CONNECTED 2D AND 3D VISUALIZATIONS FOR THE INTERACTIVE EXPLORATION OF SPATIAL INFORMATION

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ABSTRACT:

This paper describes the concepts and the successful prototypal implementation of interactively connected 2D information visualizations and data displays in 3D virtual environments for the interactive exploration of spatial data and information. Virtual globes or earth viewers such as Google Earth have become very popular over the last few years. They are used for looking at holiday destinations but more importantly also for scientific visualizations. From a geovisualization point of view we might regard 3D data or information displays as yet another representation type that adds to the multitude of information visualization methods. Combining 3D views of data sets with traditional 2D displays offers the advantage of being able to use 3D if and when this type of representation is considered useful or effective for finding new insights into a data set. The traditional and newer displays of mainly 2D information visualization may be enhanced and new insights into the data may be generated by displays of the data in a 3D virtual environment. On the other hand, data in 3D displays might be better understood by simultaneously reading and querying connected 2D representations.
The paper presents a prototypal implementation of the interactively connected visualizations of spatial information in 2D views and 3D virtual environments using the brushing technique. The prototype is implemented using the virtual globe technology i3D, a 3D geovisualization engine developed at the University of Applied Sciences Northwestern Switzerland (FHNW). SVG is used to realise the 2D graphics and diagrams of the information. The connection between the views, the interactive querying and brushing is implemented employing the scripting languages Lua and ECMAScript. This prototype implementation is applied to and tested with two different data sets: slope stability data from Brienz and statistical data of the canton of Baselland in Switzerland.
Technically, the combination and interactive linking of 2D data displays and 3D visualizations as implemented in the prototype is feasible. It seems that connecting 2D data displays to the 3D views and updating or changing them dynamically allows overcoming some of the shortcomings of using stand-alone 3D views of information. The combined use of the virtual globe technology i3D and the scripting language Lua for the 3D displays and the interaction with 2D representations (SVG and ECMAScript) bears a considerable potential for enhancing the explorative analysis of spatial information. Such combined 2D and 3D displays open up new possibilities for the explorative evaluation and analysis of spatial information in the context of the landscape. Additionally, they allow using each type of 2D and 3D representations when it is deemed appropriate and when it may be able to play out its respective strengths.

1. INTRODUCTION

Over the last few years virtual globes or earth viewers such as Google Earth (Google 2008) or NASA World Wind (NASA 2008) have become very popular not only for looking at holiday destinations but also for scientific visualizations (e.g Slingsby et al. 2008, Butler 2006). Many sets of data are visualised more or less nicely in such viewers as not many rules or guidelines for effective representations exist so far. Additionally, the usefulness and effectiveness of 3D displays is a controversial issue (e.g. Jobst and Germanchis 2007, Bleisch and Dykes 2006, Dykes et al. 2005, Wyeld 2005, Smallman et al. 2001). It is mentioned that 3D views may help the orientation and give more easily an impression of landforms and spatial aspects than traditional 2D displays where the third dimension is encoded, for example, by contour lines (e.g. Bleisch and Dykes 2008, Jones et al. 2007, Meng 2003). Other researchers refer to the additional cognitive load, arguing that having to navigate in the 3D display may outweigh the advantage of easier orientation (e.g. Rase 2003). From a geovisualization point of view we might regard 3D geodata views or information displays as yet another type of representation. Well-known and well-used visualizations such as bar charts, scatter plots, parallel plots, maps, etc. (see e.g. Spence 2007) are supplemented by different types of 3D displays. Several researchers employ and explore 3D displays for information visualization (e.g. Spence 2007, Skupin and Fabrikant 2003, Robertson et al. 1998).
Exploratory visualization or explorative data analysis uses multiple linked views to find and test various hypotheses about specific data sets (e.g. Godinho et al. 2007, Andrienko and Andrienko 2006, Roberts 2005). Combining 3D views of data sets with traditional 2D information visualization displays offers the advantages of being able to use 3D if and when this type of representation is considered useful or effective for finding new insights into a data set. Importantly, by combining different views and linking them interactively we are able to use each visualization type when it seems sensible to use it or for experimenting with different visualization types since we do not need to rely on one single representation for data exploration. It is additionally possible to compare different ideas or hypothesis about the data side-by-side in different representations.

