

2D/3D topology in a GIS: model of multilevel road network

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Abstract: Representation of environmental reality in computer systems for action, management and decision requires the most realistic modeling possible entities constituting the landscape. However one of the problems encountered in 2D GI is the inability to model these entities according to their three-dimensional representation. In this context, we are interested in this work to the topological model of multilevel roads and we proposed a 2D/3D model to integrate in a GIS and facilitate the analysis of queries in car navigation.

Key Words: 3D Model, Topology, Road Network.

1. Introduction

The three-dimensional GIS, have expanded in recent years [1], [2], [3]. In many fields, new opportunities for 3D GIS or multi-dimensional applications have been defined, as in geology, urban planning etc.. [4], [5], [6]. All these disciplines have long looked for tools to analyze and manage data as near as possible of the reality, in 3D space.

However, the methods of 3D modeling used successfully in the environment of computer-aided design (CAD), do not respond or respond poorly to the needs of GIS. This is due to the specifics of these (more oriented towards the analysis, editing possibilities, topology ...), hence the need to develop appropriate models for administering 3D objects in a GIS.

Several models have been proposed for 3D modeling [1], [3]. Each of these models involves construction techniques and special storage [7].

In this context, our contribution focuses on the proposal of a 3D topological model that can be used in many types of network structure with multiple layers. In our case we use the road network as an application.

2. Proposed 3d model

The model we propose has the distinction of being well adapted to the road network characteristics [7], in addition it requires little investment since it is an extension of an existing 2D model.

3. Principale

The road network is composed by a road set where each road is composed by a set of road segments (called arcs) that may be different types (bridges, interchanges, tunnels ...).

Road sections can intersect thus forming intersections (called nodes). These intersections can be real, as they may be virtual when it comes to an intersection between sections of different levels (intersection between a bridge and a road that goes below). In a 2D topological model, this type of intersection is accounted even if it is not real.

In passing to the third dimension, this type of intersection, "in the air" should not exist, yet it gives us information about the topology (a section is below the other).

In order to take into consideration these characteristics, we have introduced the concept of level to nodes and arcs. In the 2D model, we add a level attribute to Arc and Node elements. Adding this information makes it look 3D data.

3.1 Arc Level

The assignment of level to arcs is done manually as follows (Figure 1):

- 1- The arcs who are on the surface of sol (earth) always take the Level 0.
- 2- The arcs who are totally above ground take peers values (2, 4, 6, ...). For arcs in underground we take negative values (-2, -4, ...)
- 3- The arcs that link the intermediate arcs with peers levels take the intermediate odd value (1, 3, 5, ...). An illustration of the arcs levels is given in Figure 1. The choice of segments during the vectorization is quite important for to have consistent results.

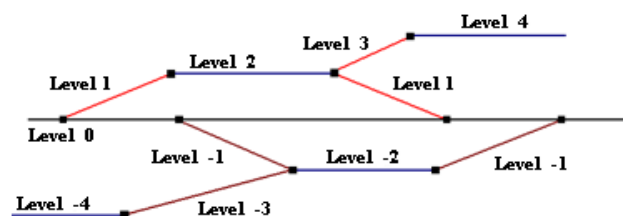


Fig. 1 Arcs levels assignment

3.2 Node Level

The node level assignment result in an automatic way: each node is necessarily end of a pair arc level, the same level is assigned to the node concerned.

The assignment of levels to the nodes and arcs eliminates unnecessary nodes (virtual intersection). Then having the

altitudes nodes of non-zero levels, we can calculate the altitude of the different points constituting the arcs which allows having a 3D view of the network.

Following the changes we have introduced, we give below (Figure 2) the class diagram of the 3D model.

