Activity Report 2016

Project-Team AVIZ

Analysis and Visualization

RESEARCH CENTER
Saclay - Île-de-France

THEME
Interaction and visualization

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Project-Team AVIZ

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Computer Science and Digital Science:

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3.1.7. - Open data
3.3. - Data and knowledge analysis
3.3.1. - On-line analytical processing
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Other Research Topics and Application Domains:

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9.5.10. - Digital humanities

1. Members

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Pierre Dragicevic [Inria, Researcher]
Tobias Isenberg [Inria, Researcher]

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Christoph Kinkeldey [Inria, Post-Doc, from May 2016]

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Evelyne Lutton [INRA, Research Scientist]
Andre Spritzer [INRA, Post-doc, until Oct 2016]

2. Overall Objectives

2.1. Objectives

Aviz (Analysis and VIsualiZation) is a multidisciplinary project that seeks to improve visual exploration and analysis of large, complex datasets by tightly integrating analysis methods with interactive visualization.

Our work has the potential to affect practically all human activities for and during which data is collected and managed and subsequently needs to be understood. Often data-related activities are characterized by access to new data for which we have little or no prior knowledge of its inner structure and content. In these cases, we need to interactively *explore* the data first to gain insights and eventually be able to act upon the data contents. Interactive visual analysis is particularly useful in these cases where automatic analysis approaches fail and human capabilities need to be exploited and augmented.

Within this research scope Aviz focuses on five research themes:

- Methods to visualize and smoothly navigate through large datasets;
- Efficient analysis methods to reduce huge datasets to visualizable size;
- Visualization interaction using novel capabilities and modalities;
- Evaluation methods to assess the effectiveness of visualization and analysis methods and their usability;
- Engineering tools for building visual analytics systems that can access, search, visualize and analyze large datasets with smooth, interactive response.

2.2. Research Themes

Aviz's research on Visual Analytics is organized around five main Research Themes:

Methods to visualize and smoothly navigate through large data sets: Large data sets challenge current visualization and analysis methods. Understanding the structure of a graph with one million vertices is not just a matter of displaying the vertices on a screen and connecting them with lines. Current screens only have around two million pixels. Understanding a large graph requires both data reduction to visualize the whole and navigation techniques coupled with suitable representations to see the details. These representations, aggregation functions, navigation and interaction techniques must be chosen as a coordinated whole to be effective and fit the user's mental map.

Aviz designs new visualization representations and interactions to efficiently navigate and manipulate large data sets.

Efficient analysis methods to reduce huge data sets to visualizable size: Designing analysis components with interaction in mind has strong implications for both the algorithms and the processes they use. Some data reduction algorithms are suited to the principle of sampling, then extrapolating, assessing the quality and incrementally enhancing the computation: for example, all the linear reductions such as PCA, Factorial Analysis, and SVM, as well as general MDS and Self Organizing Maps. Aviz investigates the possible analysis processes according to the analyzed data types.

Visualization interaction using novel capabilities and modalities: The importance of interaction to Visualization and, in particular, to the interplay between interactivity and cognition is widely recognized. However, information visualization interactions have yet to take full advantage of these new possibilities in interaction technologies, as they largely still employ the traditional desktop, mouse, and keyboard setup of WIMP (Windows, Icons, Menus, and a Pointer) interfaces. At Aviz we investigate in particular interaction through tangible and touch-based interfaces to data.

Evaluation methods to assess their effectiveness and usability: For several reasons appropriate evaluation of visual analytics solutions is not trivial. First, visual analytics tools are often designed to be applicable to a variety of disciplines, for various different data sources, and data characteristics, and because of this variety it is hard to make general statements. Second, in visual analytics the specificity of humans, their work environment, and the data analysis tasks, form a multi-faceted evaluation context which is difficult to control and generalize. This means that recommendations for visual analytics solutions are never absolute, but depend on their context.

In our work we systematically connect evaluation approaches to visual analytics research—we strive to develop and use both novel as well as establish mixed-methods evaluation approaches to derive recommendations on the use of visual analytics tools and techniques. Aviz regularly published user studies of visual analytics and interaction techniques and takes part in dedicated workshops on evaluation.

Engineering tools: for building visual analytics systems that can access, search, visualize and analyze large data sets with smooth, interactive response.

Currently, databases, data analysis and visualization all use the concept of data tables made of tuples and linked by relations. However, databases are storage-oriented and do not describe the data types precisely. Analytical systems describe the data types precisely, but their data storage and computation model are not suited to interactive visualization. Visualization systems use in-memory data tables tailored for fast display and filtering, but their interactions with external analysis programs and databases are often slow.

Aviz seeks to merge three fields: databases, data analysis and visualization. Part of this merging involves using common abstractions and interoperable components. This is a long-term challenge, but it is a necessity because generic, loosely-coupled combinations will not achieve interactive performance.

Aviz's approach is holistic: these five themes are facets of building an analysis process optimized for discovery. All the systems and techniques Aviz designs support the process of understanding data and forming insights while minimizing disruptions during navigation and interaction.

3. Research Program

3.1. Scientific Foundations

The scientific foundations of Visual Analytics lie primarily in the domains of Visualization and Data Mining. Indirectly, it inherits from other established domains such as graphic design, Exploratory Data Analysis (EDA), statistics, Artificial Intelligence (AI), Human-Computer Interaction (HCI), and Psychology.

The use of graphic representation to understand abstract data is a goal Visual Analytics shares with Tukey's Exploratory Data Analysis (EDA) [58], graphic designers such as Bertin [46] and Tufte [57], and HCI researchers in the field of Information Visualization [44].

EDA is complementary to classical statistical analysis. Classical statistics starts from a *problem*, gathers *data*, designs a *model* and performs an *analysis* to reach a *conclusion* about whether the data follows the model. While EDA also starts with a problem and data, it is most useful *before* we have a model; rather, we perform visual analysis to discover what kind of model might apply to it. However, statistical validation is not always required with EDA; since often the results of visual analysis are sufficiently clear-cut that statistics are unnecessary.

Visual Analytics relies on a process similar to EDA, but expands its scope to include more sophisticated graphics and areas where considerable automated analysis is required before the visual analysis takes place. This richer data analysis has its roots in the domain of Data Mining, while the advanced graphics and interactive exploration techniques come from the scientific fields of Data Visualization and HCI, as well as the expertise of professions such as cartography and graphic designers who have long worked to create effective methods for graphically conveying information.

The books of the cartographer Bertin and the graphic designer Tufte are full of rules drawn from their experience about how the meaning of data can be best conveyed visually. Their purpose is to find effective visual representation that describe a data set but also (mainly for Bertin) to discover structure in the data by using the right mappings from abstract dimensions in the data to visual ones.

For the last 25 years, the field of Human-Computer Interaction (HCI) has also shown that interacting with visual representations of data in a tight perception-action loop improves the time and level of understanding of data sets. Information Visualization is the branch of HCI that has studied visual representations suitable to understanding and interaction methods suitable to navigating and drilling down on data. The scientific foundations of Information Visualization come from theories about perception, action and interaction.

Several theories of perception are related to information visualization such as the “Gestalt” principles, Gibson’s theory of visual perception [51] and Triesman’s “preattentive processing” theory [56]. We use them extensively but they only have a limited accuracy for predicting the effectiveness of novel visual representations in interactive settings.

Information Visualization emerged from HCI when researchers realized that interaction greatly enhanced the perception of visual representations.

To be effective, interaction should take place in an interactive loop faster than 100ms. For small data sets, it is not difficult to guarantee that analysis, visualization and interaction steps occur in this time, permitting smooth data analysis and navigation. For larger data sets, more computation should be performed to reduce the data size to a size that may be visualized effectively.

In 2002, we showed that the practical limit of InfoVis was on the order of 1 million items displayed on a screen [49]. Although screen technologies have improved rapidly since then, eventually we will be limited by the physiology of our vision system: about 20 millions receptor cells (rods and cones) on the retina. Another problem will be the limits of human visual attention, as suggested by our 2006 study on change blindness in large and multiple displays [47]. Therefore, visualization alone cannot let us understand very large data sets. Other techniques such as aggregation or sampling must be used to reduce the visual complexity of the data to the scale of human perception.

