

Off-Screen Visualization Perspectives: Tasks and Challenges

Dominik Jäckle*
University of Konstanz

Bum Chul Kwon*
University of Konstanz

Daniel A. Keim*
University of Konstanz

ABSTRACT

The visual exploration of large data spaces often requires zooming and panning operations to obtain details. However, drilling down to see details results in the loss of contextual overview. Existing overview-plus-detail approaches provide context while the user examines details, but typically suffer from distortion or overplotting. This is why, there is great potential for off-screen visualization. Off-screen visualization is a family of techniques which provide data-driven context with the aid of visual proxies. Visual proxies can be visually encoded and adapted to the necessary data context with respect to scalability and visualization of high dimensional data. In this paper, we uncover the potential of off-screen visualization in visual data exploration by introducing its application examples to different domains through three derived scenarios. Furthermore, we categorize supporting tasks of off-screen visualizations and show areas of improvement. Then, we derive research challenges of off-screen visualizations and draw our perspectives on the issues for future research. This paper will provide guidance for future research on off-screen visualization techniques in visual data analysis.

Index Terms: Off-screen Visualization

1 INTRODUCTION

Today’s world is driven by the incessant collection of data. The amount of stored and processed data is rapidly and constantly growing. This situation makes great demands on visualizations; they need to scale to vast amounts of data while remaining interactive so that users can gain meaningful insight into data at the same time. However, visualizing ever-increasing amounts of data is often challenging due to the limited screen real estate. Instead, within the limited space, users perform effective interaction techniques to aggregate information for overview and to focus on areas of interest back and forth. In the event users apply zooming or panning operations to explore large data spaces, the operations have one important commonality: both zooming and panning imply that the user is only analyzing and/or looking at one specific area in detail. In such situations, users face the inherent trade-off between overview and detail as Jerding and Stasko defined in the following way [26, p. 43]:

“Visualizations which depict entire information spaces provide context for navigation and browsing tasks; however, the limited size of the display screen makes creating effective global views difficult.”

It is still an ongoing, unsolved research how to providing overview and the context while showing a certain area in detail. Many prior studies provide inspiring solutions, which also show inspiration and areas for improvement at the same time. Multiscale Interfaces [12] present a possible solution; using different levels of data aggregation and presentation, the interface adapts to the zooming level. While zooming, a constant switch between overview and detail is achieved. Apart from the advantage of having a representation adapted to the data, the user still loses the overview when zooming. Existing

*e-mail: {Dominik.Jaeckle, Bumchul.Kwon, Keim}@uni-konstanz.de

Overview and Detail systems append a second viewport to the visualization, either as inset or separate view. Although this approach provides both overview and detail at the same time, a drawback is that the user is forced to split her attention, which can increase cognitive load [18]. Apperley et al. [1] therefore proposed to distort the surrounding while providing a maximal focus region. Based on the degree-of-interest function [11], several so called *Focus-plus-Context* systems have been presented [6, 9, 28, 33], among others [7] - overview and detail are seamlessly integrated. Despite the advancement made in image-based approaches, we argue that data-driven, context-preserving visualizations have not been sufficiently considered, yet. Jäckle et al. propose to augment the Visual Information Seeking Mantra [34] by retaining overview while having details-on-demand: “*Overview first, zoom and filter, then overview and details-on-demand*” [24]. In this work, authors present off-screen visualizations that aggregate overview of data items while showing details of a region. Continuing the study, we explore the full potential of data-driven off-screen techniques in general applications of visualizations and visual analytics in the scope of this study.

In this paper, we propose the area of *Off-screen Visualization* as a pioneering approach, which shows lots of potential for visual data analysis. Off-screen visualization aims at providing a data-driven overview by distorting the distances to objects located outside the viewport. Yet, the design space of techniques in general applications has not been fully discovered. In particular, we attempt to investigate off-screen visualization techniques with respect to domain and nature of the data. Our paper discusses perspectives of potentials and challenges of off-screen visualization based on thorough review on prior studies.

Based on a brief introduction of off-screen visualization in Section 2, we provide three different scenarios derived from high-level task descriptions [3] in Section 3. We use these scenarios not only to give an impression of what is already possible using off-screen representations, but also to highlight shortcomings, gaps, and areas for further research. In Section 4, we discuss challenges that arise from identified gaps and conclude with takeaway messages in Section 5.

