GEOMETRIC DATA STRUCTURES AND ANALYSIS IN GIS: ISO 19107 CASE STUDY

A. François [a, *], R. Raffin [a], M. Daniel [a]

[a] Aix-Marseille University, LSIS UMR CNRS 6168, Domaine Universitaire de Saint-Jérôme,
Avenue Escadrille Normandie-Niemen, 13397 MARSEILLE CEDEX 20, France
(axel.francois, romain.raffin, marc.daniel)@lsis.org

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Nowadays Geographic Information Systems (GIS) tend to represent and analyse in three dimensions. It requires new analytical three-dimensional objects in GIS and have been initiated by the industry (databases managers, geomatics, end customers). Seeing this trend emergence, the OGC Consortium has defined a ISO standard to describe two-dimensional and three-dimensional objects. However, the work of the ISO does not allow a description of all objects: an important work remains about the modeling of three-dimensional data and their uses, either in the context of analysis (spatial query) or their modeling in a joint representation. Our goal is to build a computing the library especially allowing to characterize any defects or parts requiring greater development. We present in this paper a solution and a use case to validate a new harmonization method of construction and definition of 2D/3D objects contained in the ISO standard. In order to demonstrate if modeling and analysis operations used by this standard are sufficient, we have established a complete chain of processing containing a mechanism to identify the processing operations used by the analysis. This work is conducted within in a PhD thesis sponsored by the regional council of Provence-Alpes-Côte d'Azur and in collaboration with Geomatys company.

1. INTRODUCTION

The current economic context shows that the representation and the analysis of data in 3D space grow in Geographic Information Systems (aka GIS).

However, we see the emergence of strong demand for 3D analysis in GIS. These developments require standardizations of data structures and exchange, as defended by the Open Geospatial Consortium[1] (OGC) through the 'Geometry / Topology' standard ISO 19107 (ISO TC 211, 2003)[2]. This norm has been published in 2003, and is currently under revision by the Working Group (OGC, 2007) 'Geometry' of OGC to integrate generic parametric curves and surfaces description based on NURBS[3]. We implement the ISO 19107 norm, in collaboration between Geomatys[4] Company and LSIS CNRS 6168 public lab, in the open source framework GeoAPI 3.0[5]. As we based our work on this framework, we will release our code to permit GIS community to use 3D geometries and analysis in their specific business applications.

2. DESCRIPTION OF THE ISO 19107 STANDARD

2.1 General definition

The concept of an object in ISO 19107 is defined by three parts strongly linked. The first two allow a description of objects defined hierarchically according to their spatial dimensions (point, curve, surface, volume) and their topologies (node, edge, face, solid) as CAD industries already use it. Geometric objects have however a third necessary characteristic: they are linked to geo-referencement coordinates (e.g. coordinate references on a sphere, a plane, a geode, ... with vector basis and mathematical projection). Each geometry is related to a CRS (Coordinate Reference System) and an ISO 19107 object using the WGS84/World Mercator (World Geodetic System 1984) CRS is processed differently than the same object using the ETRS89-LAEA (European Terrestrial Reference System 1989 - Lambert Azimuthal Equal Area) CRS, because of different mathematical space properties (distance, dimension). The peculiarity of this standard is to define a single object in many coordinates system, requiring a specific processing mechanism, while CAD objects are described in a global common Euclidean basis. These objects in different CRS must be projected (if available) into a common reference system to allow their analysis or their visualization.

2.2 ISO 19107 in detail

As shown on Figure 1, a geometric object of the ISO 19107 standard is represented by a GM_Object, defining a set of functions, and a hierarchy derived. Thus, the standard defines a hierarchical construction of geometric objects. A GM_Object may be described with different types like:

- GM_Primitive object defines only a single object with its attributes, specific methods and georeferenced position (GM_DirectPosition). There are a 4 primary GM_Primitive (GM_Point, GM_Curve, GM_Surface and GM_Solid) with 31 coordinates objects

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(GM_LineString, GM_Polygon, GM_Bezier, …). We would describe some of them in this paper.

