3DArcLens: Interactive Network Analysis on Geographic Surfaces

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Abstract: Geographic datasets such as international telecommunications traffic, financial flows, trading patterns, and national migration patterns describe the movement of entities between geographical locations. In spatial relations analyses the exact route of the connections is not important. Hence, one of the most preferred methods for its depiction is a graph representation with data nodes layered over a geographical surface (such as a flat map or a virtual globe). However, a large number of arcs can produce dense visual clutters that make difficult the extraction of information from: occluded geographical surfaces, occluded nodes and occluded arcs. In this work we present a novel focus+context technique for 3D virtual environments that interactively distorts and filters arcs layouts, revealing underneath information about the three aforementioned visual elements: nodes, arcs and geographical surface. Moreover, changing the camera does not affect the geographical focus of the lens. In our use cases, we observed that such technique is an advantage for tasks that include the exploration of geographical networks.

1 INTRODUCTION

A huge amount of geographical data is available nowadays. Many of these datasets describe the movement of entities from geographical locations, represented in form of origin-destination data. In such data representation only the origin, the destination and magnitude of the flows are known. Examples of such datasets are international telecommunications traffic, financial flows, trading patterns, and national migration patterns (Tobler, 1987). Representations based on geographical maps can be useful to the study of these datasets, e.g. allow users to reason about geographic patterns of the movement. In such case a node-link structure is used to represent the information over a flat map or over a virtual globe. In such context the exact route of the connections is not important, hence links are represented as straight lines, arcs, or even curves drawn in 2D or 3D virtual environment.

According to the first law of Geography, "Everything is related to everything else, but near things are more related than distant things" (Tobler, 1970) the perception of the distance between the origin and destination of a flow is extremely important. Therefore, the use of flat map representations is not recommended if the dataset covers the entire world, e.g. with the Mercator projection, nodes located in opposite sides of a map appear very far, but in the real world the physical distance is shorter. Also, flat maps can also increase the clutter problem, e.g. links that connect nodes placed in North America with others placed in the Asia stretch across the entire map, occluding the network in Europe. Representing the Earth as a virtual globe overcomes this limitation because distances are true to scale and the length of the link (represented as a three-dimensional arc) that connects the two points is proportional to the shortest distance between them. The main limitation of 3D globes when compared to 2D maps is that only one hemisphere is visible at a time. A technique that works on a 3D space and that is not affected by the aforementioned occlusion problem is *ArcMap* (Cox et al., 1996). It is a geographic visualization that uses a two-dimensional representation of the Earth combined with three-dimensional arcs that connect the nodes.

In both, virtual globe and *ArcMap*, the depiction of considerable amount of links over an area often causes visual clutter, either on the nodes and arcs that are not visible or on the layered geographical map (Figure 1). The latter is particular important due to the geographical information encoded into the dataset. For example, if the dataset to be analyzed describes tourist flows then it can be relevant to visualize the layered map that contains the major touristic attractions in the world.

Although the user can move, pan, tilt and zoom

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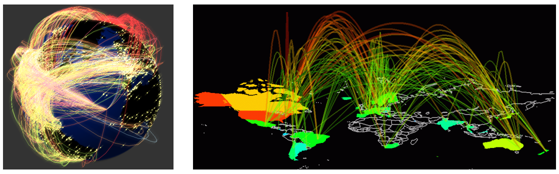


(a) (b)

Figure 1: (a) Visual clutter in a virtual globe with arcs. (b) Visual clutter in a flat map with arcs. This visualization shows Internet traffic flows between countries.

the camera, in some situations this in not enough to reveal the hidden information. In addition, the required time to compute these interactions might not be acceptable and performing the operations in 3D space can be disorienting for the user (Kaur et al., 1999). Since the nodes encode geographical information, techniques that rearrange node positions, such as graph layout approaches are not recommended.