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Various studies employ and/or research combinations of 2D and 3D displays. A number of years ago, Dykes et al. (1999) developed tools that integrate 2D and 3D information displays in the context of virtual field courses. Kreuseler (2000) combined 2D maps and 3D landscapes to explore oceano-graphic ecosystems and emphasizes the importance of displaying spatial and temporal context and allowing different forms of interaction. Empirical experiments exploring shape understanding and relative-position tasks in static 3D perspective views compared to orthogonal 2D views showed that shape-understanding greatly benefits from 3D views while relative-position tasks are easier with 2D displays (St. John et al. 2001). Tory et al. (2006) later combined 2D and 3D views for relative position estimation, orientation and volume of interest tasks. They found that each type of display is better for one or the other task but combining 2D and 3D displays has the same or better performance and the users are more confident in their findings. Hetherington et al. (2007), Chang et al. (2007) and Beard et al. (2005) employ combinations of 2D and 3D displays for exploration and communication of urban development, planning and geological structures. They all conclude that this combination allows gaining a more intuitive and deeper understanding of the model or structure displayed.

These exemplary studies and applications give an overview of combined 2D and 3D displays in the research. They support us in believing that a combination of 2D and 3D representations is sensible and allows combining the strengths of the different visualizations and possibly overcoming some of the weaknesses of them. The traditional and newer displays of mainly 2D information visualization may be enhanced and new insights into the data may be generated by displays of the data in a 3D virtual environment. On the other hand, data in 3D displays might be better understood by simultaneously reading and querying connected 2D representations. Slocum et al. (2001) mention that "Effective geovisualization environments are likely to be ones that mix methods […]". In information visualization techniques such as brushing (linking multiple views by selecting parts of data in one window and highlighting the same data in a different window) is often used to connect different views and to dynamically query the displayed data sets. Such proven techniques shall be applied to link and integrate 2D and 3D views of spatial information interactively.

1.1 Research aims

Most of the above mentioned examples combine 2D and 3D representations for specific applications or experimental testing. In our research we aim to develop and test an integrated 2D/3D visualization application that is useable in a number of different contexts. We employ a virtual globe technology as 3D visualization method to benefit from the practical knowledge of many users with virtual globes (e.g. Google Earth). For the 2D representations we use a modular approach combining interchangeable 2D displays employing well known information visualization or geovisualization techniques such as bar charts or maps.

This paper describes the concepts and development of a first prototypal implementation of such interactively connected 2D and 3D visualizations. It then presents the results of applying the prototype to two different real-world data sets and discusses the requirements and challenges involved when employing 2D and 3D visualizations of spatial data in combination.

2. CONCEPTS

2.1 Linking and interacting between 3D and 2D displays

Several geovisualization and exploratory visualization tools employ a number of different displays that are linked together (e.g. cdv (Dykes 1998), GeoVista Studio (Takatsuka and Gahegan 2002) or PRISMA (Godinho et al. 2007)). Roberts (2005) explored the concepts and techniques for using multiple linked views for exploratory visualization in detail. For our prototype we use the technique of brushing and aspects of combined navigation for the interactive connection between the different views. Brushing, as defined by Roberts and Wright (2006), "is a collection of techniques to dynamically query and directly select elements on the visual display." This technique enables the user to interactively select some objects or parts of the visualization in one window and to see how the same selection is highlighted or updated in other related data representations (Figure 1). Brushing has been found to be very effective for complex comparison, trade off, and pattern tasks (Li et al. 2003). Linking and brushing techniques have not only been applied to 2D views but also to 3D visualizations (e.g. Doleisch and Hauser 2002). Combined navigation means that interaction or especially navigation within one data view is simultaneously transferred and conducted in other data displays (e.g. Figure 2).