- GM_Aggregate is a set of GM_Primitive, which defines a new object class. For example a GM_Aggregate with a set of GM_Point, GM_Curve and GM_Surface. These objects have no connection between them.
- Complex geometric object (GM_Complex) defines an object in a set of geometric primitives, which share a common coordinate system and parts of their geometries. For example a complex object can be formed by a set of GM_Curve and GM_Surface. It is possible to decompose GM_Complex in a subset of GM_Complex.

Each object has associated functions (distance, centroid, envelope, …) and geometric description. The mathematical methods of these functions may vary, depending on the referencing system used. Moreover, the construction methods and the interpolations used for geometric objects are not described in this standard. They are leaved to the user appreciation or the library execution.

Figure 2. Examples of predicates and operations analysis

3. DECISION MECHANISM

We propose subsequently some changes to the initial publication of 2003, merged with the draft proposed by WG 'Geometry' of OGC.
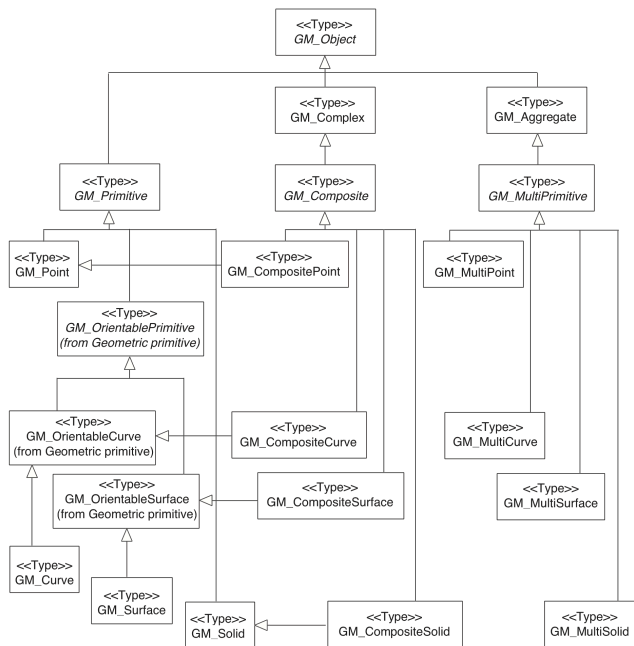

Figure 1. ISO objects hierarchy, starting from GM_Object

2.3 ISO 19107 spatial analysis

As described in Figure 2, the norm also defines spatial analysis operations on geometric objects like 'intersection', 'difference', 'contains'. These operations are described in two groups: 'predicates' and 'operations', depending on their action. Tests done by predicates return logical (i.e. boolean) value as in 'intersect', whereas the 'intersection' operation returns a resulting geometric object. These two groups are complementary as predicates indicate the operation feasibility. There is no analytic (generic) way to process these methods, as their computations depends on the selected reference system.
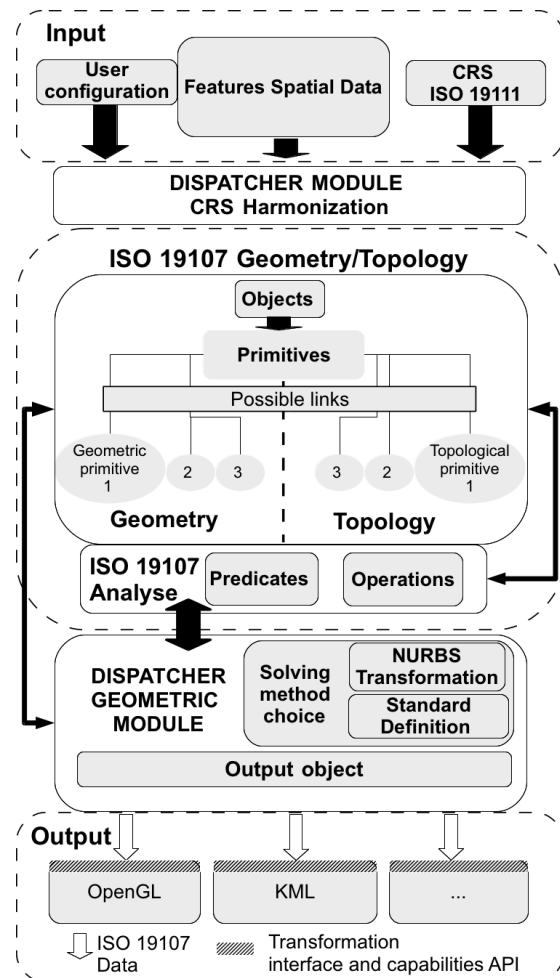