Abstracting data to reduce its size to what humans can understand is the goal of Data Mining research. It uses data analysis and machine learning techniques. The scientific foundations of these techniques revolve around the idea of finding a good model for the data. Unfortunately, the more sophisticated techniques for finding models are complex, and the algorithms can take a long time to run, making them unsuitable for an interactive environment. Furthermore, some models are too complex for humans to understand; so the results of data mining can be difficult or impossible to understand directly.

Unlike pure Data Mining systems, a Visual Analytics system provides analysis algorithms and processes compatible with human perception and understandable to human cognition. The analysis should provide understandable results quickly, even if they are not ideal. Instead of running to a predefined threshold, algorithms and programs should be designed to allow trading speed for quality and show the tradeoffs interactively. This is not a temporary requirement: it will be with us even when computers are much faster, because good quality algorithms are at least quadratic in time (e.g. hierarchical clustering methods). Visual Analytics systems need different algorithms for different phases of the work that can trade speed for quality in an understandable way.

Designing novel interaction and visualization techniques to explore huge data sets is an important goal and requires solving hard problems, but how can we assess whether or not our techniques and systems provide real improvements? Without this answer, we cannot know if we are heading in the right direction. This is why we have been actively involved in the design of evaluation methods for information visualization [55], [54], [52], [53], [50]. For more complex systems, other methods are required. For these we want to focus on longitudinal evaluation methods while still trying to improve controlled experiments.

3.2. Innovation

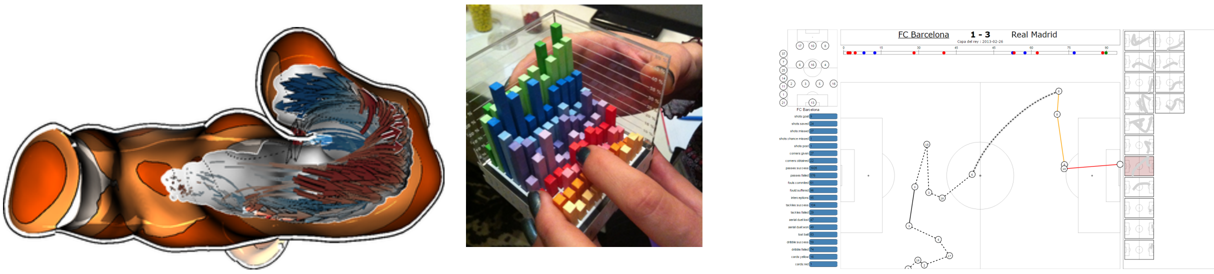

Figure 1. Example novel visualization techniques and tools developed by the team. Left: a non-photorealistic rendering technique that visualizes blood flow and vessel thickness. Middle:a physical visualization showing economic indicators for several countries, right: SoccerStories a tool for visualizing soccer games.

We design novel visualization and interaction techniques (see, for example, Figure 1). Many of these techniques are also evaluated throughout the course of their respective research projects. We cover application domains such as sports analysis, digital humanities, fluid simulations, and biology. A focus of Aviz' work is the improvement of graph visualization and interaction with graphs. We further develop individual techniques for the design of tabular visualizations and different types of data charts. Another focus is the use of animation as a transition aid between different views of the data. We are also interested in applying techniques from illustrative visualization to visual representations and applications in information visualization as well as scientific visualization.

3.3. Evaluation Methods

Evaluation methods are required to assess the effectiveness and usability of visualization and analysis methods. Aviz typically uses traditional HCI evaluation methods, either quantitative (measuring speed and errors) or qualitative (understanding users tasks and activities). Moreover, Aviz is also contributing to the improvement of evaluation methods by reporting on the best practices in the field, by co-organizing workshops (BELIV 2010, 2012, 2014, 2016) to exchange on novel evaluation methods, by improving our ways of reporting, interpreting and communicating statistical results, and by applying novel methodologies, for example to assess visualization literacy.

3.4. Software Infrastructures

We want to understand the requirements that software and hardware architectures should provide to support exploratory analysis of large amounts of data. So far, “big data” has been focusing on issues related to storage management and predictive analysis: applying a well-known set of operations on large amounts of data. Visual Analytics is about exploration of data, with sometimes little knowledge of its structure or properties. Therefore, interactive exploration and analysis is needed to build knowledge and apply appropriate analyses; this knowledge and appropriateness is supported by visualizations. However, applying analytical operations on large data implies long-lasting computations, incompatible with interactions, and generates large amounts of results, impossible to visualize directly without aggregation or sampling. Visual Analytics has started to tackle these problems for specific applications but not in a general manner, leading to fragmentation of results and difficulties to reuse techniques from one application to the other. We are interested in abstracting-out the issues and finding general architectural models, patterns, and frameworks to address the Visual Analytics challenge in more generic ways.

3.5. Emerging Technologies

Figure 2. Example emerging technology solutions developed by the team for multi-display environments, wall displays, and token-based visualization.

We want to empower humans to make use of data using different types of display media and to enhance how they can understand and visually and interactively explore information. This includes novel display equipment and accompanying input techniques. The Aviz team specifically focuses on the exploration of the use of large displays in visualization contexts as well as emerging physical and tangible visualizations. In terms of interaction modalities our work focuses on using touch and tangible interaction. Aviz participates to the Digiscope project that funds 11 wall-size displays at multiple places in the Paris area (see http://www.digiscope.fr), connected by telepresence equipment and a Fablab for creating devices. Aviz is in charge of creating and managing the Fablab, uses it to create physical visualizations, and is also using the local wall-size display (called WILD) to explore visualization on large screens. The team also investigates the perceptual, motor and cognitive implications of using such technologies for visualization.

3.6. Psychology

More cross-fertilization is needed between psychology and information visualization. The only key difference lies in their ultimate objective: understanding the human mind vs. helping to develop better tools. We focus on understanding and using findings from psychology to inform new tools for information visualization. In many cases, our work also extends previous work in psychology. Our approach to the psychology of information visualization is largely holistic and helps bridge gaps between perception, action and cognition in the context of information visualization. Our focus includes the perception of charts in general, perception in large display environments, collaboration, perception of animations, how action can support perception and cognition, and judgment under uncertainty.

4. Application Domains

4.1. Domains

Research in visual analytics can profit from the challenges and requirements of real-world datasets. Aviz develops active collaboration with users from a range of application domains, making sure it can support their specific needs. By studying similar problems in different domains, we can begin to generalize our results and have confidence that our solutions will work for a variety of applications.

We apply our techniques to important medical applications domains such as bioinformatics and brain studies. In particular, we are interested in helping neuroscientists make sense of evolving functional networks, in the form of weighted and/or dynamic graphs.

Other application domains include:

- Digital Humanities in general, with the Cendari European project with historians from most European countries, the project “Interactive Network Visualization” with Microsoft Research-Inria Joint Centre on Graph Visualization, and with our work on Word-Scale Visualizations;
- Many traditional scientific research fields such as astronomy, fluid dynamics, structural biology, and neurosciences;
- Scientific illustration that can benefit from illustrative visualization techniques for scientific data;
- Personal visualization and visual analytics in which we develop solutions for the general audience.

5. Highlights of the Year

5.1. Highlights of the Year

We had a number of highlights this year:

- Aviz researchers contributed 35 publications this year. Amongst these 6 papers were presented at IEEE VIS, the largest international Visualizations and Visual Analytics conference. One full paper was presented at UIST, one the most prestigious international conference on human computer interaction;
- Aviz researchers organized two workshops at international conferences (IEEE VIS);
- Three awards were won by Aviz researchers for papers (see below);
- We welcomed four international students to our lab for research visits;
- Aviz researchers taught four lectures at various French and international universities.