2 OFF-SCREEN VISUALIZATION

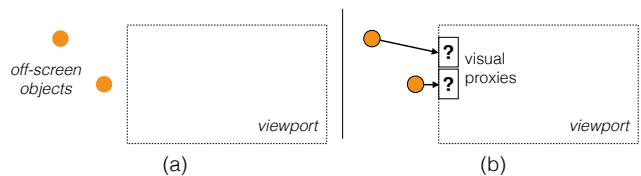


Figure 1: Off-screen visualization. Objects located (a) outside the viewport are (b) mapped back to the viewport by using different kinds of visual proxy representations (indicated by a question mark).

Generally speaking, off-screen visualization aims at preserving data-driven overview, and thus context, while maintaining maximum resolution for focused areas. Context includes the information about the data topology and characteristics. For this context, data points outside a focal area are typically visualized as visual proxies, which can show position [36], distance [2, 14, 19], up to full topology [20, 24, 25] of the data points. As Figure 1 depicts, the general

approach visualizes such off-screen data points as proxies, which can be visualized by many techniques (e.g., glyph), near surrounding areas of main viewport.

Off-screen visualization techniques have mainly been applied to map and graph visualizations [10, 15, 29, 31]. Games and Joshi [13] take first steps towards the application to other visualizations and apply off-screen visualization to bar charts. Furthermore, the techniques named HaloDot [17] and Ambient Grids [25] use aggregation to scale to vast amounts of data. Despite the recent improvements, there is greater potential for research in the areas of scalability, representation of multivariate data, and application to different domains.

3 TASKS AND PERSPECTIVES

As previously mentioned, off-screen visualization has mainly been applied to geo-spatial and graph representations, taking the relative distance and the direction of off-screen objects with respect to the viewport into account. However, there exist many potential application areas, which are mostly uncharted. To categorize the potential tasks that off-screen visualizations can support, we derive and categorize tasks from three scenarios on the basis of task description suggested by Brehmer and Munzner [3]. They proposed the Multi-Level-Typology of Abstract Visualization Tasks, which can be used to describe such applications. The authors provide abstract rather than domain-specific task descriptions, which makes it suitable to express the general application of off-screen techniques. As per the authors, a task description is formed by a combination of elements of the questions *Why?*, *How?*, and *What?*. *Why* a task is performed is described by a three level hierarchy: The highest level of *why* a task is performed is called *produce* and *consume*. *Consume* is specified by these three relevant nodes:

- **Present** refers to the visualization of information and thus is used for decision making or instructional processes. Interactive monitoring systems represent a prominent class of this node.
- **Discover** is tailored to the visual analytics process and helps to generate and verify hypotheses. An example represents the exploration of high dimensional data.
- **Enjoy** refers to visual representations that are novel, interesting and consider attention, but are not used by experts for specific analyses. Under this category, in particular, there exist many web-based interactive visualizations that are publicly available, such as data journalism articles on trending topics in social media.

The mid-level of *why* a task is performed is called *search* and consists of the nodes *lookup*, *locate*, *browse*, and *explore*. The purpose of this level is to find elements of interest, regardless of the highest level (consume). The lowest level is called *query* and has the goal to *identify*, *compare*, and *summarize* targets found in the mid-level.

How a task is performed consists of three non-hierarchical classes: *encode*, *manipulate*, and *introduce*, whereby *manipulate* consists of the nodes *select*, *navigate*, *arrange*, *change*, *filter*, and *aggregate*. *Introduce* consists of the nodes *annotate*, *import*, *derive*, and *record*. Furthermore, *What* defines the task inputs and outputs.

In three following sections, we introduce three application scenarios of off-screen visualizations and highlight gaps for future research. The scenarios result from the highest level (consume) of *why* a task is performed and are therefore aligned with the aforementioned nodes. We combine these nodes with nodes of *how* a task is performed and *what* the data input is, and propose following scenarios: (1) emergency management and response (present), (2) food composition analysis (discover), and (3) social media exploration (enjoy). Table 1 provides an overview of the scenarios, and includes their task description, partially with respect to future work – nodes whose text is **bold** are used in the description of the scenario, but state-of-the-art

techniques are not yet capable of addressing them. The table only gives a brief overview over the scenarios, which is why we abstain from providing a detailed task description per off-screen technique in text. The table also includes off-screen visualizations which are possibly capable of partially supporting the tasks described in the scenarios.

