Visual Analysis of Geo-spatial Data in 3D Terrain Environments using Focus+Context

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Abstract

Visual analysis of geo-spatial data represented within a three-dimensional frame of reference is a challenging task. Focus+Context is a common concept that aids this process. This paper addresses the question, how Focus+Context can be applied to a visualization of multivariate weather data along with 3D terrain data. For this purpose, the focus can be specified with regard to both, the terrain and the weather data, utilizing different strategies. Based on the specified focus, the associated context is derived automatically. Data within focus is emphasized, whereas context information is shown with less detail. To this end, various rendering strategies are proposed. We demonstrate our approach by several examples that were generated by the Focus+Context functionality of our visual analytics tool TedaVis.

Categories and Subject Descriptors (according to ACM CCS): Human-centered computing—Visualization—Visualization application domains—Visual analytics, Geographic visualization

1. Introduction

Getting insights of complex geo-spatial data is a difficult task. The exploration and analysis of such data can be facilitated by visual representations. This requires the depiction of both; the data space and the reference space. However, showing all the data at once, would inevitably lead to visual clutter.

Focus+Context is a widely used concept to engage this issue. It allows to concentrate on the most relevant parts of the data (focus), while simultaneously providing an overview on related information (context). Typical approaches consider a focus region either in the data space [DGH03, JKM03, NH06] or in the reference space [WC11, Tra13].

However, in certain application fields, such as applied geology or avionics, the characteristics of data as well as geometric features of the frame of reference need to be analyzed together. Hence, Focus+Context must also be applied to the data space as well as the reference space.

In this paper, we address the visual analysis of multivariate weather data within a 3D terrain presentation. To this end, we consider two types of foci—the *spatial focus* regarding the terrain and the *data focus* regarding the weather data. Both foci depend on each other, as the spatial focus can be derived from the data focus and vice-versa.

We introduce several strategies that enable the user to specify the focus as part of the 3D terrain, e.g., a certain path, or as part of the weather data, e.g., a certain value range. Based on this focus, the context for the terrain as well as for the weather data is computed automatically. Information in context regions are represented on a higher level of abstraction. However, due to the complexity of geo-spatial data and the terrain, it would still be hardly possible to communicate the context information without clutter. Therefore, we distinguish two different types of context: The *intermediate context* represents the 3D frame of reference and the data abstraction, while the *spatial context* shows only the frame of reference, e.g., for orientation purposes [ST11].

To emphasize the focus and to reduce information within the intermediate context, we describe various customized rendering strategies, tailored to the visualization of weather data embedded into a 3D terrain.

In sum, our contribution can be stated as follows:

- We apply the concept of Focus+Context to the visualization of weather data embedded into a 3D terrain.
- We provide several strategies to specify focus regions with respect to terrain and data, in order to support fundamental analysis goals.
- To assist the user, we compute context regions with respect to given constraints automatically.
- We discuss different rendering strategies to represent terrain and data with either more or less detail and prominence for Focus+Context.

The remainder of the paper is structured as follows. Section 2 introduces the general approach. We explain how Focus+Context is defined for the terrain and the data respectively, and how this affects interaction and presentation. In Section 3 we go into detail,
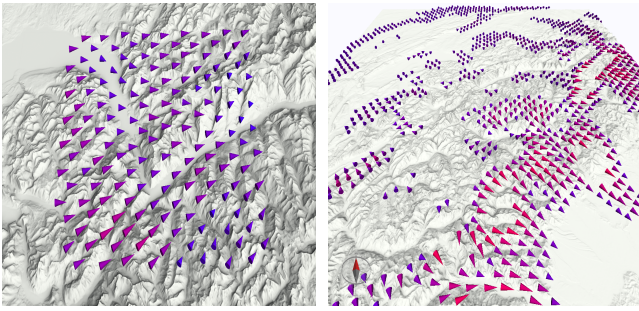
Figure 1: *Direct lookup (left) and inverse lookup (right) on wind glyphs above 3D terrain.*

how Focus+Context is realized with our 3D visual analytics tool TedaVis and how it supports analysis of weather data embedded in terrain. Section 4 concludes the paper and discusses future work.

