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ACTIVITY REPORT

Project-Team

AVIZ

Analysis and VIsualiZation

IN COLLABORATION WITH: Laboratoire Interdisciplinaire des Sciences du Numérique

DOMAIN

Perception, Cognition and Interaction

THEME

Interaction and visualization

Contents

Project-Team AVIZ

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Keywords

Computer sciences and digital sciences

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A1.3.3. – Blockchain

A3.1.4. – Uncertain data

A3.1.7. – Open data

A3.1.8. – Big data (production, storage, transfer)

A3.3. – Data and knowledge analysis

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A3.3.3. – Big data analysis

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Other research topics and application domains

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B9.6.6. – Archeology, History

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2   Overall objectives

2.1   Objectives

Aviz (Analysis and VIsualiZation) is a multidisciplinary project that seeks to improve data exploration methods, techniques, and tools based on Interactive Visualization. Visualization, in general, refers to the graphical representation of data or concepts to aid access, distribution or explanations of data. Card et al. give a general definition for visualization as

> *"the use of computer-supported, interactive, visual representations of data to amplify cognition." [73]*

Taking this definition, visualization is a means of creating visual aids that lead to insight in the underlying data sets. It is not about producing nice pictures but about making data understandable and explorable so that visualizations help viewers gain knowledge about the data. It is about aiding the process of forming a mental model for the acquired data and so helping the viewer to understand underlying concepts, patterns, and connections within the data [134]. In partiular, visualization has the goal to improve humans' sensemaking of complex data by taking advantage of the capabilities of their vision system: visual information can be processed in parallel and with a high bandwidth into the human cognitive centers [143]. Ware defines five advantages of visualization [143]:

1. **Comprehension:** Supports the comprehension of large amounts of data.

2. **Pattern Perception:** Previously unnoticed properties of data may emerge.

3. **Problem Analysis:** Problems within the data may become immediately apparent.

4. **Adaptability:** facilitates understanding of large- and small-scale features of data.

5. **Interpretation:** Hypothesis formulation is facilitated.

Three main areas of visualization have evolved in the computer science community: *Scientific Visualization*, *Information Visualization*, and *Visual Analytics*. Scientific visualization is primarily concerned with displaying real or simulated scientific data. Basic visualization techniques for this area include surface rendering, volume rendering, and animation. Typical examples include processing of satellite photographs, fluid flows, or medical data. Datasets in information visualization typically come from large information spaces or information systems and are both structured or unstructured. Examples include network data, multi-dimensional tables of abstract measurements, or unstructured data such as
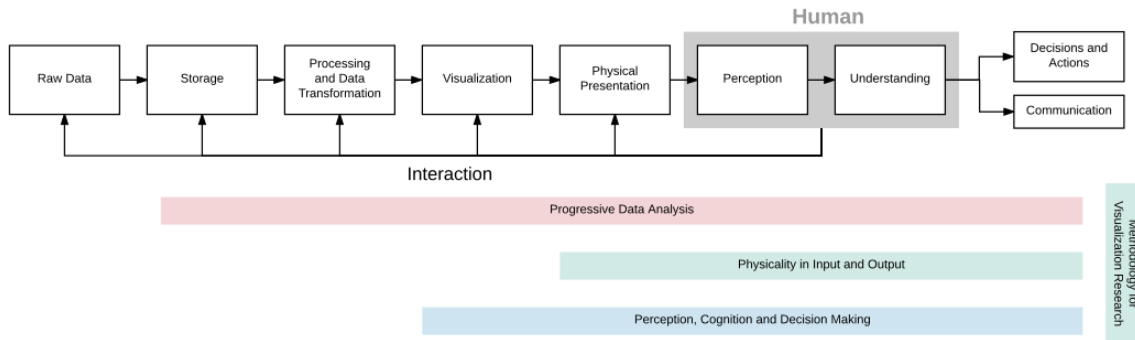
Figure 1: The conceptual Data Analysis Pipeline related with the four themes of AVIZ.

text. Visual analytics, finally, is concerned with augmenting human-led data exploration with automatic techniques such as machine learning. The Aviz team has expertise in all three areas of visualization.

As shown in Figure 1, visualization deals with the data analysis pipeline and research in visualization has been addressing all the stages with less emphasis on the two initial ones and the last one. In its initial incarnation, Aviz has been focusing on *interaction* in combination with visualization, physical presentation, and perception. We now want to expand our research to wider questions, both in the human-side and in the system side. For the human side, we want to better understand human perception and cognition to improve the visualization techniques, so as to better convey information to the human brain. We also want to better understand the human biases to overcome them when possible, or provide methods to avoid them otherwise.

On the system side, we want to expand the scope of visualization that is currently limited to relatively small datasets and relatively simple analytical methods. To achieve *scalability* in visualization, we will focus on a paradigm shift: *progressive data analysis.* Long-running computations currently hamper the exploration and visualization process because human's attention is limited by latency constraints. We want to design exploratory systems that provide continuous feedback and allow interactions at any time during computation. The new progressive data analysis paradigm offers these capabilities, but to be usable, it requires the whole analytical pipeline to be re-implemented, and visualization and interaction techniques to be adapted.

2.2   Research Themes

Aviz's research on Visualization and Visual Analytics is organized around four research themes, described in more detail in the next section. Instead of addressing point problems, each research theme will address several stages of the visualization pipeline in a holistic manner, as summarized in Figure 1.

1. Progressive Data Analysis will address visualization scalability problems. Existing data analysis systems (such as Tableau [138], R [130], or Python with its data analysis ecosystem [109]) are not scalable for exploratory analysis because their latency is not controllable. This theme will lay out the foundations of progressive data analysis systems, which generate estimates of the results and updates the analyst continuously at a bounded pace. It will focus on all the stages of the data analysis pipeline: data management mechanisms, data analysis modules, as well as visualizations, perception, understanding, and decision making.

2. Physicality in Input and Output will seek to better understand the benefits of physicality for information. Although beyond-desktop environments for visualization are generating more and more interest, theories and empirical data are lacking. This theme will consolidate the nascent areas of data physicalization, situated visualization, and immersive visualization.

3. Perception, Cognition, and Decision Making will study how we perceive and understand visualizations in order to develop generalized guidelines for optimizing effectiveness. It will generalize results obtained with simple charts to more complex visualizations of large datasets, establish theories on the use of abstraction in visualization, and contribute new empirical knowledge on decision making with visualizations.

4. Methodologies for Visualization Research will develop new methods to ground the study of the above scientific questions, and to benefit visualization more generally. This theme will develop evidence-based strategies for communicating quantitative empirical findings, and will promote methodological discussions and open research practices within the field.

3 Research program

3.1 Progressive Data Analysis

Permanent involved: Jean-Daniel Fekete

While data analysis has made tremendous progresses in scalability in the last decade, this progress has only benefited "confirmatory" analysis or model-based computation; progress in data exploration has lagged behind.

Existing data analysis systems do not support data exploration at scale because, for large amounts of data or for expensive computations, their latency is not controllable: computations can take minutes, hours, even days and months. Cognitive psychologists have shown that humans cognitive capabilities degrade when latency increases [125, 133]. Miller [125] points out that the feedback of a system should remain below 10 seconds to maintain the user's attention. Therefore, to try to limit the latency, analysts currently resort to complex, inefficient, and unsatisfactory strategies, such as sampling with its issues related to representativity.