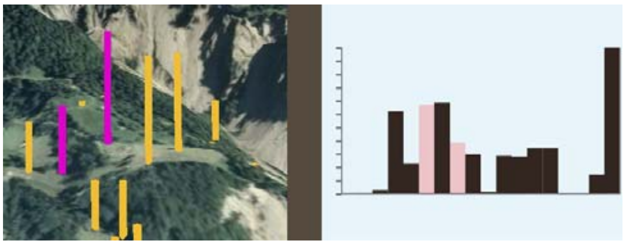

Figure 1. Brushing – selected bars in the 3D view (left) are simultaneously highlighted in the 2D bar chart (right)

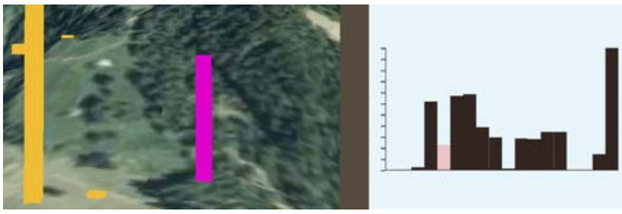

Figure 2. Navigation – double-clicking bars in the bar chart (right) centres the 3D view simultaneously on the selected bar (left)

2.2 Input and output devices

In order to make the combined 2D and 3D visualization as widely usable as possible we restrict ourselves to the usage of standard input and output devices. The 3D display is shown together with the 2D presentations on the 2D screen and input devices are keyboard and most importantly the mouse. Using the screen as output device for 2D and 3D representation only allows the direct comparison and analyses of data sets in both views. However, when a 3D virtual environment is displayed on the desktop we do not really see 3D space but rather perceive different depth cues, such as perspective cues, occlusion or structure from motion, that create the illusion of 3D space

(Ware 2004). When using 3D displays for data visualization and exploration we add additional graphics or symbols to the virtual environment. They also change their size and appearance according to the different depth cues they provide. In a different study (Bleisch et al. 2008) we have researched the use of bars to represent numeric values in desktop virtual environments. We found that some users are very successful in separating the perception of monocular depth cues such as perceived variations in the width and height of the bars in the landscape from the actual values the bars represent by their heights.

The use of the mouse as most important input device limits us to traditional mouse input such as moving the mouse over certain objects or clicking onto parts of the visualization. For the 2D views most users will be used to this form of interaction and in the 3D view too, this type of mouse interaction is quite intuitive. On the implementation side, however, a click into the 3D view is a bit more complicate to handle as we need to establish where the mouse cursor points to. Additionally, we need to incorporate the fact that the navigation of the 3D visualization (e.g. dragging the mouse for controlling the field of view) already occupies some functionality of the keyboard and mouse. Bowman et al. (2005) define the basic 3D manipulation tasks as selection, positioning and rotation. We limit ourselves in the prototypal implementation to the selection task. Thus, a user needs to be able to identify and select an object in the 3D virtual environment. This is done by touching the object with the mouse, or possibly another semi-standard pointing device, using the ray-casting or picking technique. Invisible to the user, we can think of a ray that is attached to the mouse cursor which intersects with the virtual viewpoint, the cursor and the object when an object can be selected (see Figure 3). The selection can then take place by mouse over, click or double-clicks with the left mouse button. Other button functionality could be included but that might be more difficult to learn.

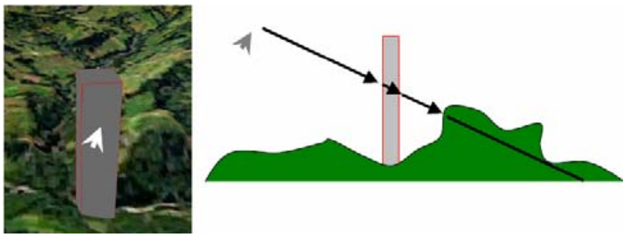

Figure 3. Selecting an object in the 3D view - a ray attached to the mouse cursor intersects with the virtual viewpoint of the user, the cursor, the object and further objects behind, such as the terrain. The first intersection normally returns the object chosen by the user. (Läderach 2007)

2.3 Data preparation

Displaying the same data in several views (2D and 3D) at the same time and connecting them to allow brushing and interaction requires some thoughts about the data preparation. To enable interaction we need to ensure that each object in any of the representations 'knows' anytime 'who' it is. We do this by using object identifiers (ids). The same object has the same id in all the representations. Additionally, all display characteristics of an object are parameterised. For example, a bar in the 3D view has, amongst others, the parameters bar width, bar height and colour. These parameters are set initially by the values of the data set that is to be displayed. Later these parameters can be updated or changed through user interaction. For example, when moving the mouse over a bar in the 2D bar chart, the parameter colour is simultaneously changed to a predefined highlighting colour for the corresponding bar representing the same object in the 3D virtual environment. Parameterisation also allows for the accommodation of a wide range of different data sets that can be pre-processed and displayed in the combined 2D and 3D display.