In this paper, we introduce a novel focus+context technique called *3DArcLens* that interactively reduces the occlusion problem without removing links or moving nodes. We define a lens technique that acts on the arcs depending on their position and incident nodes. For example, if the interactive lens intersects only with the arc and not with its incident nodes, then the arc is replaced with an aesthetically pleasing curve placed around the lens to be easily traced. If the arc has an incident node inside the lens, the node is visualized as a sphere with an unique color, meanwhile the segment inside the lens is not drawn and the rest is colored accordingly with the node's color. Due to the fact that the arcs that depict origin-destination data do not represent a real route, changing their shape or not drawing a part of them does not affect the information they represent. Combined, these two methods allow the visualization of elements inside the lens (map, nodes and arcs) to be clutter free. This interactive lens is specifically designed to support the identification of elements of geographical networks as well as the exploration of the layered map with 3D view preserving the geographic context such as the virtual globe and the *ArcMap*.

This paper is structured as follows. Section 2 describes the related work. Section 3 introduces the arc congestion problem. Section 4 describes our theoretical framework. In the Section 5 a comparison with similar techniques is made, and a discussion on the limitation of the proposed technique is done. We conclude with some remarks about the usability of the technique in Section 6.

2 RELATED WORK

This section provides a brief overview of interactive techniques for reducing the visual clutter in graph drawing domain and in 3D space.

Interactive Techniques for Clutter Reduction in Graph Drawing Domain. An approach to reduce visual clutter in graph layouts is through content filters (Wong and Carpendale, 2007). The downside of this approach is that we also lose information about purged or less relevant edges (Furnas, 1986). Becker (Becker et al., 1995) suggested an alternative that does not required purging data. The idea is to draw the arcs only half the way to their target. However, this approach requires more cognitive effort to track or find the edges destination.

Edge aggregation (i.e. *edge bundling*) is a well adopted technique that became popular in the last ten years. Holten et al. (Holten and Van Wijk, 2009) presented a force-directed algorithm in which edges are modeled as flexible springs that can attract each other while node positions remain fixed. A force-directed algorithm (Debiasi et al., 2014) is used for the automatic generation of flow maps where flows are aggregated together and the magnitude of each flow is represented by the thickness of the lines. Cui et al. (Cui et al., 2008) describes a mesh-based edge clustering method for graphs. Additional works on edge bundling are described in the survey by Zhou et al. (Zhou et al., 2013). The peculiarity of the edge bundling is that it is used to understand the overall patterns but not the single links of the graph because the connections become harder to read.

Wong et al. (Wong et al., 2003) proposed *Edge-Lens*; a technique that iteratively curves graph edges away from the point of focus. This consents to disambiguate the relationship between nodes and edges without losing information. Bearing this in mind, Schmidt et al. (Schmidt et al., 2010) used a multi-touch interaction in conjunction with some edge displacement techniques. Tominski et al. proposed to draw in a local focus region only the edges that connect certain vertices within the lens scope (Tominski et al., 2006).

Pietriga et al. (Pietriga and Appert, 2008) presented *Sigma Lenses*, a set of interactive lenses that replaces standard optical distortions with dynamic translucence to transition between focus and context areas. Another strategy presented to reduce the clutter problem is to apply a unique color to paths of interest that differentiates from background clutters (Moscovich et al., 2009). *Link Sliding* (Moscovich et al., 2009) allows users to slide a link-cursor along the edge towards the destination node. To explore crowded areas (overlapping bundles), semantic lenses can be used. *MoleView* (Hurter et al., 2011) is a semantic lens that selects a set of data elements falling within the lens position and having an attribute value defined by the user. In case of graph layout the lens moves the control points that compose the links around the lens.

Interactive Techniques for Clutter Reduction in 3D Space. Different approaches were used together with extra interactions, such as panning and tilting to reduce the visual clutter where the 3D virtual environment is projected in a 2D display. Viewpoint dependent distortion of 3D data (Sheelagh et al., 1996) highlights regions of interest by dedicating more space to them. Viega et al. (Viega et al., 1996) introduced the *3D Lens*, which is a Magic Lens with a volume, that affects objects contained within it. Bell et al. (Bell et al., 2001) introduced Toolglass and Magic Lenses as a see-through interface to modify the visual appearance of application objects, enhance data of interest or suppress distracting information. McGuffin et al. (McGuffin et al., 2003) explored an alternate strategy that uses deformations, where the user can cut into and open up parts of the volume in real time, making the interior visible while still retaining surrounding context. In contrast, the Balloon-Probe (Elmqvist and Tudoreanu, 2007) provides an inflatable force field controlled by the user that can be used in areas of locally high object congestion. Although these techniques try to solve the clutter problem in the 3D space, none of them are specifically designed for the arc congestion problem over geographic surface.