To address the scalability problem under controlled latency, instead of performing each computation in one long step that forces the analyst to wait for an unbounded amount of time, a progressive system generates estimates of the results and updates the analyst continuously at a bounded pace. The process continues until the computation is complete, or it stops early if the analyst considers that the quality of the estimates is sufficient to make a decision. During the process, a progressive system allows users to *monitor* the computation with visualizations and *steer* it with interactions.

While the topic of progressive data analysis has started to emerge in the late 90's, it has remained marginal practically because it touches three fields of computer science that are traditionally separate: data management, data analysis, and visualization. Research on progressive data analysis remains fragmented; the solutions proposed are partial and the different solutions cannot always be combined. We have organized a Dagstuhl seminar on Progressive Data Analysis and Visualization [85, 139] that acknowledged the harm of this topical separation and devised a research agenda. Aviz will participate in this agenda with specific assets.

Aviz has recently started to design and implement the ProgressiVis language that is natively progressive [86]. The language relies on a Python interpreter but its execution semantics is different in the sense that all the operations that would take time to execute are performed progressively. The ProgressiVis system touches all the stages of the conceptual data analysis pipeline of Figure 1; it integrates data management mechanisms, data analysis modules, as well as visualizations, perception, understanding, and decision making. Aviz will strengthen its work on the implementation of a natively progressive data science system. Such a system will lead to the following research topics:

1. Progressive language kernel and data management mechanisms

2. Progressive algorithms and computation strategies

3. Progressive visualizations

4. Management of uncertainties, computed from the algorithms and conveyed to the analysts.

Language: ProgressiVis relies on a Python interpreter that is convenient for quick prototyping but is inefficient. Once the semantics of the language and its core libraries become clearer, we will replace the implementation with a `C++` library that will improve performance and allow its integration in other popular data science environments such as R and Julia. We are collaborating with colleagues in the database community to tackle the challenges related to progressive data management [139, 58].

Algorithms: Existing libraries implementing algorithms are either "eager", sometimes "online", and more rarely "streaming", but very few are compatible with our progressive paradigm. We have started to work in collaboration with the University of Seoul and the University of Delft on the problem of converting existing algorithms into a progressive form. We currently have a running version of approximate k-nearest-neighbors [107], kernel density estimation [107], k-means clustering, multidimensional projection using t-SNE [107], and several other core algorithms. We want to further expand the range of algorithms we can support, and better understand how algorithms could be transformed into their progressive counterpart.

Progressive computation can trade speed, memory, and quality. When analysts want to compute rough estimates of their results quickly, several progressive algorithms offer parameters to control the tradeoffs. For example, our progressive k-nearest-neighbors algorithm [107] allows choosing the number of k-d-trees that influences the memory footprint, accuracy, and speed. Progressive data analysis also uses and adapt streaming algorithms, also called "data sketches" [87], that offer various tradeoffs between speed, memory, and quality.

Visualizations: Like algorithms need to be adapted or transformed, visualization techniques and user interfaces also need to be adapted to be used in a progressive setting. For the visualization pipeline, including the rendering phase, there has been previous work related to progressive layout computation and progressive rendering. For example, in network visualization, there is a old tradition of using iterative force-directed solvers and showing their results progressively when computing complex graph layouts. We want to generalize this approach to all the visualizations. In the recent years, we have collaborated on work related to the progressive computation of multidimensional projections, including PCA and t-SNE [129, 107], and will continue to improve the scalability of projection methods. Progressive rendering is popular in the real-time computer graphics and gaming domains, but new in visualization. Our colleague Renaud Blanch from Grenoble has started to investigate this problem [70] by designing a rendering engine that can visualize and filter a large amount of data in interactive time, transiently simplifying details when necessary. We will also explore this problem both in the context of direct rendering, when the GPU shares the memory performing the computations, and web-based rendering.

We have also started to explore the problem of requirements for progressive user interfaces [57], leading the community of researchers to understand that progressive systems need to provide effective assessments of the quality of their results to allow analysts to make early decisions. This justifies the next research topic on the management of uncertainties. We have also started to propose new data models for managing aggregated visualizations [108]. We will now continue our research to adapt existing visualization techniques and interaction environments to deal with progressive results and parameter steering.

Management of uncertainties When performing exploratory data analysis on large data, analysts start by trying some algorithms with different parameters until they obtain useful results. Therefore, it is of paramount importance to be able to realize that a specific algorithm or a specific set of parameters are not leading to a useful result and to abort an analysis before it ends to explore other methods. On the other side, in many circumstances when data is "well-behaved", progressive algorithms achieve very good results quickly, and analysts can make a decision before the end of the algorithms' execution. The assessment of a quality measure related to a computed result is a complex problem, already tackled by other communities (e.g., streaming, approximate queries). Progressive Data Analysis adds two problems: 1) controlling uncertainty during progressive computations, and 2) conveying the results of this uncertainty in a way understandable by analysts, while avoiding possible cognitive biases such as priming and anchoring [110].

To control the uncertainty during the progression of a computation, methods related to Sequential Analysis [88] should be used. They are well-known in the area of clinical trials and have evolved recently to manage large amounts of data while controlling time or quality in Approximate Query Databases such as BlinkDB [54]. These approaches should be further adapted for progressive data analysis. The topic of human cognitive bias will be developed further in subsubsection 3.3.4.

3.2 Physicality in Input and Output

Permanents involved: Pierre Dragicevic, Petra Isenberg, Tobias Isenberg, Jean-Daniel Fekete

In the past few years, researchers at Aviz have begun to investigate beyond-desktop environments for visualization [96, 95, 102, 120]. In particular, our team has made important contributions in the areas of large-display visualizations [94, 69, 93], tangible interaction for scientific visualization [61, 59, 63], and data physicalization [103, 101, 105, 117]. We will pursue and consolidate this stream of research by focusing on how to leverage physicality in visualization, both as an input channel and as an output channel. We will more specifically *i)* lay out the scientific foundations for data physicalization; *ii)* explore physically-situated and physically-embedded visualizations for personal analytics; and *iii)* study augmented-reality-based scientific visualization.

3.2.1 Scientific Foundations for Data Physicalization

In the next few years, we will work on establishing and consolidating the new area of data physicalization. Data physicalization is an emerging cross-disciplinary research area that examines how computer-supported, interactive physical representations of data, that we call "data physicalizations", can support cognition, communication, learning, problem solving, and decision-making [105, 45]. In contrast to traditional graphical on-screen data visualizations, physicalizations show data in a material form.

Although the research community, and especially the members of Aviz, have made first steps by conducting initial experiments [103] and laying out a research agenda [105],[1] the area still lacks a theoretical and empirical foundation that can guide the design of physical data representations, both static and dynamic [118, 119].

Data physicalizations can potentially offer a useful complement to flat (paper-based or screen-based) visualizations due to the ability of physical objects to tap on human skills such as active perception, depth perception, and non-visual senses; they may have the ability to support learning via direct manipulation, and can possibly engage broader audiences. However, there is currently little understanding of the underlying mechanisms, and the exact situations where physicality may be beneficial.