Figure 3. Dispatcher / ISO 19107 interaction

It covers for example generic NURBS (Piegl and Tiller, 1997) curve definition in top of ISO parametric curves (Faux and Pratt, 1979) (Bézier, B-spline, arc), insertion of new objects

'GM_Ellipsoid' or 'GM_Geode', or new methods 'AsTriangles', 'AsPoints' on continuous parametric objects. This work has also consequences on GeoAPI library (point definition, homogeneous coordinates in 3D with are CRS operations, ...). Some advances we present in this paper cover the creation of a computing library, with predicates and functions (as 'union', 'intersection', 'contains', ...) that operate on geometric georeferenced objects.

3.1 Dispatcher in detail (architecture)

Our library works with a module called 'Dispatcher'. Figure 3 describes in detail the different modules contained in the 'Dispatcher' architecture and links between the modules of the ISO 19107 standard. There are three modules (visible as dotted rectangles on the figure):

1. One that formalizes the input data;
2. A module that constructs and processes data;
3. A module that prepares the output data.

The first module is designed to prepare the data for the ISO 19107 part, taking into account the user output specifications and reference of CRS used. The second module is the operating kernel of the architecture: it is composed of the ISO 19107 part, with two sub-modules, 'Geometry/Topology' and 'Analysis', that strongly interact. The last module takes into account the constraints of output interfaces (e.g. OpenGL, Java3D, KML (Reed, 2007), ...), and finally return the processing results, in a description fixed by the uses.
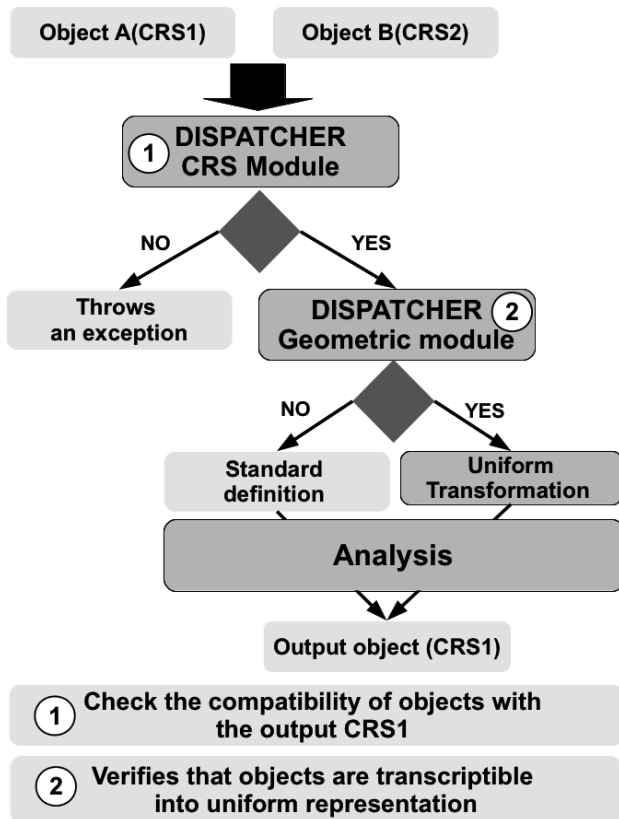