5.1.1. Awards

[8]
E. DIMARA, P. DRAGICEVIC, A. BEZERIANOS.*The Attraction Effect in Information Visualization*, in "IEEE Transactions on Visualization and Computer Graphics", 2017, vol. 23, no 1 [DOI : 10.1109/TVCG.2016.2598594], https://hal.inria.fr/hal-01355750

BEST PAPERS AWARDS:

[24]
M. LE GOC, L. H. KIM, A. PARSAEI, J.-D. FEKETE, P. DRAGICEVIC, S. FOLLMER. *Zooids: Building Blocks for Swarm User Interfaces*, in "Proceedings of the Symposium on User Interface Software and Technology (UIST)", New York, NY, United States, ACM, October 2016, pp. 97 - 109 [*DOI :* 10.1145/2984511.2984547], https://hal.inria.fr/hal-01391281

[25]
S. K. BADAM, C. KINKELDEY, P. ISENBERG. *Haztrailz: Exploratory Analysis of Trajectory and Sensor Data: VAST 2016 Mini Challenge 2 Award: Honorable Mention for Clear Analysis Strategy*, in "IEEE VIS 2016", Baltimore, United States, November 2016, https://hal.inria.fr/hal-01397007

6. New Software and Platforms

6.1. Zooids

Participants: Mathieu Le Goc [correspondant], Lawrence Kim, Ali Parsaei, Jean-Daniel Fekete, Pierre Dragicevic, Sean Follmer.

Figure 3. Zoids can be held as tokens, manipulated collectively or individually, behave as physical pixels, act as handles and controllers, and can move dynamically under machine control. They are building blocks for a new class of user interface we call swarm user interfaces.

Zooids are autonomous robots that handle both display and interaction. We distribute them as an open-source open-hardware platform for developing tabletop swarm interfaces [24]. All information, related content and material can be found at http://www.aviz.fr/swarmui.

6.2. Reorder.js

Participant: Jean-Daniel Fekete [correspondant].

Visualizing data tables and graph/network can be done using a matrix visualization. Jacques Bertin, the French cartographer and visualization pioneer explained in his book "Semiology of Graphics" that, to make sense of a matrix, it should first be correctly ordered. This is what the `Reorder.js` library is doing.

Ordering is also useful for other purposes. For example, if you want to visualize with Parallel Coordinates, you should provide an order for the dimension axes. Reorder.js can be used to find a suitable order. See also the poster paper [48].

The library also provide examples of visualizations using reordering; they are based on the d3.js library. For more information, see our survey of methods for matrix reordering [3].

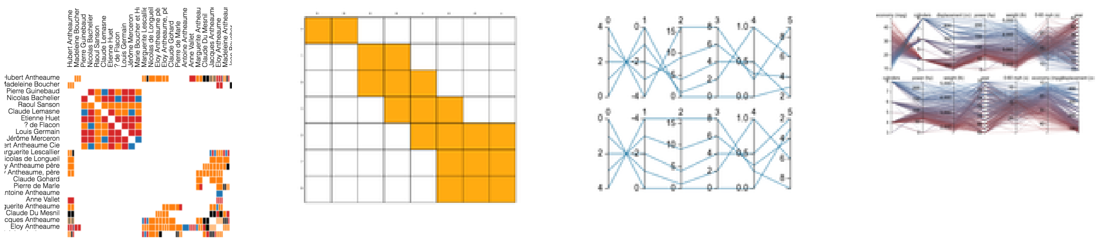

Figure 4. Correctly ordered matrices of a network (left), and parallel coordinate plots with dimensions ordered according to their correlation (right)

6.3. NetworkCube

Participants: Jean-Daniel Fekete [correspondant], Nathalie Henry-Riche, Benjamin Bach.

Network visualizations support research in a range of scientific domains from biology to humanities. NetworkCube is a platform to bridge the gap between domain scientists and visualisation researchers; NetworkCube aims in being a fast way to deploy experimental visualizations from research to domain experts analyzing dynamic networks. In turn, InfoVis researchers benefit from studying how their visualizations are used in the wild [45].

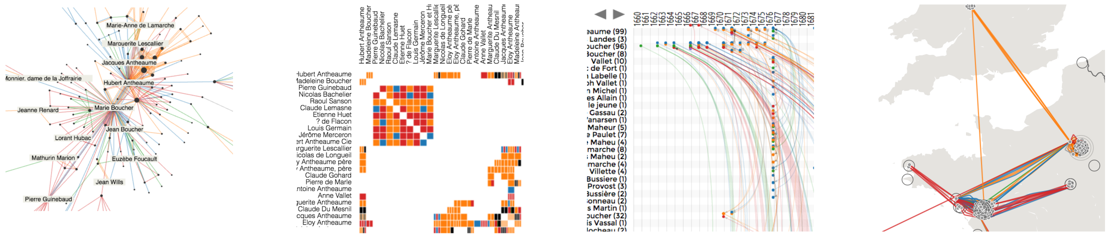

Figure 5. Four different visualization techniques to explore dynamic networks provided by NetworkCube

NetworkCube is made of three parts: a core, the Vistorian which is specialized for visualizations for historians, and the Connectoscope which is specialized for Brain Researchers. NetworkCube provides multiple representations for dynamic networks, allowing complex explorations from Web clients.

6.4. Vispubdata

Participants: Petra Isenberg [correspondant], Florian Heimerl, Steffen Koch, Tobias Isenberg, Panpan Xu, Charles Stolper, Michael Sedlmair, Torsten Möller, John Stasko.

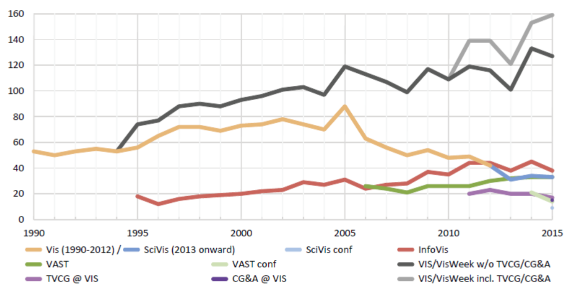

Figure 6. Overview of the files included in the dataset.

We have created and made available to all a dataset with information about every paper that has appeared at the IEEE Visualization (VIS) set of conferences: InfoVis, SciVis, VAST, and Vis. The information about each paper includes its title, abstract, authors, and citations to other papers in the conference series, among many other attributes. This data is meant to be useful to the broad data visualization community to help understand the evolution of the field and as an example document collection for text data visualization research.

6.5. Time Curves

Participants: Benjamin Bach, Pierre Dragicevic [correspondant], Conglei Shi, Nicolas Heulot.

We introduced *time curves* as a general approach for visualizing patterns of evolution in temporal data [2]. Examples of such patterns include slow and regular progressions, large sudden changes, and reversals to previous states. These patterns can be of interest in a range of domains, such as collaborative document editing, dynamic network analysis, and video analysis. Time curves employ the metaphor of folding a timeline visualization into itself so as to bring similar time points close to each other. This metaphor can be applied to

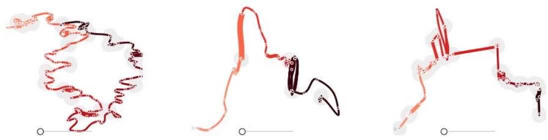

Figure 7. Wikipedia article on abortion illustrated with time curves.

any dataset where a similarity metric between temporal snapshots can be defined, thus it is largely datatype-agnostic. In our paper and on the online Website, we illustrate how time curves can visually reveal informative patterns in a range of different datasets.

More on the project Web page: www.aviz.fr/ bbach/timecurves.

6.6. CENDARI Note-Taking-Environment

SCIENTIFIC DESCRIPTION

CENDARI (http://www.aviz.fr/Research/CENDARI) Is a European Infrastructure project funded by the EU for 4 years: 2012-2016. Aviz is in charge of the Human-Computer Interface for the project, and develops a tool to allow historians and archivists to take notes, enter them online, manage their images in relations with the notes and documents, and visualize the entities they find in the documents and notes. This system is an extension of the original EditorsNotes project, integrating several innovative components asked by the historians: visualizations, relations with the Semantic Web, and a management of access rights respecting the researchers' desire of privacy for their notes, as well as desire of sharing entities and relations gathered throught the notes and documents.

FUNCTIONAL DESCRIPTION

Editors' Notes is an open-source, web-based tool for recording, organizing, preserving, and opening access to research notes, built with the needs of documentary editing projects, archives, and library special collections in mind.