In particular, work in educational psychology and tangible user interfaces has shown that physical manipulation can facilitate cognition, while research on vicarious learning has suggested that people can also learn from observation. However, it is not clear which approach is the most effective, and no study so far has started to examine how previous findings generalize to data physicalizations. We will investigate to what extent manipulable physicalizations can support data-driven cognition compared to non-manipulable physical media such as paper, and to manipulable virtual media (e.g., computer graphics). We will investigate the perception, recollection and interpretation of a data physicalization when people watch it being animated vs. they manipulate it themselves, vs. they watch a third-person manipulate it. We will attempt to conduct this research in collaboration with Barbara Tversky (Professor Emerita of Psychology at Stanford University, Professor of Psychology and Education at Columbia University, and President of the Association for Psychological Science), with whom we have been in close contact.

We will also be working on a taxonomy of physicality, in order to better untangle the factors that distinguish physical from virtual displays, and to help the community develop a coherent terminology that will serve as a thinking and communication tool.

Although we have been involved in research on digital fabrication in the context of data physicalization [135] and despite the new and exciting advances in this domain, we might not pursue this line of research so we can better focus on the research questions mentioned previously. In other words, we will focus more on *why* build data physicalizations than on the *how*.

3.2.2 Situated Data Representations for Personal Analytics

In addition to studying physical representations of data, we will study how embedding data visualizations in the physical world can empower people to make effective use of their personal data in a variety of application contexts. People generate data in many areas of daily life (e. g., data generated from shopping cards, fitness and health data). However, these types of personal data are often only exploited by the companies capturing it while they remain unused by the people who "generated" them. Rarely is personal data subjected to an in-depth analysis and used for reflection and decision making.

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[1]Aviz is also hosting a wiki on the topic (dataphys.org), and maintains a list of physical visualizations with 200 page views per day (dataphys.org/list)

Personal visual analytics is a new and growing area of research [91], but has mostly focused on desktop and mobile applications. With our work we want to go beyond the traditional platforms of personal data analytics by using *situated data visualizations*. In a situated data visualization, the data is directly visualized near the physical space, object, or person it originates from [145]. For example, a person may attach small e-ink displays embedded with sensors at various locations of their house or their workplace, to better understand their use of space, of equipment, or of energy resources. Or a person who wishes to exercise more may use an augmented reality device to visualize their past running performance in-place. New situated data visualizations like these can surface information in the physical environment—allowing viewers to interpret data in-context and take action in response to it. Because they will make it possible to explore personal data and take action in relevant physical locations, situated visualizations of personal data have the potential to radically transform how people relate to data.

This research will investigate how situated visualizations of personal data can help address problems faced by the general public by investigating a range of research hypotheses and application domains. For example, we will study how augmented reality technology can help surface digital traces of personal data in physical environments and enable people to make more informed decisions. We will also study how small, portable, and situated micro-visualizations can allow people to understand personal data in-place in changing, dynamic, and mobile contexts.

On this topic, we already have an "équipe associée" Inria grant with University of Calgary, and we are currently submitting an ANR PCR proposal in collaboration with Sorbonne Université and Université de Bordeaux.

3.2.3   Visualization using Augmented Reality Devices

Based on past work on the integration of various types of input and output devices for the visualization of inherently three-dimensional spatial data [61, 59, 63, 97, 121, 98, 99, 100], we investigate the use of, in particular, augmented reality (AR) head-mounted displays (HMDs). This combination of stereoscopically projected 3D data which provides a high amount of visual immersion with innovative interaction techniques that facilitate data exploration though immersion that arises from direct manipulation is part of the recently established subfield of visualization research which focuses on immersive analytics [84, 72] and promises to combine benefits of traditional virtual reality (VR) environments with those that use traditional, touch, or tangible input and used innovative interaction designs. We specifically focus on AR-based HMDs because they do not prevent us from using traditional data exploration environments such as workstations which are not only familiar to experts but also widely available. The AR HMD, moreover, is an easily maintainable device that does not rely on constant calibration and thus could more easily be integrated into and accepted by existing research facilities than more elaborate VR settings such as CAVEs.

Specifically, we currently have started two projects in this direction. One is a collaboration with particle physicists at the local linear accelerator laboratory as well as researchers at CERN with whom we are exploring an interactive data exploration tool of the experimental data generated at CERN from collisions of protons. In a second project we are working with climate researchers to explore novel collaborative data analysis scenarios in which several experts investigate 3D datasets together with the help of AR HMDs.

3.2.4   Other

In addition to the three major themes previously mentioned, Aviz has also been involved in research on the use of tangible input devices, both to navigate abstract data visualizations [104, 113] and to explore 3D data [99, 64, 62]. We will continue this stream of research, possibly applying emerging trends in tangible input device design [89] to data exploration.

3.3   Perception, Cognition and Decision Making

Permanents involved: Steve Haroz, Pierre Dragicevic, Petra Isenberg, Tobias Isenberg, Jean-Daniel Fekete

As we collect increasingly large amounts of data in fields such as climate science, finance, and medicine, the need to understand and communicate that data becomes more important. Data visualizations (e.g., graphs, maps, infographics, etc.) are often used to give an overview of information, however it can be challenging to predict whether these visualizations will be effective before spending resources to develop them. Consequently, researchers make use of experimental methods from visual perception and cognition to study how we perceive and understand visualizations in order to develop generalized guidelines for optimizing effectiveness. While many past studies provide a research groundwork using simple and small visualizations (such as a bar graph with four bars), there has been little research on perception and cognition for more complex visualizations used for large datasets with thousands or millions of elements. Novel techniques researched by Aviz to alleviate complexity can be more effectively used if we understand when and why these techniques become beneficial.

3.3.1 Perceiving the Gist of a Visualization

It would be highly inefficient if users of large data visualizations serially inspected individual visual elemnts. Instead, the visual system allows people to quickly get a visual gist of an overall pattern in the image [137]. But how quickly and reliably can we detect these gists when multiple groups or regions in a visualization need to be summarized seperately and compared? What happens to speed and accuracy as more items are added to a visualization? These open questions about the impact of data scale and complexity on visualization perception were discussed in the review article by Szafir, Haroz, Gleicher, and Franconeri [137]. To answer these questions, the experiment methods and findings from visual perception can be employed. Specifically, "ensemble coding" is the term used by vision scientists to describe our ability to rapidly perceive simple statistical properties of sets without the need to inspect individual items. Research has shown that we can perceive averages for sets made of simple [55] and complex [136] objects as well as the variance of sets for simple objects [127]. But it is not clear if or how we can answer more complex statistical questions about subsets within visualizations, such as:

- How different are trends between groups of line charts?

- Which group's trends are more variable?

- Is the distribution of trends uniform or normally distributed?

For the field of visual perception research, understanding how we make these statistical decisions with collections would be a novel contribution that helps explain how our brain represents and summarizes complex information, how much information is discarded to make rapid judgements, and when biases or accuracy limits arise when working with collections of items.

For the field of data visualization research, understanding the conditions when we can make these statistical judgements and the speed and precision with which we can make them will directly translate to new guidelines for optimal use of visualization for large datasets. Although much visualization software uses settings that rely on design intuition, these results would be the first science-based guidelines for large data visualization and progressive visualization.

3.3.2 Cognitive Limitations for Visually Selecting Subsets in Visualizations

A critical task for analyzing large data mentioned in the previous section is filtering and comparing subsets. But why and when are these filtering tasks difficult? And how can a visualization facilitate the identification of subsets – especially for data with many categories?

