SPATIAL DATABASES IN SQL SERVER 2008

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Objective

The objective of this project is to demonstrate in an easy and understandable manner how we can implement and manipulate spatial databases in SQL Server 2008.

At first, we will have a general introduction about spatial databases, their main domains, their shortcomings and their future developments. Afterwards, the report will explain in detail the features available in SQL Server 2008 to support the implementation of spatial databases. The third chapter will talk about a case study we used to illustrate the utility of spatial databases with those features and problems we encountered during the implementation.

Finally, we will have a conclusion summarizing the ideas found in the overall report.

Introduction

Data is ubiquitous in every aspect of the world and its physical objects can be measured, positioned and moved. For that reason, spatial databases are built as a solution to store, query, manipulate and analyze data based on information related to space. This spatial data "can be defined as pieces of information describing quantitative and/or qualitative properties that refer to space. Such properties can be represented as attributes of a set of objects or as functions of the space locations" (Belussi, Catania, Clementini, & Ferrari, 2007).

As other databases, spatial databases take advantage of the technology to solve problems and needs, especially to be able to monitor and support decision-making. The wide range of current applications that uses these spatial capabilities are related to applications for urban development, social networks, mobile phones like Waze, war strategies, insurance, medical treatments, computer-aided design (CAD), astronomy, climate, events, retail stores, agriculture, robotics, satellite images, among others. Hence, the diversity of users and the extensive number of customers have made it necessary to increasingly study and develop these kinds of databases.

Regarding the use of spatial databases, Shekhar et al. mention: "The Geographical Information System (GIS) is the principal technology motivating interest in Spatial Database Management Systems (SDBMSs). GIS provides a convenient mechanism for the analysis and visualization of geographic data. Geographic data is spatial data whose underlying frame of reference is the earth's surface" (Shekar & Chawla, 2003). Thus, it gives an idea of its main purpose and why the most of the SDBMSs are focused on supporting those functionalities.

On the other hand, nowadays applications integrate many functions from the machines where they are operating, and one of those is fully related with spatial databases, the GPS. This service is responsible to determine the device's location on Earth; it provides information about latitude, longitude and altitude, although not all of the devices offer the last one. Additionally, there are other means to collect information including physical addresses positioned in maps, IP addresses, satellites and digital images.

Furthermore, in the book Spatial Database Systems, Yeung & Hall describe the trends of the SDBMSs as integration between systems, cross platform applications, user friendly interfaces and applications evolving in order to be able to solve the changing user requirements with new technological developments. So that, they mention two main topics, spatial database systems as a service and location based services. On one hand, it is a service provided through telecommunication networks (usually Internet) using a hosted computer, which is paid either by subscription or number of transactions, this service is called also Spatial Web Service. Yeung and Hall highlight one of the best benefits of this approach: "Potentially millions of users are able to access spatial information, and obtain business or public services based on such information without special software or training" (Yeung & Hall, 2007)

On the other hand, location based services are mainly provided by mobile applications that provide localized and real-time business and information services. These applications tend to adapt to their context in order to provide information related to specific places.

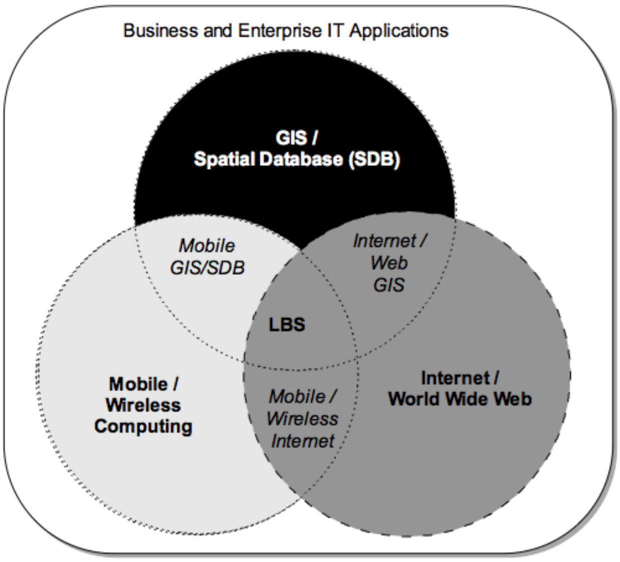


Figure 12-6. Enabling technologies of location-based services (LBS)

Figure 1. Retrieved from Yeung, A., & Hall, B. (2007). *Spatial Database Systems, Design, Implementation and Project Management.* Dordrecht, The Netherlands: Springer. Page 493.

Examples of the usage of this kind of applications are for weather, maps, touristic information, traffic, and bike rental availability, among others. So that, users know the environment where they are and can plan beforehand. Comparing to the conventional GIS used by some people, LBS has to manage hundreds or thousands of requests simultaneously. So that, "In order to maintain a high level of service in a concurrent real-time user environment, LBS demand much more stringent technology and performance standards than those required by conventional spatial database applications". Hence, LBS are based in seven main capabilities: High performance, scalability, reliability, open architecture, geographic coverage, severity and ease of use. In the Figure 1, Yeung & Hall classify the different applications and they possible relation with spatial databases.

In their book, Yeung & Hall also mention that the diversification of GIS have reached multiple areas regarding public administration (health care, security, law, transport…) in order to monitor, control and manage the information and support the decision-making. Moreover, people will continue to be one of the main reasons of spatial databases development. Finally, they list the most recent research trends in the topic: Spatial data acquisition and integration, Distributed and mobile computing, Geographic representation, Interoperability of geographic information, Open formats and GML, Geographic data infrastructures, Spatial data and society, Spatial query optimization, Use of geometry in database queries, Incorporation of time varying data into spatial databases, Use of spatial data on the web, Knowledge discovery and spatial data mining and Improvement of geospatial interoperability between systems, data types and databases.

Spatial Databases in SQL Server 2008

SQL Server 2008 is one of the most widely used database management systems to manipulate databases in general. It was chosen as the means to manipulate spatial databases in this report because of the features it provides in support of spatial databases and its accessibility. In this chapter we will discuss the main spatial features available in SQL Server 2008 and at the end of the chapter we will compare it with some other popular spatial database management systems. But first, we will describe two important ideas about spatial data that are necessary to understand the dynamics of manipulating such data with SQL Server 2008.

Geometry Shapes

Defining different spatial features – whether on earth or in abstract – mainly relies on a few basic geometry shapes that must be available in a DBMS with spatial-data support. These shapes are defined as follows:

- **Point:** a pair of coordinates that describes a specific location on a map (e.g. city, meeting point, gift shop, …)

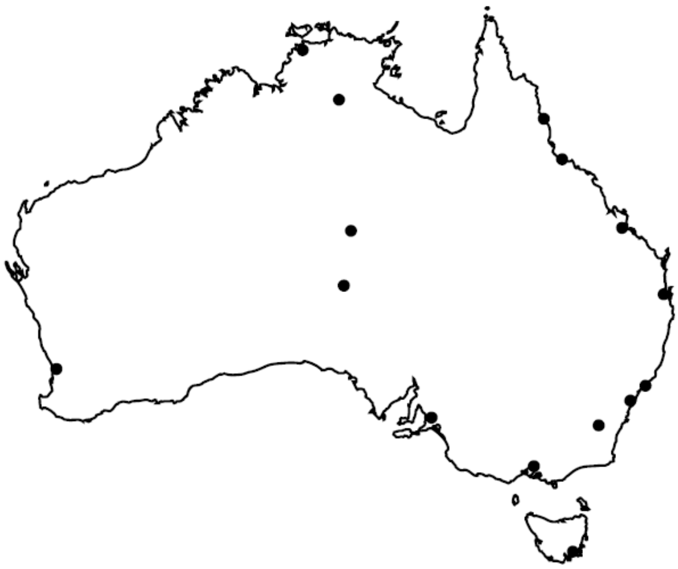


Figure 1-2. *A series of Point geometries representing cities in Australia*

Figure 2. Retrieved from Aitchison, A. (2009). ***Beginning Spatial with SQL Server 2008.*** **Apress. Page 5**

- **Line String:** a set of points that describe a continuous line with one starting and one ending point. There are several different types of line strings:
  - Simple: a line string that doesn't cross itself (e.g. street, river)
  - Closed**:** a line string where the starting and ending point are the same (e.g. F1 racing track)
  - Ring: a line string that is both simple and closed (e.g. borders of a country)

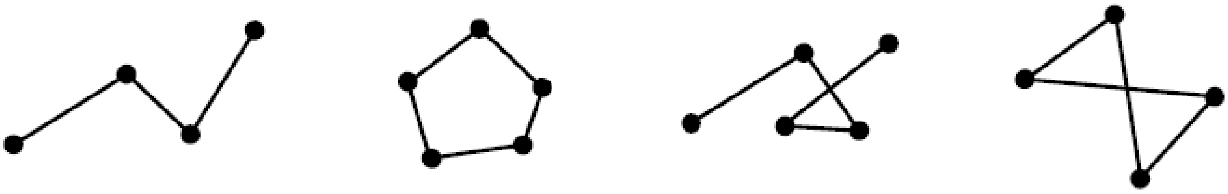


Figure 1-3. *Examples of LineString geometries (from left to right): a simple LineString; a simple, closed LineString (a ring); a nonsimple LineString; a nonsimple, closed LineString*

Figure 3. Retrieved from Aitchison, A. (2009). *Beginning Spatial with SQL Server 2008.* Apress. Page 6

- **Polygon:** a set of one or more rings (simple, closed line strings) that define a closed area (e.g. lake, island). A polygon must have one external ring but can also optionally have any number of other interior rings that define an area included in the external ring but is outside the scope of the polygon.

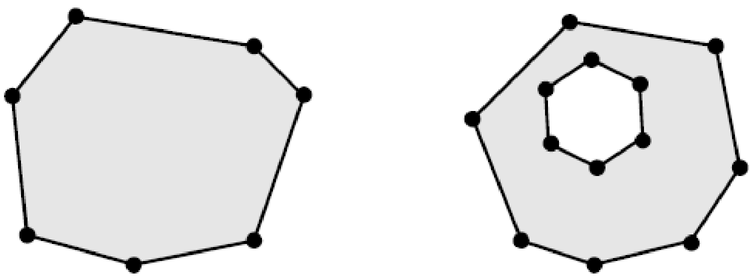


Figure 1-5. *Examples of Polygon geometries (from left to right): a Polygon; a Polygon with an interior ring*

Figure 4. Retrieved from Aitchison, A. (2009). *Beginning Spatial with SQL Server 2008.* Apress. Page 7

In addition to the three simple types mentioned above, each type has an extension, which is a set of geometries of that type. Namely, we can have:

- **MultiPoint:** a set of points (e.g. capital cities of the United States)
- **MultiLineString:** a set of line strings (e.g. 10 longest rivers in the world)
- **MultiPolygon:** a set of polygons (e.g. member countries of NATO)

These sets are used when defining more than one related geometry shape of the same kind and have a wide variety of uses.

