Overview of Methods of Visualisation and Navigation in the Context of Maps and Geographical Data
HCI Winter School Literature Review : Group 7

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ABSTRACT

In geovisualisation, the datasets used are often quite extensive. There can be multiple dimensions to the variables of interest, making it complicated to represent the data understandably for exploration and analysis. Moreover, the standard multi-scale navigation techniques are cumbersome to use and not adapted to tasks such as comparing objects of interest and collaborative work.

In this paper, we present a brief overview of geovisualisation, layer compositing, and multi-scale navigation. We cover the methodology of visualising multidimensional data and how animation can represent and visualise geographical data. Moreover, we present the studies and techniques to increase the capacity for visualising, compositing, and navigating geographical maps and big datasets. Visualisation and navigation techniques are highly dependent on the domain, datasets and tasks. Thus we try to present a diversified view of the methods from various fields.

1 INTRODUCTION

In this paper, we discuss the studies regarding geovisualisation and map navigation techniques. We further investigate the effectiveness and preference of these techniques.

Geovisualisation is a short term for Geographic Visualisation, which can be defined as a set of tools and techniques to support geospatial data analysis through interactive visualisation [17]. Geovisualisation also focuses on information transmission. Therefore, We explore diverse representation approaches concerning various geospatial datasets and their evaluation of how efficiently users complete exploratory tasks.

Due to the complexity and the large amount of geographic data, the representation is challenging, especially considering geospatial data integrating with temporal data and thematic variable. Therefore, We show particular interest in multidimensional data and layer compositing. We outline the visualisation in terms of dimensions, such as two-dimension, three-dimension, and virtual reality. Considering temporal data as a significant component in geographic data, we classify it into no time, time intervals, real-time, and animation. Furthermore, we explore layer compositing techniques, which composite thematic layers to correlate often geospatial data. The studies regarding these techniques investigate the interaction, effectiveness, and user preference, providing suggestions for designing better geographic information system under various conditions.

The map plays a crucial role in geovisualisation. It is the most direct and widely-used method of representing geographic data. Thus, we explore the effectiveness, the capacity, and navigation techniques of maps. Maps transmit information, so navigation techniques become essential for exploratory tasks due to the limited space for representation. Multi-scale navigation is defined as "spatial navigation in a multi-scale visual space, which is a space that has different visual representation depending on the zoom used to view the space" [16]. This navigation requires multiple techniques, but there is only a limited set of techniques for tactile surfaces such as pan, zoom and gestures. These techniques are not fully adapt to specific tasks due to the design purpose of general use or the **desert fog**[1] phenomenon. We explore relevant researches discussing the advantages and limitations of navigation techniques.

2 RELATED WORK

Visualisation and navigation serve various tasks, from highly analytical tasks to navigating maps on personal devices for everyday use. Therefore, we aim to introduce the researches and tools in the context of spatio-temporal geovisualisation, the use of animation in geovisualisation, their layer compositing, and multi-scale navigation for single users and multiple users.

2.1 Geovisualisation for Space-time and Multivariate Data

Complex data sets that contain geographic locations, time series, and multiple variables have become a common but underutilised resource in many domains [6], and geographic information is no exception [11]. According to Guo et al. [6], the problems can be defined as computational efficiency problem and the visual effectiveness problem. Due to our research interest in visualisation and interaction, this paper focuses on the visual effectiveness problem, which concerns each geovisualisation technique's capability of allowing users to explore correlation and gain insights from the spatio-temporal and multivariate data set.

Time is a key attribute in the data analysis [6], which is also an essential component in geovisualisation. According to Peña-Araya et al. [24], the space-time display can be categorised into juxtaposing time and juxtaposing location. The most common way of juxtaposing time approach is to use glyphs on top of a single map

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[1] the immediate environment in the viewport is devoid of navigational cues due to its multi-scale nature.