- Participants: Evanthia Dimara, Nadia Boukhelifa Sari Ali and Jean-Daniel Fekete
- Contact: Jean-Daniel Fekete
- URL: https://github.com/CENDARI/editorsnotes

6.7. Hybrid Image Visualisation

Hybrid-image visualizations blend two different visual representations into a single static view, such that each representation can be perceived at a different viewing distance. Our work is motivated by data analysis scenarios that incorporate one or more displays with sufficiently large size and resolution to be comfortably viewed by different people from various distances. Hybrid-image visualizations can be used, in particular, to enhance overview tasks from a distance and detail-in-context tasks when standing close to the display. By taking advantage of humans' perceptual capabilities, hybrid-image visualizations do not require tracking of viewers in front of a display. Moreover, because hybrid-images use a perception-based blending approach, visualizations intended for different distances can each utilize the entire display. We contribute a design space, discuss the perceptual rationale for our work, provide examples and a set of techniques for hybrid-image visualizations, and describe tools for designing hybrid-image visualizations. An example can be found in Figure 8.

KEYWORDS: Wall-Sized Displays, Perception, Hybrid Images

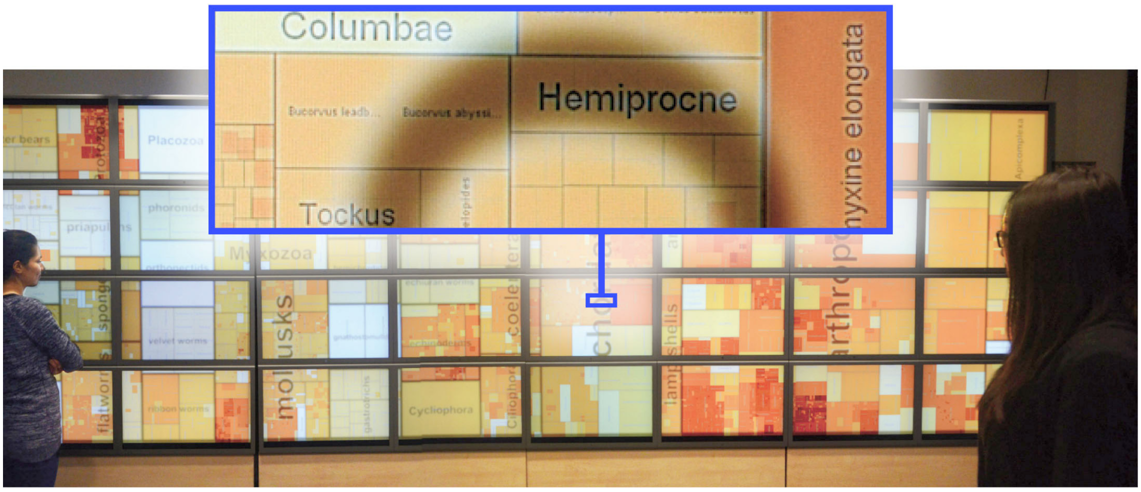

Figure 8. Hybrid image visualization software for the creation of visualizations for distant and close viewing on large displays.

FUNCTIONAL DESCRIPTION

- Participants: Jean-Daniel Fekete, Petra Isenberg, Pierre Dragicevic, Wesley Willett, Romain Primet.
- Contact: Petra Isenberg
- URL: http://aviz.fr/Research/HybridImageVisualizations

6.8. Sparklificator

KEYWORDS: Information visualization - Data visualization - Visualization

SCIENTIFIC DESCRIPTION

Sparklificator is a general open-source jQuery library that eases the process of integrating word-scale visualizations into HTML documents.

FUNCTIONAL DESCRIPTION

Sparklificator's name comes from adding sparklines to a textual document. It is a general open-source jQuery library that eases the process of integrating wordscale visualizations into HTML documents. Sparklificator provides a range of options for adjusting the position (on top, to the right, as an overlay), size, and spacing of vizualisations within the text. The library includes default visualizations, including small line charts and bar charts, and can also be used to integrate custom word-scale visualizations created using webbased visualization toolkits such as D3.

- Participants: Pascal Goffin, Wesley Willett and Petra Isenberg
- Contact: Jean-Daniel Fekete
- URL: http://inria.github.io/sparklificator/

7. New Results

7.1. Swarm User Interfaces

Participants: Mathieu Le Goc [correspondant], Lawrence Kim, Ali Parsaei, Jean-Daniel Fekete, Pierre Dragicevic, Sean Follmer.

We introduce swarm user interfaces (Fig 3), a new class of human-computer interfaces comprised of many autonomous robots that handle both display and interaction. We describe the design of Zooids, a hardware and software system: a small wheel-propelled robot with position and touch sensing capabilities that can be freely arranged and repositioned on any horizontal surface, both through user manipulation and computer control. Zooids is an open-source open-hardware platform for developing tabletop swarm interfaces. We illustrate the potential of tabletop swarm user interfaces through a set of application scenarios developed with Zooids, and discuss general design considerations unique to swarm user interfaces.

More on the project Web page: http://www.aviz.fr/swarmui.

7.2. A Systematic Review of Experimental Studies on Data Glyphs

Participants: Johannes Fuchs, Petra Isenberg [correspondant], Anastasia Bezerianos, Daniel Keim.

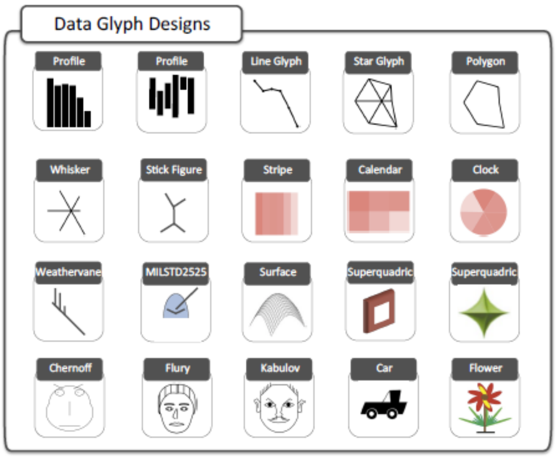

Figure 9. Overview of the glyphs reviewed in the study.

We systematically reviewed 64 user-study papers on data glyphs to help researchers and practitioners gain an informed understanding of tradeoffs in the glyph design space. The glyphs we considered were individual representations of multi-dimensional data points, often meant to be shown in small-multiple settings. Over the past 60 years many different glyph designs were proposed and many of these designs have been subjected to perceptual or comparative evaluations. Yet, a systematic overview of the types of glyphs and design variations tested, the tasks under which they were analyzed, or even the study goals and results did not yet exist. We provide such an overview by systematically sampling and tabulating the literature on data glyph studies, listing their designs, questions, data, and tasks. In addition we present a concise overview of the types of glyphs and their design characteristics analyzed by researchers in the past, and a synthesis of the study results. Based on our meta analysis of all results we further contribute a set of design implications and a discussion on open research directions.

7.3. Towards an Understanding of Mobile Touch Navigation in a Stereoscopic Viewing Environment for 3D Data Exploration

Participants: David López, Lora Oehlberg, Candemir Doger, Tobias Isenberg [correspondant].

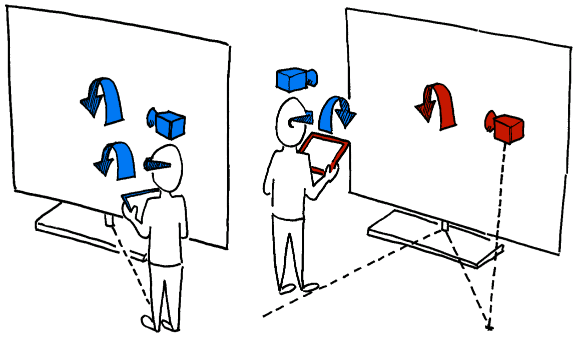

Figure 10. Illustration of the problem of mobility within a virtual environment, while interacting with a view on a tablet.

We discuss touch-based navigation of 3D visualizations in a combined monoscopic and stereoscopic viewing environment. We identify a set of interaction modes, and a workflow that helps users transition between these modes to improve their interaction experience. In our discussion we analyze, in particular, the control-display space mapping between the different reference frames of the stereoscopic and monoscopic displays. We show how this mapping supports interactive data exploration, but may also lead to conflicts between the stereoscopic and monoscopic views due to users' movement in space; we resolve these problems through synchronization. To support our discussion, we present results from an exploratory observational evaluation with domain experts in fluid mechanics and structural biology. These experts explored domain-specific datasets using variations of a system that embodies the interaction modes and workflows; we report on their interactions and qualitative feedback on the system and its workflow.