In the scope of this paper, we do not consider the **produce** node with all possible interactions falling into the category of *introduce*, because they refer to tasks where users generate new artefacts. Such tasks can be performed completely independent from off-screen visualization and are generally applicable. For this paper, we stick to existing off-screen visualization techniques for other purposes. Therefore, we leave the **produce** node out for this research, but will come back to it as a future direction in Section 3.4.

3.1 Emergency Management and Response

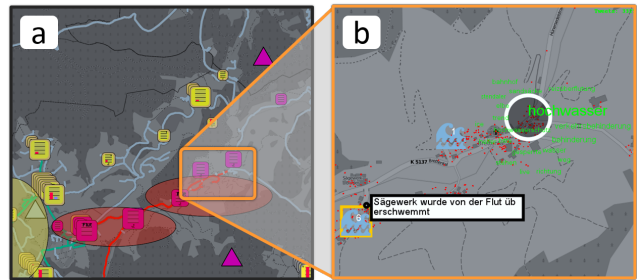


Figure 2: Emergency Scenario - Flooding. In order to get information about (a) high water levels and destruction events, operators need to see details, but when (b) drilling down to municipality and street level, vital information disappears. (adapted from Mittelstädt et al. [30])

Emergency management and response is a scenario, where users are required to make informed decisions based on rapidly updating information from an interactive monitoring task. This scenario is inspired by Mittelstädt et al. [30] and depicts a natural disaster, namely a flooding, in multiple geographic locations. An operator, who is located in the control center, monitors a power grid that consists of several transformer stations and landlines. Figure 2 shows her screen, which presents a map with icons attached to their corresponding locations. In our scenario, the flooding is destroying transformer stations, which are highlighted (violet stations) in the map overview. The operator needs to keep track of the infrastructure and to organize task forces for rescuing efforts. To accomplish this, she drills down to municipality level to gain detail (Figure 2 (b)). A detailed social media content view updates the operator in real-time about new incidents from time to time. Such information can give a possibility to selectively coordinate task forces in a more efficient way.

With the help of off-screen visualization, we can imagine to use visual proxies, such as presented by Frisch and Dachsel [10], to enable the operator to *locate* and *lookup* transformer stations and task forces when zoomed in. Besides the geographic position, the data is one-dimensional, meaning the visual proxies indicate (e.g. by encoding color as visual variable) the status. In this way, the operator can *identify* new incidents in the station areas, *compare* their situations to one another, or *summarize* stations with similar situations, while retrieving detailed information in one particular location. Transformer stations and task forces build a huge network. Meanwhile, the operator is required to be aware of the location of the nodes and the relative distances from the nodes to each other. To visualize the great amounts of geographic positions, we can use techniques using aggregation such as HaloDot [17] or Ambient Grids [25]. Considering this scenario as graph visualization, the techniques [10, 15, 29, 14] can also be applied.

Scenario	Task Description	Off-screen Technique
<p>present (3.1)</p> <p>input: low-dim. data</p>	<p>lookup locate identify compare summarize</p> <p>encode select navigate filter aggregate</p>	<p>Cues [17] [25], Graphs [10] [14] [15] [29], Interact. [22] [23] [31] [35]</p>
<p>discover (3.2)</p> <p>input: high-dim. data</p>	<p>lookup locate explore browse identify compare summarize</p> <p>encode select navigate filter arrange aggregate</p>	<p>Cues [24], Graphs [10] [15] [29], Interact. [22] [23] [35]</p>
<p>enjoy (3.3)</p> <p>input: high-dim. data</p>	<p>lookup locate explore browse identify compare summarize</p> <p>encode select navigate filter aggregate</p>	<p>Cues [13], Interact. [22] [23] [35]</p>

Table 1: Descriptions of possible tasks performed in our scenarios with respect to off-screen visualization. We derive three different scenarios from *why* a task is performed and bring them into the context of **present**, **discover**, and **enjoy**. In the task description, we move to mid-level (search) and low-level (query) indicated by the yellow boxes. The green boxes define *how* a task is performed whereby we consider how the visual representation is encoded and how users can interact with the visualization (manipulation). Gray boxes define *what* the considered data input is. Nodes whose text is **bold**, are described in our scenario, but off-screen techniques are yet not fully capable of handling them. Note that we assign the task descriptions depending on the scenario. Finally, we assign each scenario a set of existing off-screen visualizations which could be capable to partially address the tasks. The table only gives a brief overview, so that we abstain from providing a detailed task description per off-screen technique.

