NDR [16].

3.3.2.6 Description of WKBGeometry Representations

The Well-known Binary Representation for Geometry is described below. The basic building block is the representation for a `Point`, which consists of two `Double` numbers. The representations for other geometries are built using the representations for geometries that have already been defined.

```
// Basic Type definitions
// byte : 1 byte
// uint32 : 32 bit unsigned integer (4 bytes)
// double : double precision number (8 bytes)

// Building Blocks : Point, LinearRing

Point {
           double x;
           double y;
};

LinearRing  {
           uint32  numPoints;
           Point   points[numPoints];
}

enum wkbGeometryType {
           wkbPoint = 1,
           wkbLineString = 2,
           wkbPolygon = 3,
           wkbMultiPoint = 4,
           wkbMultiLineString = 5,
           wkbMultiPolygon = 6,
           wkbGeometryCollection = 7
};

enum wkbByteOrder {
```

```
            wkbXDR = 0,           // Big Endian
            wkbNDR = 1            // Little Endian
};

WKBPoint {
            byte          byteOrder;
            uint32        wkbType;                                  // 1
            Point         point;
}

WKBLineString {
            byte          byteOrder;
            uint32        wkbType;                                  // 2
            uint32        numPoints;
            Point         points[numPoints];
}

WKBPolygon {
            byte          byteOrder;
            uint32        wkbType;                                  // 3
            uint32        numRings;
            LinearRing    rings[numRings];
}

WKBMultiPoint {
            byte          byteOrder;
            uint32        wkbType;                          // 4
            uint32        num_wkbPoints;
            WKBPoint      WKBPoints[num_wkbPoints];
}

WKBMultiLineString {
            byte          byteOrder;
            uint32        wkbType;                                  // 5
            uint32        num_wkbLineStrings;
            WKBLineString WKBLineStrings[num_wkbLineStrings];
}

wkbMultiPolygon {
            byte          byteOrder;
            uint32        wkbType;                                  // 6
            uint32        num_wkbPolygons;
            WKBPolygon    wkbPolygons[num_wkbPolygons];
}

WKBGeometry {
            union {
                WKBPoint                point;
                WKBLineString           linestring;
                WKBPolygon              polygon;
                WKBGeometryCollection   collection;
                WKBMultiPoint           mpoint;
                WKBMultiLineString      mlinestring;
```

```
            WKBMultiPolygon          mpolygon;
        }
};

WKBGeometryCollection {
        byte            byte_order;
        uint32          wkbType;                                  // 7
        uint32          num_wkbGeometries;
        WKBGeometry     wkbGeometries[num_wkbGeometries];
}
```

Figure 3.2 shows a pictorial representation of the Well-known Representation for a `Polygon` with one outer ring and one inner ring.

