Multiple Views in Immersive Analytics

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ABSTRACT

We consider the challenges and potentials for multiple views when applied in immersive analytics. The changes in physical setup of very large and possibly multiple displays, potentially combined with smaller handheld displays that can be used for both input and display augmentation, in addition to new input technologies, challenges much of current practice in multiple views. In particular: coordination techniques need to be extended for multiple views across multiple displays; we may need to re-examine task and interaction behaviour in new environments; collaboration challenges may come to the fore due to the potential for immersive technologies to provide more space for team analytics; and re-considering our formalisms in light of these changes may prove fruitful.

Keywords: Coordinated and multiple views, immersive analytics, view relations, formalizations, meta-visualizations.

Index Terms: H.5.m [Information Interfaces and Presentation (e.g., HCI)]: Miscellaneous.

1 INTRODUCTION

As the data we need to work with gets more and more complex, one response has been to visualize it in more than one view. Working with many visualization views allows people to break down information into different sets or variations of data, and, in this manner, helps them compare and reason about their data. Immersive technologies such as large and/or multiple displays provide opportunities for showing many views at the same time. Recent displays offer a combination of surface area and pixel density that provides previously unparalleled opportunities for allowing people to organise views, make sense of information, and to reach collaborative conclusions based on a shared information space.

Increasing the pixel count has been seen to provide three opportunities in visualizations and visual analytics. First, some work (e.g., [1]) has centred on using the pixel count to show larger information spaces than available from desktop computing systems in a single view that covers the entire display space. Occasionally, interaction allows movement within the view such as moving nodes in force-directed layouts or re-ordering axes in parallel coordinate plots. Second, some work (e.g., [2]) has subdivided display space into multiple views, each presenting some aspect of the data. Typically, these views are algorithmically positioned, and usually resulting in tiled views (sometimes according to the nature of the hardware). While possible, it is rare that these systems allow people to move views around. Third, some work (e.g., [3]), has argued that large displays provide a large working area, in which people can make sense of information by using human spatial abilities to organise the visualized data within a single large view. Whereas the first and second approaches mostly use technical layout algorithms to subdivide space, the latter relies on humans to create this organisation. In this position paper, we extend the ideas started in the introduction of canvas-based visualization tools (e.g., [4], [5]), exploring the potential of applying **human spatial organizational capabilities** to the re-organizing and re-positioning of **visualization views**. This calls for the introduction of **meta-visualizations** where meta-visualizations are visualizations of the relationships between views and all that the views contain. As the size, scale, pixel count, and number of the displays we are using in immersive analytics grows, so do the opportunities for employing interactions that offer spatial freedoms combined with meta-visualizations.

Thus, immersive technologies provide not only new opportunities for multiple visualization views to be organised spatially, but also opportunities to offer these options interactively. For example, large displays allow views to be spread over large areas, necessitating human movement (e.g. walking the length of the display) to look at different views (e.g., [6], [7]). However, several questions surface in doing so: What changes does the ability to use more display space for analysis bring for people doing the analysis? How do we communicate the relation between many views? And, how do we create a sense of shared space between surfaces and views?

Our prior research spans a large palette of areas in immersive analytics (e.g., [8]–[14]). Based on our work in this area, we carve out research themes in immersive analytics that relates to multiple views and view relations.

Coordinated and multiple views (CMV) is an established concept in visualization and visual analytics. However, while CMV is an active research area [15], we think that there is reason to consider systematic approaches to combining immersive analytics with coordination techniques and their design spaces, collaboration, and formalizations in relation to multiple views. We see several challenges ahead:

- How do we need to change how we think about coordination of multiple views when those views are presented across multiple displays?
- How do changes in display and input technology affect the type and manner of the tasks that can be done?
- How can we better understand how the expanded opportunities that multiple display environments offer for team and collaborative analytics?
- Can we re-assess our formalisms to develop a better conceptual understanding of new design spaces?