A recent trend in 3D virtual environments made use of properties like transparency to expose hidden content. Looser et al. (Looser et al., 2004) described a 3D magic lens implementation for Augmented Reality that supports information filtering using the stencil buffer, allowing the user to see through a house. Coffin and Höllerer (Coffin and Hollerer, 2006) presented a similar technique with active interaction where the user controls a volume that is dynamically subtracted from the surrounding world geometry, again using the stencil buffer. Elmqvist et al. (Elmqvist et al., 2007) presented a technique that uses dynamic transparency for managing occlusion of important target objects in 3D visualization applications. In these techniques the focus is clearly highlighted but due to the transparency effect, part of the context is lost.

3 ARC CONGESTIONS OVER A GEOGRAPHIC SURFACE

The problem addressed by this work falls into the category of ”occlusion problems in 3D visualization” where the camera view, the environment itself and its geometrical properties cause occlusion of objects. In this particular scenario the problem is called ”arc congestion over a geographic surface”, i.e. it describes the situation where a large numbers of three-dimensional arcs occlude the nodes and their incident arcs depicted over a geometric surface.

Formally, there is a 3D space U defined by a Cartesian space $(x,y,z) \in \mathbb{R}^3$. A geographic surface S is the surface of a volume V within U (i.e., subset of U). The volume V can be a virtual globe or a flat plane just to mention the more popular examples. Nodes in the set N are points located over S. A 3D-arc a is composed by a sequence of points $p_1, p_2, ..., p_n \in U$ such that the first and the last points represent nodes (i.e. $p_1, p_n \in N$). Let S' be the *area of interest* over S (i.e. $S' \subset S$), N' contains the *nodes of interest* such that are inside S'. A line segment r is *blocked* by an object o if it intersects o. An arc a *occludes* S' if exists a line segment r between the viewpoint position v and S' such that r is *blocked* by a.

The arcs are classified, as shown in Figure 2, in the following way:

- the *arcs of interest* are the ones with one endpoint in N'.
- the *arcs of high interest* are the ones with both endpoints in N'.
- the *undesired arcs* are the arcs that *occlude* S' that are not *arcs of interest* neither *arcs of high interest*.
- the *context arcs* are the arcs in background (i.e. the arcs in the context).

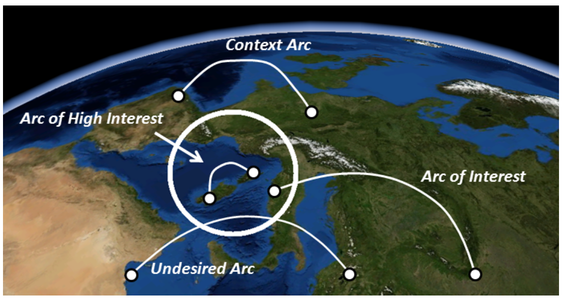
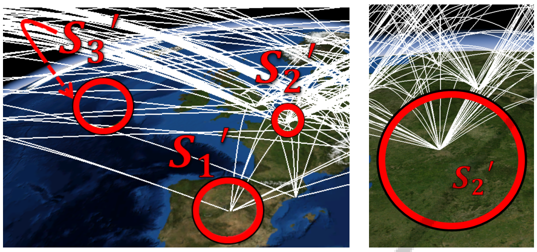


Figure 2: The arcs are classified accordingly with their relations with the area of interest.

The area S' is defined as:

- *not visible* if there exists at least one line segment r between v and S' such that r is *blocked* by V.
- *visible* if there are no line segment r between v and S' such that r is *blocked* by V.
- *fully visible* if it is *visible* and there are no *undesired arcs*.



