

# VISUALIZING COLLAPSIBLE 3D DATA IN A HYBRID GIS

Stephen Brooks

*Faculty of Computer Science, Dalhousie University, 6050 University Avenue, Halifax, Canada*

Jacqueline Whalley

*School of Computer and Information Sciences, Auckland University of Technology, Auckland, New Zealand*

**Keywords:** 2D and 3D visualization, geographical information systems, hybrid display, interactive.

**Abstract:** In this paper we present a comprehensive set of advancements to our unique hybrid Geographical Information System (GIS). Although many existing commercial 3D GIS systems offer 2D views they are typically isolated from the 3D view in that they are presented in a separate window. Our system is a novel hybrid 2D/3D approach that seamlessly integrates 2D and 3D views of the same data. In our interface, multiple layers of information are continuously transformed between the 2D and 3D modes under the control of the user, directly over a base-terrain. In this way, our prototype GIS allows the user to view the 2D data in direct relation to the 3D view within the same window. In this work we progress the concept of a hybrid GIS by presenting a set of expanded capabilities within our distinctive system. These additional facilities include: landmark layers, 3D point layers, and chart layers, the grouping of multiple hybrid layers, layer painting, the merging of layer controls and consistent zooming functionality.

## 1 INTRODUCTION

In the past, most geographical information systems (GIS) were limited to providing visualizations of data in 2D. Currently, GIS research and development still lies largely in this traditional map-based approach. But we relate to our world in three or more dimensions, which suggests that some types of data may be more readily visualized and analyzed in 3D. However, direct 3D analogues to 2D GIS are not ideal solutions because they suffer from several shortcomings and gaining insight from 3D spatial datasets can be particularly challenging.

One issue is that a high data density can make it difficult to view all the data at once due to the self-occlusion of the data. The issue can be particularly acute when attempting to display and interpret multivariate data in a meaningful way. Moreover, there can arise difficulties in viewing information in 3D GIS when the terrain is hilly due to elevated regions in the terrain occluding data. How best to simultaneously visualize different types of data in 3D is another key issue.

Studies have shown that 2D views are often used to establish precise relationships, while 3D views

help in the acquisition of qualitative understanding (Springmeyer et al., 1992). Both dimensionalities of view therefore have distinct advantages and it would be ideal if the benefits of both 2D and 3D could be incorporated into the same system.

Our hybrid system seamlessly integrates 2D and 3D views of the same data and allows the user to view the 2D data in direct relation to the 3D view within the same window. Our system visualizes layers in a combined overlay representation where multiple heterogeneous layers of information are continuously transformed between 2D and 3D over the base-terrain (see Figure 1). It is intended that this system allows the exploration and understanding of structures, patterns and processes reflected in both 2D and 3D data.

In this paper, we present a set of expanded capabilities for our unique GIS which include: hybrid landmark and chart layers, 3D point layers, the aggregate grouping of multiple hybrid layers, layer painting, unified controls for layer groups and consistent zooming functionality.

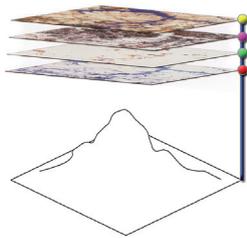


Figure 1: Multiple 2D/3D layers in our hybrid display over a 3D base terrain. The vertical translation of each layer is set with its associated control ball.

## 2 RELATED WORK

In recent years, GIS has gradually been moving into the third dimension. 3D GIS have received considerable attention and the literature surrounding the area is slowly growing. In 2002, Zlatanova et al. produced a survey of mainstream GIS software. They reviewed a number of systems including: ArcGIS (ESRI, 2006) and PAMAP GIS Topographer (PAMAP, 2006). They concluded that some initial steps forward have been made in terms of the visualization of 3D spatial data, however, 3D GIS still lack basic 2D GIS functions.

Further examples of existing 3D GIS include systems such as TerraFly (Rishe et al., 1999), GeoVR (Huang and Lin, 2002), TerraVisionII (Reddy et al., 1999), GeoZui3D (Ware et al., 2001) and VGIS (Köller et al., 1995). One noteworthy system, called GeoTime (Kapler and Wright, 2005) proposes an interesting solution to the problem of integrating timeline events into interactive GIS. Recently, Stota and Zlatanova (Stota and Zlatanova, 2003) revisited the current status of 3D GIS and postulated that 3D GIS is merely at a point where 2D GIS was several years ago.