2. Focus+Context for geo-spatial data visualization

For a long time, the Focus+Context approach has been subject of extensive research. Hall et al. [HPK*16] give a comprehensive overview on the different strategies. They distinguish between *foreground*, *midground* and *background* sets of data points. Thus, they discern the same three regions as we do: a focus, a context and an intermediate region. Preim and Bartz [PB07] also distinguish between *Focus Objects*, *Near Focus Objects* and *Context Objects* with a similar semantic concept. However, in both works the discussed approaches refer only to one Focus+Context region. In contrast, we differentiate between Focus+Context for the reference space and the data space separately. Trapp et al. [Tra13] particularly survey Focus+Context techniques for geo-spatial data. To this end, they consider spatial Focus+Context regions as well. However, the summarized approaches mostly consider 2D maps and not 3D terrain.

Our approach can be described as follows: We distinguish between a spatial focus and a data focus. The *spatial focus* can be located at a point (e.g., a landmark), along a path (e.g., a trajectory of an aircraft) or within a volume (e.g., the airspace around an airport). The *data focus* can be either a single attribute value (e.g., condensation point) or an interval of attribute values (e.g., hazardous weather conditions). By specifying one type of focus, the other one can be determined automatically. Thus, if a spatial focus is specified, the corresponding data focus consists of all data points within the selected region. Likewise, if a data focus is specified, the spatial focus consists of all regions where these data values occur. This corresponds to the elementary tasks of exploratory analysis of spatio-temporal data—direct and inverse lookup [AA06]. For direct lookup, the user is interested in *what* data values are located at a certain spatial region. Consequentially, one selects this region to specify the spatial focus. For inverse lookup, the user wants to know *where* certain data values are located and thus, selects the data focus. In Figure 1 this procedure is illustrated for terrain-embedded wind glyphs.

Since there are two types of foci, there are also two types of context: the spatial context and the data context. Both types of context contain abstracted information. However, just reducing details

might not be sufficient to keep visual clutter under control, for instance due to a rather complex frame of reference or because of too many data elements. Therefore, it is reasonable to show data only for a sub-region, the *intermediate context*, whereas the remaining context, the *spatial context*, depicts solely the terrain. In this way, the intermediate context forms a transition between the focus, and the spatial context. This matches the midground concept of Hall et al. [HPK*16].

To specify different types of focus and context and to create tailored visual representations for both regions, we developed the following procedure that consists of three fundamental steps:

i. Selection of foci: Initially, either a spatial focus or a data focus needs to be selected. The other focus is determined automatically. There are two ways to select the focus:

- *Predefined:* The focus is selected by the system. For example, the spatial focus can be calculated from the current user position or from a given path. Similarly, the data focus can be calculated from predefined data constraints.
- *Interactive:* The focus is selected interactively by the user. The spatial focus can be selected by positioning a 3D-Lens [TGBD08], whereas the data focus can be specified by selecting relevant attribute value.

ii. Computation of contexts: Based on the focus, the intermediate context is computed. This can be done in two ways:

- *Based on spatial relationships:* The intermediate context is determined depending on the distance to the spatial focus.
- *Based on data relationships:* A similarity measure is computed. Regions, which show similar data values, are assigned to the intermediate context.

The remaining regions form the spatial context.

iii. Adjustment of the visual representation: The final step is the adjustment of the representation of terrain and data within focus and context. Focus areas are emphasized and represented in detail, while context areas are de-accentuated and show less detail in order to provide an overview. There are various strategies to emphasize data representations [HPK*16], which can be applied. We decided to apply the following three widely used approaches: *abstraction*, *highlighting* and *distortion*.