2 THEMES

We discuss four themes of research that relate multiple views to the changes brought about by immersive technology, laying out currently visible knowledge gaps and suggest interesting avenues to potential solutions. For each theme, we describe the theme, the existing research, and current gaps in knowledge, and point to possible directions for closing these gaps.

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2.1 Coordination techniques for multiple views

Coordinated and multiple views is an established concept in visualization and visual analytics. The multiple views arise from visualizing different aspects of the data. The coordination deals with showing how two or more views relate to each other. Coordination is most often done in terms of concrete data points that are shown in more than one view. For example, common coordination techniques often rely on brushing and linking – brushing which selects visualization details (e. g. data points or line links), and linking which reveals the connections to the appropriate data points by explicit links or by emphasis (see Griffin and Robinson [16] for a comparison between highlighting and linking coordination techniques). However, immersive analytics poses problems in this area. **First**, the mere existence of many views makes it necessary to have good techniques to understand their commonalities and differences [8]. **Second**, existing techniques scale poorly to many views. For example, if explicit linking via lines is used, the meta-visualization may become densely cluttered and thus, unusable. **Third**, input techniques map poorly between technologies. For example, brushing works differently with mouse and touch input. With mouse, hovering provides an easy access to brushing, whereas achieving comparable access via touch input is more challenging. Translating interaction techniques between technologies often requires additional research. While retrofitting visualizations is possible (e.g., [17]), it is unclear how most of the existing techniques could be used between surfaces or devices.

Research is active in this area. Roberts [18] discussed whether CMV research had been "solved" or if we had "barely scratched the surface". Recent work (e.g., [5], [8], [16], [19]–[21]) that has contributed new techniques for representing view relations and a continued use of the CMV keyword [15], suggests the latter. However, while many inspiring and useful designs are emerging, a more structured approach to this challenge might lead to a better understanding of the design space. It would be useful to consider, what are the many different techniques that have been proposed and in which contexts would each of them best be applied? To what extent can research on hybrid visualization techniques be applied? For example, composite visualization [22] shows fruitful results from this approach.

Considering coordination techniques with immersive analytics and multiple views might:

Break existing coordination techniques: The existing coordination techniques were designed for a situation of two to perhaps eight views. With immersive analytics, people might use more than ten or twenty views simultaneously. Brushing and linking might not always not scale to this degree. We have little knowledge of how well existing techniques scale and in which situations. Understanding in which cases existing techniques break can be useful. For example, understanding why they break might lead to a choice of avoiding these situations, or perhaps to greater knowledge about how to design techniques that overcome these issues.

Amplify the need for complex interaction techniques: Moving beyond the mouse and keyboard is crucial in immersive analytics. Recent work has described touch interaction techniques for single ([23]) and multiple [24] views. Additionally, proxemics has been considered in the context of information visualization [10]. However, moving beyond a few views has not yet been explored in this context. We think that proxemics with multiple views and large displays can be fruitful. For example, to keep information fixed in peoples' periphery when they move in front of a large display [9].

Amplify the need to understand the design space of multiple and coordinated view systems: As the number of views increase, it is becoming more important to understand how views relate to each other. However, previous techniques have primarily considered either linking data points in different views, or linking entire views. We see a need for exploring these design spaces to enable us to compare these disparate ideas, and potentially show new possibilities.

Reduce the need for some existing techniques: Some techniques were created for situations with limited display space. For example, pan-and-zoom and focus plus context techniques were created to allow people to navigate a large information space, without sacrificing detail. We think their use in the context of immersive analytics and multiple views might be less relevant, than on desktop or other smaller display form factors. However, due to the potential of a combination of devices in use in immersive analytics, these might continue to be highly relevant, even in immersive analytics.

As important as novel coordination techniques, we see a unifying description of the diverse existing techniques as a logical next step. This would allow us to compare the different techniques, and start a discussion about the relative advantages and drawbacks of each technique in specific situations.