Several of the aforementioned GIS have the capability of creating 3D perspective images using elevation data. Often this is simply used for illustration or fly-bys, with limited analysis of this perspective imagery. These perspective renderings are generally accepted as showing the relationships of the GIS data to the natural terrain, but have limited the efficacy of the perspective images to 'show and tell' type applications (Stota and Zlatanova, 2003). Moreover, these representations only permits the user to view map layers as a single entity rather than being able to visualize the layers in a combined overlay representation.

Further research is required to explore the possibilities and constraints of 3D GIS in order to move beyond simple flybys and map-making.

Indeed this is the definitive aim of the research presented in this paper. But, gaining insight from 3D spatial datasets can be particularly challenging because a high data density can make it difficult to view all data at once since the data can self-occlude. There are also difficulties viewing information in 3D GIS when the terrain is hilly due to elevated regions in the terrain occluding data further back.

Attempts to overcome these issues in 3D GIS usually involve displaying the terrain from several different viewpoints in separate windows (Verbee et al., 1999). However, separate views introduce new problems since the integration and interpretation of the multiple views must occur in the mind of the user. It therefore places extra demands on the GIS professional or casual GIS user. Another issue is that the more views are displayed, the smaller each view must be rendered for a fixed screen size.

We propose that by providing 2D-to-3D transitional layers we can overcome both the self-occlusion and terrain-occlusion issues. Our layering system also offers a convenient means of handling multiple heterogeneous sets of aspatial data under user control. Additionally, the system allows the user to temporarily set aside data that is not currently relevant. Our work builds upon 3D GIS and is also somewhat related to a small number of systems that have been proposed in the area of scientific visualization.

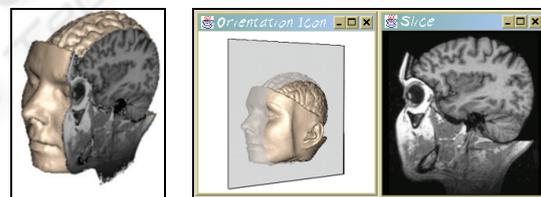


Figure 2: Medical clip-planes (left) and orientation icons (right).

Medical displays sometimes incorporate aspects of 2D and 3D in some fashion, and so, we now review these systems. Medical scans, such as Magnetic Resonance Imaging and Computed Tomography, allow users to interact with a data. 2D slices can be combined with a 3D overview using one of two main approaches: clip planes and orientation icons (Tory and Swindells, 2003). Clip planes show slice details in their exact relative position to the 3D context (figure 2, left). Whereas, in orientation icon systems (figure 2, right), the 3D overview and 2D details are in separate windows. But, as will be seen, these systems are quite different from ours.

For GIS, little has been done with respect to hybrid displays. This is despite the fact that this type of display allows the dual strengths of 2D and 3D visualization to be exploited (Tory and Swindells, 2003). What follows is an in-depth discussion of our hybrid GIS display and its implementation. In section 3 we briefly review the key features of our GIS. We follow this in section 4 with a discussion of the set of novel advancements to the GIS that we have recently designed and developed. In closing we offer a set of future directions and conclude with a summary of contributions.

### 3 THE HYBRID GIS

It is necessary to begin with a review of our hybrid GIS for the present work to be understood. Our prototype offered a preliminary set of features, as was reported in an initial paper (Anonymous, 2005).

#### 3.1 Rendering of the Base Terrain

The base terrain consists of a Digital Elevation Model (DEM) dataset. Two approaches are available for constructing a 3D model from DEM data. The first approach is to use Triangulated Irregular Network and the second is simply a regular grid. Our terrain can incorporate satellite imagery and in the absence of good satellite images, procedural textures are generated based on DEM data. Much of the data we used to develop our system was acquired from the San Francisco Regional Database and the U.S. Geological Survey repository. Our terrain data is extracted from the DEM format and vector data from the DLG format.

#### 3.2 The Hybrid 2D/3D Layer System

What makes our GIS unique is the multiple layers of information that can be continuously raised or lowered by the user directly over the base-terrain. During elevation, the transitional layers maintain their original geographical (latitude/longitude) position relative to the base terrain. When translated skywards, the height values are gradually flattened into a completely flat 2D map layer (figure 3a-c).