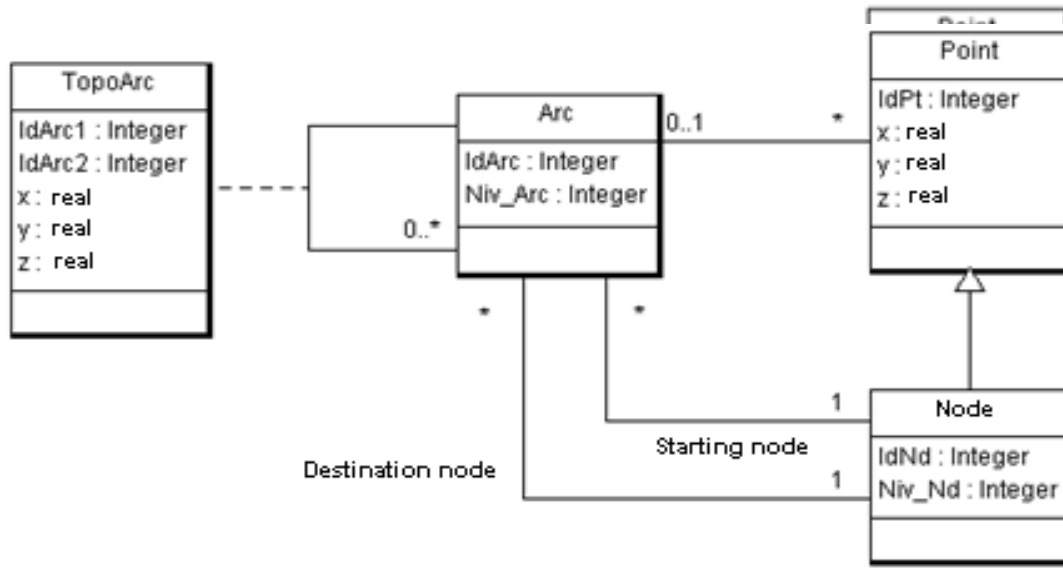


Fig. 2 Class diagram of the 3D topological model.

3.3 Transition from 2D to 3D model

Among the problems encountered after the 3D modeling, is the data acquisition. Indeed, it is interesting to develop 3D models that use existing 2D data and move to 3D with the least cost [8]. The advantage of the model we propose

is that from an existing 2D model, we can generate a 3D model with few investments. The following figure (Figure 3) shows the steps to move from the 2D model (spaghetti) to the 3D model (topological).



Fig. 3 Transition from 2D model to 3D model.

Step 1: Arcs levels assignment

From a 2D model (vector layer in spaghetti), we assign different levels to arcs based on the principle described above.

Step 2: Generation of 2D topological model

This is an automatic step which consists to generate topological relationships between points and arcs. The result of this step is the decomposition of certain arcs at the intersection points (real or virtual), and a set of Nodes.

Step 3: 2D to 3D treatment

This is an automatic step to complete the model by the 3D informations (altitude and topology). This step passes through the following phases:

- Assigning levels to nodes

Assigning levels to nodes is done following the principle described above.

Algorithm

For each Even Level Arc

Do

$Orig_Node.Nd_Level := Arc.Arc_Level;$

$Dest_Node.Nd_Level := Arc.Arc_Level;$

Done;

- **Elimination of virtual intersections and update the topology**

A virtual intersection is an intersection between two arcs of different levels. Its elimination is to cancel the intersection and link arcs decomposed by this intersection during the generation of the topological model. To maintain topology, we save the concerned arcs and the point intersection.

Algorithm

```

For each Node
Do
Select all Arcs having current node as extremity;
For each pair of Arcs
Do
    Calculate the Level Difference (LD)
    If LD > 1
    Then /*Update topology
        Save the point ;
        Save the 2 Arcs (Low Level, High Level);
        Eliminate Intersection;
        Link decomposed Arcs;
    EndIf;
Done;
Done;

```

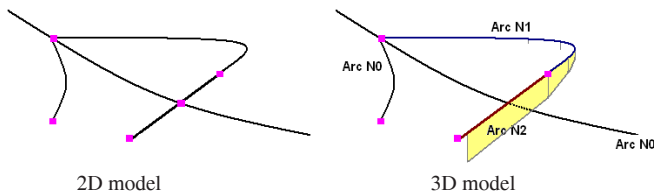


Fig. 4 2D Topological Model and the 3D Model Proposed.