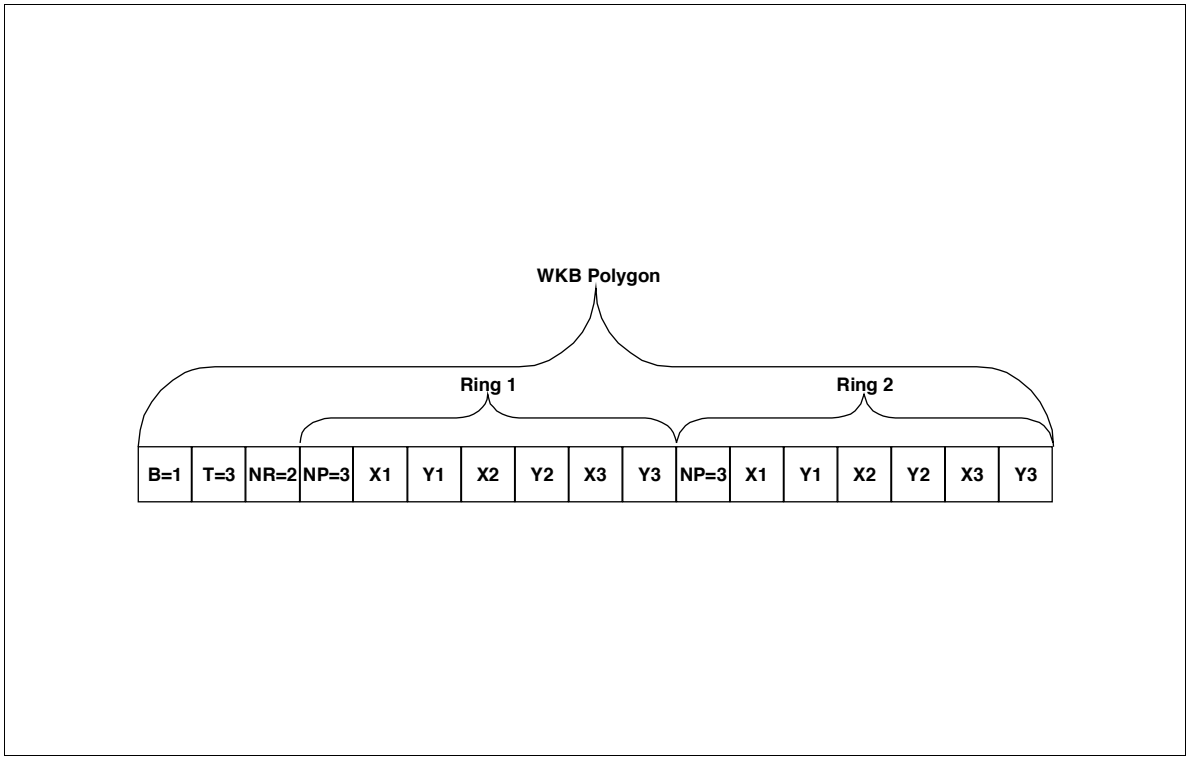


Figure 3.2—Well-known Binary Representation for a `Geometry` value in NDR format (B=1) of type Polygon (T=3) with 2 linear rings (NR = 2) each ring having 3 points (NP = 3).

3.3.2.7 Assertions for Well-known Binary Representation for Geometry

The Well-known Binary Representation for Geometry is designed to represent instances of the geometry types described in the Geometry Object Model and in the OpenGIS Abstract Specification. **Any `WKBGeometry` instance must satisfy the assertions for the type of `Geometry` that it describes**. These assertions may be found in the section 2.1.

These assertions imply the following for Rings, Polygons and MultiPolygons:

3.3.2.8 Linear Rings

Rings are simple and closed, which means that Linear Rings may **not** self-touch.

3.3.2.9 Polygons

No two Linear Rings in the boundary of a Polygon may cross each other, the Linear Rings in the boundary of a polygon may intersect at most at a single point but only as a tangent.

3.3.2.10 MultiPolygons

1. The interiors of 2 Polygons that are elements of a MultiPolygon may not intersect.

2. The Boundaries of any 2 Polygons that are elements of a MultiPolygon may touch at only a *finite* number of points.

For more details on the above assertions and for the assertions for each geometry type the reader is referred to the Geometry Object Model section of this specification.

3.4 Well-known Text Representation of Spatial Reference Systems

3.4.1 Component Overview

The Well-known Text Representation of Spatial Reference Systems provides a standard textual representation for spatial reference system information.

3.4.2 Component Description

The definitions of the well-known text representation are modeled after the POSC/EPSG coordinate system data model.

A spatial reference system, also referred to as a coordinate system, is a geographic (latitude-longitude), a projected (X,Y), or a geocentric (X,Y,Z) coordinate system.

The coordinate system is composed of several objects. Each object has a keyword in upper case (for example, `DATUM` or `UNIT`) followed by the defining, comma-delimited, parameters of the object in brackets. Some objects are composed of objects so the result is a nested structure. Implementations are free to substitute standard brackets ( ) for square brackets [ ] and should be prepared to read both forms of brackets.

The EBNF (Extended Backus Naur Form) definition for the string representation of a coordinate system is as follows, using square brackets, see note above:

```
<coordinate system> = <projected cs> | <geographic cs> | <geocentric cs>

<projected cs> = PROJCS[‘<name>‘, <geographic cs>, <projection>, {<parameter>,}* <linear
unit>]

<projection> = PROJECTION[‘<name>‘]

<parameter> = PARAMETER[‘<name>‘, <value>]

<value> = <number>
```

A data set’s coordinate system is identified by the `PROJCS` keyword if the data are in projected coordinates, by `GEOGCS` if in geographic coordinates, or by `GEOCCS` if in geocentric coordinates.