One important note here is the difference between a MultiLineString and a Polygon. While both of them have one or more line strings, the Polygon's line strings must all be rings while those of MultiLineString do not have such a condition and instead simply represent a set of different line strings.

Spatial Reference Systems

Defining one of the above-mentioned geometry shapes is usually accompanied with positioning that shape on a map of the earth. A Spatial Reference System (SRS) defines the set of properties and features that give meaning to the position of a shape on a map. An SRS usually consists of the following:

- **Coordinate System:** it is the set of axis that the coordinates should be mapped onto. There are two main types:
  - Geographic coordinate system: uses the latitude and longitude axis to map coordinates onto a three-dimensional model of the earth
  - Projected coordinate system: uses the linear (x) and (y) axis to map the coordinates onto a projected two-dimensional model of the earth
- **Datum:** a "datum" contains information about the shape and size of the earth as it is used to map the coordinates on the coordinates system. It consists of the following:
  - Reference Ellipsoid: since the shape of the earth cannot be accurately modeled in maps, the reference ellipsoid describes the used 3D shape of the earth. It can be a perfect sphere at times but it's usually a different pre-defined ellipsoid.
  - Reference Frame**:** defines the point with coordinates (0, 0) on the reference ellipsoid and this point will be used as a reference for all other coordinates.
- **Prime Meridian:** the axis from which the longitude coordinate will be measured (the most commonly used prime meridian is that running through Greenwich, London)
- **Unit of Measure:** determines the unit that the coordinates will be measured in. It depends on the type of the coordinate system:
  - Geographic coordinate systems use angular units (usually degree or radian)
  - Projected coordinate systems use linear units (usually meters but can also be foot, yard, mile for example)
- **Projection Parameters:** in addition to all of the above, the projected coordinate system must also have a set of projection parameters that defined the method used to project a 3D real-life feature on a 2D model of the earth. The full set of parameters is explained in detail in (Aitchison, 2009).

Instead of having to define all of the above parameters every time we want to define a spatial data instance, SQL Server 2008 has an internal list of pre-defined SRS stored in the table ***sys.spatial_reference_systems***. All of the SRS in this table are regulated by the European Petroleum Survey Group (EPSG) and each has its own unique SRID with which it can be referenced when initializing spatial data.

Data Types

Exactly like number, varchar, float, int, etc, SQL Sever 2008 also has two main data types specifically used to represent spatial data. These two types are called **Geography** and **Geometry**. There are several similarities and differences between the two types in terms of usage, storage and properties.

These similarities and differences are demonstrated in the below table:

	Geography	Geometry
Representation	Both represent spatial data	
Storage	- Both store data internally as a string of bytes in the same format - Both are variable-length data types (storage size depends on the	

data itself)

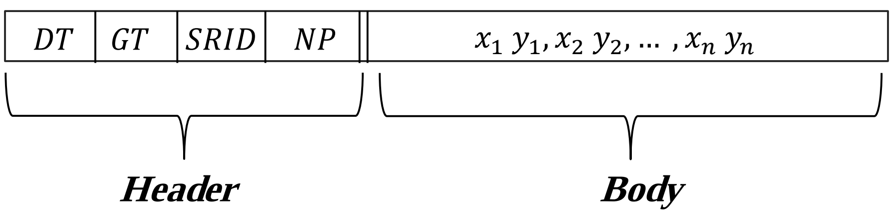
Analysis	Both have the same methods to analyze spatial data	
Earth Shape	Round	Flat
Coordinate System	Geographic	Projected
Spatial Reference System	Necessary *Default is WGS 84 (ID 4326)*	Not necessary *Default value is 0*
Coordinate Values	Latitude and longitude	Cartesian coordinates (x and y)
Ring orientation *	Significant	Not significant
Usage	Unprojected maps	- Projected maps - Shapes and data not related to earth
Accuracy	Excellent accuracy	Introduces some distortion because of projection
Performance	Slow (spherical computations are more complex)	Fast (regular Cartesian computations)

**** Ring Orientation:** when defining a Polygon ring using the "Geography" type, points must be stated in counter-clockwise order. However in the "Geometry" type, order of points isn't important.*

Storage

As mentioned in the table above, both Geography and Geometry data types are stored as a binary string of bytes holding the different properties of the spatial element they represent.

In general, the spatial data stored in SQL has the following structure:



Where:

- **DT**: data type (Geography vs. Geometry)
- **GT**: Geometry type (Point, LineString, Polygon, …)
- **SRID**: Spatial Reference System ID (default to 0 with Geometry data type)
- **NP**: Number of points in the body
- **Body**: contains the coordinates of each point representing the shape (each coordinate is stored as an 8-byte floating point number)

Although this storage is identical to how SQL would store any other data type, there is one big difference with the spatial data types. In order to make it easier for the user to manipulate spatial data, SQL identifies spatial data variables as objects of a class using an extended integration with Microsoft .NET CLR.

This allows the user to benefit from all the functionalities of object-oriented programming when handling spatial data in SQL Server 2008. In particular, the following properties of OOP are used:

- **Abstraction:** Geography and Geometry data types are abstract classes that cannot be instantiated
- **Encapsulation:** Each class has its own methods to manipulate the data type it represents
- **Polymorphism:** several sub-classes of the main Geography and Geometry exist, each representing a specific geometry shape (e.g. point, line, polygon)
- **Static methods:** used to instantiate instances of the specific class when creating new spatial data

This is clarified in the following diagram depicting the OOP nature of SQL Server's spatial data types *(diagram taken from* (Aitchison, 2009)*)*:

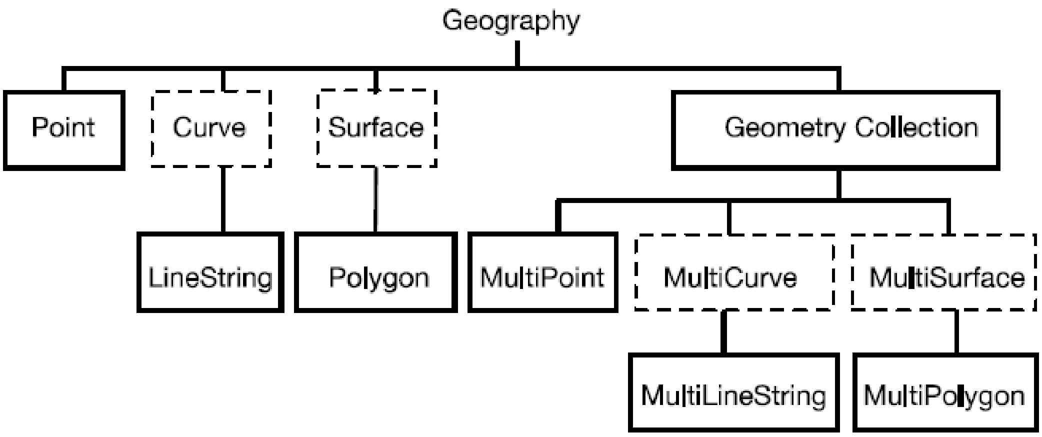


Figure 3-3. *The inheritance hierarchy of objects in the geography datatype. Instantiable types—those types from which an instance of data can be created in SQL Server 2008—are shown with a solid border.*

Creating New Spatial Data

Before we start experimenting and analyzing spatial data with SQL Server 2008, we must first have spatial data stored.

There are several ways we can introduce spatial data into our database:

- Create spatial data manually
- User-selected data using online map-editors
- Import data from online sample data sources

The choice we made will be explained thoroughly in the next chapter. However, regardless of the method we choose, the introduced data must be represented in a way that SQL Server 2008 can understand and interpret correctly.

SQL Server 2008 has internal support for three different formats of spatial data representation. They will be explained next.

Well-Known Text (WKT):

- Natural language text written in a pre-defined format
- SQL Server parses the text and creates the corresponding geometry shape
- **Format:**
  - $Point\ (x\ y\ z)$: (z) is an optional third coordinate representing the depth of the point relative to the surface of the earth
  - $LineString\ (x_1\ y_1, x_2\ y_2, \dots\ x_n\ y_n)$
  - $Polygon\ ((x_{11}\ y_{11}, x_{12}\ y_{12}, \dots\ x_{11}\ y_{11})\ (x_{21}\ y_{21}, x_{22}\ y_{22}, \dots\ x_{21}\ y_{21})\ (x_{m1}\ y_{m1}, x_{m2}\ y_{m2}, \dots\ x_{m1}\ y_{m1}))$ each LineString in the polygon definition must be a ring (i.e. must start and end at the same point)

Well-Known Binary (WKB):

- Binary string of bytes in a pre-defined format
- Different from the binary format that SQL Server uses to internally store spatial data
- SQL Server converts this WKB to the format used in storage
- **Format:**
  - Point: [Type] = 1

```
[ByteOrder][Type][X][Y]
```

  - LineString: [Type] = 2

```
[ByteOrder][Type][NumPoints][X1][Y1][X2][Y2] … [Xn][Yn]
```

  - Polygon: [Type] = 3

```
[ByteOrder][Type][NumRings][NumPoints][X1][Y1]…[Xn][Yn][NumPoints][X1][Y1]…[Xn][Yn]
                                <--------- Ring 1 --------->< -------- Ring 2 --------->
```

In the above formats, [ByteOrder] can be either 0 (big-endian) or 1(little-endian).

Geography Markup Language (GML):

- An XML-based markup language using pre-defined tags
- SQL Server can import the XML file and convert the XML data into the storage binary representation
- **Format:**
  - Point:

```
<Point xmlns="http://www.opengis.net/gml">
  <pos>40.4 -2.31667</pos>
</Point>
```

- LineString:

```
<LineString xmlns="http://www.opengis.net/gml">
  <posList>-6 4 3 -5</posList>
</LineString>
```

- Polygon:

```
<Polygon xmlns="http://www.opengis.net/gml">
  <exterior>
    <LinearRing>
      <posList>0 0 100 0 100 100 0 100 0 0</posList>
    </LinearRing>
  </exterior>
  <interior>
    <LinearRing>
      <posList>10 10 20 10 20 20 10 20 10 10</posList>
    </LinearRing>
  </interior>
  <interior>
    <LinearRing>
      <posList>75 10 80 10 80 20 75 20 75 10</posList>
    </LinearRing>
  </interior>
</Polygon>
```

It should be noted that all of the formats explained above can be used to:

- Create both Geography and Geometry spatial data.
- Create sets of the above mentioned geometry shapes (i.e. MultiPoint, MultiLineString and MultiPolygon).