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in 2D or 3D, while juxtaposing location method is the small multiple techniques which juxtapose multiple small maps at the same time in terms of different periods. The animation is another approach to juxtaposing time. Nevertheless, we distinguish animation into another section due to its particular features.

Peña-Araya et al. [24] focused on evaluating the 2D static visualisation strategies which combine spatial and temporal data into one visual representation. The strategies associate two variables: juxtaposing time or space, and encoding variables using symbols overlaid on top of map features or visual channels of the map features. The researchers compared how effective users identify the correlation between various thematic variables in terms of different combinations and granularity levels of both space and time. The result shows that the small-multiples technique, which juxtaposes values for all locations at a given time step, is best for representing spatial complexity data. On the contrary, the technique juxtaposing time data on a single map effectively represents temporal complexity data.

Compared with Peña-Araya et al.'s research [24], Guo et al. [6] discussed the visualisation based on larger and more complex data set. They developed a geovisual analytic approach regarding complex patterns across multivariate, spatial, and temporal dimensions. The approach integrates multivariate abstractions and matrix views to visualise spatial-temporal multivariate patterns by implementing self-organising maps and parallel coordinate plots. The matrix is reorderable, allowing users to organise and reveal multivariate patterns in various views. The representation is small-multiple base. According to Peña-Araya et al.'s result [24], Guo et al.'s application [6] has the advantage of presenting multivariate and complex spatial data set, but sacrifice the effectiveness for presenting temporal complexity data.

Jankowski et al. [12] expanded the use of map, suggesting that map-based visualisation can be a decision support tool in multi-criteria spatial decision-making beyond the use for completing exploratory tasks. They propose three principles. First, the integrated visualisation of criterion and decision spaces can open up an opportunity to observe the correlation between data and spatial patterns. Second, decision-makers can explicitly select candidates for the solution by selecting them directly on a map. The last principle is the designers should reduce the cognitive complexity for users. Following these principles, Jankowski et al. create a prototype and validate the effectiveness in making decisions, pointing out a new direction of map-based support for decision making.

Apart from the widely used flat map, 3D visualisation can be a new solution. Amini et al. [1] explored 3D maps' advantages with a third axis to represent time. The experiment evaluates 2D and 3D visualisation of movement data on how effectively users understand the correlation between space and time. The comparison shows that 3D visualisation performs better when users need to examine sequences of events to identify a complex behaviour within object movement data set. Participants also have a strong preference for 3D visualisation in subjective evaluation.

The spatio-temporal movement data can be visualised in a virtual environment as well. Filho et al. [7] investigated immersive space-time cubes to represent movement trajectories. Users can interact with the map by mid-air hand gesture, which has a lower mental workload than 3D application. The virtual application performs better than traditional desktop-based application in the subjective evaluation due to the intuitive and tangible control. The quantitative measurement, however, does not show a significant difference between VR and 3D.

Considering movement data, we cannot ignore the use of real-time maps for monitoring traffic. Nevertheless, most of the researches [2, 10] focus on improving the algorithm for generating live maps due to the nature that systems need to real-time process a large amount of data, which is the computational efficiency problem that we will not discuss in this paper.

2.2 Animation

Monitoring and understanding the geographic changes and movements across space and time are essential, but it can be challenging for both designers and users, considering a large amount of geodata. The animation can be a unique solution.

Peña-Araya et al. [23] compared the animated maps against small-multiple maps and a single map with glyphs. Evaluating by undertaking five analysing tasks (*scope*, *direction*, *speed*, *peaks*, and *spatial jumps*). They concluded that small multiple map visualisation performs best overall. Yet, both animation and maps with glyphs outperform them for some tasks (*scope* and *arrival* for maps with glyphs; *direction* and *hops* for animated maps). Especially, the animated maps obtain the highest self-reported confidence score.