The `PROJCS` keyword is followed by all of the ‘pieces’ which define the projected coordinate system. The first piece of any object is always the name. Several objects follow the projected coordinate system name: the geographic coordinate system, the map projection, 0 or more parameters, and the linear unit of measure. All projected coordinate systems are based upon a geographic coordinate system so we will describe the

pieces specific to a projected coordinate system first. As an example, UTM zone 10N on the NAD83 datum is defined as:

```
PROJCS['NAD_1983_UTM_Zone_10N',
    <geographic cs>,
    PROJECTION['Transverse_Mercator'],
    PARAMETER['False_Easting',500000.0],
    PARAMETER['False_Northing',0.0],
    PARAMETER['Central_Meridian',-123.0],
    PARAMETER['Scale_Factor',0.9996],
    PARAMETER['Latitude_of_Origin',0.0],
    UNIT['Meter',1.0]]
```

The name and several objects define the geographic coordinate system object in turn: the datum, the prime meridian, and the angular unit of measure.

```
<geographic cs> = GEOGCS['<name>', <datum>, <prime meridian>, <angular unit>]

<datum> = DATUM['<name>', <spheroid>]

<spheroid> = SPHEROID['<name>', <semi-major axis>, <inverse flattening>]

<semi-major axis> = <number>   NOTE: semi-major axis is measured in meters and must be > 0.

<inverse flattening> = <number>

<prime meridian> = PRIMEM['<name>', <longitude>]

<longitude> = <number>
```

The geographic coordinate system string for UTM zone 10 on NAD83 is

```
GEOGCS['GCS_North_American_1983',
    DATUM['D_North_American_1983',
    SPHEROID['GRS_1980',6378137,298.257222101]],
    PRIMEM['Greenwich',0],
    UNIT['Degree',0.0174532925199433]]
```

The `UNIT` object can represent angular or linear unit of measures.

```
<angular unit> = <unit>

<linear unit> = <unit>

<unit> = UNIT['<name>', <conversion factor>]

<conversion factor> = <number>
```

`<conversion factor>` specifies number of meters (for a linear unit) or number of radians (for an angular unit) per unit and must be greater than zero.

So the full string representation of UTM Zone 10N is

```
PROJCS['NAD_1983_UTM_Zone_10N',
    GEOGCS['GCS_North_American_1983',
    DATUM[  'D_North_American_1983',SPHEROID['GRS_1980',6378137,298.257222101]],
    PRIMEM['Greenwich',0],UNIT['Degree',0.0174532925199433]],
    PROJECTION['Transverse_Mercator'],PARAMETER['False_Easting',500000.0],
    PARAMETER['False_Northing',0.0],PARAMETER['Central_Meridian',-123.0],
    PARAMETER['Scale_Factor',0.9996],PARAMETER['Latitude_of_Origin',0.0],
    UNIT['Meter',1.0]]
```

A geocentric coordinate system is quite similar to a geographic coordinate system. It is represented by

```
<geocentric cs> = GEOCCS['<name>', <datum>, <prime meridian>, <linear unit>]
```

4 Supported Spatial Reference Data

4.1 Supported Linear Units

Meter	1.0
Foot (International)	0.3048
U.S. Foot	12/39.37
Modified American Foot	12.0004584/39.37
Clarke's Foot	12/39.370432
Indian Foot	12/39.370141
Link	7.92/39.370432
Link (Benoit)	7.92/39.370113
Link (Sears)	7.92/39.370147
Chain (Benoit)	792/39.370113
Chain (Sears)	792/39.370147
Yard (Indian)	36/39.370141
Yard (Sears)	36/39.370147
Fathom	1.8288
Nautical Mile	1852.0

4.2 Supported Angular Units

Radian	1.0
Decimal Degree	π/180
Decimal Minute	(π/180)/60
Decimal Second	(π/180)/36000
Gon	π/200
Grad	π/200

4.3 Supported Spheroids

Name	Semi-major Axis	Inverse Flattening
Airy	6377563.396	299.3249646
Modified Airy	6377340.189	299.3249646
Australian	6378160	298.25
Bessel	6377397.155	299.1528128
Modified Bessel	6377492.018	299.1528128
Bessel (Namibia)	6377483.865	299.1528128
Clarke 1866	6378206.4	294.9786982
Clarke 1866 (Michigan)	6378693.704	294.978684677
Clarke 1880 (Arc)	6378249.145	293.466307656
Clarke 1880 (Benoit)	6378300.79	293.466234571
Clarke 1880 (IGN)	6378249.2	293.46602
Clarke 1880 (RGS)	6378249.145	293.465
Clarke 1880 (SGA)	6378249.2	293.46598