(a) (b)

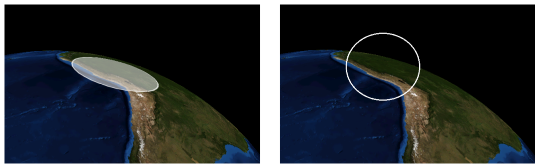
Figure 3: Arc congestion over a geographic surface. (a) *fully visible* area (S'_1), *visible* area (S'_2) that is partially hidden by *undesired arcs* and *not visible* area (S'_3) occluded by the globe. (b) After moving the camera the area S'_2 becomes *fully visible*.

Figure 3 shows examples of arc congestion over a geographic surface. There are three *area of interests* S'_1,S'_2, and S'_3 identified by a colored circle. In Figure 3(a), S'_1 is *fully visible*, it is possible to see the nodes inside the area and their connected arcs. S'_2 is *visible*, in fact some arcs occlude a part of its area, thus also some nodes inside. Figure 3(b) shows the same area S'_2 but from a different camera view v, in this case S'_2 is *fully visible*. S'_3 is placed in the hidden hemisphere so it is *not visible*, i.e. hidden by the globe.

This paper proposes a solution to the following question: How can we reduce the arc congestion in a given area, revealing information about the nodes, the arcs and the geographic surface independently from the camera view?

This question is formalized by the definition of the following requirements, which the desired solution has to satisfy:

1. No arc or node is removed from the scene to preserve all the information related to the visible elements of the network.
2. Nodes are not moved due to the importance of their geographical location.
3. The surface S must not be deformed due to the importance of its geographical context.
4. The hidden information on the *visible* area S' must be revealed, in particular about the following visual primitives, listed by importance in descending order: (a) The location of the nodes in N'. (b) The *arcs of high interest*. (c) The *arcs of interest*. (d) The map layered on S'. (e) The *undesired arcs*, although they cause the clutter, they may encode useful information to the viewer. (f) The *context arcs*.
5. A *visible* selected S' must be *fully visible* without the need to change the viewpoint v.
6. After selecting an *area of interest*, the solution must work also if the camera view is changed. Let S' the *visible* selected area for a set of viewpoints V, S' must be always *fully visible*.



(a) (b)

Figure 4: (a) The lens is represented as a circle over the globe, hence the lens' shape is not distortion-free. (b) Our adopted approach: the lens is a circle in 2D screen space.

4 PROPOSED APPROACH

As mentioned in Section 1, our goal is to facilitate the exploration of both geographical network and layered map with 3D view when arc congestion situations occur. Our proposed technique uses a lens metaphor that is defined by a given point of focus and a radius.

The lens can be represented as a circle that follows the terrain. Therefore, its shape is not distortion-free. As shown in Figure 4(a), if the camera is tilted the area of the lens becomes oval. For this reason we opted to represent the lens as a circle in screen space with the radius r in pixels. Hence, the camera movement does not affect the lens' shape (Figure 4(b)) and the zoom interaction does not change the lens radius. Up to now we refer to S' as the *area of interest* that is covered by the lens.

As shown in Figure 5, the lens works in the following way: the *undesired arcs* are distorted in a way that they do not pass though the surface of the globe covered by the lens (i.e. S'). The distortion is applied not only to the subsegments affected by the lens, but also to the entire curve making arcs easier to trace. In fact the arcs are depicted as splines composed by a sequence of control points. The arc congestion can be also affected by *arcs of interest*, thus their subsegments inside the lens are filtered out from the visualization. This strategy permits to clearly identify the nodes inside the lens and the *arcs of high interest*. What is important to know about each arc is not its

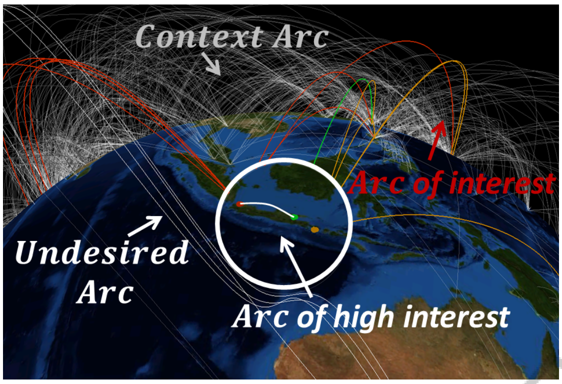
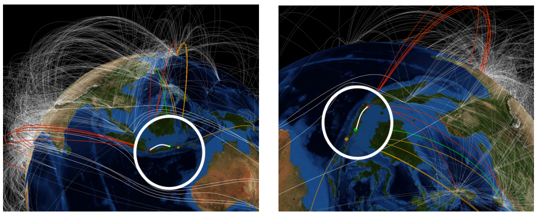