Figure 4. Dispatcher transformation process

As detailed in Figure 4, the 'Dispatcher' module permits:

- To evaluate CRS of each input data versus another, and in conjunction to the desired output CRS (step 1 on the figure). This will define the working CRS for the library, possible operations (space transforms, distances, ...) and the precision bias introduced. This processing part is made with GeoAPI and ISO 'Referencing' (ISO 19111 (ISO TC 211, 2007)) support;
- To choose the geometric transformations to be made on data (a conversion from grid surface to parametric surface patch for example), to facilitate geometric operations (step 2). In a 2D object case, the 'Dispatcher' module can choose to use the well-known 'JTS' library (Davis and Aquino, 2003) while in full 3D, ISO 19107 library would be a better choice;
- To evaluate the processing tree (with dependences of all basic operations), in order to gain in computation time and precision. This part can also proposes the user to stop/pause the process workflow, to obtain rough but fast results. It is useful in a complex dynamic environment (for example: aerial traffic or meteorology model).

The methods of 'Dispatcher' are based on the transformation of continuous models (parametric type curves NURBS, GM_Curve) into discrete models (GM_LineSegment type) on the fly, so as to keep the maximum accurate mathematical representations of objects. The library is also the base of geospatial analysis capabilities of highest level, for example with the complex query: "What are the buildings in the field of emission of this antenna, taking into account the digital elevation model?".
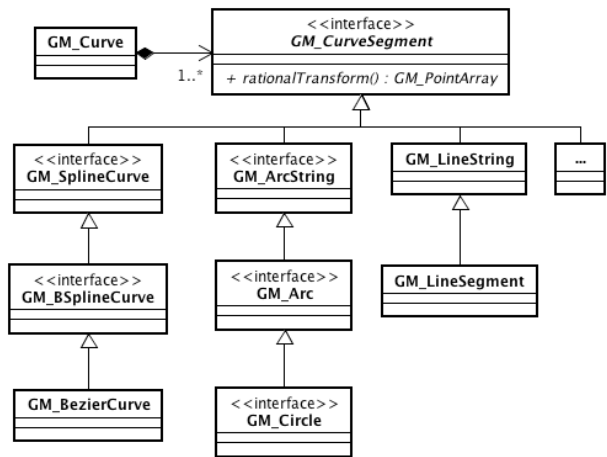

Figure 5. GM_Curve UML diagram example

UML Figure 5 shows the changes made to the ISO 19107 standard for classes inheriting from GM_Curve. The set of children classes (GM_BezierCurve, GM_Arc, GM_Circle, …) contain the information used for harmonization like the knot vector or weights values. We've added a processing method, which is contained in the GM_CurveSegment class. It is capable of returning a DirectPosition array corresponding to the rationalized curve control polygon.

4. UNIFORM REPRESENTATION

The use-case we base our work is a terrestrial geode, with analysis and visualization functions in addition to geometric objects features. First of all, we use the GM_Sphere object of ISO 19107 library. Thereafter this object is transformed in a parametric NURBS object. In order to use a same representation with other objects already harmonized (GM_LineString, GM_Arc, GM_BezierCurve, …) and allow generic analysis operations with any harmonized object. This type of object is rational, so that it allows an exact representation of conic sections unlike Bézier and B-Spline curve (Farin, 2001). Moreover, they can be used independently of the dimensions and allow controlling the curvature with differential calculus. The NURBS surfaces are formed from a tensor product of NURBS curves (Eqs. 1). The control points of the surface defined by a tensor product of two NURBS curves are defined by the following formula:

$$S(u,v) = \frac{\sum_{i=0}^{p}\sum_{j=0}^{q} w_{i,j} \cdot P_{i,j} \cdot N_{i,m}(u) \cdot N_{j,n}(v)}{\sum_{i=0}^{p}\sum_{j=0}^{q} w_{i,j} \cdot N_{i,m}(u) \cdot N_{j,n}(v)} \quad u,v \in [0,1] \quad (1)$$