The following table explains the main properties of each of them, the similarities and differences between them and the main areas of use:

	Well-Known Text (WKT)	**Well-Known Binary (WKB)**	**Geography Markup Language (GML)**
Format	Text-based	Binary-based	Text-based
Accuracy	Low – due to rounding errors	High – because of binary representation	Low – due to rounding errors
Processing	Normal	Fast	Normal
Storage	Normal	Small	Large
Easy to	Very easy	Hard – low error	Very easy

understand		detection	
Area of use	Manual insertion	Importing data from other sources	Exporting data and system integration
Order of Coordinates	Longitude – Latitude	Longitude – Latitude	Latitude – longitude
Possibility of defining Z coordinate	Yes	No	No

Visualizing Spatial Data

Visualizing spatial data in one of the more important aspects of handling that kind of data. In contrast to regular data types, a simple text representation is often not enough to make the data easy to understand for the user. Hence, we must find a way to display our spatial data in a way that conveys the necessary information.

There are two main methods of visualizing spatial data:

- Use the internally supported visualization methods in SQL Server Management Studio 2008
- Integrate the database with an external map viewer (e.g. Virtual Earth, Google Maps) and display the data using the available GUIs

As with the previous section, our choice will be explained in detail in the next chapter. We will continue in this section explaining the internally supported visualization methods.

After executing a query that returns at least one spatial column, SQL Server MS gives us the option to see the results on a map through the “Spatial results” tab.

After selecting the tab, we must choose the options that will affect the display of our result:

- **Spatial column:** we can only visualize *one* spatial column at a time and we select the column here
- **Label column:** an optional column to introduce a label to our spatial data
- **Projection Type:** this is the most important option as it will greatly affect the visualization of the data. The supported projection types in SQL Server 2008 are the following *:
    - Equirectangular:
        - Models the earth as a rectangle with a width to height ratio of 2:1
        - Easiest to model and map but introduces a lot of distortion
        - Normally only used for small-scale tests
    - Mercator:
        - Uses a cylindrical projection method
        - One of the most widely used projection methods
        - Introduces some distortion near the poles
    - Robinson:
        - Developed by Dr. Arthur Robinson using a table of manual values instead of a mathematical formula
        - Balances distortion across all aspects of a map (e.g. area, distance, shape) for a better result

- Bonne:
    - All the parallels of latitude are constructed from the concentric arcs of a circle
    - Usually introduces a lot of distortion when used for the map of the whole world and hence it is mostly used for maps of smaller parts (e.g. continents or countries)

  Please note that since the Geometry data type is already projected, this option is only available when visualizing Geography data.

** More information about these projection types and illustrations of the differences between them is mentioned in* (Aitchison, 2009).

Query Support

After introducing the main spatial data types in SQL Server 2008, we will talk about how these data types are in integrated into T-SQL language and what are the main features available to handle them in a spatial-related manner.

Continuing with the object-oriented approach that SQL Server 2008 takes when is dealing with spatial data, many attributes and functions are available to handle the defined spatial data in the same way it is created.

Getting attributes of spatial data instances

The following attributes can be retrieved using specific "get" methods. Unless otherwise noted, all methods are valid for both the Geography and Geometry data types:

- Get **type of geometry** (point, lineString, …)
- Get **number of dimensions**
- Test the properties of a lineString (**simple** / **closed** / **ring**) *(Geometry type only)*
- Get **number of points** in a geometry shape
- Get **coordinates** of a point (x and y for Geometry, longitude and latitude for Geography)
- Get **start point** and **end point** of a geometry shape
- Get the **centroid** of a polygon *(Geometry type only)*
- Get the **envelope center** of a polygon *(Geography type only, takes into consideration the 3D nature of the polygon)*
- Get **length** / **area** of a geometry shape
- Get **exterior ring** / **number of interior rings** / **a specific interior ring** of a polygon

Relations between two spatial data instances

Another important aspect of support for spatial data is defining the relations between two spatial data instances. SQL Server 2008 also has a number of functions to define the most used binary relations, listed below:

- Get the **union** / **intersection** / **difference** / **symmetric** difference of two geometry shapes (all these relations are defined as set operations on the set of points of each geometry and return the simplest shape possible containing the points that satisfy the relation)
- Testing **equality** of two shapes (also points-wise)
- Calculate **distance** between two geometry shapes (shortest direct path)
- Testing if two geometry shapes **intersect** or are **disjoint**

- Testing if two geometry shapes **touch** each other (two shapes “touch” each other if all of the points they share lie on the boundary of both of them)
- Testing if two polygons **overlap**
- Testing the **containment** of one geometry shape in another

Spatial indices

As with other types of queries, spatial queries might need a very long time to execute. For examples, testing a binary relation between two shapes might consume a long time depending on the complexity of the shapes and the size of the spatial data set we have.

In order to enhance the performance, SQL Server 2008 uses a special type of indices called “spatial indices”. A spatial index is implemented as a grid index with a structure similar to a B-Tree in principle. It basically works in the following way:

- Divide the space of spatial data into *(n)* different cells
- Divide each cell into another *(n)* squares
- Repeat the above until we reach a pre-defines *(h)* number of levels *(number of level in SQL is set to h = 4 and cannot be changed)*

```
CREATE SPATIAL INDEX idxGeometry ON RandomPoints ( geom )
USING GEOMETRY_GRID
WITH (
  BOUNDING_BOX = (-180, -90, 180, 90),
  GRIDS = (
    LEVEL_1 = MEDIUM,
    LEVEL_2 = MEDIUM,
    LEVEL_3 = MEDIUM,
    LEVEL_4 = MEDIUM),
  CELLS_PER_OBJECT = 16
)
GO
```

The code above creates a spatial index and has the following variables:

- **USING GEOMETRY_GRID** indicates that this index is built on a Geometry typed column.
- **BOUDING_BOX** specifies the area that the index must cover and split into squares.
- **GRIDS** specify the number of cells in each level of the index (low: 4 x 4, medium: 8 x 8, high: 16 x 16).
- **CELLS_PER_OBJECT** specifies the maximum number of index cells of each object (when this number is reached, cells will no longer be split).

Comparison

Every database management system implements standards in different ways, some of their features are common and others make them particular, Boston Geographic Information Systems provides a comparison table of three of the main spatial databases in the market, there is shown some of the features that have to be taken into account at the moment of using a spatial database (Boston Geographic Information Systems, 2008):

Feature	SQL Server 2008 (RC0)	MySQL 5.1/6	PostgreSQL 8.3/PostGIS 1.3/1.4
OS	Windows XP, Windows Vista, Windows 2003, Windows 2008	Windows XP, Windows Vista, (haven't tested on 2008), Linux, Unix, Mac	Windows 2000+ (including Vista and 2003, haven't tested on 2008), Linux, Unix, Mac
Licensing	Commercial - Closed Source, Various levels of features based on version, Express version has full spatial support but limitation on database size and only use one processor.	Commercial Open Source (COSS), some parts GPL. Here is an interesting blog entry on the subject MySQL free software but not Open Source. The comments are actually much more informative than the article itself.	FLOSS (PostgreSQL is BSD, PostGIS is GPL Open Source - you can use for commercial apps but if you make changes to the core libraries of PostGIS, you need to give that back to the community)
Free GIS Data Loaders	shp dataloader for SQL Server 2008 developed by Morten Nielsen(doesn't yet work with RC0)	OGR2OGR, shp2mysql.pl script	included shp2pgsql, OGR2OGR, QuantumGIS SPIT, SHP loader for PostGIS also developed by Morten using SharpMap.NETvarious others
Commercial GIS Data Loaders	Manifold, Safe FME Objects, ESRI ArcGIS 9.3 (in a later service pack)	Safe FME Objects	Manifold, FME Objects, ESRI ArcGIS 9.3
Application drivers available specifically for spatial component	? Not yet - SharpMap.NET eventually and probably built into new ADO.NET 3.5+	GDAL C++, SharpMap via OGR, AutoCAD FDO	SharpMap.Net, JDBC postgis.jar included with postgis, JTS etc. tons for Java, GDAL C++, AutoCad FDO beta support
Free Object/Relational Mapping	NHibernateSpatial (this is a .NET object relational spatial mapper) - beta support	Hibernate Spatial - this is a java object relational mapper	NHibernateSpatial and HibernateSpatial
Free Desktop Viewers and Editors	Will be built into SQL Manager, but not available in RC0 and only useful for viewing	GvSig	OpenJump, QuantumGIS, GvSig, uDig
Commercial Desktop Viewers and Editors	ESRI ArcGIS 9.3 Server SDE later service pack, Manifold, FME	FME	ESRI ArcGIS 9.3 Server, ZigGIS for desktop, Manifold, FME
Web Mapping ToolKits - it must be said things like OpenLayers and various other scripting frameworks that can accept GML will work with any of these databases and your favorite web scripting language	Manifold, MapDotNet, ArcGIS 9.3 (in later service pack), UMN MapServer see, MapGuide Open Source (using beta FDO driver)	UMN Mapserver, GeoServer, MapGuide Open Source	Manifold, MapDotNet, ArcGIS 9.3, UMN Mapserver, GeoServer, FeatureServer, MapGuide Open Source (using beta FDO driver)
Spatial Functions	Both OGC SFSQL MM and Geodetic custom (over 70 functions)	OGC mostly only MBR (bounding box functions) few true spatial relation functions, 2D only	Over 300 functions and operators, no geodetic support except for point-2-point non-indexed distance functions, custom PostGIS for 2D and some 3D, some MM support of circular strings and compound curves
Spatial Indexes (from reports Oracle also uses some sort of R-Tree indexing scheme and can use quadtree, IBM DB2 uses quadtree,	Yes - 4 level Multi-Level grid hierarchy (BOL says its B-Tree based) with tessalation as described Isaac Kunen Multi-Level Grid requires defining an index grid for optimal performance	R-Tree quadratic splitting - indexes only exist for MyISAM	GIST - a variant of R-Tree

Spherical Voronoi Tessalation, IBM Informix uses R-Tree. Note R-Tree indexes are self-tuning and do not require grid setup			
True Geodetic support - support for true measurement along a spherical coordinate (it must be noted Oracle and IBM provide geodetic support, although IBM Informix/DB2 have it as an additional Blade add-on in addition to standard spatial)	Yes - with caveats - must use Geography type which has the following constraints, no single geometry may overlap hemispheres, intersections, some operations are undefined for two geometries in separate hemispheres. SRID must be defined in spatial ref. Orientation of polygons is important in Geography. According to BOL - ST_Distance is only supported when one of the geography instances is a point (NOTE: Isaac Kunen says the BOL docs are wrong about ST_Distance and this restriction has been lifted) . Fewer spatial functions available for geography than geometry	No	No
Shared Hosting	Many	Many	Much fewer, but ramping up. It must be noted that if you have a dedicated Linux/Windows server, and aren't afraid to be your own admin (or to get a qualified consultant such as us), then your options are much wider.List of community recommended PostGIS Hosters

As is shown above, the first statement to be considered is the environment available where the spatial data is going to be stored, some tools are restricted to work in specific operative systems. For example, if the machine is running under Linux or Mac, Sql Server has to be discarded. Secondly, the financial resources assigned to the project have to be enough in order to acquire a platform (every database has different prices depending of the capabilities). Additionally, other aspects are relevant to select a specific tool to work with; these attributes are related to data loaders, integration tools, technical functionalities, support, among others.