3. PROTOTYPE IMPLEMENTATION

3.1 Structure of 2D and 3D displays

For the prototypal implementation of combined 2D and 3D visualizations we tried to integrate the 3D and 2D technologies as closely as possible. The technologies used (details below) allow handling them all in the same window. The user interface is structured as shown in Figure 4. The 3D display technology i3D allows the integration of an HTML page that in turn integrates SVG graphic modules. Theoretically, an arbitrarily number of SVG graphic modules can be included (limited by common sense, space and usefulness). Normally, we would propose to include two to four 2D data display modules that best integrate with or complement the data display in the 3D virtual environment.

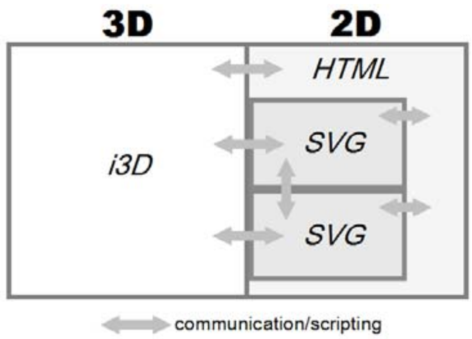

Figure 4. Structure of the user interface combining 2D and 3D displays (arrows show interaction by scripting technologies)

3.2 Display technologies

3D: The Prototype was implemented using the 2007 version of the virtual globe technology i3D. The i3D viewer is a 3D geovisualization engine developed at the University of Applied Sciences Northwestern Switzerland (FHNW). The viewer uses spherical rendering based on the WGS-84 Ellipsoid. The engine is highly optimized for current generation GPUs (Graphics Processing Units). It uses the OpenGL Graphics API and is cross platform (Windows, MacOS X and Linux). The virtual 3D terrain can hold several terabytes of aerial imagery and elevation data. This data can be streamed over a network or can be loaded from a local hard drive. There are also channels for 3D objects, including city models, POI, and 2D vectors. For the prototypal implementation we included 3D bars only.

With its built-in web browser, the i3D viewer is capable of rendering HTML pages including multimedia content. This enables the close integration of 2D data displays with the 3D virtual environment.

Using the 'in-house' technology i3D gives us the possibility to implement and evaluate content types as well as navigation and interaction features, which may not be available in commercial virtual globe technologies such as Google Earth.

2D: The various 2D graphics within the HTML page are realised using SVG – Scalable Vector Graphics. This open standard enables the flexible and parameterised creation of different data and information displays, such as bar charts, map overviews or parallel plots. For each information visualization type we define a SVG graphic module that can be populated by values from different data sets. It is then possible to select from a number of SVG graphic modules the one(s) best suitable to visualise the data set at hand in combination with the data display in the 3D virtual environment.

3.3 Communication technologies

The connection between the views, the interactive querying, brushing and navigation is implemented using the scripting languages Lua (Lua 2008) and ECMAScript (ECMA 1999). Lua is a fast, light-weight and extensible programming language mainly used for games. Almost all functionality of the 3D display technology i3D which is structured in a scene graph with different nodes and fields can be accessed through the embedded scripting language Lua (see Figure 5 for an example Lua script section). ECMAScript handles the interaction and communication in the 2D displays (HTML and SVG) and additionally the communication and exchange of information with Lua and consequently the 3D view. The scripting interfaces between the different data displays (Figure 4, represented by the arrows connecting the different display types) listen for various mouse and keyboard events, such as pressing a key or clicking into a display, and subsequently change or update the parameters in one or several other displays defined to be changed through these user interactions.