2.2 Understanding tasks and behavior

Visualization tasks are central in information visualization research. While immersive technologies might change to the tasks that people need to do, it is more likely to bring changes to how we think about and model these tasks. For example, temporal and spatial dimensions of tasks might result in difficulties using current models. We can imagine immersive data analysis sessions that might last several hours and include many people. How do our current task models fit this expanded context?

Brehmer and Munzner [25] recently provided a flexible task typology. We think this is valuable in thinking about tasks in the context of immersive analytics. As a concrete example, we have observed people doing analysis work, constructing and using secondary views on a large display as tools that helps them solve their primary task. We see this behaviour as working on meta-tasks, and as relating the secondary views to meta-instruments in instrumental interaction [26]. While the task typology did not account for interleaving tasks, their model is easily adapted to fit our observations.

However, a range of open issues remain. For example, Brehmer and Munzner note that their typology does not address collaborative use of visualization tools. Isenberg et al. [27] show an example where collaboration might play a role in task models. They observed collaborators spending time discussing and planning their collaborative analysis process, which individuals working alone did not seem to spend time on. Also, while this model accounts for the creation of new artifacts (e.g., views), removing or filtering is only considered in the context of data. Can the process of deleting a view be described in any existing task models, and is this important?

With multiple views and immersive analytics, we:

Question whether existing task models are effective: Given complex analyses in the context of large displays that involves many views and occur over long stretches of time, existing models might be less useful, due to a more fluid allocation of tasks over time and space. Would we, for example, be able to use the multilevel task typology [23] to describe an analysis lasting or day, or is this beyond the possibilities of any existing task models?

Observe that the need to understand the role of a specific visualization in longer analysis processes is amplified: With immersive analytics, we think the boundary between menus, tools, and visualizations get blurrier. Some visualizations that, on their own, could be viewed to provide insights, might in a larger process, appear more as a tool to help achieve other insights? This might warrant considering e.g., instrumental interaction [26] in the context of visualization tasks.

To approach answering these questions requires more observational studies: both in terms of understanding collaboration and in terms of understanding how people conduct analysis with immersive technology. With this, we might, for example, be able to answer whether immersive technologies change temporal aspects of analysis. More importantly, these studies will provide new insights that we can use to build task models and to create better designs.

2.3 Designing for collaboration

With immersive technologies, the available display space increases to afford opportunities for collaborative analysis. Additionally, multiple devices can be utilised. These opportunities for collaboration change the design opportunities and goals of potential visualization systems. For example, in a collaborative context, global selection techniques might not be optimal. Instead, we might consider proxemics interaction techniques (e.g., [10], [28]–[30]).

Isenberg et al. [31] provided an excellent overview of collaborative visualization. As they note, collaboration in visualization has been considered both as combinations of co-located and remote, as well as synchronous and asynchronous. For immersive analytics, we primarily see a connection to co-located synchronous collaboration. A large part of the work in this area has focused on adapting interaction techniques for collaboration (e.g., [32]) and how to share visualization progress (e.g., [12]). Some insights from human-computer interaction can also be readily applied to immersive analytics (e.g., [33]).

It is less clear how the larger collaborative analysis process should be supported. Knudsen et al. [9] described how analysis provenance might be summarised by collaborators during co-located analyses. Dunne et al. [5] showed how keeping a provenance trail allowed collaborators to understand each other's analysis process, even though this work did not consider co-located work. However, neither of these provide designs that supports that broader collaborative analysis process. We suggest that the related literature of remote or asynchronous collaboration might provide further clues. For example, in their provenance review, Ragan et al. [34] found techniques related to collaboration, such as shared annotations, brushing and linking, and shared activity indicators.

Collaborating on immersive analytics, multiple views might:

Necessitate spatial and temporal scopes of interaction: When people use desktop computers or other individual devices, the spatial and temporal scope of interaction is clear. These limitations are not present when sharing a work area, for example provided by a large display. Can we use knowledge of visualization tools on desktops (e.g., [35]) to create novel solutions for immersive analysis? Lark [12] used the visualization pipeline to bring awareness to collaborators' work, and by that provided temporal and spatial scoping. Proxemics might also provide a way to scope interactions. However, other possibilities for scoping interactions might exist beyond these.