Case Study

Sample Data

Before starting with our implementation, we will talk in a small section about the sample data we collected and manipulated in the project.

In our case, we did not need data that was 100% accurate since we are only demonstrating the spatial functionalities of SQL Server 2008. However, in real-world spatial applications, gathering spatial data takes up a big part of the project because of the inaccuracy and limitations of most data sources available on the web.

Data Source

We collected all of our sample data from **VDS Technologies** (http://www.vdstech.com/home.aspx). They offer free spatial data for GIS and mapping purposes. We used the following data sets from their World Map Data source:

- World Political Map: contains countries of the world as geometry polygons
- Coast Lines: contains the coastal lines of the world defined as line strings
- City Areas: contains major cities of the world described as polygons and not as points
- Airports: contains the major airports of the world (civilian / cargo / military) defined as geometry points
- Railroads: contains the major railroads of the world defined as line strings
- Lakes: contains the major lakes of the world defined as polygons

All of the above data was coded in Shapefile format which is one of the most commonly used spatial file formats. Each data source consists of three main files:

- .shp: this file contains the raw spatial data. It can only hold data of one kind (e.g. polygon, point, line string)
- .shx: contains the spatial index of the .shp file. It has an entry for each shape in the accompanying .shp file
- .dbf: contains additional non-spatial info for each shape in .shp file (e.g., name of country)

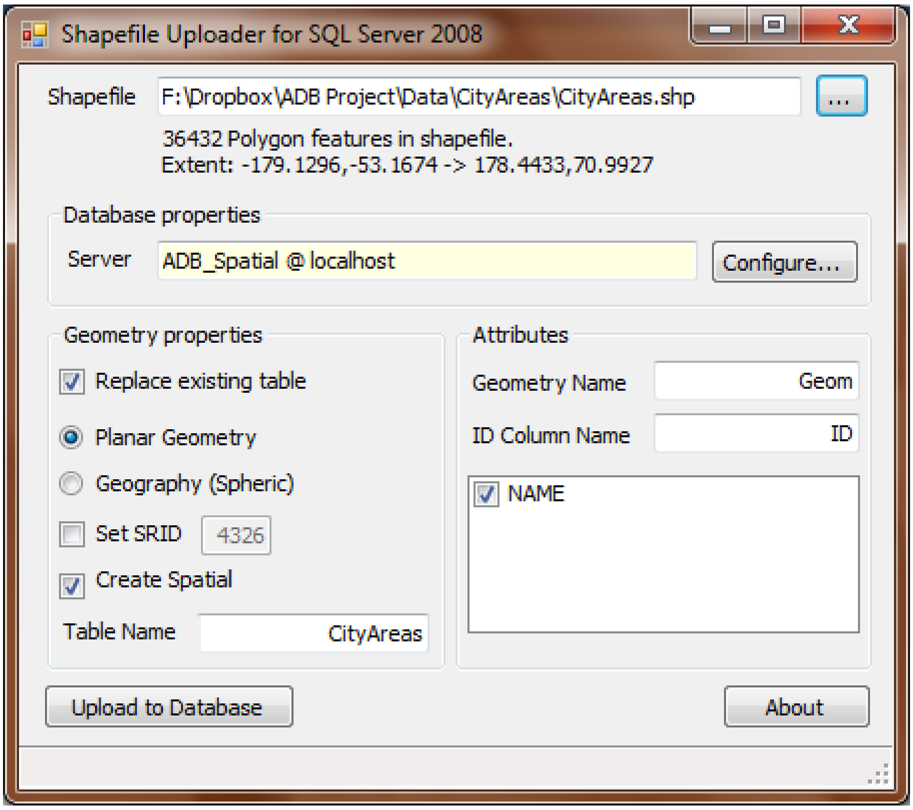
All of the data in the files represent Geometry shapes. The shapes were projected using the WGS 1984 Coordinate System on a scale 1:1,000,000.

Importing data into SQL

Importing the Shapefile data into SQL was done using the **Shape2SQL** tool (http://sharpgis.net/page/SQL-Server-2008-Spatial-Tools.aspx). Shape2SQL is a popular free tool built specifically to import Shapefiles into SQL Server 2008.

Importing is done on a file-by-file basis. The screenshot below demonstrates the simple interface of Shape2SQL. Several options are given including the type of data (geometry / geography), creating a spatial index, and the choice of attributes to include from the .shp file.

Once the correct options are chosen, the file is imported and a corresponding table is created in the database.



Visualization Tools

As stated before, Geographical Information Systems (GIS) gives the possibility to manage, analyze and present all types of geographical data. So that, GIS help users to visualize geographical data through interactive actions, usually the topics are related to land, water, transportation, geomarketing, urban planning, among others. Here, will be presented 4 of these GIS, each of those with its differences.

- ArcGIS

This GIS, as its website states, is a: "comprehensive system that allows people to collect, organize, manage, analyze, communicate, and distribute geographic information. As the world's leading platform for building and using geographic information systems (GIS), ArcGIS is used by people all over the world to put geographic knowledge to work in government, business, science, education, and media. ArcGIS enables geographic information to be published so it can be accessed and used by anyone. The system is available everywhere using web browsers, mobile devices such as smartphones, and desktop computers" (ESRI). Thus, throughout a robust variety of products, users can create, share and use maps; create and manage geographic databases and make spatial analysis, in diverse platforms (desktops, web, mobile).

- Open Jump

Open Jump is a solution open source written in the Java programming language, developed and maintained by volunteers. It can read and write shape (.shp) and simple GML files. And, as is stated in its website "It has limited support for the display of images and good support for showing data retrieved from WFS and WMS web-services. So you can use it as GIS Data Viewer. However, its particular strength is the editing of geometry and attribute data" (Open Jump, 2011).

- SQL Server Reporting Services 2008 (SSRS)

This tool, provided by Microsoft, is included in the SQL Server 2008. It is made to create and manage customized reports. Reports can include tables, charts, maps, gauges, indicators, spark lines and data bars and can be connected with different sources of data. To present the information to the users, these reports can be showed locally or published to a server or SharePoint site (Microsoft).

- SQL Server Management Studio 2008 (SSMS)

SSMS is an application developed by Microsoft for windows platforms. It gives the possibility to access, manage, configure and administer SQL Server components (Microsoft). Combining the capabilities for advanced and beginner users, it contains script editors for SQL queries and graphical viewers to show spatial results, as well, managing tools for SQL Server Database Engine, Analysis Services, Reporting Services, among others.

For this project, were checked different tools to store, manipulate and represent spatial data. Finally, we decided to use SQL Server Management Studio due to the ease of acquiring the software and the integration of components. The data was imported from shape files and stored in the SQL Server database. Then, the queries were written in the SSMS and the spatial results shown in the same program.

Query Implementation

After introducing all of the components necessary to implement spatial databases with SQL Server, we will talk in this section about the different queries we used to test SQL Server spatial capabilities.

One function that will be used extensively throughout the examples here is **MakeValid()**. This function checks if a geometry shape is defined correctly and if not, tries to make it valid (e.g., if a polygon is defined with only 2 points, it converts it to a line string).

We needed to use this function because SQL Server 2008 allows the user to define geometry shapes incorrectly but doesn't allow the application of any methods on them. To our surprise, while executing the tests we found that several instances of the sample data were defined incorrectly and needed the use of MakeValid() before applying the actual method we wanted to test.

1. Unary Operations

Several unary operations are available on spatial data. We will test two of the most popular:

- **STLength:** returns the length of a geometry (in case of a polygon, it returns the total length of the line strings comprising the boundary of that polygon)
  Example: Find the length of the borders of Belgium
  Query:

```
SELECT WM.Geom.MakeValid().STLength()
FROM WorldMap WM
WHERE WM.NAME = 'Belgium'
```

Results | Messages

	(No column name)
1	11.6367395041929

- **STArea:** returns the area contained within a geometry
  Example: Select the top 10 largest countries of the European Union according to area
  Query:

```
SELECT TOP 10 WM.NAME, WM.Geom.MakeValid().STArea()
FROM WorldMap WM
WHERE WM.NAME IN ('Austria', 'Belgium', 'Bulgaria', 'Croatia', 'Cyprus', 'Czech',
                  'Denmark', 'Estonia', 'Finland', 'France', 'Germany', 'Greece', 'Hungary', 'Ireland', 'Italy', 'Latvia',
                  'Lithuania', 'Luxembourg', 'Malta', 'Netherlands', 'Poland', 'Portugal', 'Romania', 'Slovakia', 'Slovenia',
                  'Spain', 'Sweden', 'United Kingdom')
ORDER BY WM.Geom.MakeValid().STArea() DESC
```

Results | Messages

	NAME	(No column name)
1	Sweden	78.3840855831315
2	France	66.2224818729665
3	Finland	62.9890884564732
4	Spain	54.300735799015
5	Germany	46.678349763984
6	Poland	41.3862422250419
7	United Kingdom	33.9856692243848
8	Italy	33.6165975917495
9	Romania	27.449492875234
10	Greece	14.0905571927147

Query executed successfully.

Note: the unit of measurement in the above examples is the same as the unit of coordinates (i.e., the length of a lines string between (2, 2) and (5, 6) is 5 units, regardless of the actual unit of measurement).