In the following section, we will describe this approach in more detail.

3. Design and Implementation

Building on our visual analysis tool TedaVis (Terrain and Data Visualizer) [DRTS17], which provides a rich functionality for interactively visualizing data within 3D terrain, we implemented our described Focus+Context concept. For this purpose, we inserted a pipeline that matches the three-step procedure as described in the previous section: focus selection, computation of the context, and rendering. The last step of the pipeline can utilize the provided rendering functionality of the tool. Hence, several types of weather data can be presented in various ways. However, for reasons of simplicity, we will demonstrate our Focus+Context extension only by
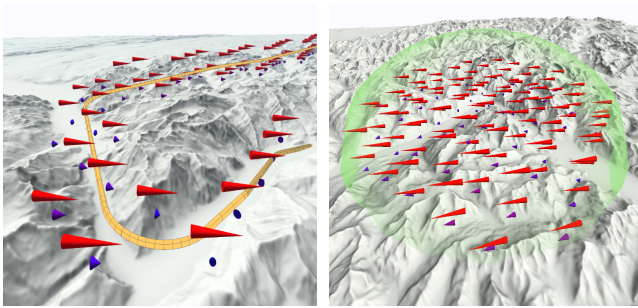
Figure 2: *The focus can be predefined along a path (left), or selected interactively by the user, using a 3D lens (right).*

Figure 3: *The intermediate context can be computed, using spatial relationships (left), or data relationships (right).*

the example of drawing wind glyphs. The glyph encodes the wind direction through its orientation, and the wind speed through its length and color.

3.1. Focus selection

Our extended tool provides multiple options to specify the focus. A predefined spatial focus can be set either by the current position of the user, or along a path. In the first case, the corresponding data focus captures information in spatial proximity of the user. This facilitates an intuitive exploration of weather data by interactively navigating through the terrain. In the second case, the spatial focus captures information in the neighborhood of a trajectory. This allows, for instance, analyzing weather conditions along a flight path of an aircraft (Figure 2(a)).

The interactive focus specification can be achieved by different selection techniques [ZTM*13]. In order to define a spatial focus, our tool supports a 3D Lens as suggested by Trapp et al. [TGBD08]. In our implementation, the shape of the lens is either a sphere or a cuboid. The spatial focus will be determined by positioning the lens within the terrain (Figure 2(b)). Our tool ensures interactive frame rates while gathering the corresponding data values and updating the rendering accordingly. Hence, moving the lens within the 3D terrain facilitates an interactive data exploration.

The data focus, however, will be specified through the GUI of our tool. The user selects particular attribute values or a data range of interest to set the data focus. Afterwards, the corresponding regions of the terrain will be computed and rendered accordingly.

3.2. Computation of the intermediate focus

The computation step addresses two tasks: computing the intermediate context and gathering the corresponding data. The intermediate context is computed based on spatial or data relationships. Spatial relationships support the understanding of spatial correlations, whereas data relationships communicate data correlations. In our software, spatial relationships are utilized automatically, if a spatial focus was selected. To this end, regions in a specified Euclidean distance are assigned to the intermediate context. The threshold can be interactively adjusted and directly affects the size of the intermediate context. Likewise, if a data focus was selected, our software
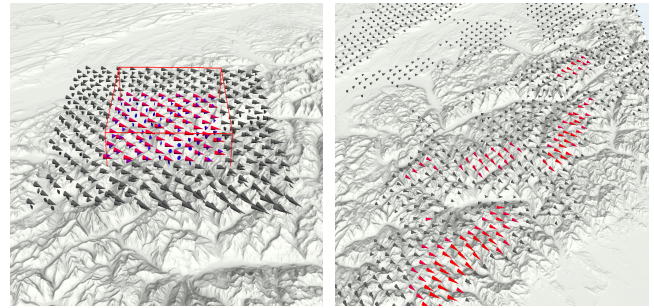
utilizes data relationships. In general, different similarity measures would be applicable. For the purpose of illustration, we apply a simple distance measure: Two data values are considered as similar, if the difference of these values is smaller than a given threshold. If a data range was specified, the same measurement is applied to the endpoints of the interval. Figure 3 shows the intermediate context calculated either by a spatial (a) or an attributive relationship (b).