Amplify the need for a notion of view ownership: With immersive technologies such as large displays, collaborators might create many views. Thus, it is useful to have an overview of who created a view and potentially when. Additionally, people might combine or remove views. This relates to visualization provenance [34] which has mainly been considered on the desktop. However, the question of ownership becomes less clear with immersive analytics. For example, is it more important who created a view initially, or who last interacted with it? When a view is removed, should designers provide mechanisms to assure that collaborators agree on this action, or should they rely on social contexts?

Amplify the need for supporting many devices and situations: Collaborations often take the form of a mix of close and loose collaboration (e.g., [36]). Additionally, we have observed situations of analysis stretches that lasted multiple days, consisting of longer stretches of independent and collaborative work sessions. To imagine supporting these analysis situations, we think an important next step is to consider tools or systems that work across device types. However, a range of questions arise from this. For example, how should visualizations and visualization views adapt to display form factor? Likewise, how can collaborators take their insights with them after a focused immersive analytics session?

Amplify the need for annotating and recording visualization states: Based on the understanding that collaborations often take the form of a mix between close and loose collaboration (see previous point), we have seen a need for supporting annotation and recording summaries and conclusions (see e.g., [9]). But how might we summarise visualizations? What are the important parts of a long analysis session?

To take steps to provide broader support for collaborative analysis processes, we suggest taking inspiration from related literature, to create designs that support these needs. This might shed light on new challenges and opportunities.

2.4 Formalizations for multiple views

Immersive technologies necessitate a fresh look on formalizations in visualization and visual analytics. Part of the reason for this need is that these technologies have the potential to show many views at the same time.

Several models and formal descriptions have been proposed in information visualization. Bertin [37] provided the first systematization of graphics in terms of visual variables. Mackinlay [38] studied these empirically to understand and compare these. Visualization specification languages (e.g., [39]–[41]), visual query languages (e.g., [42], [43]), and formal notations for views (e.g., [11], [21]) have emerged more recently, along with models for visualization similarity (e.g., [44]–[46]). In the same vein, the first visualization pipeline model [47] was described almost twenty years ago. Subsequent suggestions of extensions include adding in presentation space [48] and extending the pipeline model to account for physicalizations [49].

Despite the many advances, these formalizations have not been considered in the context of multiple views. For example, a connection between the existing formalizations, and coordinated and multiple view techniques is unclear. Thus, taking any of two specifications of a visualization, can we explore potential techniques for showing their relation?

We think that multiple views in immersive analytics:

Amplify the utility of scagnostics: Helping people understand similarities and differences between visualization views are important, when they are faced with many similar views. We think that models of visualization similarities might be a useful way to do this. Scagnostics is one approach to considering view similarities, and has been applied in the context of recommender systems. Are these ideas also applicable in combination with existing coordination techniques?

Might warrant revisiting the visualization pipeline model: As outlined in this paper, immersive analytics might multiply the amount of views presented simultaneously. The visualization pipeline model only accounts for a single view at a time. We consider extending the pipeline model to include multiple views, and are curios about the benefits this might bring.

3 Conclusion

We suggest that there is a need to reconsider challenges and potentials for multiple views when they are applied in immersive analytics. We did so, since immersive technologies offer opportunities for showing many views, but at the same time causes many changes in the environment. Existing knowledge of coordinated and multiple views is just a starting point. We described four themes in which the current practice in multiple views is challenged:

- Coordination techniques need to be extended for multiple views across multiple displays;
- Task and interaction behaviour in new environments may need to be re-examined;
- Collaboration challenges may come to the fore, based on the promise of more space for team analytics;
- Re-considering our formalisms in light of all these changes may prove fruitful.

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