As mentioned before, changes are essential for understanding geographical processes and, while simple animations of satellite time-series data are capable of using, they also represent data that is irrelevant or not presented in the proper resolution. Harrower [9] tried to solve the problem by proposing a geovisualisation system called *VoxelViewer*. With dynamic temporal and aggregation tools, the application allows users to control the size represented by a pixel and the temporal intervals, and therefore the resolution. The particular interface components enhance usability, providing better animation control and a closer association between animations and results. Nevertheless, while the efficiency had not evaluated yet, it provides exciting ideas that enable users to identify changes and filter unnecessary data, allowing users to focus on the critical dynamics.

Before-and-after images are also beneficial to visualise the effects of natural phenomena or human activity. Lobo et al. [19] introduced *Baia*, an animation model that generates intermediate images between a "before" and an "after" picture using animation plans, generating animations where images change pixel by pixel. *Baia* aims to receive better attention from users, increase the capacity for identifying changes from multiple images, and allow users to present more accurate depictions by the dynamics rather than by classic monolithic blending animations. Lobo et al. compared the pleasantness and the realism of *Baia*'s progressive satellite animations with uniform animations. The result indicates that the new kind of animation is more realistic and delighting. Lobo et al. also developed an animation creation tool based on *Baia* framework. The completion time was measured by asking participants to replicate the showed animations. Users can generate accurate replications in an exceptionally short amount of time (average 7.8 minutes).

The limitation of *Baia*, however, is not suitable for depicting moving objects. Lobo et al. proposed implementing explicit encoding as a potential solution for the future. *Baia* also has the potential to apply to images with different spatial alignments other than satellite images.

2.3 Layer Compositing

Layer compositing is a powerful tool for users to correlate geographic data. Layers often represent thematically spatial data. Therefore, different layers need to composite by the same position to gain insights [13].

Lobo et al. [20] outlined five most commonly used map comparison techniques: *Juxtapose, Translucent Overlay, Swipe, Blending Lens*, and *Offset Lens*. The techniques employ two operators: juxtaposition and superimposition [8, 14]. *Translucent Overlay* completely implements superimposition which overlaps layers but has the highest level of visual interference; *Juxtapose* uses juxtaposition which displays the layers on the screen simultaneously but tends to divide users' attention the most. Other techniques represent the trade-offs between visual interference and divided attention. Each technique infers a different scanning or comparison strategy. *Translucent Overlay* fully implements a visual-driven scanning strategy; *Swipe, Blending Lens*, and *Offset Lens* implements motor-driven scanning strategies.

The research evaluated each technique of how effective do users identify the difference between the two layers. The result shows that *Translucent Overlay* is the best choice while implementing only one technique. Additionally, the combination of *Translucent Overlay* and *Blending Lens* can be considered because *Blending Lens*, a strategy when two images are superimposed consisted of using a magic lens [4] to show the lower layer in a locally-bounded region around the cursor, performs better in some case and is the best motor-driven scanning strategy.

The continuous research [18] implemented the insights of using *Blending Lens* [20]. They developed MapMosaic, a new approach based on dynamic visual compositing. Unlike traditional static and monolithic layer compositing, Users can dynamically filter out the components on each map layer. This interaction model helps GIS experts explore data from multiple layers more effectively than existing systems.

Since *Translucent Overlay* is the best scanning strategy [20], it is not surprising that overlaying images is the most commonly used and discussed technique [5, 21]. Luz and Masoodian [21] manipulated the foreground layer's transparency to evaluate the effectiveness of *Translucent Overlay*. The result demonstrate that 50% of transparency is an ideal design. Nevertheless, the map interpretation task and the map region type both significantly affect map readability. Additionally, Brewer et al. [5] compared the readability of topographic map designs following *Translucent Overlay* principle. The orthoimage design varies by colour, hillshade, vector features, and translucency. Nevertheless, the result shows that the factor which significantly influences the readability is not the map design but the location.