Figure 5: Each class of arcs is represented in a different way. *Context arcs* are drawn with transparency, *undesired arcs* are deformed, *arcs of interest* are colored differently and parts of them are filtered out, and *arcs of high interest* are white colored.

shape but which are the incident nodes. Bearing this in mind, each *node of interest* is represented as a colored sphere and each *arc of interest* is colored with the same color of its incident node inside the lens. *Nodes of interest* are therefore easily identified together with their incidents arcs. Moreover, the surrounding map is also revealed (requirement 4). If the user navigate, tilt or pan the camera (i.e v changes) the lens still reveal hidden information of S' previously covered by the lens (i.e. S' remains *fully visible* thus the requirement 6 is satisfied). In fact its movement is snapped to the terrain to improve the system usability; the camera movement affects the lens position in screen coordinates but not its geographical position, (Figure 6).

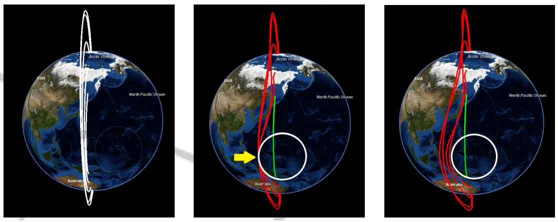


(a) (b)

Figure 6: Navigation and panning using the lens to highlight the edges and the nodes over a given location. The latter is always focused from different camera view.

Moreover, the effect of the lens is transient, i.e. the deformed arcs return to their original shape when not marked as *undesired arcs*. If the user detects an area that requires further investigation and that is cluttered by arcs (i.e., S' is *visible* but not *fully visible*), then without moving the camera (i.e. v does not change), he/she can drag the lens to that geo-location to reveal the hidden information (i.e. S' becomes *fully visible* thus the requirement 5 is satisfied).

It might happen that arcs might share a common space from a given perspective, as depicted in Figure 7(a). Hence, that arcs are shifted to the border of the lens and because of its intersection (yellow arrow on Figure 7(b)) the two sides of the arcs can no longer be traced. Although this drawback can be solved by applying different color for each arc, we instead decided to update the arcs's distance to the lens circumference based on its distance to the point of focus (see Figure 7(c)).



(a) (b) (c)

Figure 7: (a) Arcs sharing a common area. (b) Arcs affected by the lens sharing a common area. (c) Arcs affected by the lens with shapes easier to trace. In these images green arcs are *arcs of interests* and red arcs are *undesired arcs*.

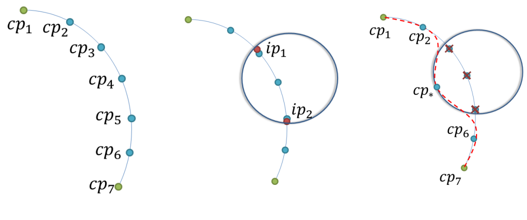
This distortion can have negative implications in (1) the *context arcs* that are near the lens area, (2) the deformed *undesired arcs*, (3) the *arcs of interest* and consequently their incident nodes. However, in the first case the arcs are the *context* thus for the analysis of those visual elements the user can move the lens over that location or increase the size of the lens. To limit the second case all the *context arcs* are colored with a medium level of transparency. Regarding the last case, during the rendering phase the *arcs of interest* are drawn on top of the other elements.

4.1 Implementation Details

Each arc is designed as a relaxed cubic spline composed by a sequence of points $p_1, p_2, ..., p_n \in R^3$ that are defined by a sequence of equal-distance control points $cp_1, cp_2, ..., cp_m \in R^3$ where cp_1 is the source node and cp_m is the target node, see Figure 8(a). We use this kind of curve because it is possible to design a polynomial curve segments controlling their shape in an easy way and that pass through given data points.