- Assignment of altitudes at different points For the automatic assignment of elevations at different points, we set the following hypothesis: « Arcs of non-zero level (other than arcs located on the soil) have a constant slope».
- For elevations of the different nodes, they can be resulting from different techniques of georeferencing.
- The heights of points belonging to the arcs of level 0 (soil) are acquired directly from the DEM.
- For the altitudes of the remaining points: on the basis of the assumption made, the calculation of elevations of the intermediate points which constitute the arc is as follows (Figure 5) :

Algorithm

```

For each Arc
Do

$$H := |Z_{Orig\_Node} - Z_{Des\_Node}| ;$$

For each Point of Arc
Do

$$Z_p := \frac{(X_p - X_{Orig\_Node})H}{X_{Dest\_Node} - X_{Orig\_Node}}$$

Done ;
Done ;

```

where H is the height between the start node and destination node.

L_i and L represent the distance between the starting node and the orthogonal projections of points respectively the orthogonal projection of final node along the same plane.

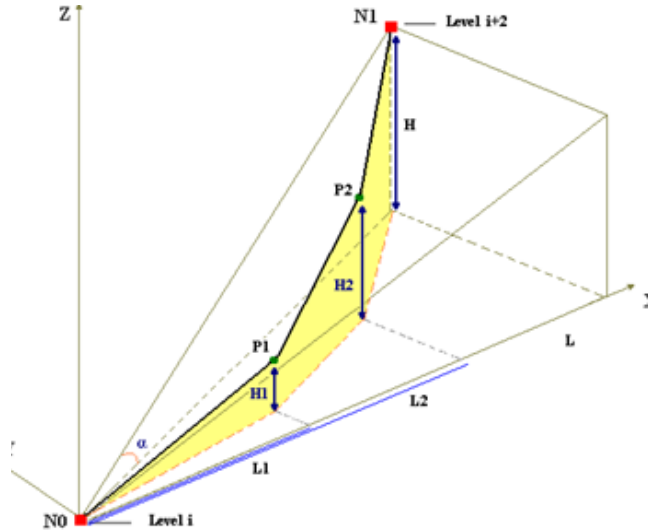


Fig. 5 Assignment of altitudes at different points.

4. Application

The basic data of our system must be a 2D vector layer on which we will execute the process of transition from 2D to 3D model. Unfortunately, the lack of data is always a problem in this kind of application. For this, we have created our own data; in fact we made raster images from Google Earth of the area between the airport and the port of Algiers. After a georeferencing operation using the ENVI software, we have vectorized the road network layer using MapInfo, the result was a vector layer in spaghetti mode. In order to generate topological relationships between points, arcs, we have exploited the 'universal translator' of MapInfo to convert a file into a topological ESRI shape file Arcinfo (E00) of ArcGIS.

The assignment of the different altitudes points is a semi-automatic operation, in fact, as a first step we introduce altitudes of nodes with non-zero level. This set of nodes is generally quite small compared to the number of network nodes. Due to lack of material (GPS), we assigned a default height of 4.5 m per level.

We have implemented the model in the ArcGIS environment. For validation, we have tested it for calculating the shortest path between two points of the road network of a portion of the east of Algiers (Algeria) (Figure 6).