How much information we can visually select and attend to and the minimum size of a selection are strongly limited, and this limitation is impacted by the layout of items in an image and the types of visual features and tasks employed [90]. Past visual cognition research on the cause of attentional limits [92] generally presumed that we focus on information in a roughly circular region. But subsets in a visualization are often irregularly shaped, and the limitations of attention selection for more chaotic images like visualizations are not understood. Researching how people select irregularly shaped subsets would be a novel contribution to our understanding of visual cognition and could inform how progressive visualization techniques can show datasets such that all subsets can be visually compared.

3.3.3   Illustrative Visualization

We will continue our work in the area of illustrative visualization. This sub-field of visualization takes inspiration from illustrators' decades to centuries of experience in using knowledge from perception and cognition to better portray scientific subject matter. Another input arises from the field of non-photorealistic rendering which has developed numerous techniques of stylizing images and other input data. Traditionally, illustrative visualization has thus been applied primarily to data with a concrete spatial mapping in 2D and, more frequently, in 3D space. Nonetheless, some efforts for understanding the potential benefit of illustrative visualization to non-spatial data have been documented, including some of our own team [80, 56]. An interesting aspect in this context is the role of depiction style can play in how visualizations or other forms of depiction are interpreted and understood. For example, we recently investigated the effect of stylization on emotion for images [66], and will extend this work in the future to study how we can use stylization to change the way people perceive, consume, and understand visualizations. One hypothesis to investigate, for example, is that a more hand-drawn depiction style [83] could lead to viewers spending more time with a visualization, and thus take more time to understand and interact with it.

Another main future direction of research in this context is the question of what the role of abstraction is in illustrative visualization [141] as well as visualization in general, and specifically how we can provide dedicated means to control the abstraction being applied to visual representations of data. This means that we need to go beyond seeing abstraction only as a side-product of stylization as it has traditionally been viewed in many approaches in non-photorealistic rendering as well as illustrative visualization to date, and investigate how we can interactively adjust it to provide practitioners with a means to find the best visual representations for a given task. For example, we have investigated this question recently in the context of structural biology [123, 146] and DNA nanostructures [124, 122], but also want to expand this work to other application domains in the future.

3.3.4   Decision Making with Visualizations

Aviz has recently started a novel stream of research on the topic of judgment and decision making with visualizations [77, 76, 75]. Human decision making and cognitive biases are important research topics in the fields of psychology, economics and marketing, but until recently, the presence of cognitive biases in visualization-supported decision making has not been investigated. Yet, visualization systems are increasingly used to support decision making: large companies switch to visualization solutions to improve their decisions in a range of areas, where large sums of money or human lives are at stake. More and more, the ultimate goal of visualization is not to understand patterns in the data and get insights as was traditionally assumed, but to make good decisions. In order to fully understand how information visualizations can support decision making, it is important to go beyond traditional evaluations based on data understanding, and study how visualizations interact with human judgment, human heuristics, and cognitive biases.

We will pursue this important stream of research by investigating yet-unexplored areas, such as group decision-making with visualizations, decision making in the presence of uncertainty and incomplete information (in connection with the topics discussed in Sections 3.1 and 3.4.2), and the use of visualizations to support social choice and group decisions in the presence of conflicts of interest. How cognitive biases interact with visual perception is also an important and difficult question that has remained largely unexplored. In terms of application domains, we will be focusing more on evidence-based decision making in everyday life, e.g., how can visualizations be useful (or harmful) when choosing medicines, food products, means of transportation, charity donations, or when electing politicians. For example, a recent study has investigated whether specific infographic designs can lead people to feel more empathy towards suffering populations [71], but with inconclusive or negative results. In collaboration with the University of Campina Grande in Brazil, we are currently investigating designs that we believe are more likely to be effective. We will be evaluating these designs using metrics that are more likely to be correlated with prosocial decision making than empathy, as it has been shown that the emotion or empathy is not always conducive to helping behavior.

3.4   Methodology for Visualization Research

Permanents involved: Petra Isenberg, Steve Haroz, Pierre Dragicevic, Tobias Isenberg

An important aspect of any scientific research is to establish and follow rigorous and effective methodologies for acquiring new knowledge. In the field of Visualization in particular, scientific discourse on the validity, use, and establishment of methodologies is important as the field is highly interdisciplinary, with diverse influences and opinions. It is important to establish, for example, what level of rigor the field should require of its methods, how to choose among established methods and methodologies, and how to best communicate the results of our empirical research. Aviz researchers have in the past been very active in contributing critical reflection on ways to assess different forms of value offered by visualization and visual analytics research and design (e. g., [79, 106, 111, 112, 115, 131, 142]). This included work on novel research methods but also existing methods and tools such as statistics. As part of the new team we will focus our efforts on three main topics related to visualization research methodologies.

3.4.1   Promoting and Following Open Research Practices

Fundamental tenants of scientific research are that it is accessible, scrutinizable, and can be built-upon. For visualization research, the low rate of accessibility of both published articles and supporting materials makes it almost impossible to question the claims made in publications or to extend them. We measured the state of some of these issues for the IEEE VIS conference, finding serious problems across every facet of openness [114]:

1. Open Artifacts: Questioning the veracity of research claims is difficult if the supporting evidence and methods are not available for scrutiny. Without these supporting research artifacts, reviewers and readers cannot thoroughly verify, replicate, or reproduce research, and readers may have difficulty extending and applying research. Such artifacts include but are not limited to: Code, resource files, parameters, sample datasets, and documentation needed to reproduce software, toolkits, or experiment procedures Raw empirical data collected or analyzed to support a paper's conclusions Analysis code or scripts used to support a paper's conclusions

2. Transparency in Decisions: To clarify distinctions between exploratory and confirmatory research, to reduce hidden flexibility in research (i.e., unreported researcher degrees of freedom [144], and to minimize publications bias, researchers must be educated about the impact of these issues and use approaches such as preregistration and registered reports where appropriate [128][114].

3. Transparency in statistical reporting: Researchers must report the outcomes of their statistical analyses in a way that does not prompt misinterpretations. This aspect will be further developed in the next subsection.

For these issues to be addressed, educational materials and guidelines need to be written, so researchers have clarity about how to make their research more credible. Moreover, Aviz members are working with the organizing bodies of the visualization research community to establish incentives for making research artifacts and potentially establish minimal requirements for openness in published articles. Meanwhile, it is important to continue measuring and cataloging openness in the field to monitor progress. The goal is to improve the credibility and applicability of the field's research.

3.4.2   The Communication of Statistics Results

Statistics are tools to help end users accomplish their task. In experimental sciences, to be qualified as usable, statistical tools should help scientists advance scientific knowledge by supporting and promoting the effective communication of research findings. Yet many areas of experimental science have adopted tools that have proven to be poor at supporting these tasks [78]. One very common but particularly damaging practice is "dichotomous inference", i.e., the classification of statistical evidence as either sufficient or insufficient, for example by looking at whether a p-value is above or below the .05 threshold [60]. Dichotomous inference encourages practices that distort the scientific literature, such as publication bias, outcome reporting bias, and significance chasing [140]. All of these issues contribute to making published studies less trustworthy and less likely to replicate.