Everest 1830	6377276.345	300.8017
Everest 1975	6377301.243	300.8017
Everest (Sarawak and Sabah)	6377298.556	300.8017
Modified Everest 1948	6377304.063	300.8017
GEM10C	6378137	298.257222101
GRS 1980	6378137	298.257222101
Helmert 1906	6378200	298.3
International 1924	6378388	297.0
Krasovsky	6378245	298.3
NWL9D	6378145	298.25
OSU_86F	6378136.2	298.25722
OSU_91A	6378136.3	298.25722
Plessis 1817	6376523	308.64
Sphere (radius = 1.0)	1	0
Sphere (radius = 6371000 m)	6371000	0
Struve 1860	6378297	294.73
War Office	6378300.583	296
WGS 1984	6378137	298.257223563

4.4 Supported Geodetic Datums

Adindan
Afgooye
Agadez
Australian Geodetic Datum 1966
Australian Geodetic Datum 1984
Ain el Abd 1970
Amersfoort
Aratu
Arc 1950
Arc 1960
Ancienne Triangulation Francaise
Barbados
Batavia
Beduaram
Beijing 1954
Reseau National Belge 1950
Reseau National Belge 1972
Bermuda 1957
Bern 1898
Bern 1938
Bogota
Bukit Rimpah
Camacupa
Campo Inchauspe
Cape
Carthage
Chua
Conakry 1905
Corrego Alegre
Cote d'Ivoire
Datum 73
Deir ez Zor
Deutsche Hauptdreiecksnetz
Douala
European Datum 1950
European Datum 1987
Egypt 1907
European Reference System 1989
Fahud
Gandajika 1970
Garoua
Lisbon
Loma Quintana
Lome
Luzon 1911
Mahe 1971
Makassar
Malongo 1987
Manoca
Massawa
Merchich
Militar-Geographische Institute
Mhast
Minna
Monte Mario
M'poraloko
NAD Michigan
North American Datum 1927
North American Datum 1983
Nahrwan 1967
Naparima 1972
Nord de Guerre
NGO 1948
Nord Sahara 1959
NSWC 9Z-2
Nouvelle Triangulation Francaise
New Zealand Geodetic Datum 1949
OS (SN) 1980
OSGB 1936
OSGB 1970 (SN)
Padang 1884
Palestine 1923
Pointe Noire
Provisional South American Datum 1956
Pulkovo 1942
Qatar
Qatar 1948
Qornoq
RT38
South American Datum 1969
Sapper Hill 1943
Schwarzeck

Geocentric Datum of Australia 1994	Segora
Guyane Francaise	Serindung
Herat North	Stockholm 1938
Hito XVIII 1963	Sudan
Hu Tzu Shan	Tananarive 1925
Hungarian Datum 1972	Timbalai 1948
Indian 1954	TM65
Indian 1975	TM75
Indonesian Datum 1974	Tokyo
Jamaica 1875	Trinidad 1903
Jamaica 1969	Trucial Coast 1948
Kalianpur	Voirol 1875
Kandawala	Voirol Unifie 1960
Kertau	WGS 1972
Kuwait Oil Company	WGS 1972 Transit Broadcast Ephemeris
La Canoa	WGS 1984
Lake	Yacare
Leigon	Yoff
Liberia 1964	Zanderij

4.5 Supported Prime Meridians

Greenwich	0° 0' 0"
Bern	7° 26' 22.5" E
Bogota	74° 4' 51.3" W
Brussels	4° 22' 4.71" E
Ferro	17° 40' 0" W
Jakarta	106° 48' 27.79" E
Lisbon	9° 7' 54.862" W
Madrid	3° 41' 16.58" W
Paris	2° 20' 14.025"E
Rome	12° 27' 8.4" E
Stockholm	18° 3' 29" E