Despite such potential benefits, we also see areas for improvement as well. For instance, off-screen visualizations require improvement with respect to scalability. Existing techniques use degree-of-interest functions [15, 29] or integrate interaction with aggregated off-screen insets [10, 15] to tackle this issue. Although automatic filter functions and interaction address the issue of scalability, they either skip possibly important information or require too much time to retrieve overview. Also, to the best of our knowledge, off-screen visualizations are yet not able to visually distinguish between different datasets within the same visualization as it is the case in our scenario; we need to visualize transformer stations as well as task forces.

In addition to the representation of off-screen elements, interaction can be significantly helpful for the data analysis process. Once off-screen information is included in the detail view, the operator can interactively *navigate* the map, *select* visual proxies for further information, *filter* information accordingly, or change the *aggregation* level. Techniques such as Hopping [23], Predictive Jumping [35], Edgesplit [22], and Bring & Go / Link Sliding [31] offer expedient solutions and facilitate navigation. However, these techniques yet are limited to the navigation to off-screen objects. In contrast, Ghani et al. [15] and Frisch and Dachselt [10] provide additional interaction to resolve clutter issues. We see potential in augmenting the interaction space for off-screen visualizations, for instance by allowing the user to interactively change the representation, include more than one dataset, or even use a context zoom in order to magnify off-screen objects without losing the details. Table 1 summarizes the tasks of this scenario and highlights that filter mechanisms have not been used widely.

3.2 Food Composition Analysis

Food typically contains many different nutrients and thus is inherently high dimensional. For dietitians, health care experts, and even general population, it is interesting to learn which kinds of foods form groups according to their nutrients and whether correlations exist between them. For this purpose, we often use dimension reduction methods to project the high-dimensional data into lower dimensional space. In order to get an overview of interesting subspaces and thus interesting dimensions, we can arrange combinations of dimensions in a scatterplot matrix. Such matrix exponentially grows bigger as the number of dimensions increases. If the amount of considered scatterplots increases to a certain extent, then it becomes inevitable to drill down the visualization to get details. Thus, there is a clear need to preserve the contextual overview. For the purpose of discovering correlations and clusters across a number of dimensions,

a user needs to keep an eye on the entire high dimensional space while inspecting a handful set of them.

When drilling down to certain dimensions of interest, we can apply off-screen visualization to show the dimension *aggregation* overview. One main challenge of this approach is to effectively handle the high dimensional space of the data. Jäckle et al. [24] show how to encode high dimensional data by integrating glyph representations into a dedicated border region of the display. Though the authors only encode two dimensions in the study, the technique shows the potential towards the integrated visualization of higher dimensional data. We can also simply provide minified scatterplot icons, as glyphs, and link the projected data items via brushing to the focus region. In this way, analysts can *lookup* and *locate* dimensions of interest. Furthermore, the exploratory analysis is enabled in order to *browse* and *explore* the entire high dimensional space. Analysts can also *identify* dimension of interest, *compare* dimensions to each other to derive correlations, and *summarize* dimensions to visual correlations.

Interaction can also help to identify patterns and correlations in the data and thus supports the overall discovery process. Users can *navigate* the space, *select* data objects, or *re-arrange* dimensions to facilitate correlation analysis. At the same time, they can change the *aggregation* level and *filter* for dimensions. This represents a clear need for new off-screen interaction techniques. Besides being able to *navigate* [22, 23, 31, 35], there is a clear need for linking and brushing techniques, interactions to re-arrange and filter off-screen data, among others. According to the summarization of Table 1, there is a clear need for developing techniques for the visualization and analysis of high dimensional data. Furthermore, future research can also investigate the interaction ideas of Frisch and Dachselt [10] or Ghani et al. [15]. We think that in the case of high dimensional data analysis, degree-of-interest functions [15, 29] are beneficial in order to automatically fade out information based on the users' interest.

3.3 Social Media Exploration

Social media accompany us in our day-to-day lives, and allow us to share information through our social networks and communities. In social media, we typically seek for trending topics, connections to the world, but at the same time our browsing behavior reflects our work, emotional state, or even our attitude to life. Impressive visualizations such as the Visual Backchannel [8] have been presented to follow online conversations about large scale events and definitively arouse everyones interest. As social media generate the increasing

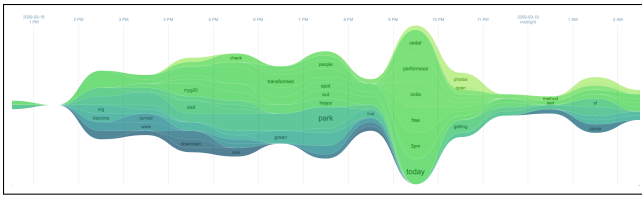


Figure 3: Screenshot of the Visual Backchannel, adapted from Dörk et al. [8]. Topics evolve over time; the visualization shows trending topics in relative size to each other.

amount of data every second, it is inevitable to provide tools that show overview and detail.