A commonly advocated solution is to focus on effect sizes and their interval estimates rather than on p-values. However, interval estimates do not offer a sure protection against dichotomous inference [60]. Therefore, many modern statisticians and methodologists urge researchers to think of evidence as gradual rather than binary when interpreting their results, irrespective of the statistical methods used. However, there is a lack of guidance on how to do to so. We will be conducting research on how to design statistical charts that prompt nuanced interpretations, and more generally, charts that convey statistical uncertainty in a honest and transparent manner. The two main targeted populations will be *i)* experimental scientists (who use research papers as a medium to communicate about scientific findings) and *ii)* the general population (who use newspapers and online articles to inform themselves about recent science advances). One goal will be to develop guidelines for faithful statistical communication that are evidence-based instead of being based on personal opinions. This research lies at the intersection of statistical cognition [67] and information visualization.

Besides studying visual representations that encourage non-dichotomous inferences, we will pursue one line of research we just started at Aviz, which considers the research paper as a user interface, and seeks to look at how this interface can be improved to help scientists communicate their results in a more transparent manner than using conventional research papers [82].

As a longer-term goal, we are planning to develop conceptual models in order to better understand and better reflect about the diverse phenomena underlying data-driven scientific communication. This includes the process of communicating empirical data between scientists, from scientists to people, and from journalists to people: we will attempt to better understand and describe the entire information pipeline, where information can be lost or distorted, and how to make the pipeline more robust to [self-]deception [81].

3.4.3 Shaping the Scientific Visualization Community

In the past, Aviz researchers have been heavily involved in the organization structure of IEEE visualization conferences, the most prestigious conference in our field, by proposing workshops, tutorials, serving on various organizing committees, steering committees, editorial boards, and even the IEEE Visualization Executive Committee that oversees the whole IEEE Visualization conference. We will continue to do so but will, in addition, be involved in newly created committees that help to restructure the community and prepare it for future growth and inclusivity. We will, in particular, aid the process by providing data collection and analysis services through the vispubdata.org dataset that we are collecting, cleaning, and making available to the community. The dataset has already been used in research (e. g., [116]) but also to shape the scientific community by proposing program committee members, new processes, and is currently used by the Visualization Restructuring Committee (ReVISe). We are also involved in the EuroVis community and participate at multiple levels to its organization and management.

4 Application domains

4.1 Natural Sciences

As part of a CORDI PhD project, we collaborate with researchers at CERN on interactive data visualization using augmented reality, with the goal to better understand this new visualization environment and to support the physicists in analysing their 3D particle collision data. As part of another CORDI PhD project, we collaborate with researchers at the German Center for Climate Computation (DKRZ) and the Helmholtz-Zentrum Hereon (formerly Helmholtz-Zentrum Geesthacht, HZG), to better understand collaborative data exploration and interaction in immersive analytics contexts. Finally, as part of the Inria IPL "Naviscope," we collaborate with researchers at INRAE (as well as other Inria teams) on interactive visualization tools for the exploration of plant embryo development.

4.2 Social Sciences

We collaborate with social science researchers from EHESS Paris on the visualization of dynamic networks; they use our systems (GeneaQuilts [68], Vistorian [132], PAOHVis [28], PK-Clustering [4]) and teach them to students and researchers. Our tools are used daily by ethnographers and historians to study the

evolution of social relations over time. In the social sciences, many datasets are gathered by individual researchers to answer a specific question, and automated analytical methods cannot be applied to these small datasets. Furthermore, the studies are often focused on specific persons or organizations and not always on the modeling or prediction of the behavior of large populations. The tools we design to visualize complex multivariate dynamic networks are unique and suited to typical research questions shared by a large number of researchers. This line of research is supported by the DataIA "HistorIA" project, and by the "IVAN" European project. We also collaborate on the BART initiative, a joint project with IRT-SystemX on the analysis and visualization of blockchain data, in collaboration with economists from Université Paris-Saclay.

4.3 Medicine

We collaborate with the Health-Data-Hub on the analysis and visualization of CNAM Data "parcours de santé" to help referent doctors and epidemiologists make sense of French health data. In particular, we are working on a subset of the CNAM Data focused on urinary problems, and we have received a very positive feedback from doctors who can see what happens to the patients treated in France vs. what they thought happened through the literature. This project is starting but is already getting a lot of traction from our partners in medicine, epidemiology, and economy of health.

5 Social and environmental responsibility

5.1 Impact of research results

Aviz' work on illustrative visualization (e. g., see Sections 3.3.3 and 8.3) has the potential to be integrated into future teaching materials for students in schools, visitors in museums, or similar.

Aviz' work on visualization of large documents corpora with Cartolabe is used to present the results of the French "Grand débat", as well as other citizen expressions.

Aviz' work on anthropographics (Section 8.6) is aiming at improving assistance to populations in need.

Open science: Aviz regularly shares full research material on the repository of the Center for Open Science to facilitate scrutiny, reuse, and replication:

- Antropographic studies [34] – osf.io/xqae2/

- Anthropographics Design Space [126] – osf.io/wfgmp/

- Open Science Tutorial – osf.io/vfnwp/

- Point specification in AR [23] – osf.io/43j9g/ and osf.io/7a6yr/

- Readability of micro visualizations on mobile devices – osf.io/yz8ar/

- Reducing Affective Responses to Surgical Images through Color Manipulation and Stylization [65] – osf.io/4pfes/ and osf.io/34vzj/

- Selection techniques for tightly packed 3D objects [32] – osf.io/cewhn/ and osf.io/yze5n/

- Smart watch survey – osf.io/nwy2r/

- Spatial 3D Visualization interfaces [8] – osf.io/jtx75/

- Study on the discovery and selection of cells in 3D plant embryo datasets – osf.io/yze5n/

- Threats of a Replication Crisis in Empirical Computer Science [74] – osf.io/hkqyt/

- Transparency of CHI Research Artifacts – osf.io/csy8q/

- User Study of Annotation 3D Placements in Collaborative Augmented Reality Environments – osf.io/7a6yr/

- VIS open practice resources – osf.io/dc6mt/

- Visualization errors and bias [16] – osf.io/u8ejr/

6   Highlights of the year

6.1   Awards

Best paper award for

- IEEE VIS 2021: Wesley Willett, Bon Adriel Aseniero, Sheelagh Carpendale, Pierre Dragicevic, Yvonne Jansen, Lora Oehlberg, and Petra Isenberg. "Perception! Immersion! Empowerment!: Superpowers as Inspiration for Visualization." IEEE Transactions on Visualization and Computer Graphics (2021).

Best paper runner-up/honorable mention award:

- IEEE ICBC 2021: Natkamon Tovanich, Nicolas Soulié, Nicolas Heulot, Petra Isenberg. "An empirical analysis of pool hopping behavior in the Bitcoin blockchain." IEEE International Conference on Blockchain and Cryptocurrency.

7   New software and platforms

Natkamon Tovanich developed and tested MiningVis, a visual analytics system for studying mining activities across the history of the bitcoin blockchain.

7.1   New software

7.1.1   Cartolabe

Name: Cartolabe

Keyword: Information visualization

Functional Description: The goal of Cartolabe is to build a visual map representing the scientific activity of an institution/university/domain from published articles and reports. Using the HAL Database, Cartolabe provides the user with a map of the thematics, authors and articles . ML techniques are used for dimensionality reduction, cluster and topics identification, visualisation techniques are used for a scalable 2D representation of the results.

Cartolabe has in particular been applied to the Grand Debat dataset (3M individual propositions from french Citizen, see https://cartolabe.fr/map/debat). The results were used to test both the scaling capabilities of Cartolabe and its flexibility to non-scientific and non-english corpuses. We also Added sub-map capabilities to display the result of a year/lab/word filtering as an online generated heatmap with only the filtered points to facilitate the exploration. Cartolabe has also been applied in 2020 to the COVID-19 kaggle publication dataset (Cartolabe-COVID project) to explore these publications.