Each layer's translation is set with an associated user-positioned control ball. These control balls are shown to the right in figure 3 and diagrammatically in figure 1. The color of the control ball is unique for each layer. In addition the layer is trimmed along its edge with the same color as its associated control ball. For example, in figure 3 the layer and control

ball are color coded yellow. This application of consistent color coding finds support in user interface design principles (Hix and Hartson, 1993).

When a layer is high above the terrain, it flattens out to a true 2D map. This allows the user to analyze information in 2D and also provides a way of viewing information that may have been hidden by near elevations in the 3D view. It also allows the user to move information out of view when he or she is not interested in the content of a particular layer. This is achieved by simply raising the layer to the top of the screen (Figure 3d).

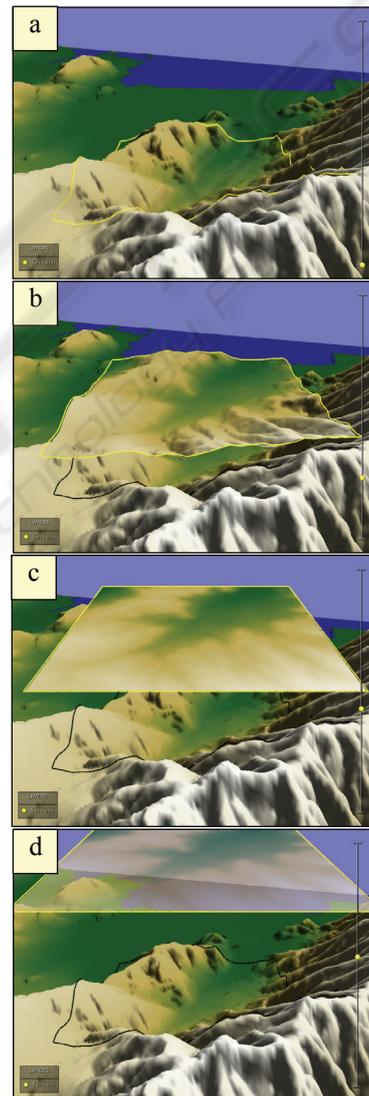


Figure 3: The layer is shown gradually rising from image *a* to image *d*. As the layer rises it morphs into a flat plane. Image *c* shows the layer completely flat. Above the flat level, the layer becomes increasingly transparent as shown in image *d*.

At a certain height the layer becomes flat, and above this height the layer becomes increasingly transparent, until all that is visible is its colored outline which trims the layer's edge. The trim is not affected by the change in transparency.

It is important that the user is able to mentally map a flattened 2D layer to the 3D terrain that it is residing over. To aid this, a ground level shadow of the layer system is provided which indicates the correlation between the data in the 2D/3D layers and the 3D base terrain.

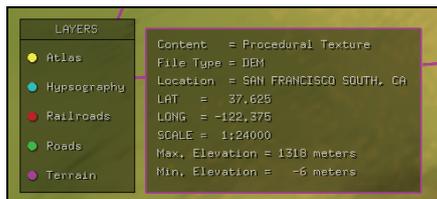


Figure 4: Text based meta-data pop-up legend for a layer.

In our initial prototype system we presented a number of thematic layers in addition to the terrain layer. These included a number of vector line data layers (such as road and hypsography layers) and color coded texture layers (such as an atlas layer). Each of these layers required that its own meta-data be available in an auxiliary pop-up legend (figure 4). In section 4 we expand the range of possible hybrid layers; in particular we will allow a variety of 3D objects to be embedded in layers.

## 4 NEW HYBRID GIS FACILITIES

This section expands the capabilities of our distinctive hybrid GIS. We first discuss the aggregate grouping of layers, unified control mechanism for the grouped constituents, and direct layer painting. We then introduce several new types of 3D layer content including: landmark layers, chart layers and 3D point layers. The last subsection discusses a consistent zooming capability.

### 4.1 Layer Grouping

Our layering system offers a convenient means of handling multiple heterogeneous sets of aspatial data by separating the data content into hybrid layers, with each layer's height controllable via its associated control ball. We now add the ability to group two or more layers into a single entity. The user can form a new layer group simply by raising

(or lowering) layer A's control ball onto the control ball of layer B. The only required difference in the interaction is that the user must drag the control ball of layer A with the right mouse button (rather than the usual left button). Layers can also be added to an existing group by dragging additional control balls to the same height (again with the right mouse button pressed). An example of three grouped layers is shown in figure 5, left. The layers are: atlas, railroads and hypsography.