Spur et al. [28] provided a study for presenting multilayered geospatial information in virtual reality. They implement a multiple and coordinated design using vertical stack and assessment from their user study. Additionally, they compared the novel design with other traditional methods: the grid of layers and switching layers. The subjective and objective evaluations show that no one system is universally better, only better suited for specific users' reading behaviours. The result infers that the flexibility of exploring geospatial data may be necessary.

2.4 Multi-scale Navigation

Multi-scale visual spaces, such as maps, allow us to show significant and detailed datasets can be quite complicated as it does not fit on the screens we have, but to navigate those spaces the tools called "multi-scale navigation techniques" are needed. Therefore, in this section, we will present some general navigation techniques and point out some research done on multi-scale navigation for group work on tabletops.

Navigation techniques for single user

Multi-scale navigation is becoming increasingly important for everyday tasks, and there is a limited set of techniques (Pan, Zoom, fisheye lenses) and gestures (slide, pinch, rotate) for navigation. Therefore, many researchers face the challenges of improving or developing more effective navigation techniques.

Considering the problem of multi-scale navigation for visualisation of one-dimensional temporal information on mobile phones, Pelurson and Nigay [22] chose to use pressure-based gestures to minimise screen occlusion. Pressure-based gestures are bimanual gestures relying on using the non-dominant hand to apply pressure and the dominant hand to navigate to minimise screen occlusion. Thus, they designed four different pressure-based gestures (continuous, continuous inertia, discrete, discrete inertia), then compared their performance with touch gestures (drag-flick and drag-drop). As a result, the continuous pressure-based gesture and drag-drop are the fastest gestures, proving an advantage to using pressure-based gestures since they can be as fast as touch ones and reduce screen occlusion.

On the other hand, for the two-dimensional multi-scale visual space, Fisheye lenses with spatial distortion were critiqued for not always matching the shapes of objects of interests, so objects with less interest from users can be intruded in focus view. To address this issue, Pindat et al. [25] came up with *JellyLenses*: two interactive focus+context techniques, *PathLens* and *AreaLens*, which adapt the the geometry of objects of interest dynamically. *PathLens* is a deformable lens that is circular by default and tries to adjust itself to fit the shape of the closest object of interest. *AreaLens* using a dispersion mapping and a magnification mapping to consider multiple objects of interest in an area of interest. The cited study evaluated *AreaLens* by comparing it to classic fisheye lenses and found that it was both faster and preferred by the users. They did not evaluate *PathLens* in this study and suggested that further work could give a better insight on the strengths and limitation of both *AreaLens* and *PathLens*, which would be interesting as they were designed to be complementary and used together. They also suggested broadening the concept to other navigation techniques than zooming, like rotation, and involving the user more by specifying the objects of interest.

PolyZoom, introduced by Javed et al. [16], is another technique which allows focusing on the object of interest but without the distortion of the lenses is *PolyZoom*. This technique enables users to build a hierarchy of focus regions without losing the whole space's awareness (overview). *PolyZoom* also allows to simultaneously visualise several hierarchies of focus regions to compare them side by side, without distortion or overlap between the focus regions. In addition, this tool automatically adjusts the size of the views depending on their level of the hierarchy and whether the user activates them, and it makes the relationship between parents and children explicit by using colour-coded frames and links. They conducted two studies with standard techniques (Pan and Zoom) to validate this new technique: (1) the first one compares their performance on multi-scale visual search, by asking the participant to find a target in the lowest scale level, this task required them to navigate through different visual cues (views) in each level of scale, and (2) the second study compares them on multi-focus interaction by asking users to compare potential targets to a specific source object. These two studies concluded that *PolyZoom* performs slightly better than the current standard techniques.

Similarly, but in a more concrete example, Wang et al. [31] proposed an algorithm that can generate hierarchical route maps to facilitate navigation by following a route. They developed this method for frequently zooming in and out while navigating maps. Their algorithm receives route data from search engine and then evaluates its scale. Next, it initiates tree construction and then optimises it. Authors implements two applications using their algorithm: *Route-Zoom*, and *TreePrint*. Furthermore, they run a user study to evaluate *RouteZoom* application. Finally, their result shows that users can follow a route with less interaction with their device.