After gathering the data of the intermediate context, the rendering step is carried out.

3.3. Rendering

Finally, appropriate representation styles need to be chosen, in order to accentuate terrain and data in focus, while de-accentuating them in intermediate context. For that purpose, our tool provides three commonly used render techniques: abstraction, highlighting and distortion.

Abstraction Abstraction [EF10] is used to simplify the visual representation and refers to both; *what to show* and *how to show*. Abstracting the data leads to a reduced amount of information to be visualized. Abstracting the visual encoding leads to less complex visual primitives. We apply these concepts for terrain and data.

For abstracting the terrain representation, we render just silhouettes and contours, rather than shaded surfaces (Figure 4(a)). For data abstraction, we aggregate data values in spatial proximity, e.g. by averaging. After aggregation, one data point—in our case one wind glyph—replaces a set of data points. In this way the number of data elements is reduced in order to provide an overview. On top of that, the glyph can be visually simplified. For instance, instead of encoding wind direction and wind speed, a simplified glyph would only encode directions through its orientation. This visually de-emphasize the glyphs in the context (Figure 4(b)).

The degree of visual abstraction for terrain and data can be steered separately. Moreover, due to the fact that we can apply the entire rendering functionality of our visual analytics tool, we have many more different options for adjusting the Focus+Context display (cf. [DRTS17]).

Highlighting Highlighting addresses the aspect *how to show*. It aims at accentuating information in the focus in order to guide the
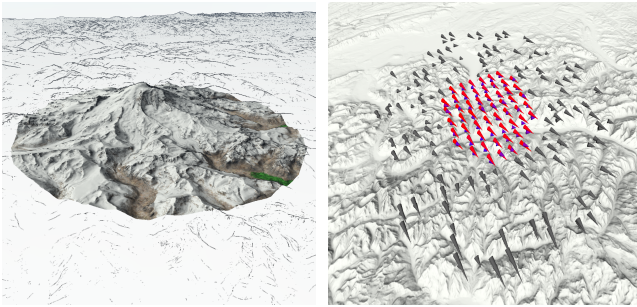
Figure 4: *Visually abstracting the terrain representation (left), or the data representation (right).*
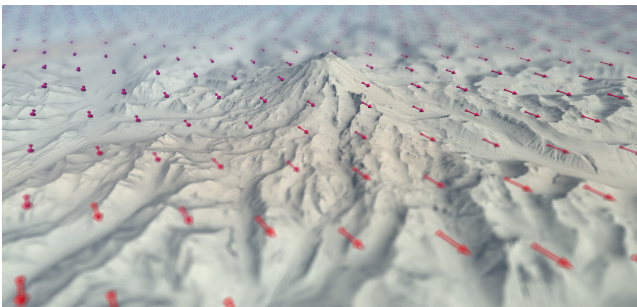

Figure 5: *De-emphasizing context information using depth-of-field to show data and terrain in focus crispy, and context areas blurry.*

user's attention [Rob11, TBPD11]. Highlighting can be achieved by emphasizing the focus or by de-emphasizing the context. To keep the visual presentation in the focus consistent, we only de-emphasize the context. We implemented two highlighting methods: adjustment of color and depth-of-field.

The colors are adjusted by decreasing brightness or saturation. In the context, the geometry of the terrain is rendered with less light, and the glyphs are represented with de-saturated colors. This de-emphasizes context regions.

Depth-of-field simulates the focal area of a real-world camera and thus depicts areas in focus sharply and blurs the regions outside. This matches nicely with the concept of Focus+Context. Our tool provides a corresponding depth-of-field technique that blurs context areas as seen in Figure 5.