The altitude of the control points over the geographical surface follows the formula of similar works (Cox et al., 1996; Munzner et al., 1996): $1 + H\sin(x\pi)$ where H is the maximum height and x varies between 0 and 1 along the arcs path. In order to take into account the path length l, the H parameter is equal to $l/4$.

To detect whether a point that composes the arc or a node is contained inside the lens area we use the two combined approaches: (1) in screen coordinates



(a) (b) (c)

Figure 8: The steps required to apply the effects of the lens over the arcs are: (a) each arc is composed by m control points, (b) one or more couples of consecutive *intersecting points* are detected, (c) for each couple a new control point is used to deform the arc.

the distance between the element and the lens center must be less that the lens radius. (2) using a ray-cast technique we check if the line that connects the viewpoint with the element in the world space does not intersect the surface.

Arcs Deformation. The main aspect of the deformation of *undesired arcs* is that the original control points are removed and then new control points are created making curves more aesthetically pleasing and easier to trace. For this class of arcs the algorithm is defined by two steps that are executed at every frame, before the main rendering phase:

Step 1. In the first step the *undesired arcs* are found and the *intersecting points* between these arcs and the circumference of the lens are detected. These points are defined as $ip_1, ip_2, \ldots \subset p_1, p_2, \ldots, p_n$ such that, in screen coordinates, they are the nearest to the real intersection points $\in R^2$. Then, the algorithm identifies the couples of consecutive *intersecting points* that will be used to create the new control points of the cubic curve (see Figure 8(b)). This step is based on a GPU-based implementation to achieve an acceptable frame rate. The points that compose the lines are passed to the GPU into a single buffer and then a geometry shader computes the *intersecting points* to be passed to the next step using the *transform feedback buffer*.

Step 2. In this step, the sets of control points are updated and the arcs are redrawn. As shown in Figure 8(c), for each undesired arc, the control points inside the lens are removed and a new control point $cp_\star$ is created and placed over the lens' circumference.

The formula to calculate the screen coordinates of the new control point $cp_\star$ starting from the couple of points $\{ip_1, ip_2\}$ is the following:

$mp = (ip_1 + ip_2)/2;$

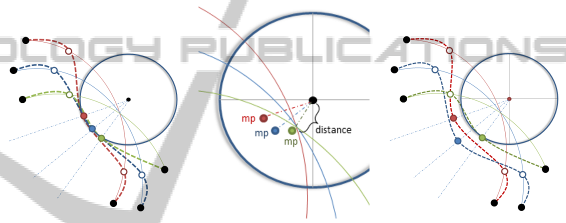
$cp_\star = c + r * (\widehat{mp - c});$

mp is the middle point between ip_1 and ip_2, c is the center of the lens and r is the radius of the lens. The aforementioned formula is applied to the x and y attribute of $cp_\star$, meanwhile the z dimension, that is the screen depth-coordinate, is calculated taking the middle value between the z of ip_1 and ip_2. Finally the deformed arc is drawn reconverting the $cp_\star$ in world coordinates and recomputing the points $p_1, p_2, \ldots, p_n$.

Control Points Relocation. A feature that improves the scenario where the shifted arcs can no longer be traced, (see Figure 9(a)), is described in the following steps:

Step 1. The lens is divided in p sections of equal area. For each new control point $cp_\star$, the distance in screen coordinates between its associated mp and the center lens is stored, (see Figure 9(b)). Therefore for each section, a list of control points ordered accordingly with their distance is computed.

Step 2. Each control point is moved from the lens center, accordingly to the distance as depicted in Figure 9(c). A maximum distance is defined to limit the effect in a closed area around the lens.



(a) (b) (c)

Figure 9: (a) the basic solution: new control points are placed around the lens. (b) the lens is subdivided in sections. Control points are ordered accordingly to the distance factor relative to their sector. (c) control points are placed at different distances from the lens center around the lens.

The sector-based approach is applied to separate the control points that do not share the same location in screen space. For example if there are two deformed arcs respectively on the opposite sides of the lens, due to the fact that are in different sections no control point will be relocated.