When multiple layers are grouped it is important to provide a visual indication of the grouping and of the individual member layers. We achieve this in two complementary ways. Firstly, the edge trim that surrounds each layer is adapted to the grouped state. Each of the representative colors for each of the layers is incorporated into the new edge trim in an alternating dash pattern. Secondly, we alter the control balls into onion-like configuration. We use the term *onioning* to describe how the control balls of grouped layers collected and visualized. We display the combined control balls as if they are each a layer of an onion that has been sliced in half. This offers a further visual cue to the user and is also a practical means of control. An example of the alternating color trim and the combined control balls for three layers is shown in figure 5.

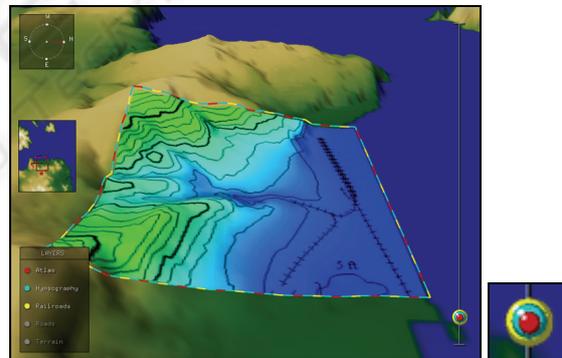


Figure 5: Left: Multiple thematic layers grouped into a single unit. Right: close-up of multiple control balls in an united state. Also note the layer edge trim pattern which has a matching color set.

Once a group is formed, the user can drag all united control balls at once with the left mouse button to raise and lower the combined layers as a single entity. The flattening of layers into 2D and the transparency of layers at a top height proceed as normal. To separate a layer from a group, the user simply drags the grouped control ball (again with the right mouse button). We refer to this reverse process as *de-onioning*. The layer that was added last to the group is removed first. This is in keeping

with the onion metaphor, in that we are peeling outer layers off the united group.

We also need to clarify exactly how layers are shown with respect to other layers in the same group. For this we need to consider the interaction of three types of layer: 2D raster (image or array data based), 2D vector (line-based) and 3D layers. A selection of 3D layers is discussed in sections 4.2-4.4. We first briefly list a number of cases that do *not* pose difficulties:

1. Multiple vector layers, since vector lines do not occlude.
2. Vector layers with a single raster layer, since vector layers can be placed slightly above the single raster layer, without occlusion.
3. One or more 3D layers with vector layers and a single raster layer.

However, the case that does pose difficulties is using multiple raster layers in a single group, as they completely occlude each other. To overcome this issue, we introduce the notion of direct *layer painting* which allows the user to reveal the data contained in one raster layer at the expense of all other raster layers in the same group. This effect is localized to wherever the user ‘paints’.

Let us consider an example layer group that contains 3 raster layers added in this order: A, B and C. Initially, the raster layer that is completely visible is the first layer, A, that was added to the group. Layers B and C are not initially visible. This default arrangement may not be sufficient as the user may wish to see certain portions of all three layers, A, B, and C, at the same time.

To tailor visibility within the group, the user performs layer painting. The user first clicks on the name of the layer (within the layer legend) that he or she wishes to reveal portions of. We will assume this is layer B. The user then paints with the mouse directly onto the rendered area of the layer group. The areas that the user paints over will then only show raster information contained within layer B, thereby hiding data from layers A and C. The user can therefore adjust the visibility of all layers in a given group in this fashion, by constructing disjoint sets of visible data from layers A, B and C.

Figure 6 shows an example of this where 3 disjoint regions are shown painted for the 3 separate raster layers within the same group. Note that the regions have been colour coded in this figure illustrate the concept. Normally, the corresponding raster data from the 3 layers would be shown.



Figure 6: Colour coded disjoint regions shown painted for 3 separate raster layers in a layer group.

## 4.2 Point Layers

Point layers are standard in traditional 2D GIS; in our system each point of data can be represented by a 3D sphere (figure 7). The size of the sphere can represent one aspatial aspect of the data points. For example, if each data point represents the population of a town, the location of the sphere could represent the spatial data for the town. The size of the sphere can then represent an aspatial data value for that town, such as the population density value.