NURBS are piecewise curves by approximation with control polyhedron $P_{i,j}$, weights $w_{i,j}$ and 'Basic-Spline' functions N defined by $P_{i,j}(u,v)$ along two knots vector T_u and T_v with for each of them $t_0, t_1, ..., n+t_p$ and $t_0, t_1, ..., m+t_q$ where n and m is equal to the number of control points and p is the order. More important the degree of freedom of a surface is, and more its free form feature points out. The role of the 'Dispatcher' is to seamlessly transform any objects before performing the analysis. Thus, it will use the same mathematical model for all objects presented in the ISO 19107 standard, and process through generic methods.

4.1 GM_Sphere ISO 19107

The ISO 19107 sphere object is defined by a simple grid of control points, implying circular paths joining these points. The well-known quadratic equation $ax^2 + by^2 + cz^2 = r^2$ is one of the definitions used by ISO, but expressing the parametrical form of the sphere (Eqs. 2) implies a spherical coordinates system.

$$\begin{cases} x(\theta,\phi) = r\sin\theta\cos\phi \\ y(\theta,\phi) = r\sin\theta\sin\phi \text{ for } \theta \in \left[\frac{-\pi}{2}, \frac{\pi}{2}\right[\text{ and } \phi \in [-\pi,\pi[\\ z(\theta,\phi) = r\cos\theta \end{cases} \quad (2)$$

These mathematical informations are necessary to construct the object, according to the reference system used. This object uses an ISO 19107 GM_GridSurface, which contains all GM_DirectPosition, used for the definition of circular arcs of three points, which describe a set of GM_Circle and GM_Arc (see Figure 6).
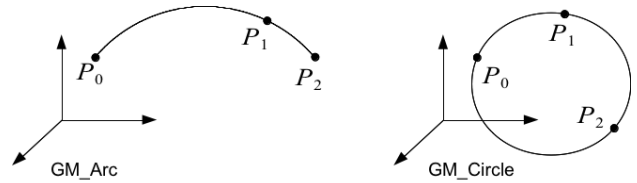

Figure 6. GM_Arc and GM_Circle examples

4.2 Rational GM_Sphere

We present now the classical geometric transformation method in rational GM_Sphere. As we have seen in section 4 for the NURBS surface represented the GM_Sphere, each curve u and v must be defined. For this, we can use a NURBS curve with 9 control points already used for the definition of GM_Circle. As shown in Figure 7 the control polyhedron using 4 ISO-Curve (equals has GM_Circle). For our example, we use 9 ISO-curve to have a square matrix 9×9.
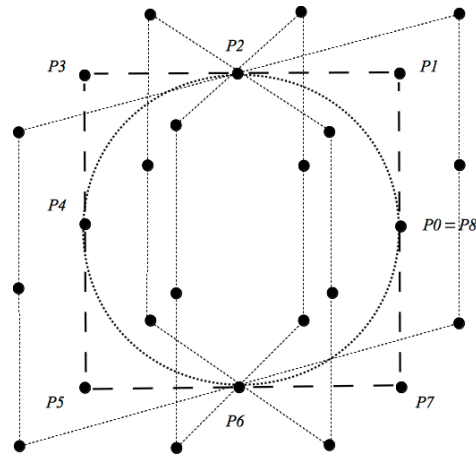