The display technologies i3D and SVG in combination with the scripting languages Lua and ECMAScript provide a very rich set of opportunities for interaction, communication, navigation and dynamic change. The prototypal implementation does not make full use of the possibilities yet but will be extended in the future.

```
--DA10: 3D-Objekte
function draw(fromHTML)

    split(fromHTML,",")

    if Ocounter~="undefined" then

        transformation()
        i3d.Print(Oobji3d)
        if (Oobji3d=="0") then

            idlsep=i3d.InsertNode("","i3dNodeSeparator")
            idlcub=i3d.SetPropertyFromString(idlsep,"Node Name","mySeparator")

                idlcubGT=i3d.InsertNode(idlsep,"i3dNodeGeoTranslation")
                    i3d.SetPropertyFromString(idlcubGT,"Longitude",Laenge)
                    i3d.SetPropertyFromString(idlcubGT,"Latitude",Breite)
                    i3d.SetPropertyFromString(idlcubGT,"Ellipsoid Height",Hoehe)

                idlcubMTS=i3d.InsertNode(idlsep,"i3dNodeMetricTerrainScale")
                    i3d.SetPropertyFromString(idlcubMTS,"Meter",1)

                idlcubS=i3d.InsertNode(idlsep,"i3dNodeScale")
                    i3d.SetPropertyFromString(idlcubS,"Scale X",barWidth)
                    i3d.SetPropertyFromString(idlcubS,"Scale Y",barWidth)
                    i3d.SetPropertyFromString(idlcubS,"Scale Z",Ototal*barHeightFactor)

                idlcubT=i3d.InsertNode(idlsep,"i3dNodeTranslation")
                    i3d.SetPropertyFromString(idlcubT,"Translation Vector.z",-0.3)

                OidPC=Oid.."pc"
                idlcubPC=i3d.InsertNode(idlsep, "i3dNodePrimaryColor")
                    i3d.SetPropertyFromString(idlcubPC,"Node Name",OidPC)
                    i3d.SetPropertyFromInteger(idlcubPC, "PrimaryColor.RGB Color.r",DSred)
                    i3d.SetPropertyFromInteger(idlcubPC, "PrimaryColor.RGB Color.g",DSgreen)
                    i3d.SetPropertyFromInteger(idlcubPC, "PrimaryColor.RGB Color.b",DSblue)

                idlcubC=i3d.InsertNode(idlsep,"i3dNodeCube")
                    i3d.SetPropertyFromString(idlcubC,"Node Name",Oid)
                    i3d.SetPropertyFromInteger(idlcubC, "Enable Collision Test" , 1)
```

Figure 5. Example of a Lua script section for inserting the 3D bars as used in the prototype implementation

4. DATA AND APPLICATIONS

The prototype implementation was applied to and tested with two different data sets: slope stability data from Brienz and statistical data of the canton of Baselland in Switzerland. These two quite different data sets gave us information about the effectiveness of the implemented parameterisation and tested the workflow of generating such combined 2D and 3D displays.

4.1 Slope stability data Brienz

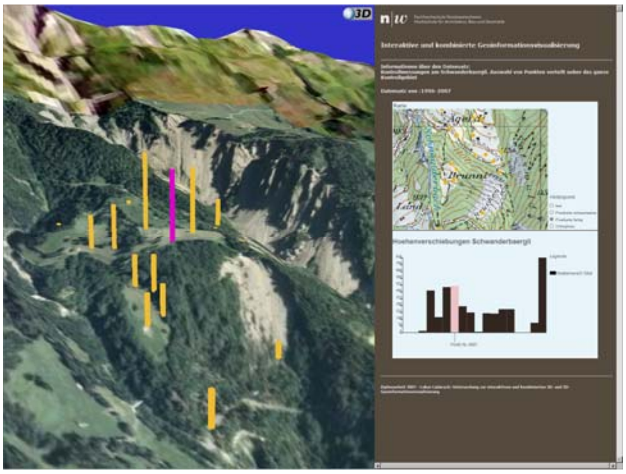

Figure 6. Absolute sizes of point displacement vectors on the partially instable slope above Brienz as bars in the 3D virtual environment (left), as locations on a map (right above) and as bar chart (right below)

The set of slope stability data (Figure 6) as included in this test visualization is quite small. It represents measurements at discrete points in a geographically small area above Brienz. The interpretation of slope stability data values in the 3D display in this or similar cases might benefit from the direct and intuitive comparison and relation of the measured values to the landform in the area. The 2D displays have informally been found to help the orientation and the exact comparison of data values.