Streaming visualizations such as the Visual Backchannel (Figure 3) are inspired by ThemeRiver [21]. Off-screen techniques have yet not been applied to representations different from maps or graphs. Games and Joshi [13] take first steps and apply off-screen visualization to bar charts and scatterplots, which could be also applied to a drilled down version of ThemeRiver. However, we argue that simple visual proxies may not be enough. We can think of using the left-hand and the right-hand sides of the display to provide context about topic developments from past and future, respectively. To allow the user to *lookup* and *locate* known targets as well as to *browse* and *explore* data to find events of interest, the applied off-screen visualization needs to *aggregate* information over time without losing the temporal context. Once this is achieved, users can *identify*, *compare*, and *summarize* targets.

Users can *navigate* the visualization space and draw conclusions through *selection* of high dimensional data located off-screen. Furthermore, users are enabled to *filter* and change the *aggregation* level. This means, topics are evolving over time and thus also change their relation and position to each other. Some topics may completely disappear at one time, but appear again some time later. In order to compactly visualize such events, there is need for tailored aggregations and visualizations. Since social media typically generates text, one needs to choose the aggregation wisely; the aggregation will need to update at high costs when for example zooming. Table 1 depicts that the area of off-screen techniques for visualizations, other than maps and scatterplots, is mostly uncharted.

3.4 Summary

We are aware that the choice of these scenarios is somewhat arbitrary, because they are partially artificial and also limited by means of the use case. However, the scenarios highlight areas for improvement and future work in context of vivid, real-world tasks from three different domains. Regarding *why* a task is performed, we see potential in the area of *producing* artifacts. This goes hand in hand with *how* a task is performed, namely needed interaction techniques such as *annotate* (add annotations), *import* (add new data elements), *derive* (compute new data elements), and *record* (capture visualization elements).

However, we see the main necessity for new off-screen techniques for visualizations other than maps or scatterplots, taking also high dimensional data into account. Tailored techniques can support and also enrich the analysis process. Examples represent matrices, charts of any kind, multivariate graphs, streaming visualizations, to name a few. Following, we will outline challenges that are related to future work.

4 CHALLENGES

To achieve efficient off-screen visualizations, we need to tackle certain challenges. We list the most important challenges below, which will be useful references for future direction of off-screen techniques.

4.1 Computational Efficiency and Scalability

One of the main technical challenges represents scalability of off-screen visualizations regarding large datasets and high dimensional data. Since off-screen visualizations aim to provide overview and details at the same time while users are performing interactions, it is highly desirable to process the computation of aggregation and update of cues in a timely manner. Due to the limited computational resources, one needs to find a balance between accurate representation of data and fast processing to ensure seamless interaction. Designers will encounter numerous questions to define scalable approaches to resolve issues, such as: How do we aggregate data up to several dimensions in visualizations? How do we simplify representations for efficient overview? How do we make sure users maintain accurate awareness of data objects while performing interactions?

First steps towards data aggregation have been proposed by Gonçalves et al. [17] and Jäckle et al. [25, 24], but require improvement with respect to scalability. Furthermore, we are not aware of techniques that are able to handle the possibly sheer amounts of streaming data. Streaming data holds additional challenges such as fluctuations, or the context of incoming data to each other. At many points in time it is not clear if new incoming data is connected to already visualized data.

4.2 Context-Preservation

Several considerations come together for the design space to preserve context. This challenge is primarily related to how is context provided and which methods are used. Following, we list according to our opinion the most important design considerations. Depending on each point the overall context can be significantly improved.

- **Projection Method** refers to how off-screen objects are projected to the viewport. For example, to be aware of nearby objects we can choose a logarithmic distance mapping, linear otherwise.
- **Topology Preservation** refers to the capability of the off-screen visualization technique to maintain the overall topology of objects even when projected back to the viewport. This partially addresses the desert fog problem [27] – the user is aware of empty areas and saves zooming and panning operations. However, the need for topology preservation depends on the task at hand.
- **Visual Proxy Design** refers to the appropriate design of visual proxies. Depending on the design, context may be preserved in a better or worse way. Also the quality of the topology preservation is reflected by the design.