More on the project Web page: https://tobias.isenberg.cc/VideosAndDemos/Lopez2016TUM.

7.4. CAST: Effective and Efficient User Interaction for Context-Aware Selection in 3D Particle Clouds

Participants: Lingyun Yu, Konstantinos Efstathiou, Petra Isenberg, Tobias Isenberg [correspondant].

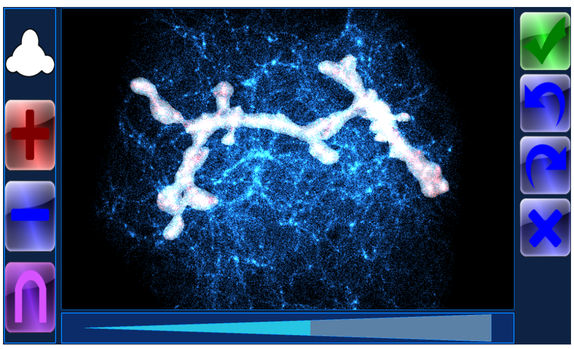

Figure 11. Illustration of the complexity metrics used in the study.

We present a family of three interactive Context-Aware Selection Techniques (CAST) for the analysis of large 3D particle datasets. For these datasets, spatial selection is an essential prerequisite to many other analysis tasks. Traditionally, such interactive target selection has been particularly challenging when the data subsets of interest were implicitly defined in the form of complicated structures of thousands of particles. Our new techniques SpaceCast, TraceCast, and PointCast improve usability and speed of spatial selection in point clouds through novel context-aware algorithms. They are able to infer a user's subtle selection intention from gestural input, can deal with complex situations such as partially occluded point clusters or multiple cluster layers, and can all be fine-tuned after the selection interaction has been completed. Together, they provide an effective and efficient tool set for the fast exploratory analysis of large datasets. In addition to presenting Cast, we report on a formal user study that compares our new techniques not only to each other but also to existing state-of-the-art selection methods. Our results show that Cast family members are virtually always faster than existing methods without tradeoffs in accuracy. In addition, qualitative feedback shows that PointCast and TraceCast were strongly favored by our participants for intuitiveness and efficiency.

More on the project Web page: https://tobias.isenberg.cc/VideosAndDemos/Yu2016CEE.

7.5. Hybrid Tactile/Tangible Interaction for 3D Data Exploration

Participants: Lonni Besançon [correspondant], Paul Issartel, Mehdi Ammi, Tobias Isenberg.

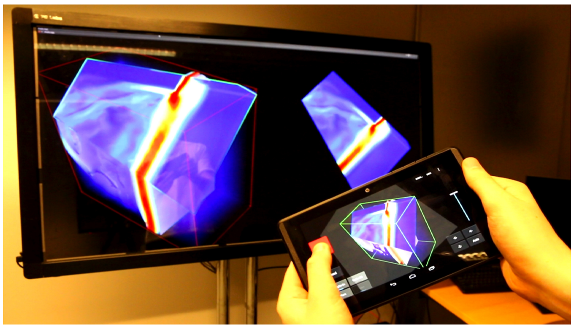

Figure 12. Picture of the hybrid interaction system.

We present the design and evaluation of an interface that combines tactile and tangible paradigms for 3D visualization. While studies have demonstrated that both tactile and tangible input can be efficient for a subset of 3D manipulation tasks, we reflect here on the possibility to combine the two complementary input types. Based on a field study and follow-up interviews, we present a conceptual framework of the use of these different interaction modalities for visualization both separately and combined—focusing on free exploration as well as precise control. We present a prototypical application of a subset of these combined mappings for fluid dynamics data visualization using a portable, position-aware device which offers both tactile input and tangible sensing. We evaluate our approach with domain experts and report on their qualitative feedback.

More on the project Web page: http://lonni.besancon.pagesperso-orange.fr/Projects/HybridInteraction/HybridInteraction.html.

7.6. A Tangible Volume for Portable 3D Interaction

Participants: Paul Issartel, Lonni Besançon [correspondant], Tobias Isenberg, Mehdi Ammi.

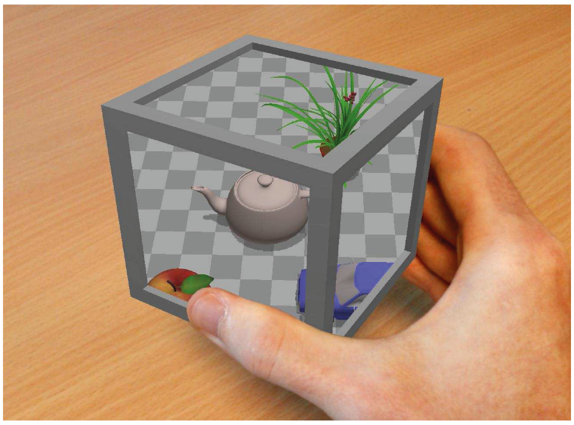

Figure 13. Image of the Cube.

We present a new approach to achieve tangible object manipulation with a single, fully portable and self-contained device. Our solution is based on the concept of a "tangible volume". We turn a tangible object into a handheld fish-tank display. The tangible volume represents a volume of space that can be freely manipulated within a virtual scene. This volume can be positioned onto virtual objects to directly grasp them, and to manipulate them in 3D space. We investigate this concept through two user studies. The first study evaluates the intuitiveness of using a tangible volume for grasping and manipulating virtual objects. The second study evaluates the effects of the limited field of view on spatial awareness. Finally, we present a generalization of this concept to other forms of interaction through the surface of the volume.

More on the project Web page: http://lonni.besancon.pagesperso-orange.fr/Projects/TangibleCube/TangibleCube.html.

7.7. Preference Between Allocentric and Egocentric 3D Manipulation in a Locally Coupled Configuration

Participants: Paul Issartel, Lonni Besançon [correspondant], Steven Franconeri.

We study user preference between allocentric and egocentric 3D manipulation on mobile devices, in a configuration where the motion of the device is applied to an object displayed on the device itself. We first evaluate this preference for translations and for rotations alone, then for full 6-DOF manipulation. We also investigate the role of contextual cues by performing this experiment in different 3D scenes. Finally, we look at the specific influence of each manipulation axis. Our results provide guidelines to help interface designers select an appropriate default mapping in this locally coupled configuration.

More on the project Web page: http://lonni.besancon.pagesperso-orange.fr/Projects/Mappings/Mappings.html.

7.8. Embedded Data Representations

Participants: Wesley Willett, Yvonne Jansen, Pierre Dragicevic [correspondant].

We introduces *embedded data representations* as the use of visual and physical representations of data that are deeply integrated with the physical spaces, objects, and entities to which the data refers [16]. Technologies like lightweight wireless displays, mixed reality hardware, and autonomous vehicles are making it increasingly easier to display data in-context. While researchers and artists have already begun to create embedded data representations, the benefits, trade-offs, and even the language necessary to describe and compare these approaches remain unexplored.

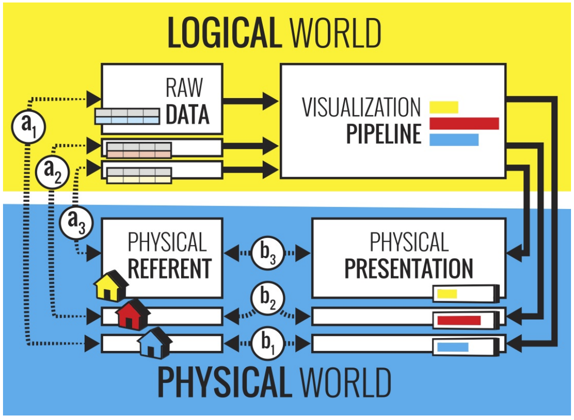

Figure 14. Conceptual model for situated and embedded data representations.

In this paper, we formalize the notion of physical data referents – the real-world entities and spaces to which data corresponds – and examine the relationship between referents and the visual and physical representations of their data. We differentiate situated representations, which display data in proximity to data referents, and embedded representations, which display data so that it spatially coincides with data referents. Drawing on examples from visualization, ubiquitous computing, and art, we explore the role of spatial indirection, scale, and interaction for embedded representations. We also examine the tradeoffs between non-situated, situated, and embedded data displays, including both visualizations and physicalizations. Based on our observations, we identify a variety of design challenges for embedded data representation, and suggest opportunities for future research and applications

7.9. Space-Time Cube Framework

Participants: Benjamin Bach, Pierre Dragicevic [correspondant], Dominique Archambault, Christophe Hurter, Sheelagh Carpendale.