Arc Segments Filtering. For the creation of the *arcs of interest* the steps are the following:

Step 1. As preprocessing phase a different color is assigned for each node. During the rendering phase, if the node is inside the lens and it is visible, than a sphere colored with the node's color is generated.

Step 2. Every part of the arc inside the lens is drawn completely transparent using the *blending function*, and the rest of the arc is colored with the same color of its incident node inside the lens.

In order to facilitate the interaction with the system, we added two graphical components to the GUI: a slider interface allowing the user to readjust the lens radius and a button to place the lens at the center of the screen. This last feature is handy when the user loses sight of the lens while navigating.

4.2 Input Parameters

The parameters required by the algorithm affect directly the quality of the result. The first parameter is the number of control points m. If the number of control points is too high the deformation technique affects only a small localized area and if m is too low the edges are deformed along their entire length. As depicted in Figure 10, the advantage of using low number of control points appears evident, however, if the geographical surface is over a globe and both incidents nodes are placed in different hemisphere, there are extreme cases where the curve may pass through the geographical surface. For such reason, we set m equal to 7, to avoid to overlapping with the globe. The second parameter is the number of sections p, if p is high, only the control points close with each other will be placed with different distances from the lens center. As opposite, if the value is too low, more layers will be used. This decision is up to the user. In our tests we used $p = 4$. Another parameter is the number of points n that compose each arc. Higher the value is and smoother will be the curve. We set $n = 200$ to have a good balance between the aesthetic result and the performance. The last parameter is the radius of the lens r. Since this value has a considerable impact on the effectiveness of the proposed technique, the user can modify the lens size during the exploration of the network.

4.3 Performance

In order to measure the performance of our technique we take as metric the frame rate. *3DArcLens* was developed extending *NASA WorldWind*[1], an open source virtual globe, and was tested on a single processor Intel Xeon 2.26 GHz equipped with an NVIDIA GeForce GTX 280 with 1024 MB dedicated video memory. Table 1 shows the *fps* on *WorldWind* with and without *3DArcLens* taking into account datasets with different number of arcs *tot arcs*.

Table 1: The *fps* are shown with and without the use of *3DArcLens* on *WorldWind*.

tot arcs	fps (WW)	fps (WW + 3DArcLens)
600	55 - 56	20 - 22
3000	33 - 35	15 - 17
15000	8 - 10	6 - 7

The performance of *3DArcLens* depends mainly on the number of arcs that are distorted. The Table 2 shows the *fps* on *WorldWind* taking into account the deformed arcs of the dataset with 3000 arcs.

[1]http://worldwind.arc.nasa.gov/java/

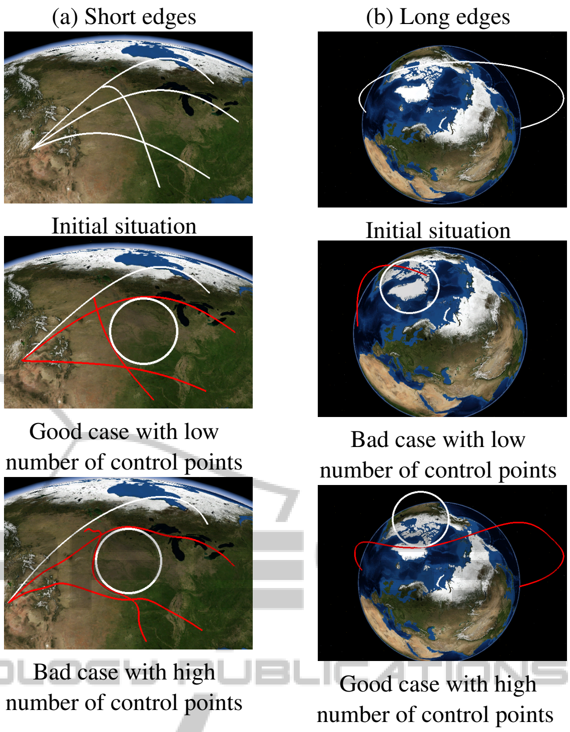


Figure 10: Two situations, one with short length edges (a) and one with long edges (b). Examples showing advantages and drawbacks of using high and low number of control points. In these images the red color is used to depict *undesired arcs*.