Each sphere is embedded in a layer and as the layer flattens, the spheres also flatten to form a 2D view. The spheres also become transparent with the layer if the layer is raised sufficiently high. Also, it is possible to form multiple point-layers for different data content. Each point-layer is assigned its own color and meta-data legend entry.

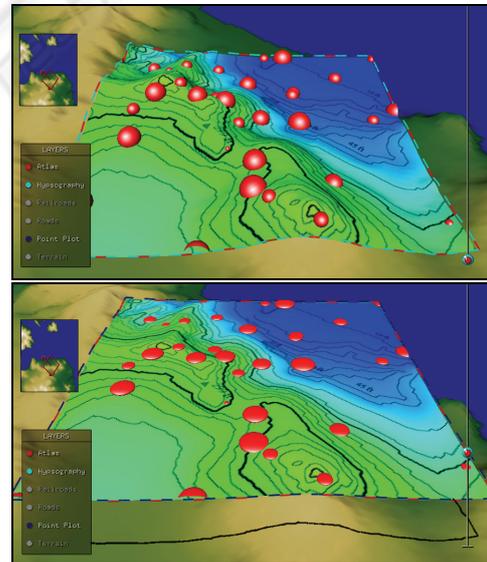


Figure 7: A partially transitioned point layer using sphere and disk symbols.

### 4.3 Landmark Layers

We have also integrated higher levels of detail into our GIS. Our system now includes representations of major landmarks such as buildings in a cityscape (figure 8, top). As a cityscape is raised using the associated control ball, the buildings flatten gradually becoming 2D. And as with other map layer types, when the layer is at the top of the elevation bar the landmarks become translucent.

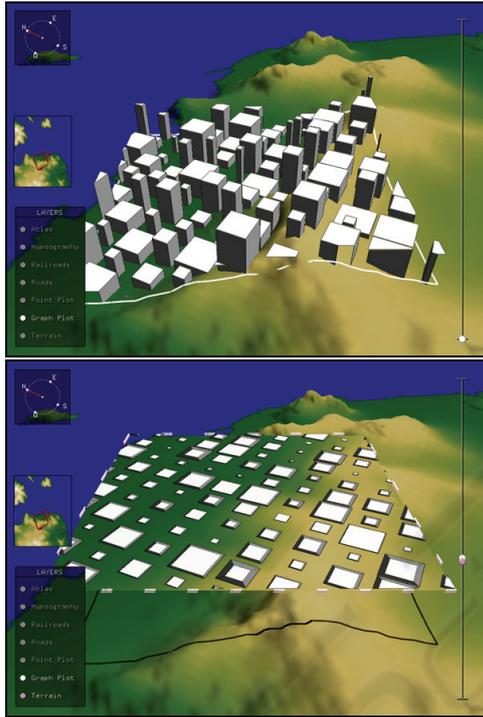


Figure 8: A landmark layer a ground-level (top) and at the flattening level (bottom).

As the landmark layer flattens, 3D the buildings become 2D polygons on a 2D plane. During this flattening process the spatial information provided by the 3D view with respect to the relative building heights is lost. As a consequence, we have integrated visual cues for the height of building when flat.

For this, we add a scaled edge trim for each building, indicative of the building's height when visualized in 2D (figure 8, bottom). This scaled edge trim is implemented by scaling the top of the 3D building inwardly, proportional to the height of the building. In other words, the taller the building, the more of an 'edge' there is around the building when flat. This gives cue as to the building height even though the building is 2D.

The inward scaling factor,  $f$ , for the tops of the buildings, is calculated as:

$$f(p, s) = p + (1 - p)s \quad (1)$$

where:

$$p = \min(1, \max(0, 1 - h/H) + c) \quad (2)$$

$$s = 1 - (b/B) \quad (3)$$

$h$  is current layer height,  
 $H$  is the height at which layers become flat,  
 $b$  is the current building's height,  
 $B$  is the height of the tallest building, and  
 $c$  is the minimum scale factor (default = 0.5).

Equation 3 computes a scaling factor,  $s$ , which scales the tops of taller buildings more than shorter buildings. Equation 2, places limits on this scaling so that the tops of the tallest buildings do not scale to a zero size. Equation 2 also takes into account the current layer height with respect to the maximum allowable layer height. In practice, this will mean that the higher the layer is raised, the more we need to scale all building tops inwardly.