We presented a descriptive model for visualizations of temporal data based on a generalized space-time cube framework [1]. Visualizations are described as operations on a conceptual space-time cube, which transform the cube's 3D shape into readable 2D visualizations. Operations include: extracting subparts of the cube, flattening it across space or time, or transforming the cube's geometry and content. We introduced a taxonomy of elementary space-time cube operations and explained how these operations can be combined and parameterized.

The generalized space-time cube has two properties: a) it is purely conceptual without the need to be implemented, and b) it applies to all datasets that can be represented in two dimensions plus time (e.g., geospatial, videos, networks, multivariate data). The proper choice of space-time cube operations depends on many factors, e.g., density or sparsity of a cube, hence we proposed a characterization of structures within space-time cubes, which allowed us to discuss strengths and limitations of operations. We also reviewed interactive systems that support multiple operations, allowing a user to customize his view on the data. With this framework, we hope to facilitate the description, criticism and comparison of temporal data visualizations, as well as encourage the exploration of new techniques and systems.

More on the project Web page: spacetimecubevis.com.

7.10. The Attraction Effect in Information Visualization

Participants: Evanthia Dimara [correspondant], Anastasia Bezerianos, Pierre Dragicevic.

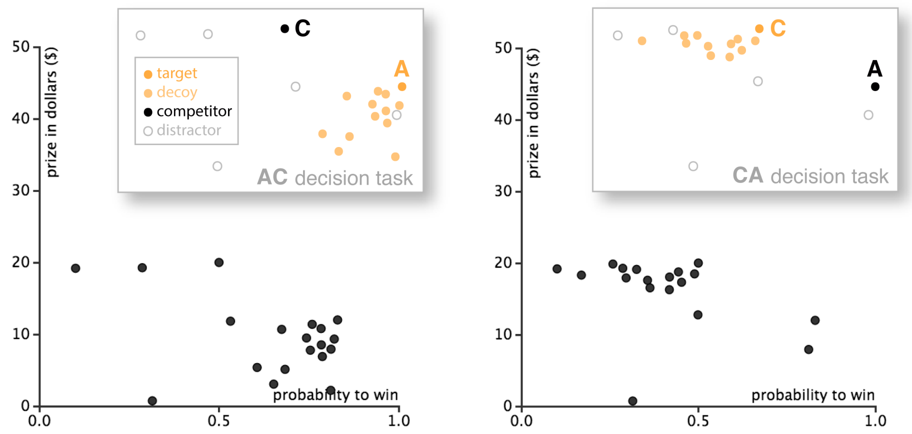

Figure 15. Illustration of the extension of the attraction effect in large datasets. Example of two matched decision tasks AC and CA in scatterplots.

The attraction effect is a well-studied cognitive bias in decision making research, where one's choice between two alternatives is influenced by the presence of an irrelevant (dominated) third alternative. We examine whether this cognitive bias, so far only tested with three alternatives and simple presentation formats such as numerical tables, text and pictures, also appears in visualizations. Since visualizations can be used to support decision making — e.g., when choosing a house to buy or an employee to hire — a systematic bias could have important implications. In a first crowdsource experiment, we indeed partially replicated the attraction effect with three alternatives presented as a numerical table, and observed similar effects when they were presented as a scatterplot. In a second experiment, we investigated if the effect extends to larger sets of alternatives, where the number of alternatives is too large for numerical tables to be practical. Our findings indicate that the bias persists for larger sets of alternatives presented as scatterplots. We discuss implications for future research on how to further study and possibly alleviate the attraction effect.

More on the project Web page: www.aviz.fr/decoy.

7.11. An Exploratory Study of Word-Scale Graphics in Data-Rich Text Documents

Participants: Pascal Goffin [correspondant], Jeremy Boy, Wesley Willett, Petra Isenberg.

We investigated the design and function of word-scale graphics and visualizations embedded in text documents. Word-scale graphics include both data-driven representations such as word-scale visualizations and sparklines, and non-data-driven visual marks. There has been little research attention on their design, function, and use so far. We present the results of an open ended exploratory study with nine graphic designers. The study resulted in a rich collection of different types of graphics, data provenance, and relationships between text, graphics, and data. Based on this corpus, we present a systematic overview of word-scale graphic designs, and examine how designers used them. We also discuss the designers' goals in creating their graphics, and characterize how they used word-scale graphics to visualize data, add emphasis, and create alternative narratives. We discuss implications for the design of authoring tools for word-scale graphics and visualizations building on these examples, and explore how new authoring environments could make it easier for designers to integrate them into documents.

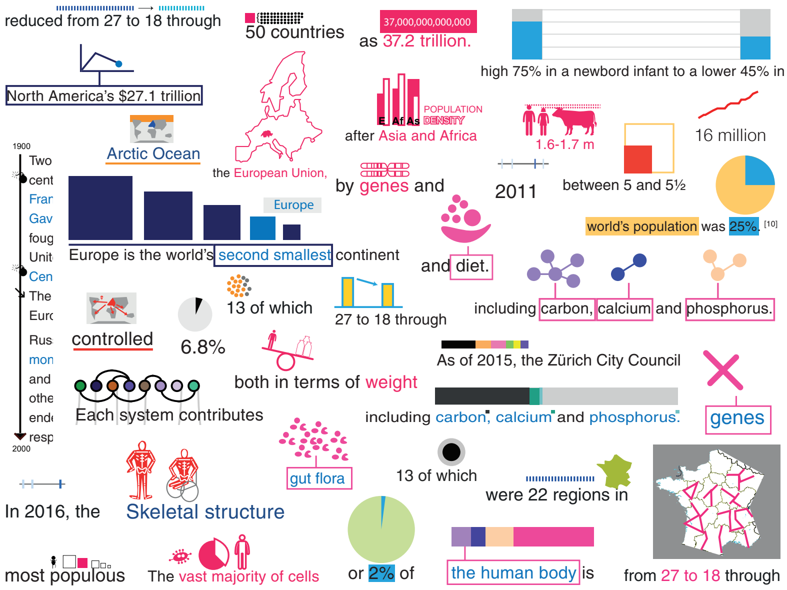

Figure 16. Examples of word-scale graphics collected during the study.

8. Partnerships and Cooperations

8.1. National Initiatives

8.1.1. ANR FITOC: From Individual To Collaborative Visual Analytics

Participants: Petra Isenberg [correspondant], Jean-Daniel Fekete, Pierre Dragicevic, Pascal Goffin, Wesley Willett.

The goal of this project is to help bringing collaboration to existing individual visual data analysis work. It is situated in the domain of information visualization, a subdomain of computer science, but views and tries to support data analysis as a social process. The work is motivated by the fact that a large amount of data analysis work is conducted by individuals in isolated tool, such as Excel, R, SPSS, Tableau, and others. Synthesis and sharing of the results then happens in another set of tools such as notes, email, or office documents. The research is situated in the domain of visualization which has a long tradition of building tools and techniques for individual data analysis. Currently there are technological innovations under way to help people analyze data together, but there is still a disconnect between the two modes of data analysis (collaborative and individual). In this project, we want to find ways in which information can best be used and shared visually while transitioning between individual and collaborative data analysis activities.

The project ended in July, 2016.