URL: http://www.cartolabe.fr/

Publication: hal-02499006

Contact: Philippe Caillou

Participants: Philippe Caillou, Jean-Daniel Fekete, Michèle Sebag, Anne-Catherine Letournel

Partners: LRI - Laboratoire de Recherche en Informatique, CNRS

7.1.2   BitConduite

Name: BitConduite Bitcoin explorer

Keywords: Data visualization, Clustering, Financial analysis, Cryptocurrency

Functional Description: BitConduite is a web-based visual tool that allows for a high level explorative analysis of the Bitcoin blockchain. It offers a data transformation back end that gives us an entity-based access to the blockchain data and a visualization front end that supports a novel high-level view on transactions over time. In particular, it facilitates the exploration of activity through filtering and clustering interactions. This gives analysts a new perspective on the data stored on the blockchain.

Authors: Jean-Daniel Fekete, Petra Isenberg, Christoph Kinkeldey

Contact: Petra Isenberg

7.1.3   PAOHvis

Name: Parallel Aggregated Ordered Hypergraph Visualization

Keywords: Dynamic networks, Hypergraphs

Functional Description: Parallel Aggregated Ordered Hypergraph (PAOH) is a novel technique to visualize dynamic hypergraphs [28]. Hypergraphs are a generalization of graphs where edges can connect more than two vertices. Hypergraphs can be used to model co-authorship networks with multiple authors per article, or networks of business partners. A dynamic hypergraph evolves over discrete time slots. A PAOH display represents vertices as parallel horizontal bars and hyperedges as vertical lines that connect two or more vertices. We believe that PAOH is the first technique with a highly readable representation of dynamic hypergraphs without overlaps. It is easy to learn and is well suited for medium size dynamic hypergraph networks such as those commonly generated by digital humanities projects - our driving application domain (see Fig. 4).

URL: https://aviz.fr/paohvis

Contact: Paola Tatiana Llerena Valdivia

7.1.4   AR Collaborative Visualization

Name: AR Collaborative Visualization

Keywords: Augmented reality, Collaborative science, Android

Functional Description: Allows to look at VTK datasets using AR-HMD (Microsoft HoloLens) in multi-users environments (i.e., one headset per user). A Multi-touch tablet is provided per user to manipulate the environment.

Contact: Tobias Isenberg

7.1.5   MiningVis

Name: MiningVis: Exploring the Bitcoin Mining Economy

Keywords: Bitcoin, Visual analytics, Data visualization

Scientific Description: https://hal.archives-ouvertes.fr/hal-03348145

Functional Description: MiningVis aims to help analysts understand the evolution and dynamics of the Bitcoin mining ecosystem, including mining market statistics, multi-measure mining pool rankings, and pool hopping behavior. Each of these features can be compared to external data concerning pool characteristics and Bitcoin news.

Release Contributions: This is the first version of the tool as described in the following publication: https://hal.archives-ouvertes.fr/hal-03348145

Publication: hal-03348145

Contact: Natkamon Tovanich

Participants: Natkamon Tovanich, Petra Isenberg

Partner: IRT SystemX

7.1.6   Statcheck Simple Edition

Keyword: Statistics

Functional Description: You can copy text with statistical tests, and Statcheck Simple Edition will detect statistical tests and check if they are correct.

URL: http://steveharoz.com/statchecksimple

Contact: Steve Haroz

7.1.7   ARSciVis

Name: ARSciVis

Keywords: Augmented reality, Data visualization

Functional Description: This software allows to visualize, in a collaborative way, a set of data (for the moment .vtk datasets) with augmented reality headsets like the HoloLens. This software is composed of three major sub-software: -A server application to link all the devices. -An application for augmented reality headsets. -An application for multi-touch tablets which allow to interact with the data.

In order to avoid copying the code in the different sub-components, this application is also composed of several libraries written by me.

The whole software is based on the following libraries and technologies:

-The standard UNIX library -The Android SDK/NDK (with Java 8) -The Unity SDK -C#/.NET Core -GLM (MIT license or the Happy Bunny License (Modified MIT)) -lib3DS (LGPL v2.1 License) -libpng PNG Reference Library License version 2 (www.libpng.org/pub/png/src/libpng-LICENSE.txt) -VRPN (BSL licence, https://github.com/vrpn/vrpn/)

Contact: MickaËl Sereno

7.2   New platforms

7.2.1   Vispubdata.org

Participants: Petra Isenberg *(Inria Paris-Saclay, correspondent)*, Tobias Isenberg *(Inria Paris-Saclay).*

AVIZ members are making available for research a dataset of IEEE VIS publications at vispubdata.org. This dataset is actively being used for research and conference organization.
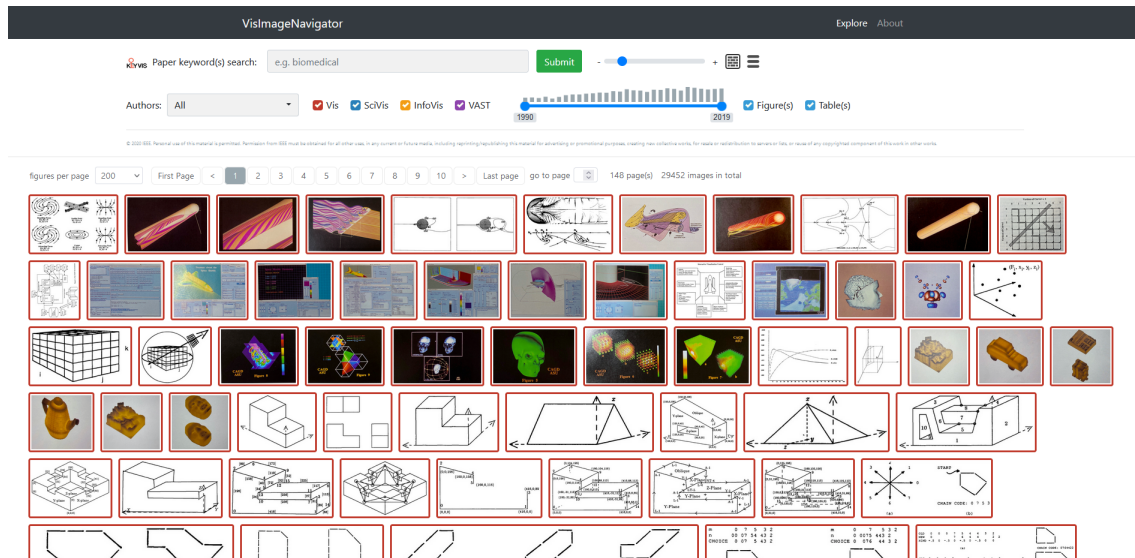
Figure 2: The VisImageNavigator interface.

7.2.2 VisImageNavigator

Participants:	Petra Isenberg *(Inria Paris-Saclay, correspondent)*, Tobias Isenberg *(Inria Paris-Saclay)*.

AVIZ members are contributing to making available for research a dataset of IEEE VIS images at ieee-dataport.org/open-access/ieee-vis-figures-and-tables-image-dataset [10]. The set of images can be browsed online at vispubfigures.github.io/VisPubFigures/. The work is primarily led by Jian Chen at Ohio State University.