Figure 7. GM_Sphere control polyhedron example

As shown on Figure 8 by definition of ISO-curve, each P_i is determined by reference to GM_DirectPosition representing the centre of GM_Circle. They are then distributed according to cardinal points. The distribution is given for nodal vector by $T = t_0, t_1, ..., t_p$ and for weights by w_i for each P_i. Each weight is obtained by $w_i = \|\cos(\theta)\|$ where θ is an angle equal to half the angular extent of the desired arc. However, we have weights for the diagonal circles that are contained in different circles in the planes (x,y), (z,y) and (z,x). If the T vector has a multiplicity equals to the order 3 (degree + 1) at its beginning and at its end (insuring interpolation), the curve passes through the end points (i.e. P_0 and P_8).
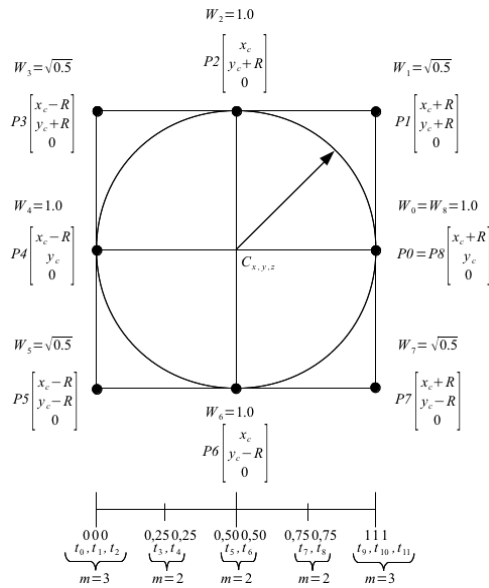
Figure 8. Representation of a ISO curve used for GM_Sphere
(9 control points, 12 knots and multiplicity)

Now the Earth geoid can be represented by a GM_Sphere using two types of definition. The advantage of this last formulation that allows a representation identical to the objects already defined as GM_BezierCurve, GM_BSplineCurve, or GM_Arc and GM_Circle which were presented in (François and al., 2010). Therefore we use the same method of analysis between all the objects in this standard.

5. FIRST RESULTS

Our primary approach to ISO 19107 implementation was to enrich our library with objects even more complex. To demonstrate geometric objects description, we model the terrestrial globe with a sphere object (GM_Sphere) as defined in the ISO 19107 standard. Afterwards, we make it generic with a NURBS surface.

5.1 Earth render representation

Once the NURBS sphere defined, the results thus obtained are then sent to a 3D engine based on the widely used OpenGL[6] API: Ardor3D[7], which is practical to handle 3D context events and objects visualization.
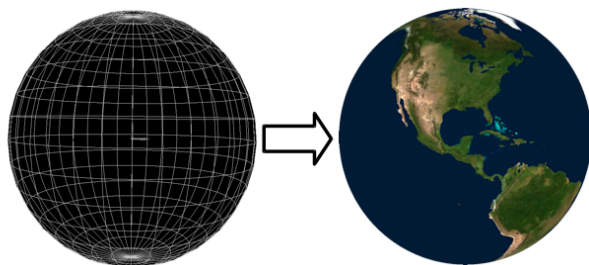

Figure 9. NURBS Earth representation

Figure 9 shows a GM_Sphere using a NURBS parametric representation textured with NASA[8] 'Blue Marble' coverage. As NURBS is continuous, each georeferenced point on the surface can be computed.
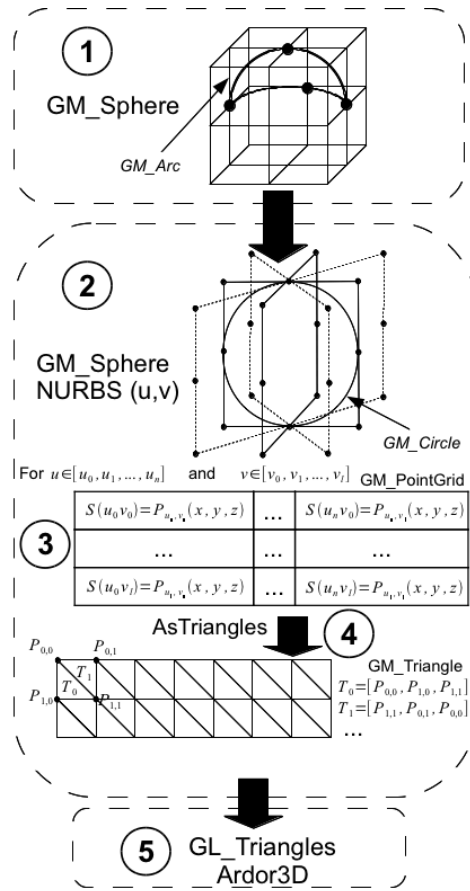