4.6 Supported Map Projections

Cylindrical Projections	**Conic Projections**
Cassini	Albers conic equal-area
Gauss-Kruger	Lambert conformal conic
Mercator	**Azimuthal or Planar Projections**
Oblique Mercator (Hotine)	Polar Stereographic
Transverse Mercator	Stereographic

4.7 Map Projection Parameters

central_meridian	the line of longitude chosen as the origin of x-coordinates.
scale_factor	used generally to reduce the amount of distortion in a map projection.
standard_parallel_1	a line of latitude that has no distortion generally. Also used for 'latitude of true scale.'
standard_parallel_2	a line of latitude that has no distortion generally.
longitude_of_center	the longitude which defines the center point of the map projection.
latitude_of_center	the latitude which defines the center point of the map projection.
latitude_of_origin	the latitude chosen as the origin of y-coordinates.
false_easting	added to x-coordinates. Used to give positive values.
false_northing	added to y-coordinates. Used to give positive values.
azimuth	the angle east of north which defines the center line of an oblique projection.
longitude_of_point_1	the longitude of the first point needed for a map projection.
latitude_of_point_1	the latitude of the first point needed for a map projection.
longitude_of_point_2	the longitude of the second point needed for a map projection.
latitude_of_point_2	the latitude of the second point needed for a map projection.

5 References

1. The OpenGIS Abstract Specification: An Object Model for Interoperable Geoprocessing, Revision 1, OpenGIS Consortium, Inc, OpenGIS Project Document Number 96-015R1, 1996.

2. OpenGIS Project Document 96-025: Geodetic Reference Systems, OpenGIS Consortium, Inc, October 14, 1996.

3. POSC (Petrotechnical Open Software Consortium) Epicentre Model V2.1, fttp://posc.org/public/geodetic, July 1995.

4. Clementini, Eliseo, Di Felice, P., van Oostrom, p., A Small Set of Formal Topological Relationships Suitable for End-User Interaction, in D. Abel and B. C. Ooi (Ed.), Advances in Spatial Databases—Third International Symposium. SSD '93. LNCS 692. Pp. 277-295. Springer-Verlag. Singapore (1993).

5. Clementini E. and Di Felice P., A Comparison of Methods for Representing Topological Relationships, Information Sciences 80, 1-34, 1994.

6. Clementini, Eliseo, Di Felice, P., A Model for Representing Topological Relationships Between Complex Geometric Features in Spatial Databases, Information Sciences 90 (1-4):121-136 , 1996.

7. Clementini E., Di Felice P and Califano, G. Composite Regions in Topological Queries, Information Systems, v 20, no 6, pp 33-48, 1995.

8. Egenhofer, M.F. and Franzosa, Point Set Topological Spatial Relations, International Journal of Geographical Information Systems, vol 5, no 2, 161-174, 1991.

9. Egenhofer, M.J., Clementini, E. and Di Felice, P., Topological relations between regions with holes, International Journal of Geographical Information Systems, vol 8, no 2, pp 129—142, 1994.

10. Egenhofer, M.J. and Herring, J., A mathematical framework for the definition of topological relationships. Proceedings of the Fourth International Symposium on Spatial Data Handling, Columbus, Ohi, pp. 803-813.

11. Egenhofer M.J. and Herring, J., Categorizing binary topological relationships between regions, lines and points in geographic databases, Tech. Report., Department of Surveying Engineering, University of Maine, Orono, ME 1991.

12. Egenhofer. M.J. and Sharma, J., Topological Relations between regions in $\Re^2$ and Z^2, Advances in Spatial Databases—Third International Symposium, SSD '93, vol. 692, Lecture Notes in Computer Science, pp. 36-52, Springer Verlag, Singapore (1993).

13. Worboys, M.F. and Bofakos, P. A Canonical model for a class of areal spatial objects, Advances in Spatial Databases—Third International Symposium, SSD '93, vol. 692, Lecture Notes in Computer Science, pp. 36-52, Springer Verlag, Singapore (1993).

14. Worboys, M.F. A generic model for planar geographical objects, International Journal of Geographical Information Systems, 1992, vol 6, no 5, 353-372.

15. http://www.omg.org/corba/sectrans.htm : CORBAservices : Common Object Services Specification, Ch 8. Externalization Service Specification, OMG.

16. http://www.microsoft.com/oledev : Distributed Component Object Model Protocol Specification—DCOM 1.0, Microsoft Corporation.