7.2.3 Gender in Visualization Dataset

Participants:	Natkamon Tovanich *(System X)*, Pierre Dragicevic *(Inria Bordeau)*, Petra Isenberg *(Inria Paris-Saclay, correspondent)*.

In the context of our paper on "Gender in 30 Years of IEEE Visualization" we make available data about the diversity of the Visualization community in terms of the gender of authors, organizing, and program committee members as well as award winners: www.aviz.fr/Research/Gender-in-Vis.

8 New results

8.1 Superpower-Inspired Framework for Data Visualization

Participants:	Wesley Willett *(Univ. Calgary)*, Bon Adriel Aseniero *(Autodesk)*, Sheelagh Carpendale *(Simon Fraser Univ.)*, Pierre Dragicevic *(Inria Bordeaux)*, Yvonne Jansen *(CNRS, LaBRI)*, Lora Oehlberg *(Univ. Calgary)*, Petra Isenberg *(Inria Paris-Saclay, correspondent)*.

We explored how the lens of fictional superpowers can help characterize how visualizations empower people and provide inspiration for new visualization systems [29] . Researchers and practitioners often
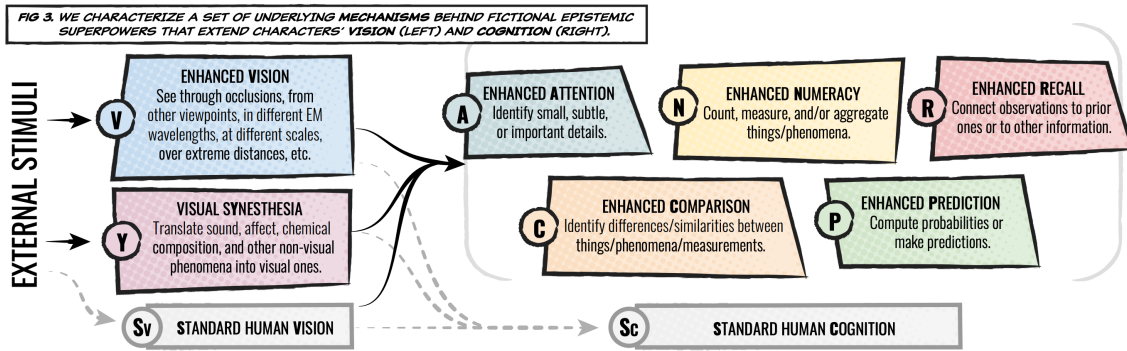
Figure 3: Underlying mechanisms behind fictional epistemic superpowers that extend characters' vision (left) and cognition (right).

tout visualizations' ability to "make the invisible visible" and to "enhance cognitive abilities." Meanwhile superhero comics and other modern fiction often depict characters with similarly fantastic abilities that allow them to see and interpret the world in ways that transcend traditional human perception. We investigated the intersection of these domains, and showed how the language of superpowers can be used to characterize existing visualization systems and suggest opportunities for new and empowering ones. We introduced two frameworks: The first characterizes seven underlying mechanisms that form the basis for a variety of visual superpowers portrayed in fiction. The second identifies seven ways in which visualization tools and interfaces can instill a sense of empowerment in the people who use them. Building on these observations, we illustrated a diverse set of "visualization superpowers" and highlighted opportunities for the visualization community to create new systems and interactions that empower new experiences with data. Material and illustrations are available under CC-BY 4.0 at osf.io/8yhfz.

8.2   Visualization and Clustering of Hypergraphs

Participants: Jean-Daniel Fekete *(correspondant)*, Paola Valdivia *(Inria&Telecom Paris)*, Alexis Pister *(Inria&Telecom Paris)*, Catherine Plaisant *(Inria&Univ. of Maryland)*, Paolo Buono *(Univ. of Bari)*.
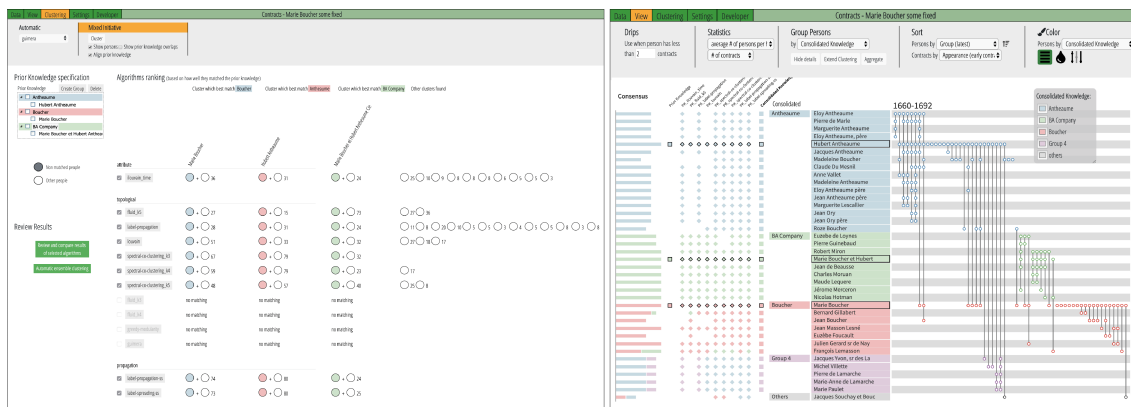

Figure 4: Using Dynamic Hypergraphs to Reveal the Evolution of the Business Network of a 17th Century French Woman Merchant.

We propose a new paradigm, called PK-clustering [22], to help social scientists create meaningful clusters in social networks. Many clustering algorithms exist but most social scientists find them difficult to understand, and tools do not provide any guidance to choose algorithms, or to evaluate results taking

into account the prior knowledge of the scientists. Our work introduces a new clustering paradigm and a visual analytics user interface that address this issue. It is based on a process that 1) captures the prior knowledge of the scientists as a set of incomplete clusters, 2) runs multiple clustering algorithms (similarly to clustering ensemble methods),3) visualizes the results of all the algorithms ranked and summarized by how well each algorithm matches the prior knowledge, 5)evaluates the consensus between user-selected algorithms and 6) allows users to review details and iteratively update the acquired knowledge. We believe our clustering paradigm offers a novel constructive method to iteratively build knowledge while avoiding being overly influenced by the results of often-randomly selected black-box clustering algorithms. PK-clustering relies the PAOHVis representation [28] for dynamic hypergraphs.

This work is conducted in the context of the HistorIA project funded by DataIA, and of the IVAN project.

More on the project web page aviz.fr/pkclustering.