4.3 Interaction Challenges

Interaction is crucial for off-screen visualizations because users are supposed to have full control of the viewport but also of objects located outside the viewport. Besides existing interaction techniques that have been proposed so far [15, 22, 23, 31, 35], there is still a clear need for improvement as depicted in Section 3. Interaction with off-screen located objects needs tailored solutions. Users can adjust the granularity of abstraction in their off-screen visualizations depending on their needs. Not only those, users can be given numerous parameters and specifications of viewports to maximize value of off-screen visualizations. Then, the question is whether users will benefit by such interaction, if so, how we can support their interaction through automation or feedback. In more detail, we also have numerous questions about how to let users interact with the main viewport and the off-screen viewport at the same time. Furthermore, there will be challenges of scaling users' interaction between the main viewport and the off-screen viewport and vice versa.

4.4 High Dimensional Data

Different datasets provide new challenges for off-screen visualization techniques. To the best of our knowledge there is lack of techniques taking into account multiple dimensions of the presented data. A starting point can be the visualization of uncertainty data [24], which integrates two dimensions into a glyph representation. Proceeding this idea, we can think of using higher dimensional glyphs to encode high dimensional off-screen information. However, this is just a first concept. The main challenges on how to aggregate high dimensional off-screen data and how to present it remain.

4.5 Evaluation Challenges

Evaluations are task dependent. Most evaluations have so far been carried out for the well-known techniques, namely halos, arrows, and wedges [4, 5, 20]. Within these studies, they have also been partially compared to Overview-and-Detail systems (application of a second viewport). To the best of our knowledge, existing evaluations have only considered up to 124 off-screen objects, which were presented in an aggregated manner [16]. This evaluation was also carried out against the usage of a second viewport. However, we argue that a minified map does not meet the requirements of being scalable to several thousands of off-screen objects. Techniques like Dynamic Insets [15] used bigger datasets, but at the same time applied a degree-of-interest function making the amount of to be presented off-screen objects shrink significantly. Evaluation of off-screen techniques inherently presents a challenge. Almost every presented off-screen technique provides an evaluation. However, we need to ask ourselves: How do you compare a fully topology-preserving technique to a technique which only provides distance and location of off-screen objects? Also, how do you evaluate design decisions that are not comparable to other off-screen techniques? If for example somebody comes up with a new way of visualizing high dimensional data, it is not clear to which off-screen technique to compare to. The same applies to off-screen techniques applied to different visualizations then maps or scatterplots. Furthermore, a comparison to focus-plus-context systems seems justified at first sight, but remains questionable – focus-plus-context systems primarily are used to distort the image space not taking data characteristics into account.

Moreover, interaction techniques have also been evaluated, like e.g. [32], but newly introduced techniques also need to show their effectiveness with respect to interaction.

5 CONCLUDING REMARKS

We presented three scenarios that show the possible potential of off-screen visualization techniques. We pointed out areas of improvement and gaps for future research, and discussed possible applications with respect to domain, nature of the data, and interaction. In conclusion, we observe that off-screen visualization is an evolving topic showing lots of potential. We wish to emphasize the area of off-screen visualization and hope for many interesting papers in the near future.

ACKNOWLEDGEMENTS

The authors wish to thank Florian Stoffel and Sebastian Mittelstädt for their input and fruitful discussions.