2. Distance Calculation

- **STDistance():** this function calculates the shortest distance between two shapes (e.g., if the shapes were a point and a polygon, it would calculate the shortest distance from the point to the polygon)
- **Example:** List the 10 closest airports to Istanbul, Turkey
- **Query 1:**

```
DECLARE @IstanbulCity GEOMETRY;
SELECT @IstanbulCity = CA.GEOM
FROM CITYAREAS CA
WHERE CA.NAME = 'ISTANBUL';

SELECT TOP 10 A.Name, A.GEOM.STAsText()
FROM AIRPORTS A
ORDER BY A.GEOM.MakeValid().STDistance(@IstanbulCity) ASC;
```

	Name	(No column name)
1	ATATURK	POINT (28.82111679077148 40.976890563964844)
2	SAMANDIRA	POINT (29.21666717529297 40.993057250976562)
3	YALOVA	POINT (29.375556945800781 40.684444427490234)
4	BURSA	POINT (29.009166717529297 40.231666564941406)
5	YENISEHIR	POINT (29.563056945800781 40.254722595214844)
6	CORLU	POINT (27.919082641601562 41.138248443603516)
7	TOPEL	POINT (30.083332061767578 40.735279083251953)
8	BANDIRMA	POINT (27.977693557739258 40.317970275878906)
9	BALIKESIR	POINT (27.924749374389648 39.619056701660156)
10	KUTAHYA	POINT (30.018611907958984 39.426944732666016)

- **Query 2:** As mentioned before, the cities in the sample data are represented as polygons and not as points so as a variant, let us consider the same query but calculate the distance from the center of Istanbul. This can be given by applying the **STCentroid** function:

```
DECLARE @IstanbulCenter GEOMETRY;
SELECT @IstanbulCenter = CA.GEOM.STCentroid()
FROM CITYAREAS CA
WHERE CA.NAME = 'ISTANBUL';

SELECT TOP 10 A.Name, A.GEOM.STAsText()
FROM AIRPORTS A
ORDER BY A.GEOM.MakeValid().STDistance(@IstanbulCenter) ASC;
```

	Name	(No column name)
1	SAMANDIRA	POINT (29.21666717529297 40.993057250976562)
2	ATATURK	POINT (28.82111679077148 40.976890563964844)
3	YALOVA	POINT (29.375556945800781 40.684444427490234)
4	BURSA	POINT (29.009166717529297 40.231666564941406)
5	YENISEHIR	POINT (29.563056945800781 40.254722595214844)
6	CORLU	POINT (27.919082641601562 41.138248443603516)
7	TOPEL	POINT (30.083332061767578 40.735279083251953)
8	BANDIRMA	POINT (27.977693557739258 40.317970275878906)
9	BALIKESIR	POINT (27.924749374389648 39.619056701660156)
10	KUTAHYA	POINT (30.018611907958984 39.426944732666016)

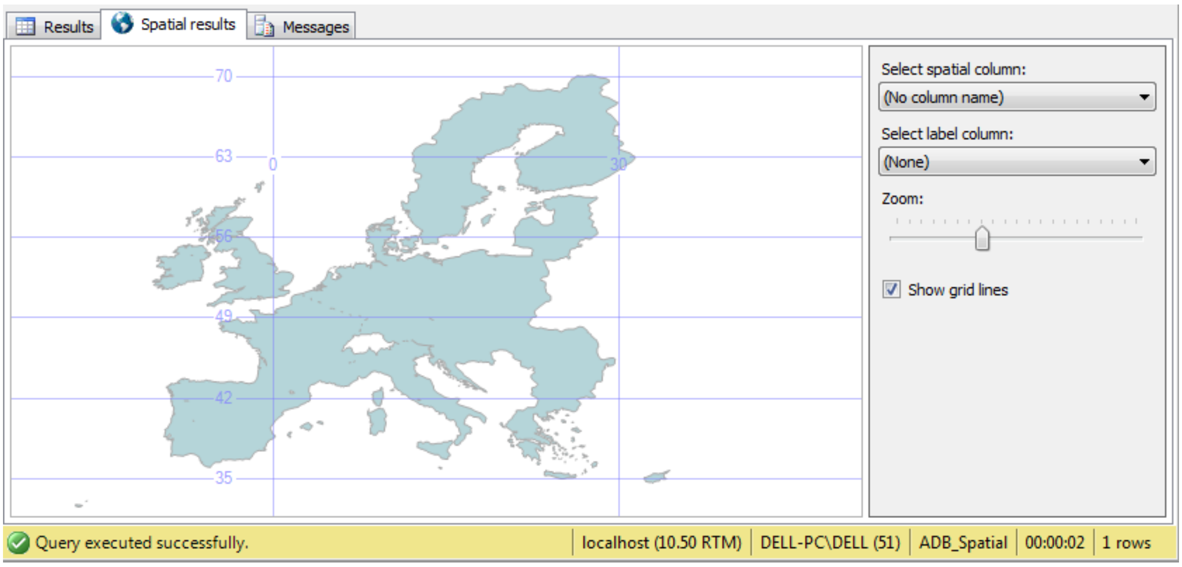
3. Set Operations

To demonstrate how SQL Server supports set operations on spatial data, we will consider the following cases:

- **STUnion():** merges geometry shapes together and the result is the most simple type that can contain all the shapes to be merged
  Example: Construct the geometry shapes representing the European Union and the Schengen Area
  Query 1:

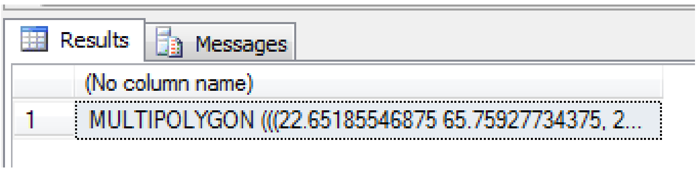
```
DECLARE @EuropeanUnion GEOMETRY = 'POLYGON EMPTY';
SELECT @EuropeanUnion = @EuropeanUnion.STUnion(WM.Geom.MakeValid())
FROM WorldMap WM
WHERE WM.NAME IN ('Austria', 'Belgium', 'Bulgaria', 'Croatia', 'Cyprus', 'Czech',
                  'Denmark', 'Estonia', 'Finland', 'France', 'Germany', 'Greece',
                  'Hungary', 'Ireland', 'Italy', 'Latvia', 'Lithuania', 'Luxembourg',
                  'Malta', 'Netherlands', 'Poland', 'Portugal', 'Romania', 'Slovakia',
```

```
                    'Slovenia', 'Spain', 'Sweden', 'United Kingdom');

    SELECT @EuropeanUnion
```



We check the internal representation of the resulting shape using the following query:

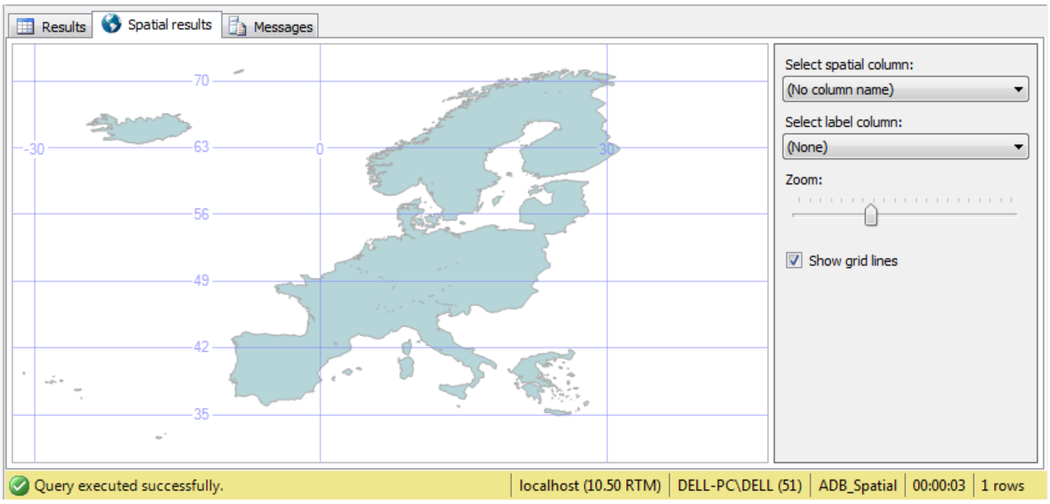
```
SELECT @EuropeanUnion.STAsText()
```



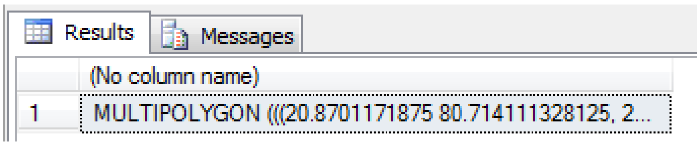
Note that the resulting shape is a MultiPolygon which is the simplest possible shape to contain all the polygons representing the different countries (if all countries bordered each other, then the resulting shape would be a simple Polygon).

- **Query 2:** Similarly, we construct the shape representing the Schengen Area:

```
DECLARE @SchengenArea GEOMETRY = 'POLYGON EMPTY';
SELECT @SchengenArea = @SchengenArea.STUnion(WM.Geom.MakeValid())
FROM WorldMap WM
WHERE WM.NAME IN ('Austria', 'Belgium', 'Czech', 'Denmark',
                 'Estonia', 'Finland', 'France', 'Germany', 'Greece', 'Hungary', 'Iceland',
                 'Italy', 'Latvia', 'Liechtenstein', 'Lithuania', 'Luxembourg',
                 'Malta', 'Netherlands', 'Norway', 'Poland', 'Portugal', 'Slovakia',
                 'Slovenia', 'Spain', 'Sweden', 'Switzerland');

SELECT @SchengenArea
```



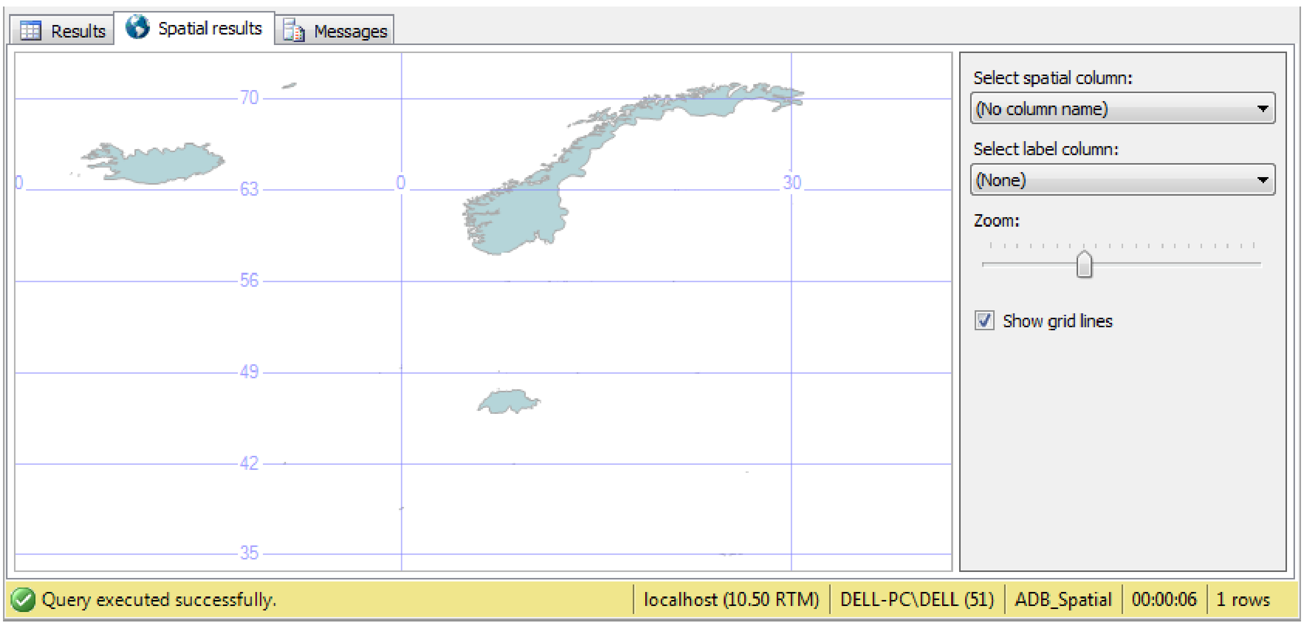
Checking the internal representation of the Schengen Area shape would give MultiPolygon for the same reasons as above:




```
SELECT @SchengenArea.STAsText()
```