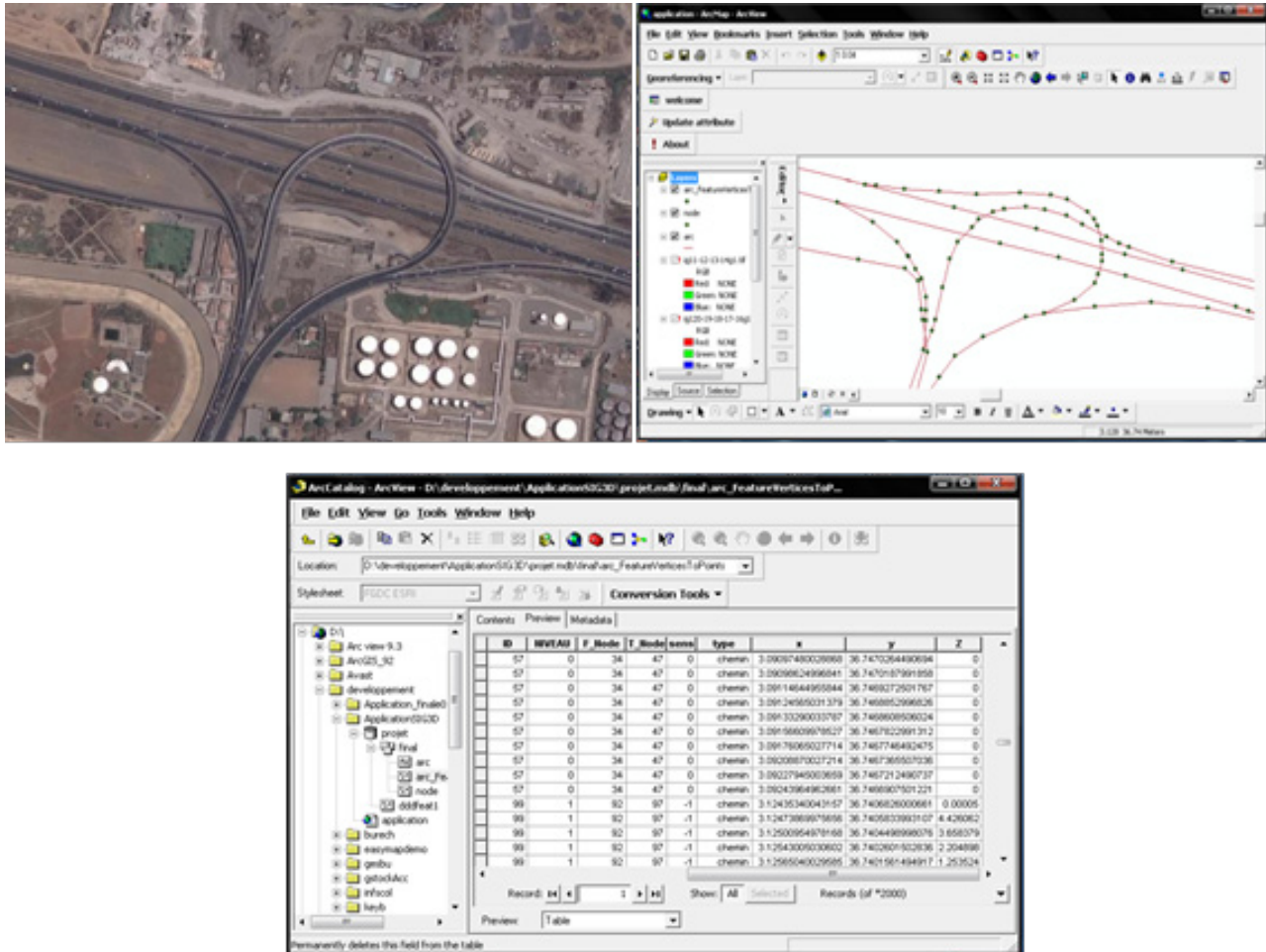


Fig. 6 Application results.

5. Conclusion

The model we have proposed allows moving from an existing 2D representation to a 3D representation by introducing the level concept to the nodes and arcs. This information allows us to eliminate the virtual intersections and calculate the altitudes of different points by having only the altitude of nodes in non-zero level. The points belonging to arcs of levels 0 come from the DEM. When we eliminate virtual intersection, we update a topology table by saving topologic relationship between arcs (Arc1 Is Under Arc2) and the altitude of the virtual intersection point which allows us to manage such constraint in any application.

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