REFERENCES

- [1] M. D. Apperley, I. Tzavaras, and R. Spence. A bifocal display technique for data presentation. In *Proceedings of Eurographics*, volume 82, pages 27–43, 1982.
- [2] P. Baudisch and R. Rosenholtz. Halo: a technique for visualizing off-screen objects. In *Proceedings of the 2003 Conference on Human Factors in Computing Systems, CHI 2003, Ft. Lauderdale, Florida, USA, April 5-10, 2003*, pages 481–488, 2003.
- [3] M. Brehmer and T. Munzner. A multi-level typology of abstract visualization tasks. *IEEE Trans. Vis. Comput. Graph.*, 19(12):2376–2385, 2013.
- [4] S. Burigat and L. Chittaro. Visualizing references to off-screen content on mobile devices: A comparison of arrows, wedge, and overview + detail. *Interacting with Computers*, 23(2):156–166, 2011.
- [5] S. Burigat, L. Chittaro, and S. Gabrielli. Visualizing locations of off-screen objects on mobile devices: a comparative evaluation of three approaches. In *Proceedings of the 8th Conference on Human-Computer Interaction with Mobile Devices and Services, Mobile HCI 2006, Helsinki, Finland, September 12-15, 2006*, pages 239–246, 2006.
- [6] M. S. T. Carpendale and C. Montagnese. A framework for unifying presentation space. In *UIST*, pages 61–70, 2001.
- [7] A. Cockburn, A. K. Karlson, and B. B. Bederson. A review of overview+detail, zooming, and focus+context interfaces. *ACM Comput. Surv.*, 41(1):2:1–2:31, 2008.
- [8] M. Dörk, D. M. Gruen, C. Williamson, and M. S. T. Carpendale. A visual backchannel for large-scale events. *IEEE Trans. Vis. Comput. Graph.*, 16(6):1129–1138, 2010.
- [9] N. Elmqvist, Y. Riche, N. H. Riche, and J. Fekete. Melange: Space folding for visual exploration. *IEEE Trans. Vis. Comput. Graph.*, 16(3):468–483, 2010.
- [10] M. Frisch and R. Dachselt. Visualizing offscreen elements of node-link diagrams. *Information Visualization*, 12(2):133–162, 2013.
- [11] G. W. Furnas. Generalized fisheye views. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, CHI '86*, pages 16–23, New York, NY, USA, 1986. ACM.
- [12] G. W. Furnas and B. B. Bederson. Space-scale diagrams: Understanding multiscale interfaces. In *Human Factors in Computing Systems, CHI '95 Conference Proceedings, Denver, Colorado, USA, May 7-11, 1995*, pages 234–241, 1995.
- [13] P. S. Games and A. Joshi. Visualization of off-screen data on tablets using context-providing bar graphs and scatter plots. In *IS&T/SPIE Electronic Imaging*, pages 90170D–90170D. International Society for Optics and Photonics, 2013.
- [14] T. Geymayer, M. Steinberger, A. Lex, M. Streit, and D. Schmalstieg. Show me the invisible: visualizing hidden content. In *CHI Conference on Human Factors in Computing Systems, CHI '14, Toronto, ON, Canada - April 26 - May 01, 2014*, pages 3705–3714, 2014.
- [15] S. Ghani, N. H. Riche, and N. Elmqvist. Dynamic insets for context-aware graph navigation. *Comput. Graph. Forum*, 30(3):861–870, 2011.
- [16] T. Gonçalves, A. P. Afonso, M. B. Carmo, and P. P. de Matos. Evaluation of halodot: Visualization of relevance of off-screen objects with over cluttering prevention on mobile devices. In *Human-Computer Interaction - INTERACT 2011 - 13th IFIP TC 13 International Conference, Lisbon, Portugal, September 5-9, 2011, Proceedings, Part IV*, pages 300–308, 2011.
- [17] T. Gonçalves, A. P. Afonso, M. B. Carmo, and P. Paulo. Halodot: Visualization of the relevance of off-screen objects. In *SIACG 2011: V Ibero-American Symposium in Computer Graphics*, pages 117–120, 2011.
- [18] J. Grudin. Partitioning digital worlds: focal and peripheral awareness in multiple monitor use. In *Proceedings of the CHI 2001 Conference on Human Factors in Computing Systems, Seattle, WA, USA, March 31 - April 5, 2001*, pages 458–465, 2001.
- [19] S. Gustafson, P. Baudisch, C. Gutwin, and P. Irani. Wedge: clutter-free visualization of off-screen locations. In *Proceedings of the 2008 Conference on Human Factors in Computing Systems, CHI 2008, 2008, Florence, Italy, April 5-10, 2008*, pages 787–796, 2008.
- [20] S. Gustafson and P. Irani. Comparing visualizations for tracking off-screen moving targets. In *Extended Abstracts Proceedings of the 2007 Conference on Human Factors in Computing Systems, CHI 2007, San Jose, California, USA, April 28 - May 3, 2007*, pages 2399–2404, 2007.
- [21] S. Havre, E. G. Hetzler, and L. T. Nowell. Themeriver: Visualizing theme changes over time. In *IEEE Symposium on Information Visualization 2000 (INFOVIS'00), Salt Lake City, Utah, USA, October 9-10, 2000*, pages 115–123, 2000.
- [22] Z. Hossain, K. Hasan, H. Liang, and P. Irani. Edgesplit: facilitating the selection of off-screen objects. In *Mobile HCI '12, Proceedings of the 14th international conference on Human-computer interaction*

with mobile devices and services, San Francisco, CA, USA, September 21-24, 2012, pages 79–82, 2012.