8.2. European Initiatives

8.2.1. FP7 & H2020 Projects

8.2.1.1. CENDARI

Title: Collaborative EuropeaN Digital/Archival Infrastructure

Programm: FP7

Duration: February 2012 - January 2016

Coordinator: Trinity College - Dublin

Partners:

Consortium of European Research Libraries (United Kingdom)

Koninklijke Bibliotheek (Netherlands)

Fondazione Ezio Franceschini Onlus (Italy)

Freie Universitaet Berlin (Germany)

King's College London (United Kingdom)

"matematicki Institutnu, Beograd" (Serbia)

Narodni Knihovna Ceske Republiky (Czech Republic)

Societa Internazionale Per Lo Studio Del Medioevo Latino-S.I.S.M.E.L.Associazione (Italy)

The Provost, Fellows, Foundation Scholars & The Other Members of Board of The College of The Holy & Undivided Trinity of Queen Elizabeth Near Dublin (Ireland)

Georg-August-Universitaet Goettingen Stiftung Oeffentlichen Rechts (Germany)

The University of Birmingham (United Kingdom)

Universitaet Stuttgart (Germany)

Universita Degli Studi di Cassino E Del Lazio Meridionale (Italy)

Inria contact: L. Romary

'The Collaborative EuropeaN Digital Archive Infrastructure (CENDARI) will provide and facilitate access to existing archives and resources in Europe for the study of medieval and modern European history through the development of an 'enquiry environment'. This environment will increase access to records of historic importance across the European Research Area, creating a powerful new platform for accessing and investigating historical data in a transnational fashion overcoming the national and institutional data silos that now exist. It will leverage the power of the European infrastructure for Digital Humanities (DARIAH) bringing these technical experts together with leading historians and existing research infrastructures (archives, libraries and individual digital projects) within a programme of technical research informed by cutting edge reflection on the impact of the digital age on scholarly practice. The enquiry environment that is at the heart of this proposal will create new ways to discover meaning, a methodology not just of scale but of kind. It will create tools and workspaces that allow researchers to engage with large data sets via federated multilingual searches across heterogeneous resources while defining workflows enabling the creation of personalized research environments, shared research and teaching spaces, and annotation trails, amongst other features. This will be facilitated by multilingual authority lists of named entities (people, places, events) that will harness user involvement to add intelligence to the system. Moreover, it will develop new visual paradigms for the exploration of patterns generated by the system, from knowledge transfer and dissemination, to language usage and shifts, to the advancement and diffusion of ideas.'

8.3. International Initiatives

8.3.1. Inria International Partners

8.3.1.1. Informal International Partners

- Univ. of Konstanz, Jean-Daniel Fekete collaborates with Michael Behrischon network exploration based on matrices [4], [3].

- NYU, Jean-Daniel Fekete collaborates with Enrico Bertini and his students on multidimensional visualization and exploration [23]/
- Microsoft Research Redmond, Jean-Daniel Fekete collaborates with Nathalie Henry-Riche on the visualization of dynamic networks (see 6.3).
- Stanford University. Mathieu Le Goc, Jean-Daniel Fekete and Pierre Dragicevic collaborate with Sean Follmer on Swarm User Interfaces and the design of the Zooids (section 7.1).
- Univ of Calgary. Pierre Dragicevic collaborates with Wesley Willett on situated data visualization.
- Univ of Washington, Univ Chicago and Univ Zurich. Pierre Dragicevic collaborates with Matthew Kay, Steve Haroz and Chat Wacharamanotham on transparent statistical reporting.
- Microsoft Research, Redmond, University of Waterloo, University of Calgary. Petra Isenberg and Tobias Isenberg collaborate with Bongshin Lee, Mark Hancock, Diane Watson, and Sheelagh Carpendale on touch vs. mouse interaction
- Microsoft Research, Redmond. Petra Isenberg collaborates with Bongshin Lee on mobile visualization research.
- Univ. of Vienna, Austria: Petra Isenberg and Tobias Isenberg collaborate with Torsten Möller and Michael Sedlmair on visualization practices and evaluation of visualization.
- Univ. of Maryland, Baltimore County, USA: Petra Isenberg and Tobias Isenberg collaborate with Jian Chen on visualization practices and evaluation of visualization.
- Georgia Tech, USA: Petra Isenberg and Tobias Isenberg collaborate with John Stasko on visualization practices.
- Univ. Groningen, the Netherlands: Petra Isenberg and Tobias Isenberg collaborate with Lingyun Yu and Konstantinos Efstathiou on context-aware 3D selection.
- Univ. of Granada, Spain: Tobias Isenberg collaborates with Domingo Martín on non-photorealistic rendering.
- Techn. Univ. of Vienna, Austria: Tobias Isenberg collaborates with Ivan Viola on illustrative visualization.
- Univ. of Bergen, Norway: Tobias Isenberg collaborates with Stefan Bruckner on interactive visualization.
- Univ. of Ulm, Germany: Tobias Isenberg collaborates with Timo Ropinski on interactive visualization.
- Worms Univ. of Appl. Sciences, Germany: Tobias Isenberg collaborates with Alexander Wiebel on interactive visualization.
- Univ. Koblenz-Landau, Germany: Tobias Isenberg collaborates with Kai Lawonn on illustrative visualization.
- Univ. Magdeburg, Germany: Tobias Isenberg collaborates with Bernhard Preim on illustrative visualization.

8.4. International Research Visitors

8.4.1. Visits of International Scientists

8.4.1.1. Internships

- Sriram Karthik Badam, PhD, Univ. of Maryland, from Jun 2016 until Sep 2016
- Yanhong Wu, PhD, Hong-Kong Univ. of Science and Technology, from May to Sep. 2016

9. Dissemination

9.1. Promoting Scientific Activities

9.1.1. Scientific Events Organisation

9.1.1.1. Member of the Organizing Committees

- Jean-Daniel Fekete co-organizing the LIVVIL 2016 workshop on "Logging Visualization and Visualizing Logs" at IEEE VIS.
- Jean-Daniel Fekete served on the best paper committee for EuroVis 2016
- Pierre Dragicevic was Doctoral Colloquium co-chair at IEEE VIS 2016.
- Petra Isenberg co-organized the Beliv 2016 workshop on "Beyond Time and Error: Novel Evaluation Techniques for Visualization" at IEEE VIS.
- Petra Isenberg served as Posters co-chair for VIS 2016
- Petra Isenberg served on the best short-paper committee for EuroVis 2016
- Tobias Isenberg was posters co-chair for EuroVis 2016.
- Tobias Isenberg was visualization area co-chair for ISVC 2016.

9.1.2. Scientific Events Selection

9.1.2.1. Member of the Conference Program Committees

- Jean-Daniel Fekete was a member of the program committees for Graph Drawing 2016
- Jean-Daniel Fekete was a member of the program committees for EuroVis 2016
- Jean-Daniel Fekete was a member of the program committees for ACM AVI 2016
- Pierre Dragicevic was a member of the program committee for VIS 2016.
- Pierre Dragicevic was a member of the program committee for CHI 2017.
- Petra Isenberg was a member of the program committee for CHI 2016.
- Petra Isenberg was a member of the program committee for Beliv 2016.
- Petra Isenberg was a member of the program committee for EuroVA 2016.
- Petra Isenberg was a member of the program committee for InfoVis 2016.
- Tobias Isenberg was a member of the program committee for IEEE SciVis 2016.
- Tobias Isenberg was a member of the program committee for IEEE VISAP 2016.
- Tobias Isenberg was a member of the program committee for Expresssive 2016.
- Tobias Isenberg was a member of the program committee for IEEE 3DUI 2016.
- Pascal Goffin was a member of the program committee for 9. Forum Medientechnik 2016.

9.1.2.2. Reviewer

- Jean-Daniel Fekete: VIS, CHI
- Pierre Dragicevic: VIS, UIST, IHM
- Petra Isenberg: EuroVA, EuroVis, InfoVis, Nordic Forum for Human-Computer Interaction Research (NordiCHI), UIST Beliv (Workshop), DFG (Funding Agency)
- Tobias Isenberg: 3DUI, CHI, EuroVis, Expressive, ISS, PacificVis, SciVis, VISAP
- Christoph Kinkeldey: CHI
- Lonni Besancon: CHI EA, ISMI, SUI, CHI
- Mathieu Le Goc: CHI

9.1.3. Journal

9.1.3.1. Member of the Editorial Boards

- Tobias Isenberg is associate editor of Elsevier Computers & Graphics.
- Petra Isenberg and Tobias Isenberg were guest editors of a special issue of Sage Publishing's Information Visualization on visualization evaluation.