Table 2: The *fps* and the number of deformed arcs are shown on *WorldWind*.

def arcs	fps (WW + 3DArcLens)
0	21
150	18
300	15
400	13

5 DISCUSSION

At the current stage of the research there are no interaction techniques that can effectively reveal the information about arcs, nodes and geographical surfaces hidden behind an area congested in a 3D virtual environment.

EdgeLens (Wong et al., 2003) is a technique that iteratively curves graph edges, that are represented by 2D straight lines, away from the point of focus in a 2D plane. Although it helps to disambiguate the relationship between nodes and edges without losing information, it can not solve the arc' congestion problem due to the following:

Arcs' Shape. In a 2D space, a straight line is deformed by taking into consideration the start and end points (together with the lens focus and radius). With 3D arcs, the distortion and selection of these objects is more complex.

The View Camera Information. The behavior of the lens depends also on the position of the view camera; if the view camera changes, the arcs affected can differ in both number and shape.

The Occlusion Problem. In 3D virtual environments the effect of occlusion has to be considered; arcs that intersect the lens having their extremities behind a geographical surface can generate undesirable behaviors.

The coordinate systems. In 3D virtual environments, the distortion process must take into account the screen coordinates and the world coordinates.

MoleView (Hurter et al., 2011) is another interactive technique to reveal what is hidden behind a congested area. The control points of the edges are moved around the lens meanwhile the edges which are selected in the lens stay unmoved, making them easy to spot. Although this technique gives satisfactory results it differs from *3DArcLens* in the following:

Information About Arcs. *3DArcLens* puts more effort on the traceability of arcs. In particular, the control points affected by the lens are replaced with others that are placed in different "orbits" around the lens. Additionally, the arcs that are contained inside the lens are clutter free.

Geographical Context. Our technique allows not only the graph elements to be visualized but also the map inside the lens to be depicted without visual clutters.

Interactive Navigation. In our technique the camera view is also taken into account. This implies that if the lens highlights a geographical area and the camera view moves, then the lens remains still but the way it reveals what is hidden in that area maybe differ.

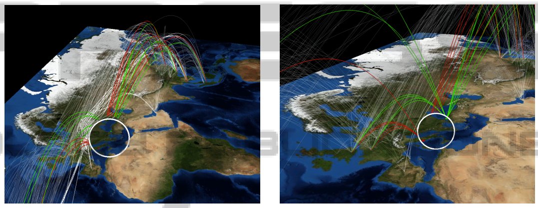
Although choosing suitable colors is fundamental for an effective utilization of *3DArcLens* the definition of a proper color pattern is not the aim of this work. Moreover, the effectiveness of the colors assigned to nodes depends on the task that has to be accomplish. For example one task might involve information about node attributes that can be encoded in a color pattern defined at priori.

A potential shortcoming may arises if the dataset presents a large number of connected nodes in a small location that is totally covered by the lens. In such case the visual clutter is caused by the *arcs of high interest*. However, if the *area of interest* is reduced, changing the lens radius or zooming in, can considerably alleviate this issue.

6 CONCLUSION

In this paper we describe *3DArcLens*, an interactive technique for exploring both geographical networks and geographic surfaces.

Our aim is to enrich tools that can depict geographical networks, e.g. the virtual globes implemented by Cox et al. (Cox et al., 1996), Munzner et al. (Munzner et al., 1996), Buschmann (Buschmann et al.,), *Google Earth*[2] and NASA WorldWind, as well as the *ArcMap* technique, see Figure 11.



(a) (b)

Figure 11: 3DArcLens applied on an *ArcMap*.

In our informal test cases, we observed certain advantages in applying our technique to the exploration of geographical networks. Overall our technique can increase the effectiveness on low-level tasks for graph analysis. Since it is locally applied to a specific area, higher-level tasks such as finding connectivity patterns remain difficult. Also, for datasets with ~3000 edges the frame rate was acceptable. Yet, it might drop for much larger datasets. Future improvements include shifting the generation of the splines to the GPU side and the definition of an evaluation strategy.

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[2] http://www.google.com/earth/

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