- **STDifference:** returns the simplest shape representing the set difference of two shapes (all of the shapes that exist in the first shape but not in the second)
  Example: Give the countries that are in the Schengen Area but are not members of the European Union
  Query:

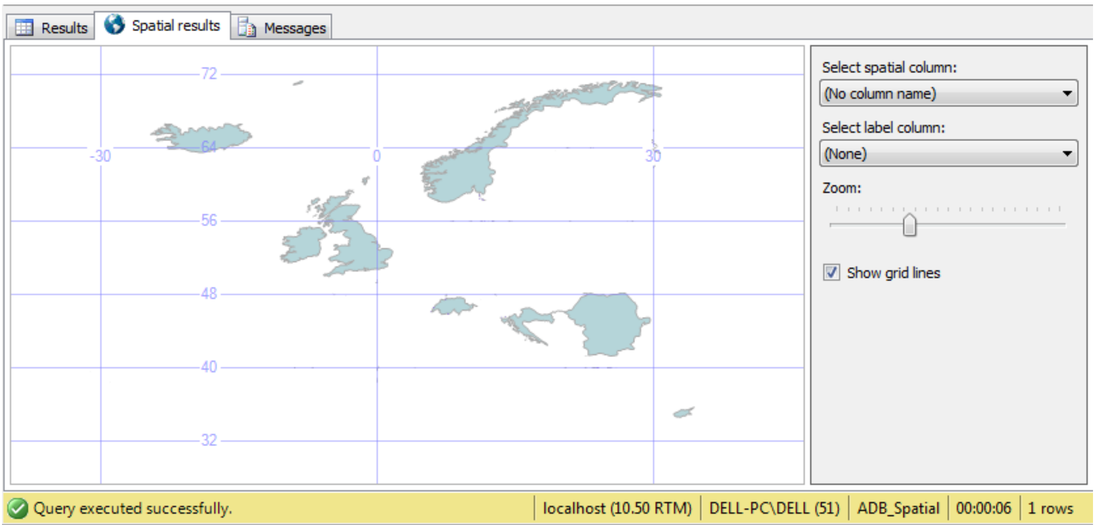
  ```
  SELECT @SchengenArea.STDifference(@EuropeanUnion);
  ```



Note that the above map indeed shows the 4 countries satisfying the criteria (Norway, Iceland, Liechtenstein and Switzerland)

- **STSymDifference:** returns the simplest shape representing the symmetric difference of two shapes (all of the shapes that are in either one of the shape *but not* in both)
  Example: Give all the countries that are in either the EU or the Schengen Area but not in both
  Query:

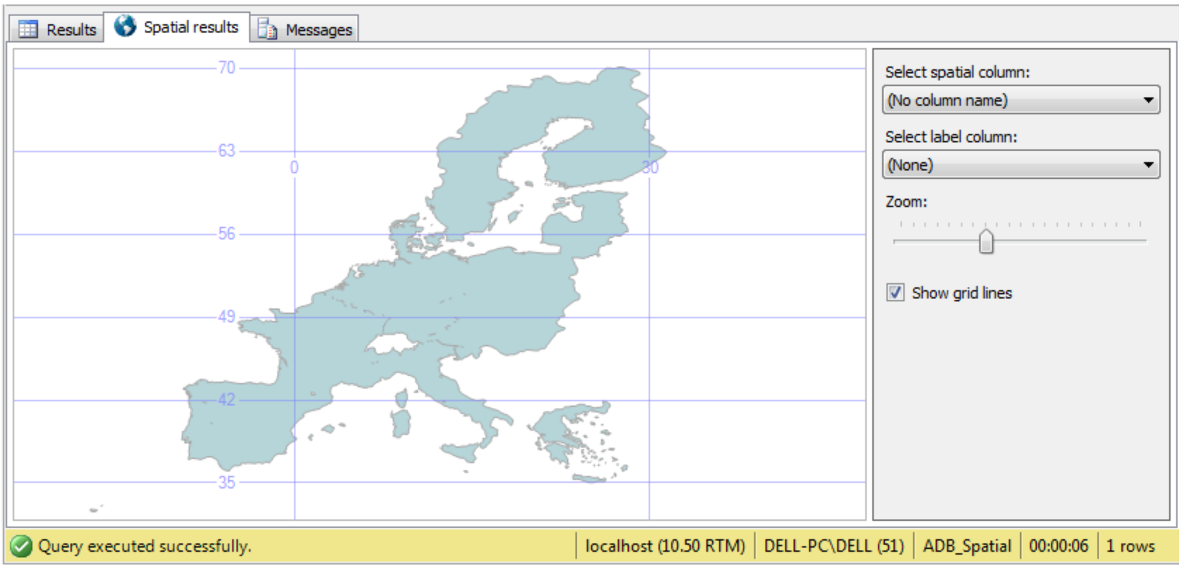
```
SELECT @SchengenArea.STSymDifference(@EuropeanUnion);
```



  This map shows the countries contained in the first map plus the 6 EU countries that are not part of the Schengen Area (Bulgaria, Croatia, Cyprus, Ireland, Romania and UK)

- **STIntersection:** returns the simplest shape representing the intersection between two geometry shapes (simple or sets)
  Example: Give the countries that are in both the EU and the Schengen Area
  Query:

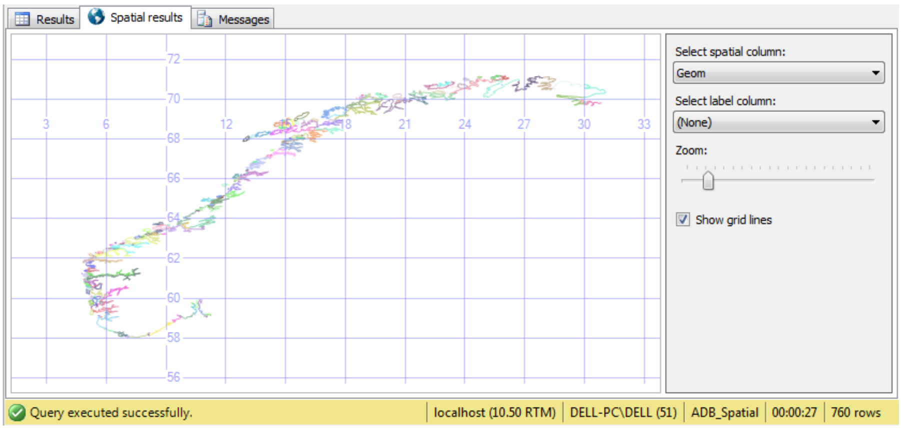
```
SELECT @SchengenArea.STIntersection(@EuropeanUnion);
```



Note that the result of this query gives all the countries that are *not* given by the previous test (STSymDifference).

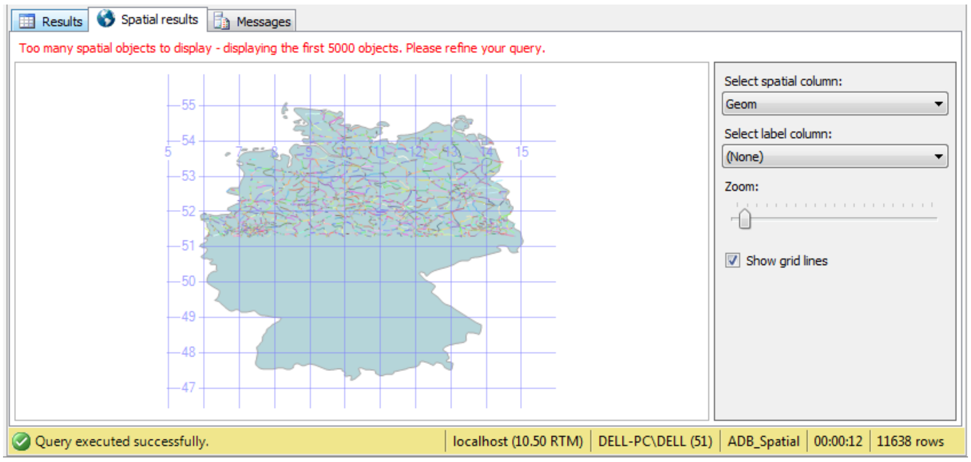
- **STIntersects:** tests if two geometry shapes intersect or not. The main difference between this function and STIntersection is that STIntersects only tests for intersection without actually returning the intersection result.
  Example: Draw a map of the coast of Norway (one of the longest in the world)
  Query:

```
DECLARE @NorwayPolygon GEOMETRY;
SELECT @NorwayPolygon = WM.Geom
FROM WorldMap WM
WHERE WM.NAME = 'Norway'

SELECT CL.Geom
FROM CoastLines CL
WHERE CL.GEOM.STIntersects(@NorwayPolygon) = 1
```



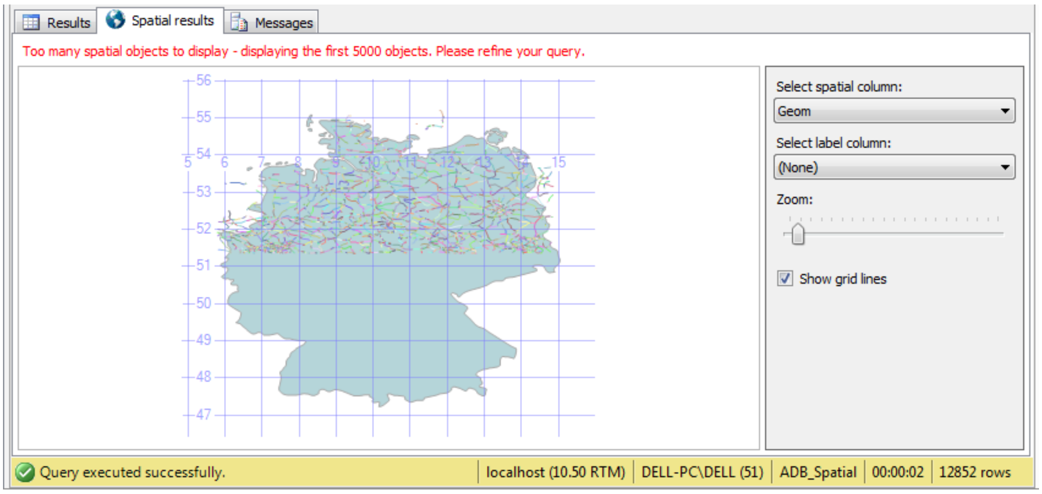
- **Filter:** this function essentially does the same job as the STIntersects function. However, instead of testing each pair of points in our dataset it uses an approximation based on dividing the data space into grid cells and performing the intersection test in the respective cells. This gives a tremendous performance benefit as the STIntersects function is extremely slow for large datasets.
  Example: Give all the railroads that cross Germany
  Query 1: Executing this with STIntersects *(execution time: 12 seconds)*

```
(SELECT WM.Geom
FROM WorldMap WM
WHERE WM.NAME = 'Germany')
UNION ALL
(SELECT R.Geom
FROM WorldMap WM, RAILROADS R
WHERE WM.NAME = 'Germany'
 AND WM.GEOM.STIntersects(R.GEOM) = 1)
```