9.1.3.2. Reviewer - Reviewing Activities

- Petra Isenberg: Big Data Journal,CG&A, Journal of Graph Algorithms and Applications (JGAA), Information Visualization Journal (IVS), TVCG
- Tobias Isenberg: C&G, IV, TVCG
- Christoph Kinkeldey: JoEP (Journal of Economic Psychology), IJGI (ISPRS International Journal of Geo-Information), CP (Cartographic Perspectives), CaGIS (Cartography and Geographic Information Science)

9.1.4. Invited Talks

- Jean-Daniel Fekete: Bilan du programme ANR Kinsources, Paris, "Visualisation de réseaux dynamiques", July 8th, 2016
- Jean-Daniel Fekete: 2nd European Conference on Social Networks (EUSN), Paris, "Challenges in Social Network Visualization: Bigger, Dynamic, Multivariate.", June 16th, 2016
- Jean-Daniel Fekete: School in Geomatique (GIS), Lyon, "DataVis and InfoVis", May 31th, 2016.
- Jean-Daniel Fekete: Invited Talk, Aarhus University, "ProgressiVis: a New Workflow Model for Scalability in Information Visualization", Apr 20, 2016
- Jean-Daniel Fekete: Invited Talk, Inria Lille, "ProgressiVis: a New Workflow Model for Scalability in Information Visualization", Apr 15, 2016
- Pierre Dragicevic: "Bad Stats are Miscommunicated Stats". Invited talk at RWTH Aachen, 5 Feb 2016.
- Pierre Dragicevic: "Statistical Dances: Why No Statistical Analysis is Reliable and What To Do About It". Keynote talk at the BioVis 2016 symposium, 23 Oct 2016.
- Tobias Isenberg: "Tactile Navigation and Selection for 3D Data Exploration". University of Granada, Spain, May 25, 2016.
- Christoph Kinkeldey: "Challenges in Visually-Supported Reasoning with Uncertainty". VIA group, Telecom ParisTech, 23 June 2016.

9.1.5. Leadership within the Scientific Community

- Jean-Daniel Fekete is the chair of the Steering Community of the IEEE Information Visualization conference.
- Jean-Daniel Fekete is a member of the Visualization Steering Committee for the IEEE VIS conference
- Jean-Daniel Fekete is a member of the Steering Community of the EuroVis conference.
- Jean-Daniel Fekete is a member of the publication board of Eurographics.
- Tobias Isenberg is a member of the Steering Committee of the Expressive conference.
- Tobias Isenberg is a member of the Executive Committee of the Visualization and Computer Graphics Technical Committee of the IEEE Computer Society.

9.2. Teaching - Supervision - Juries

9.2.1. Teaching

- "Visual Analytics" taught by Jean-Daniel Fekete at Ecole Centrale Paris, France

- “Block Course Visual Analytics” taught by Petra Isenberg at the University of Dresden, Germany
- “Visual Analytics” taught by Petra Isenberg at Ecole Centrale Paris, France
- “Introduction to Human-Computer Interaction” taught by Petra Isenberg at Ecole Centrale Paris, France
- “Information Visualization” co-taught by Petra Isenberg at Université Paris Sud
- “Non-Photorealistic Rendering” taught by Tobias Isenberg at the University of Granada, Spain
- “Introduction to Computer Graphics” taught by Tobias Isenberg at Polytech Paris-Sud
- “Photorealistic Rendering” taught by Tobias Isenberg at Polytech Paris-Sud and Université Paris-Saclay

9.2.2. Supervision

PhD: Evanthia Dimara, Information Visualization for Decision Making, Université Paris-Sud, 2014, Pierre Dragicevic and Anastasia Bezerianos

PhD: Mathieu Le Goc, Supporting Versatility in Tangible User Interfaces Using Collections of Small Actuated Objects, Université Paris-Sud, Defense date 15 Dec 2016, Pierre Dragicevic and Jean-Daniel Fekete

PhD: Pascal Goffin, From Individual to Collaborative Work, Université Paris-Sud, defended October 2016, Petra Isenberg and Jean-Daniel Fekete

PhD: Lonni Besançon, An Interaction Continuum for Scientific Visualization, Université Paris-Sud, 2014, Tobias Isenberg

9.2.3. Juries

- Jean-Daniel Fekete: Julien Tierny, HdR (Tenure) "Contributions à l’Analyse Topologique de Données pour la Visualisation Scientifique" , LIP6, Paris, Apr 29, 2016.
- Jean-Daniel Fekete: Matthias Nielsen, "Interactive Visual Analytics of Big Data A Web-Based Approach", Aarhus, Denmark, Apr 20, 2016
- Jean-Daniel Fekete: Mi-term PhD evaluation committee of Lobo María-Jesús, Saclay, May 2016.
- Jean-Daniel Fekete: Hiring Committee, Univ. Toulouse 1, France
- Pierre Dragicevic: Commission Scientifique Inria Saclay
- Pierre Dragicevic: PhD committee of Chat Wacharamanotham: Input Accuracy for Touch Surfaces. RWTH Aachen University, defended 5 February 2016.
- Pierre Dragicevic: Mi-term PhD evaluation committee of Nolwenn Maudet. 8 Sep 2016.
- Pierre Dragicevic: Mi-term PhD evaluation committee of Rafael Morales. 26 May 2016.
- Pierre Dragicevic: Post-doctoral assessment committee, project “Shareable Dynamic Media in Design and Knowledge Work”, Aarhus University. Nov 2016.
- Petra Isenberg: Jury CR2 Inria Saclay

9.3. Popularization

- Pierre Dragicevic and Yvonne Jansen: the Curated List of Physical Visualizations is continuously being updated.
- Elsa Ferreira’s interview with Mathieu Le Goc, Zooids: mais qui sont ces robots mignons?, Makery Magazine, 26 Nov 2016.
- Stéphanie Dupont’s interview with Mathieu Le Goc, Jean-Daniel Fekete and Pierre Dragicevic: Nouvelle interface homme-machine: des mini robots pour l’affichage et l’interaction. 26 Oct 2016.
- Petra Isenberg, Tobias Isenberg, and collaborators published an open dataset of IEEE VIS publications at http://vispubdata.org

- Petra Isenberg, Tobias Isenberg, and collaborators published an online tool to explore keywords of the IEEE Visualization conference at http://keyvis.org
- Pascal Goffin: "Enrichir le mot écrit – Intégrer texte et données avec les Word-Scale Visualizations (visualisations mots)". EnsadLab/Spatial Media/Hist3D Colloquium: Les images du numérique. Histoires et futurs des images produites par ordinateur. Paris, France, 21 Mar 2016.
- Mathieu Le Goc and Zooids co-authors: Material for Zooids.

10. Bibliography

Publications of the year

Articles in International Peer-Reviewed Journals

[1] B. BACH, P. DRAGICEVIC, D. ARCHAMBAULT, C. HURTER, S. CARPENDALE. *A Descriptive Framework for Temporal Data Visualizations Based on Generalized Space-Time Cubes*, in "Computer Graphics Forum", April 2016 [*DOI :* 10.1111/CGF.12804], https://hal-enac.archives-ouvertes.fr/hal-01303506

[2] B. BACH, C. SHI, N. HEULOT, T. MADHYASTHA, T. GRABOWSKI, P. DRAGICEVIC. *Time Curves: Folding Time to Visualize Patterns of Temporal Evolution in Data*, in "IEEE Transactions on Visualization and Computer Graphics", January 2016, vol. 22, n^o 1 [*DOI :* 10.1109/TVCG.2015.2467851], https://hal.inria.fr/hal-01205821

[3] M. BEHRISCH, B. BACH, N. HENRY RICHE, T. SCHRECK, J.-D. FEKETE. *Matrix Reordering Methods for Table and Network Visualization*, in "Computer Graphics Forum", 2016, vol. 35, 24 p. [*DOI :* 10.1111/CGF.12935], https://hal.inria.fr/hal-01326759

[4] M. BEHRISCH, B. BACH, M. HUND, M. DELZ, L. VON RÜDEN, J.-D. FEKETE, T. SCHRECK. *Magnostics: Image-based Search of Interesting Matrix Views for Guided Network Exploration*, in "IEEE Transactions on Visualization and Computer Graphics", 2017, 1 p. [*DOI :* 10.1109/TVCG.2016.2598467], https://hal.inria.fr/hal-01377861

[5] L. BESANÇON, P. ISSARTEL, M. AMMI, T. ISENBERG. *Hybrid Tactile/Tangible Interaction for 3D Data Exploration*, in "IEEE Transactions on Visualization and Computer Graphics", January 2017, vol. 23, n^o 1, pp. 881–890 [*DOI :* 10.1109/TVCG.2016.2599217], https://hal.inria.fr/hal-01372922

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