4.2 Statistical data "Baselland in Zahlen"

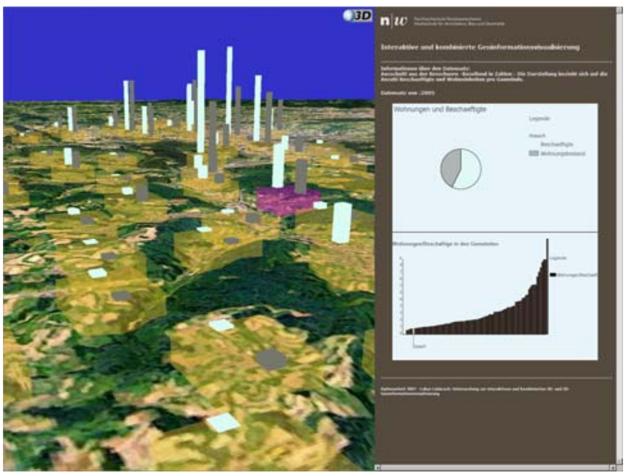

Figure 7. Number of available flats compared to employment rates (Baselland) displayed as bars in the 3D virtual environment (left) and 2D pie and bar charts (right)

The statistical information displayed in this example (Figure 7) is denser than the slope stability data. This introduces some difficulties with overlapping bars even though they are dispersed over a bigger area. However, in the 3D visualization this problem can be avoided through navigation and by looking at the data from different viewpoints. For the 2D displays different types of visualizations could be chosen which are more suitable for the display of larger amounts of data than the bar and pie charts implemented here. In the case of this data set, we might ask ourselves, why we need to display the data in a 3D virtual environment as there is no direct comparison and relation of the data to the landform. However, informally some test users have rated the combined visualization as very interesting. Also in this example the 3D display or the combination of 3D and 2D views might yield insights into the data that cannot be gained by looking at 2D displays only.

5. CONCLUSIONS AND OUTLOOK

The implementation of the prototype has shown that technically, the combination and interactive linking of 2D and 3D visualizations poses some challenges especially regarding the interaction and fluent update of information but that it is feasible. The combined use of the virtual globe technology i3D, SVG and the scripting languages Lua and ECMAScript for the displays and the interaction between the representations bears a considerable potential for enhancing the explorative analysis and evaluation of spatial information. It seems that connecting 2D data displays to the 3D views and updating or changing them dynamically allows overcoming some of the shortcomings of using stand-alone 3D views of information. This includes difficulties with navigation, occlusion of content, lower information density or projective distortion of the display. We assume, supported by combined 2D/3D displays that have already been tested as mentioned in the introduction and by our own experiences with the prototypal implementation described in this paper, that combining 2D displays with data representations in 3D virtual environments will certainly lead to new possibilities and ways for explorative analysis of spatial information. This may especially be true for data sets that have a direct relation to the landscape, landform, the 3D shape of objects such as bridges or buildings or layers of the atmosphere. Developments and research in the area of sensor networks (OGC 2006) may lead to various such data sets in the future. Additionally, combining 2D and 3D displays allows using each type of 2D and 3D representations when it is deemed appropriate and when it may be able to play out its respective strengths regarding the generation of new insights into data sets or providing an overview.

So far the prototype only supports the display of bars in the 3D view and four different types of 2D information visualization. For an efficient integration of large data sets in combined 2D and 3D views libraries of various 2D and 3D display and object prototypes will be needed. Such definitions may be stored in separate style files and loaded dynamically. A different project starting in summer 2008 will work on a workflow for 3D data visualization generation and a library of 3D data representations as single objects or diagrams. In terms of interaction, the current prototype uses brushing as the main interface technique between the different views. However, other techniques of interaction between the visualizations or combined navigation might prove useful and effective.

Ongoing research at our institute explores the effectiveness and usefulness of combined 2D and 3D displays and also of 3D visualizations on their own for users in different application areas. Or as Slocum et al. (2001) note "[…] the most sophisticated technology will be of little use if people cannot utilize it effectively." In their research agenda they have defined a number of issues that need to be explored to make effective use of virtual environments.

For the future we hope that data displays in 3D virtual environments will become a standard representation type that is fully integrated and connected interactively in various ways with other representation or information visualization types such as maps, bar charts or parallel plots and thus help in generating insights into geospatially related data sets.

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