Prouzeau et al. [26] also worked on traffic control, but from a supervision point of view, by developing a prototype that runs on a wall screen and supports direct touch and input from workstations and mobile devices. This prototype includes traffic simulations to predict the outcome of possible actions that highlight differences between them and current traffic. They provide two techniques that visually combine simulated and realistic situations on large display space. These two techniques are *Multiviews* [15, 30] and *DragMagic* [3]. According to their experiments, *DragMagic* performs slightly better than Multi-Views as the number of simulations increases, but when the number of area of interest increases, there is no difference between *MultiViews* and *DragMagic*.

Navigation techniques for Multi-users on tabletops

Tabletops are useful for group work, but they still lack multi-user systems, either because of hardware limitations or software ones. Due to this limitation, Tse et al. [29] applied a multi-modal multi-user interaction through speech and gestures in a single-user application on tabletops. The design was implemented on *Google earth* and *Warcraft III* with different settings of gestures and speech commands for each one by directly mapping each command to either a keyboard or mouse command. They analysed the feasibility and limitation of single user application for multi-user interaction on tabletops on different levels (Orientation, full views, feedback and feed-through, interacting speed and gestures, mapping, and turn taking) which demonstrated some benefits to their design like the simplification of commands for google earth, or the high level

of awareness that we can't find on distant separated users of shared window systems.

Similarly in the context of tabletops allowing group work but intending to identify gestures and navigation techniques for tabletops, Rusnak et al. [27] conducted a guessability study to explore the gestures users will associate to a separate action on tabletops in the present of the conflict of specifying the target. Rusnak et al. then used the result of the first experiment to develop two interface designs differing in the way to specify the target for the action : (1) the first design is gesture-based and rely on using non-dominant hand to specify the target, and (2) the second one use widgets. Comparing these two interface designs demonstrates that both of the designs are quickly learned by the user, suggesting that it is best to use the visually minimalistic one (gesture-based navigation), which allows adding more context-related functionalities in the application.

3 CONCLUSION

Geovisualisation and its extending navigation aim to help users explore geographic information. Thus, most of the literature discusses the techniques' effectiveness of completing exploratory tasks from different perspectives.

We discuss the methodology of visualising data across space, time, and multivariate data. Each data set has its dominant 2-dimensional representation strategy, which can be different from others. 3-dimensional and virtual reality maps improve interaction and usability compared with traditional maps.

Animation can provide handy tools for visualising geographical changes and movement, even though it has limitations. It cannot be perfectly realistic due to the need for creating intermediary images. Nevertheless, viewers benefit from the process's dynamic, which catches users' attention and brings pleasure.

The literature regarding layer compositing introduces various techniques to composite thematic map layers. The compositing strategy, interaction style, region type, and user task mutually influence the readability and user preference. There is no all-in-one layer compositing solution.

Moreover, the research on multi-scale navigation focuses on investigating the limitation of its set of tools for expansion and adaption based on users' needs. The improvement can be inspired by the performance of *PolyZoom*, lenses and the various gestures for navigation, or the capacity of collaborative works by speech and gesture commands.

In sum, each technique has an advantage in a particular situation. Geovisualisation and map navigation is based on the geographic data set. Thus, the performance is highly related to the user task, data complexity and characteristics. While implementing the technique, designers need to identify the purpose and information behind to develop the most suitable application. Some of the researches show differences between individuals. Therefore, providing flexibility to switch between different visualisations and techniques is also recommended.

This paper remains a brief overview and does not give a complete view of the subject, but it gives insight into various techniques that have been used and what can be done on the topic.

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Some sections are very well-written, some are OK, and some are really hard to follow. Still, you've looked at a lot of literature and it is mostly coherent. Good job.