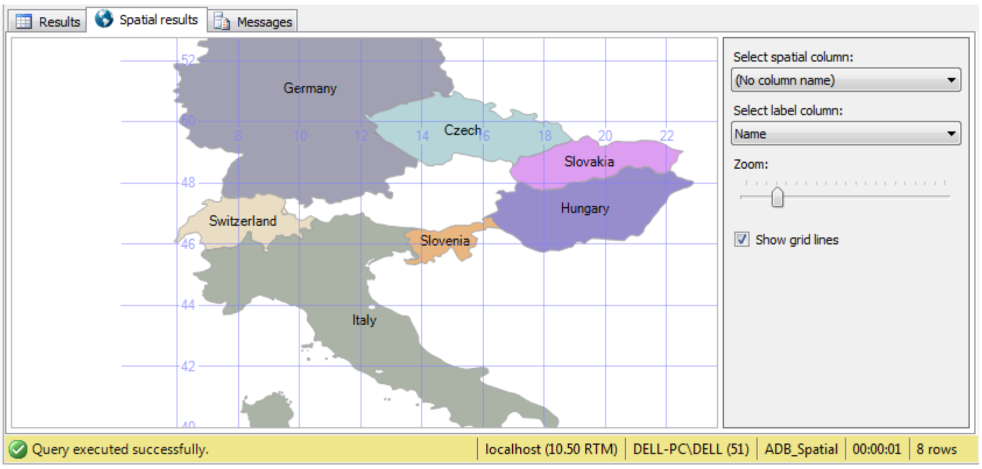
Query 2: Executing this with Filter *(execution time: 2 seconds)*

```
(SELECT WM.Geom
FROM WorldMap WM
WHERE WM.NAME = 'Germany')
UNION ALL
(SELECT R.Geom
FROM WorldMap WM, RAILROADS R
WHERE WM.NAME = 'Germany'
 AND WM.GEOM.Filter(R.GEOM) = 1)
```



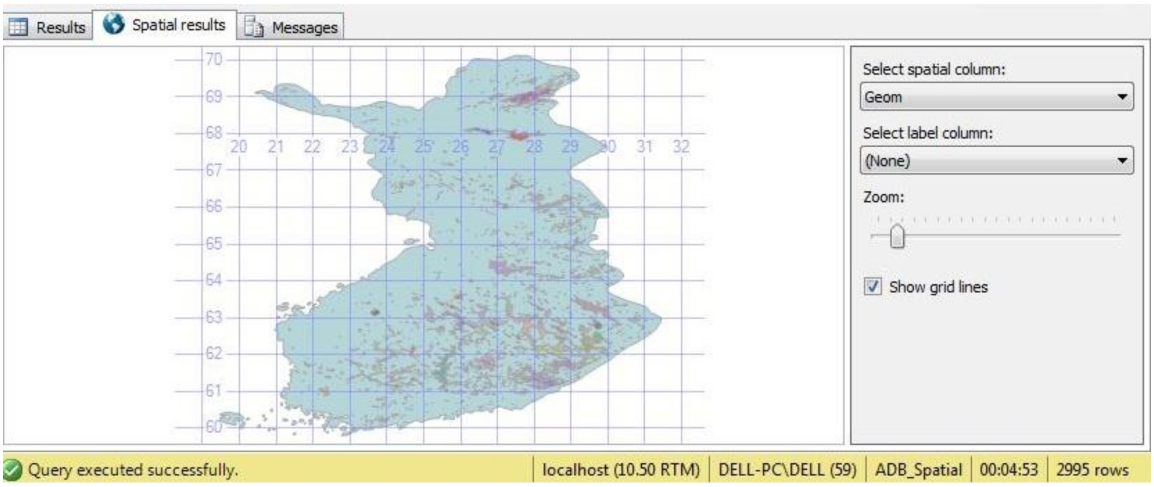
- **STTouches:** this function tests for a special kind of intersection where the shared points between the shapes are *only* on the boundary of that shape (this is specifically interesting in case of polygons since the boundary of a Point or a LineString is actually the whole shape).
  Example: Draw a map of the countries that border Austria ("the heart of Europe")
  Query:

```
DECLARE @AustriaPolygon GEOMETRY;
SELECT @AustriaPolygon = WM.Geom
FROM WorldMap WM
WHERE WM.NAME = 'Austria'

SELECT WM.Name, WM.Geom.MakeValid()
FROM WorldMap WM
WHERE WM.Geom.MakeValid().STTouches(@AustriaPolygon) = 1
```



- **STContains:** test if one shape contains all of the points of the other shape
  Example: Draw a map of Finland showing all of the lakes within the country (over 180,000 lakes!)
  Query:

```
(SELECT WM.Geom
FROM WorldMap WM
WHERE WM.NAME = 'Finland')
UNION ALL
(SELECT L.Geom
FROM WorldMap WM, Lakes L
WHERE WM.NAME = 'Finland'
 AND L.GEOM.MakeValid().STWithin(WM.GEOM.MakeValid()) = 1)
```



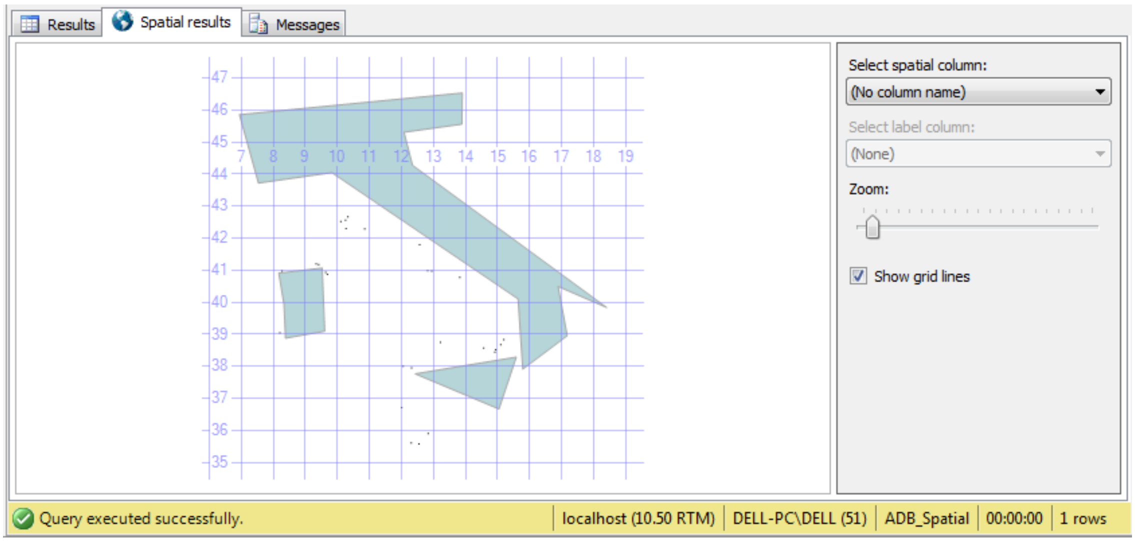
4. Advanced Functions

In this section we will talk about 2 functions that are less common than the ones above but that are useful and can be used in a wide range of areas:

- **Reduce:** this function is used to "reduce" the number of points used to represent a shape. The parameter passed to the function is a floating-point value representing the tolerance (measured in coordinates) of the deviation between the resulting points and the original points of the shape. This can be very useful when we want to decrease the size of our dataset at the expense of losing some accuracy.

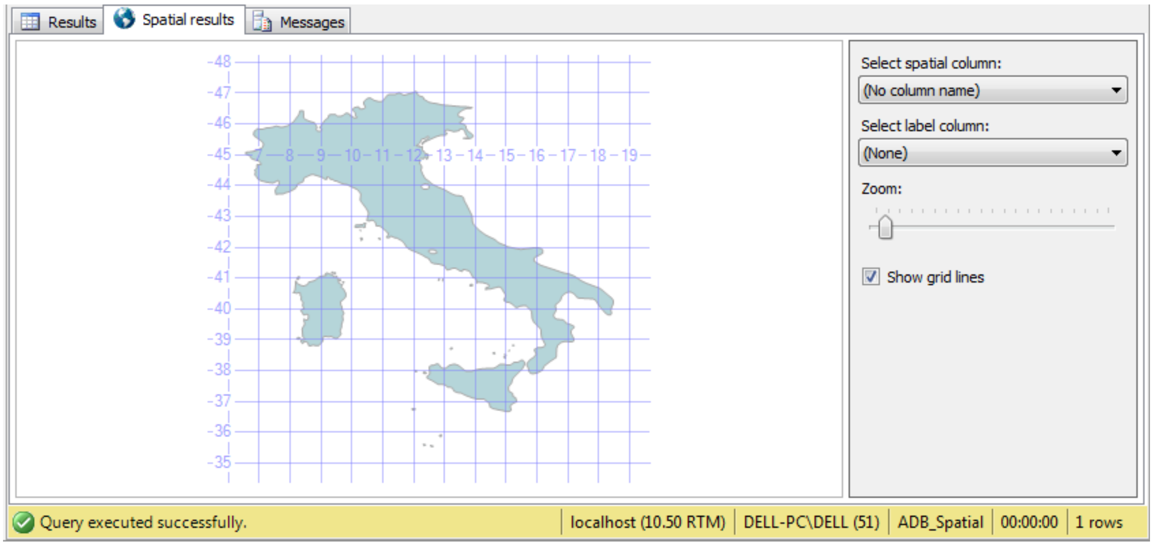
Example: Reduce the map of Italy by a tolerance of 0.75
Query:

```
SELECT WM.GEOM.MakeValid().Reduce(0.75)
FROM WorldMap WM
WHERE WM.NAME = 'Italy'
```



Whereas the original map of Italy is:

```
SELECT WM.GEOM.MakeValid()
FROM WorldMap WM
WHERE WM.NAME = 'Italy'
```



- **STConvexHull:** this function is used to create the Convex Hull of a geometry shape. The Convex Hull is the simplest polygon that contains all of the points of the original shape. This function can be applied to any type of geometry shape and always returns a shape of type Polygon.
  Example: Draw the Bermuda Triangle on the world map by creating the Convex Hull of the three most widely used points to represent the triangle (Miami in Florida, San Juan in Puerto Rico and Bermuda)

Query:

- Get the centroid of the three points:

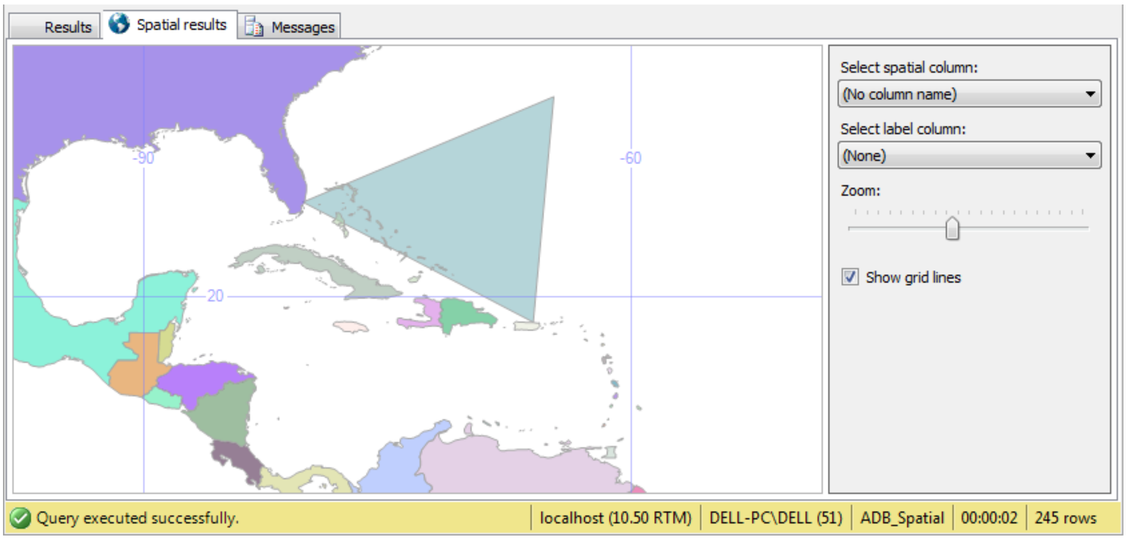
```
DECLARE @SanJuanPoint GEOMETRY;
SELECT @SanJuanPoint = CA.GEOM.MakeValid().STCentroid()
FROM WorldMap WM INNER JOIN CityAreas CA
 ON WM.NAME = 'Puerto Rico'
 AND CA.NAME = 'SAN JUAN'
 AND CA.GEOM.MakeValid().STIntersects(WM.Geom) = 1

DECLARE @BermudaPoint GEOMETRY;
SELECT @BermudaPoint = WM.GEOM.MakeValid().STCentroid()
FROM WorldMap WM
WHERE WM.NAME = 'Bermuda'

DECLARE @MiamiPoint GEOMETRY;
SELECT @MiamiPoint = CA.GEOM.MakeValid().STCentroid()
FROM CityAreas CA
WHERE CA.NAME = 'MIAMI'
```

- Create a MultiPoint geometry containing the above three points:

```
DECLARE @BermudaTrianglePoints GEOMETRY = 'MULTIPOINT EMPTY';;
SET @BermudaTrianglePoints = @BermudaTrianglePoints.STUnion(@SanJuanPoint);
SET @BermudaTrianglePoints = @BermudaTrianglePoints.STUnion(@BermudaPoint);
SET @BermudaTrianglePoints = @BermudaTrianglePoints.STUnion(@MiamiPoint);
```

- Create the Convex Hull of the MultiPoint defined above:

```
(SELECT @BermudaTrianglePoints.STConvexHull())
UNION ALL
(SELECT WM.GEOM
FROM WorldMap WM);
```



Observations

In this section, we will talk about some of the observations / difficulties we faced while dealing with SQL Server 2008 spatial features:

- Visualization Limit

Although SQL Server Management Studio 2008 has native support for visualization of spatial data, it does have a lot of limitations in that area. Namely, we faced the following difficulties:

- We can only visualize one spatial column at a time: this made some simple queries a bit more complex to handle since we cannot display more than one spatial column
- We can only display 5000 spatial objects: we faced this problem when trying to display all the railroads in Germany, which is a fairly simple example compared to most real-world applications

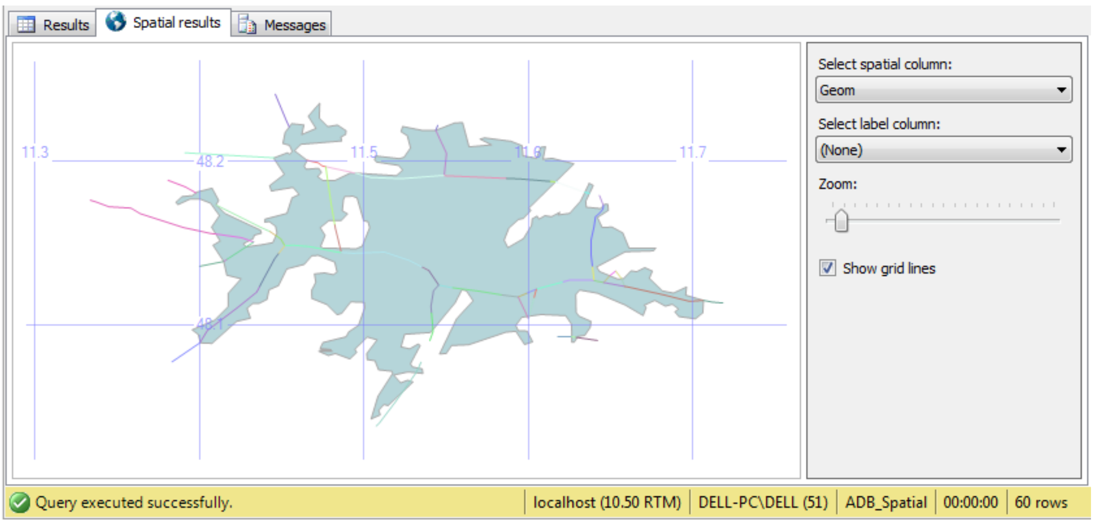
This demonstrated the limitations of the visualization capabilities of SQL Server MS 2008 and hence, we recommend the use of another visualization tool when developing real-world spatial applications

- Filter vs. STIntersects

Earlier in the report, we demonstrated the difference between the functions Filter and STIntersects and the results showed that Filter performs the intersection much faster. However, since Filter only does an approximate intersection test, this might produce erroneous results in some queries such as in the example explained below.

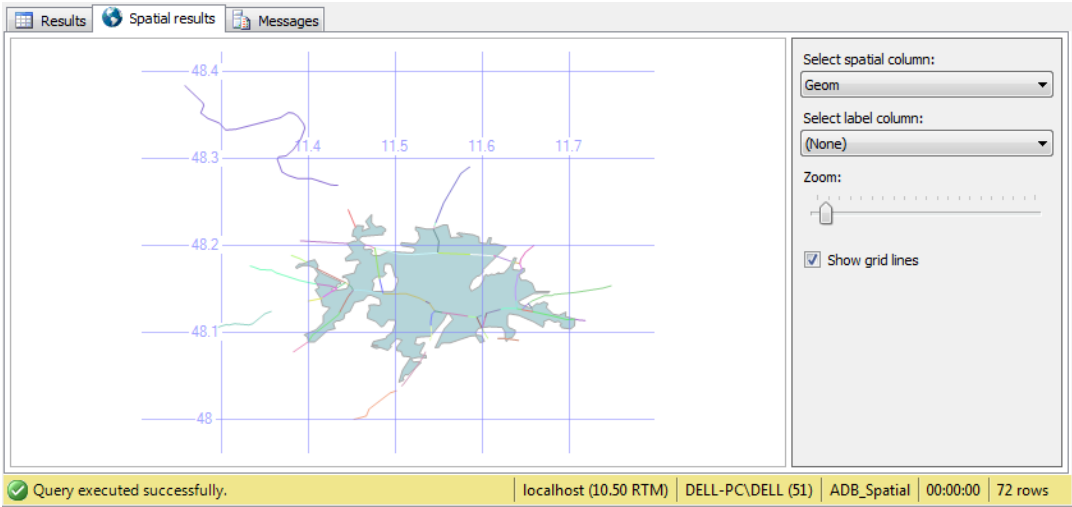
Assume we want to draw a map of all the railroads passing through the city of Munich. Let's first use the STIntersects function as follows:

```
(SELECT CA.Geom
FROM CityAreas CA
WHERE CA.NAME = 'MUNICH')
UNION ALL
(SELECT R.Geom
FROM CityAreas CA, RAILROADS R
WHERE CA.NAME = 'MUNICH'
 AND CA.GEOM.STIntersects(R.GEOM) = 1)
```



Now, notice how executing the same query with Filter gives us different results:

```
(SELECT CA.Geom
FROM CityAreas CA
WHERE CA.NAME = 'MUNICH')
UNION ALL
(SELECT R.Geom
FROM CityAreas CA, RAILROADS R
WHERE CA.NAME = 'MUNICH'
 AND CA.GEOM.Filter(R.GEOM) = 1)
```

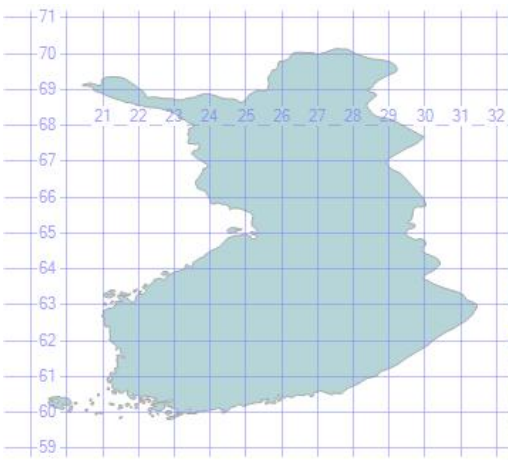


This difference in results is due to the fact that Filter only does approximate intersection test. Hence, one should be careful when using the Filter function because it might give different – usually erroneous – results.

- Projection affects

It is a known fact that projection of 3D objects onto a 2D plane introduces distortion. This was particularly noticeable in our test when trying to draw the map of Finland with the lakes in the country.

We did a small comparison between the two following maps of Finland. The first drawn from our data set using SQL Server 2008 and the other taken from Google Maps:



What seems to be an extreme difference in the shape of the country is merely a difference in the projection type used. This distortion becomes particularly clear near the poles and that is why it is specifically obvious in the map of Finland.

Conclusion

During this project, we have identified the main definitions in the topic of spatial data and explored what SQL Server 2008 has to offer in support of this ever-growing field.

We first explained how spatial data is represented and handled in SQL Server 2008 and then moved to a case study wherein we implemented several queries that demonstrate the spatial capabilities of SQL Server 2008 against a sample data set consisting of 2D projected geometry shapes.

While most of the basic functions would work similarly on the Geography data type, the limited scope of the project meant that the Geography data type could not be explored in more depth.

Regarding the data used in the project, despite its limitations, such as the need to use the MakeValid() function explained in the report, it was comprehensive and varied enough to fit the purpose of this project.

In general, we can say that we have explored spatial data support in SQL Server 2008 to a degree where we can implement a real-world application with ease.

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