The  $c$  value in the equation 2 adjusts the maximum inward scaling for the top of the tallest building in the landmark layer when the layer is completely flat. All other buildings will scale by lesser amounts, proportionally.

Another key visual cue is that, although we flatten the buildings and scale the tops of buildings inwardly, we do not change the lighting properties of the buildings. In other words, we shade a building as if it was 3D, even though it has actually become flat. Technically, this means that we do not alter the surface normals on the buildings as it flattens. Visually, the scaled edge trim has the same shadowing as the building when it is not flattened.

For clarity, it is important to note that we provide an additional option to the user, allowing them to toggle between the two meanings of 'building height', as denoted by the value  $b$ . By default this is set to the height above sea level of the roof of the building. However, this might not always be what a user is concerned about. The other case that we allow for  $b$  is the height of the building itself, irrespective of the height of the terrain that it sits on. The user simply toggles between these two cases with a menu item to switch the meaning of 'height'.

### 4.4 Chart Layers

Chart layers have also been integrated into the system and provide a way of visualizing aspatial data attributes using classifications. Our chart layers include 3D to 2D transitioning symbology. The pie

chart layer illustrated in figure 9 shows such a hybrid chart layer. Classifications include both pie-size and color. The semantics of the classifications are available in an auxiliary attribute-classification legend. This legend is a pop-up legend that is visible when the chart layer is selected (figure 10).

One might argue that when the chart layer is viewed in 3D, it offers an immediate impression of the overall data with respect to the 3D spatial terrain data. In the 2D mode it is more visually precise and eliminates potential occlusions.



Figure 9: A transitioned chart layer employing a pie chart view.

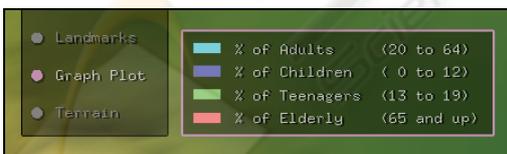


Figure 10: Auxiliary legend for pie chart classifications.

### 4.5 Zooming with the Layer System

A further addition to our hybrid GIS is a seamless approach to camera zooming. This zooming feature allows the expansion and contraction of the terrain coverage, while maintaining a constant screen size of the layer system interface. When zooming in and out, the layers, control balls and slider, legend and

navigation tools all remain fixed in position and size relative to the camera. The only aspects that increase and decrease are the amount of terrain covered by the layers.

In order to explain how this is implemented we must consider how each layer is rendered. Each layer's geometry is essentially the same as the base terrain itself. But, in addition to being (possibly) flattened, the layer is clipped on four sides with four clipping planes that are perpendicular to the layer. Each clipping plane is the same distance from the centre of the layer system but along four opposing vectors. This ensures that we see a layer as a square area of the grid rather than the entire terrain.

In order to zoom, while maintaining a fixed layer size relative to the camera, we must simultaneously:

- 1) adjust the positions of the four clipping planes surrounding the layers with respect to the center of the layer system, and
- 2) move the camera backward or forwards along the camera's line of sight.

For example, if we are zooming-out to see a larger portion of the terrain, we must move all four clipping plane outwards with respect to the center of the layer system and simultaneously move the camera backwards along its line of sight (figure 11). The relative rates of movement of both the camera and the four clipping planes must be precisely coordinated in order to maintain the appearance of a constant layer system size.

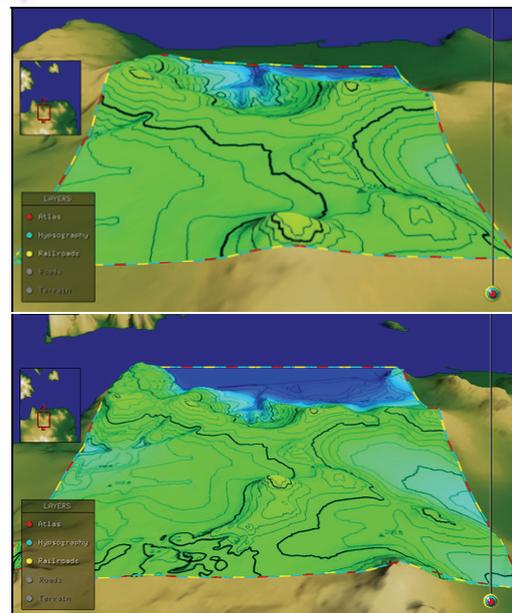


Figure 11: Zooming in (top) and out (bottom) on a layer group.