Distortion   Distortion [LA94, CCF97, CKB09] also addresses the aspect *how to show*. They decrease the space in the context area, but enlarge the space in the focus area. In our case, data and terrain are connected via fixed spatial relationships. Therefore, distortion always affects the representation of data and terrain simultaneously.

We apply this concept with care. To facilitate the interpretation of size and distances, only well-defined scaling steps are possible. More precisely, we use a piece-wise linear scaling in power of two (Figure 6). Moreover, to visually communicate where the boundaries of the enlarged and the compressed regions are located, we depict the borders either through lines or through halos (Figure 2(b)).
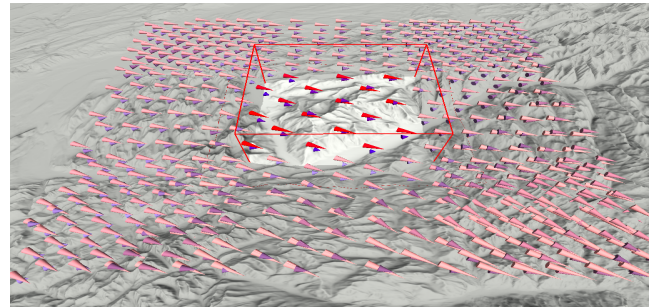

Figure 6: *Using distortion to enlarge the focus region and compress context regions.*

4. Conclusion

The overarching goal of our work addresses the visual analysis of geo-spatial data embedded into a three-dimensional terrain. Based on the given analysis tasks, however, not all information might be relevant, and should be communicated at the same degree of detail. Depending on the complexity of information, this might even be impossible. To solve this problem, we apply a Focus+Context approach. We distinguish between two types of foci: data focus and spatial focus. Thereby the fundamental exploratory tasks for geo-spatial data analysis can be supported: direct and indirect search [AA06]. Besides spatial and data context, we specify an additional intermediate context. The intermediate context represents the terrain and data from the data context in an abstracted manner, whereas the spatial context just depicts major features of the terrain. Moreover, we developed a three-step procedure to generate appropriate Focus+Context displays, and integrated it into our visual analytics tool.

There are several research options for future work:

- Selection of data focus: So far, the data focus can only be selected by specifying a range of relevant data values. However, the user might want to use more complex operators to select important data. For instance, the user might want to brush certain data characteristics in a visualization of the data space as suggested in [ZTM*13].
- Computing the intermediate context: Currently, the intermediate context is determined by either spatial distances or data similarity. We could imagine to apply further strategies, such as constructing the intermediate context from regions that have previously been in focus, or to let the user set the context interactively.
- Representation of the focus: Though the data focus specifies the most important information, it cannot be guaranteed that this data is visible in the user's view. One way to engage this problem might be adding visual cues that lead to hidden information.

Besides these more technically driven tasks, a major issue for future work is evaluation. We developed the approach in tight co-operation with our domain experts, and thus we can state that it matches their requirements. However, further tests are necessary. Hence, we plan an evaluation with users of our partners.

References

[AA06]   ANDRIENKO N., ANDRIENKO G.: *Exploratory analysis of spatial and temporal data: a systematic approach*. Springer Science & Business Media, 2006. `doi:10.1007/3-540-31190-4`. 2, 4

[CCF97]   CARPENDALE M. S. T., COWPERTHWAITE D. J., FRACCHIA F. D.: Extending distortion viewing from 2d to 3d. *IEEE Computer Graphics and Applications 17*, 4 (1997), 42–51. 4

[CKB09]   COCKBURN A., KARLSON A., BEDERSON B. B.: A review of overview+detail, zooming, and focus+context interfaces. *ACM Comput. Surv. 41*, 1 (Jan. 2009), 2:1–2:31. `doi:10.1145/1456650.1456652`. 4