- [23] P. Irani, C. Gutwin, and X. Yang. Improving selection of off-screen targets with hopping. In *Proceedings of the 2006 Conference on Human Factors in Computing Systems, CHI 2006, Montréal, Québec, Canada, April 22-27, 2006*, pages 299–308, 2006.
- [24] D. Jäckle, H. Senaratne, J. Buchmüller, and D. A. Keim. Integrated Spatial Uncertainty Visualization using Off-screen Aggregation. In E. Bertini and J. C. Roberts, editors, *EuroVis Workshop on Visual Analytics (EuroVA)*. The Eurographics Association, 2015.
- [25] D. Jäckle, F. Stoffel, B. C. Kwon, D. Sacha, A. Stoffel, and D. A. Keim. Ambient Grids: Maintain Context-Awareness via Aggregated Off-Screen Visualization. In E. Bertini, J. Kennedy, and E. Puppo, editors, *Eurographics Conference on Visualization (EuroVis) - Short Papers*. The Eurographics Association, 2015.
- [26] D. F. Jerding and J. T. Stasko. The information mural: a technique for displaying and navigating large information spaces. In *IEEE Symposium On Information Visualization 1995, InfoVis 1995, 30-31 October 1995, Atlanta, Georgia, USA*, pages 43–50, 1995.
- [27] S. Jul and G. W. Furnas. Critical zones in desert fog: Aids to multi-scale navigation. In *ACM Symposium on User Interface Software and Technology*, pages 97–106, 1998.
- [28] J. D. Mackinlay, G. G. Robertson, and S. K. Card. The perspective wall: detail and context smoothly integrated. In *Conference on Human Factors in Computing Systems, CHI 1991, New Orleans, LA, USA, April 27 - May 2, 1991, Proceedings*, pages 173–176, 1991.
- [29] T. May, M. Steiger, J. Davey, and J. Kohlhammer. Using signposts for navigation in large graphs. *Comput. Graph. Forum*, 31(3):985–994, 2012.
- [30] S. Mittelstädt, X. Wang, T. Eaglin, D. Thom, D. A. Keim, W. J. Tolone, and W. Ribarsky. An integrated in-situ approach to impacts from natural disasters on critical infrastructures. In *48th Hawaii International Conference on System Sciences, HICSS 2015, Kauai, Hawaii, USA, January 5-8, 2015*, pages 1118–1127, 2015.
- [31] T. Moscovich, F. Chevalier, N. Henry, E. Pietriga, and J. Fekete. Topology-aware navigation in large networks. In *Proceedings of the 27th International Conference on Human Factors in Computing Systems, CHI 2009, Boston, MA, USA, April 4-9, 2009*, pages 2319–2328, 2009.
- [32] G. A. Partridge, M. Nezhadasl, P. Irani, and C. Gutwin. A comparison of navigation techniques across different types of off-screen navigation tasks. In *Human-Computer Interaction - INTERACT 2007, 11th IFIP TC 13 International Conference, Rio de Janeiro, Brazil, September 10-14, 2007, Proceedings, Part II*, pages 716–721, 2007.
- [33] G. G. Robertson and J. D. Mackinlay. The document lens. In *ACM Symposium on User Interface Software and Technology*, pages 101–108, 1993.
- [34] B. Shneiderman. The eyes have it: A task by data type taxonomy for information visualizations. In *VL*, pages 336–343, 1996.
- [35] K. Takashima, S. Subramanian, T. Tsukitani, Y. Kitamura, and F. Kishino. Acquisition of off-screen object by predictive jumping. In *Computer-Human Interaction, 8th Asia-Pacific Conference, APCHI 2008, Seoul, Korea, July 6-9, 2008, Proceedings*, pages 301–310, 2008.
- [36] P. Zellweger, J. D. Mackinlay, L. Good, M. Stefik, and P. Baudisch. City lights: contextual views in minimal space. In *Extended abstracts of the 2003 Conference on Human Factors in Computing Systems, CHI 2003, Ft. Lauderdale, Florida, USA, April 5-10, 2003*, pages 838–839, 2003.