## 5 FUTURE DIRECTIONS

There remain many opportunities for extending the system beyond its current form. One major extension will involve the addition of advanced query facilities. The integration of such querying functionality will make our system broadly applicable to a variety of tasks. The query results will form new layers and will exhibit 3D icons and labels. In order to provide such functionality we will need to integrate 3D spatial data into a database management system.

To complement the querying facilities we also propose to add a data editing framework. It is also our aim to undertake a usability study to confirm that a hybrid system such as ours is advantageous to the GIS community.

## 6 CONCLUSIONS

Our unique Geographical Information System seamlessly integrates 2D and 3D views of the same data. The system allows the user to view the 2D data in direct relation to the 3D view within the same view. By combining traditional 2D GIS with a 3D view we are able to take advantage of both types of representations each with complementary strengths. This is implemented as multiple layers of information that are continuously transformed between the 2D and 3D modes under the control of the user, directly over the 3D base-terrain.

We propose that by providing a 2D-3D transitional layer we can overcome both the self-occlusion and terrain-occlusion issues. Our layering system also offers a convenient means of handling multiple heterogeneous sets of aspatial data under user control. The system allows one to temporally set aside data that is not currently relevant.

In this paper we have presented an array of expanded capabilities for our distinctive hybrid GIS. These additional facilities include: landmark layers, chart layers, 3D point layers, layer grouping, unified control of grouped layers, layer painting, and zooming functionality.

## ACKNOWLEDGEMENTS

This work was supported by an NSERC discovery grant and a CFI New Opportunities Grant.

## REFERENCES

- Brooks, S., Whalley, J., 2005. A 2D/3D hybrid geographical information system. In *Proceedings of ACM GRAPHITE*, Dunedin, 323-330.
- ESRI ArcGIS. (n.d.). Retrieved May 1, 2006, from <http://www.esri.com/software/arcgis/>.
- Hix, D., Hartson, H. R., 1993. *Developing User Interfaces: Ensuring usability through product and process*, Wiley, New York.
- Huang, B., Lin, H., 1999. GeoVR: a web-based tool for virtual reality presentation from 2D data. In *Computers and Geosciences*, 25, 1167-1175.
- Kapler, T., Wright, W., 2005. Geo-time information visualization. *Information Visualization* 4, 2, 136-146.
- Köller, D., Lindstrom, P., Ribarsky, W., Hodges, L. F., Faust, N., Turner, G., 1995. Virtual GIS: A real-time 3D geographic information system. In *Proceedings of the IEEE Conference on Visualization '95*, 94-100.
- PAMAP GIS Topographer. (n.d.). Retrieved May 1, 2006, from <http://www.pigeomatics.com>.
- Reddy, M., Leclerc, Y., Iverson, L., Bletter, N., 1999. TerraVisionII: Visualizing massive terrain databases in VRML. In *IEEE Computer Graphics and Applications*, 19, 2, 30-38.
- Rishe, N., Sun, Y., Chekmasov, M., Andriy, S., Graham S., 2004. System architecture for 3D terrafly online GIS. In *Proceedings of the IEEE Sixth International Symposium on Multimedia Software Engineering (MSE2004)*, 273-276.
- Springmeyer, R. R., Blattner, M. M., Max, N. L., 1992. A characterization of the scientific data analysis process. In *Proceedings IEEE Visualization*, 235-242.
- Stota, J., Zlatanova, S., 2003. 3D GIS, where are we standing? In *Workshop on Spatial, Temporal and Multi-Dimensional Data Modeling and Analysis*.
- Tory, M., Swindells, C., 2003. Comparing ExoVis, orientation icon, and in-place 3D visualization. In *Proceedings of Graphics Interface*, 57-64.
- Verbee, E. G., van Maren, R., Germs, F.J., Kraak, M., 1999. Interaction in virtual views – linking 3D GIS with VR. In *International Journal of Geographics Information Systems*, 13, 4, 385-396.
- Ware, C., Plumlee, M., Arsenault, R., Mayer, L. A., Smith, S., 2001. GeoZui3d: data fusion for interpreting oceanographic data. In *Proceedings of Oceans 2001*, 3, 1960-1964.
- Zlatanova, S., Rahman, A., Pilouk, M., 2002. Trends in 3D GIS development. *Journal of Geospatial Engineering*, 4, 2, 1-10.