[DGH03]   DOLEISCH H., GASSER M., HAUSER H.: Interactive feature specification for focus+context visualization of complex simulation data. In *Proceedings of the Symposium on Data Visualisation 2003* (Aire-la-Ville, Switzerland, Switzerland, 2003), VISSYM '03, Eurographics Association, pp. 239–248. 1

[DRTS17]   DÜBEL S., RÖHLIG M., TOMINSKI C., SCHUMANN H.: Visualizing 3d terrain, geo-spatial data, and uncertainty. *Informatics 4*, 1 (January 2017), 6. `doi:10.3390/informatics4010006`. 2, 3

[EF10]   ELMQVIST N., FEKETE J.-D.: Hierarchical aggregation for information visualization: Overview, techniques, and design guidelines. *IEEE Transactions on Visualization and Computer Graphics 16*, 3 (2010), 439–454. 3

[HPK*16]   HALL K. W., PERIN C., KUSALIK P. G., GUTWIN C., CARPENDALE S.: Formalizing emphasis in information visualization. *Computer Graphics Forum 35*, 3 (2016), 717–737. 2

[JKM03]   JANKUN-KELLY T. J., MA K.-L.: Moiregraphs: radial focus+context visualization and interaction for graphs with visual nodes. In *IEEE Symposium on Information Visualization 2003 (IEEE Cat. No.03TH8714)* (Oct 2003), pp. 59–66. `doi:10.1109/INFVIS.2003.1249009`. 1

[LA94]   LEUNG Y. K., APPERLEY M. D.: A review and taxonomy of distortion-oriented presentation techniques. *ACM Transactions on Computer-Human Interaction (TOCHI) 1*, 2 (1994), 126–160. 4

[NH06]   NOVOTNY M., HAUSER H.: Outlier-preserving focus+context visualization in parallel coordinates. *IEEE Transactions on Visualization and Computer Graphics 12*, 5 (Sept 2006), 893–900. `doi:10.1109/TVCG.2006.170`. 1

[PB07]   PREIM B., BARTZ D.: *Visualization in medicine: theory, algorithms, and applications*. Morgan Kaufmann, 2007. 2

[Rob11]   ROBINSON A. C.: Highlighting in geovisualization. *Cartography and Geographic Information Science 38*, 4 (2011), 373–383. 4

[ST11]   SCHUMANN H., TOMINSKI C.: Analytical, visual and interactive concepts for geo-visual analytics. *Journal of Visual Languages & Computing 22*, 4 (2011), 257–267. `doi:10.1016/j.jvlc.2011.03.002`. 1

[TBPD11]   TRAPP M., BEESK C., PASEWALDT S., DÖLLNER J.: Interactive rendering techniques for highlighting in 3d geovirtual environments. In *Advances in 3D Geo-Information Sciences*. Springer, 2011, pp. 197–210. 4

[TGBD08]   TRAPP M., GLANDER T., BUCHHOLZ H., DÖLLNER J.: 3d generalization lenses for interactive focus+ context visualization of virtual city models. In *Information Visualisation, 2008. IV'08. 12th International Conference* (2008), IEEE, pp. 356–361. 2, 3

[Tra13]   TRAPP M.: *Interactive Rendering Techniques for Focus+Context Visualization of 3D Geovirtual Environments*. PhD thesis, University of Potsdam, 2013. 1, 2

[WC11]   WANG Y. S., CHI M. T.: Focus+context metro maps. *IEEE Transactions on Visualization and Computer Graphics 17*, 12 (Dec 2011), 2528–2535. `doi:10.1109/TVCG.2011.205`. 1

[ZTM*13]   ZHANG Z., TONG X., MCDONNELL K. T., ZELENYUK A., IMRE D., MUELLER K.: An interactive visual analytics framework for multi-field data in a geo-spatial context. *Tsinghua Science and Technology 18*, 2 (April 2013), 111–124. `doi:10.1109/TST.2013.6509095`. 3, 4