Figure 10. Earth ISO transformation

The mechanism of transformation is detailed on Figure 10. It is divided into five steps.

1) The first step constructs GM_Sphere object with a set of GM_Arc using arc 3 points interpolation;
2) The GM_Sphere is translated into rational NURBS surface using a set of GM_Circle as ISO-Curve;
3) The set of points that composes the NURBS surface is contained in an object GM_PointGrid;
4) GM_PointGrid is translated into a GM_Triangle list with our new method 'AsTriangles';
5) The last step translates ISO 19107 triangles into Ardor3D triangles.

5.2 Demo analysis

At first, we gave the opportunity for the application to display and use a 'shape' file (representing geopolitical boundaries). We have developed a conversion tool SHP / ISO19107. It takes care of all the transformed primitive geometric objects in ISO 19107 (see Figure 11). These data are then available for the 'Dispatcher'.
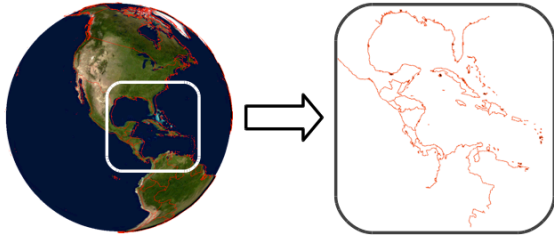

Figure 11. Shape file on the NURBS Earth

The following Figure 12 shows an analysis operation between the transportation networks of North America (green) and borderland (red). It is thus possible to find all intersections between these two types of geometry. These objects are defined with GM_MultiCurve for the first and GM_MultiSurface for the second.
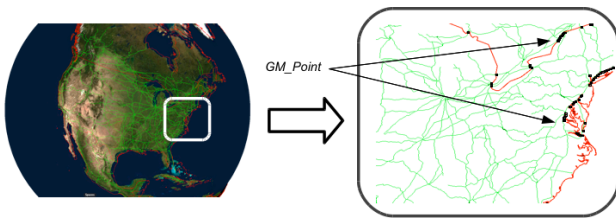

Figure 12. Intersection example between GM_MultiCurve/GM_MultiSurface

Each 'shape' layer contains an aggregate, composed of a set of primitives GM_Curve for the first and GM_Surface for the second. Analysis module 'Dispatcher' decomposes each of these elements and analyzes them using with the 'Intersection' function.

6. CONCLUSION AND FUTURE WORKS

Future versions will use a better approximation of the Earth surface represented with an ellipsoid. This type of object is not present in the standard, we will create another object infrastructure. Afterwards, we wanted to give a more accurate representation of terrestrial globe with the use of primitive 'Solid'. It allows us to represent the Earth geode, to store and display geologic data, and conduct spatial analysis between 3D objects. It can also be applied in the case of a 3D visualization of space and trajectories of an aerial traffic. Each object in the scene uses a primitive contained in the ISO 19107 standard: aircraft trajectories are represented with parametric curves (GM_BSplineCurve) and airspace limits by solids (in with a plane can be 'interior' of GM_Solid). Another example would be to represent and analyze a meteorological model where different layers of wind vector objects are represented by ISO 19107. Then, we perform the analysis using methods of the 'Dispatcher' module. Currently, all analysis methods are performed by projection in a Euclidean space.

Finally, we present results on our virtual globe, ISO 19107 based, with some geometric objects (geo-referenced, multi-source) and spatial analysis.

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