8.3   Spatially controlled illustrative visualization of the genome

Participants: Sarkis Halladjian *(Inria Paris-Saclay)*, Haichao Miao *(TU Wien)*, David Kouřil *(TU Wien)*, M. Eduard Gröller *(TU Wien)*, Ivan Viola *(KAUST)*, Tobias Isenberg *(Inria Paris-Saclay, correspondant)*.
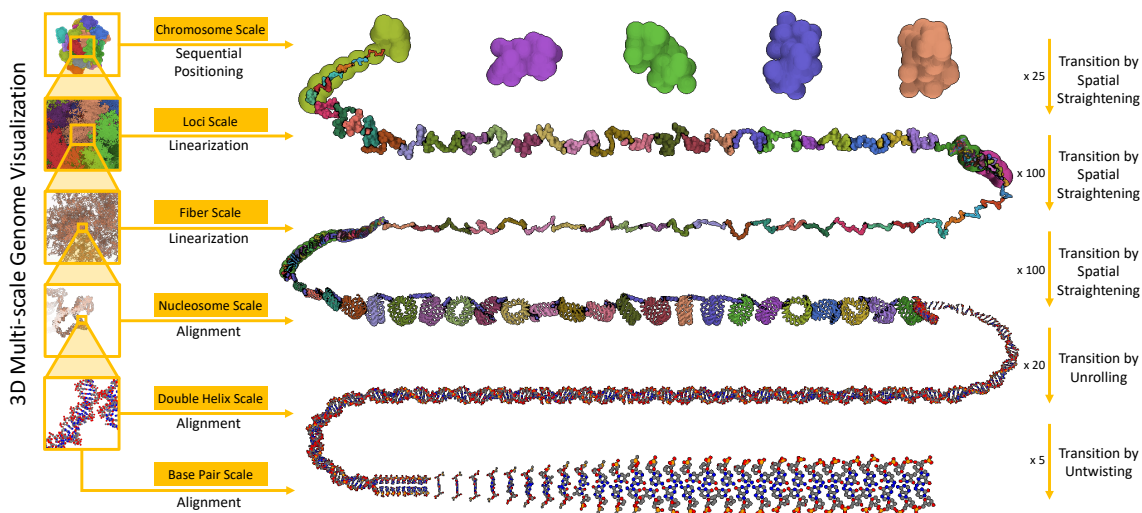

Figure 5: Spatially-controlled, seamless illustration of the genome, from the nucleus of a cell down to the atoms.

We present Multiscale Unfolding [1], an interactive technique for illustratively visualizing multiple hierarchical scales of DNA in a single view, showing the genome at different scales and demonstrating how one scale spatially folds into the next. The DNA's extremely long sequential structure—arranged differently on several distinct scale levels—is often lost in traditional 3D depictions, mainly due to its multiple levels of dense spatial packing and the resulting occlusion. Furthermore, interactive exploration of this complex structure is cumbersome, requiring visibility management like cut-aways. In contrast to existing temporally controlled multiscale data exploration, we allow viewers to always see and interact with any of the involved scales. For this purpose we separate the depiction into constant-scale and scale transition zones. Constant-scale zones maintain a single-scale representation, while still linearly unfolding the DNA. Inspired by illustration, scale transition zones connect adjacent constant-scale zones via level unfolding, scaling, and transparency. We thus represent the spatial structure of the whole DNA macro-molecule, maintain its local organizational characteristics, linearize its higher-level organization, and use spatially controlled, understandable interpolation between neighboring scales. We also contribute interaction techniques that provide viewers with a coarse-to-fine control for navigating

within our all-scales-in-one-view representations and visual aids to illustrate the size differences. Overall, Multiscale Unfolding allows viewers to grasp the DNA's structural composition from chromosomes to the atoms, with increasing levels of "unfoldedness," and can be applied in data-driven illustration and communication.

8.4   Survey of collaborative work in augmented reality

Participants: Mickaël Sereno *(Inria Paris-Saclay)*, Xiyao Wang *(Inria Paris-Saclay)*, Lonni Besançon *(Linköpping University)*, Michael J. McGuffin *(École de technologie supérieure)*, Tobias Isenberg *(Inria Paris-Saclay, correspondant)*.
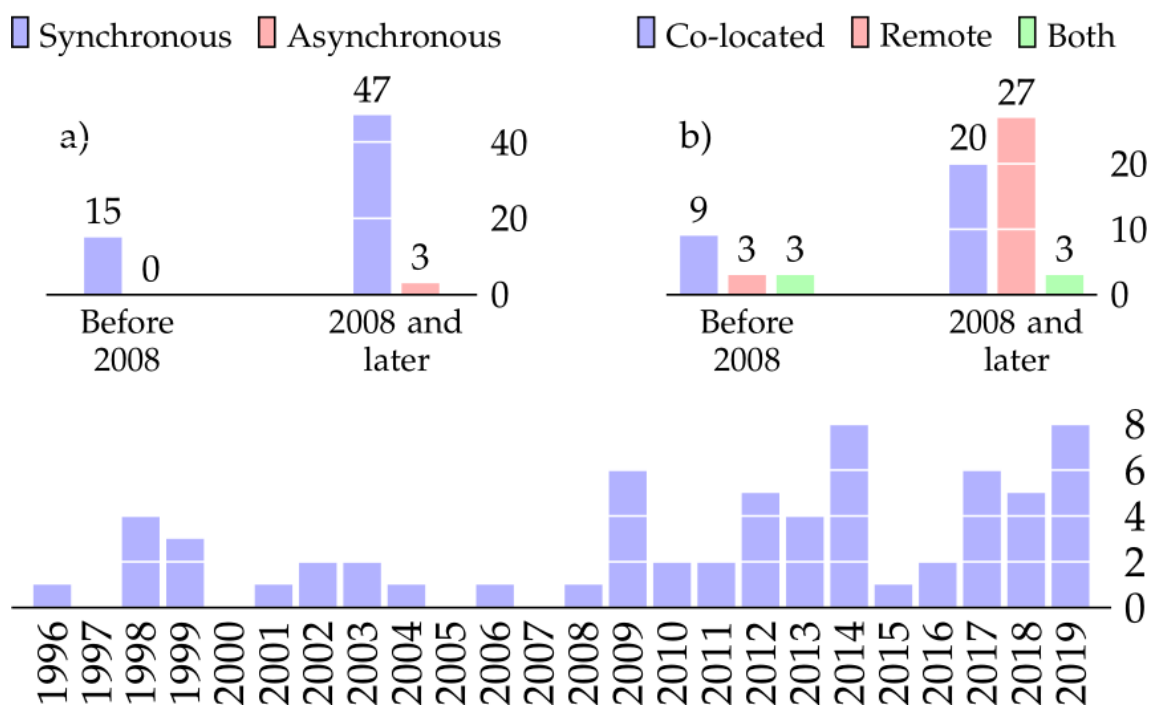

Figure 6: Historic distribution of papers on collaborative work in augmented reality.

In Augmented Reality (AR), users perceive virtual content anchored in the real world. It is used in medicine, education, games, navigation, maintenance, product design, and visualization, in both single-user and multi-user scenarios. Multi-user AR has received limited attention from researchers, even though AR has been in development for more than two decades. We present the state of existing work at the intersection of AR and Computer-Supported Collaborative Work (AR-CSCW) [5], by combining a systematic survey approach with an exploratory, opportunistic literature search. We categorize 65 papers along the dimensions of space, time, role symmetry (whether the roles of users are symmetric), technology symmetry (whether the hardware platforms of users are symmetric), and output and input modalities. We derive design considerations for collaborative AR environments, and identify underexplored research topics. These include the use of heterogeneous hardware considerations and 3D data exploration research areas. This survey is useful for newcomers to the field, readers interested in an overview of CSCW in AR applications, and domain experts seeking up-to-date information.

8.5   Visualization for monitoring and exploration of the Bitcoin blockchain

Participants: Natkamon Tovanich *(SystemX, correspondant)*, Nicolas Heulot *(SystemX)*, Jean-Daniel Fekete *(Inria)*, Nicolas Soulié *(Université Paris-Saclay, Univ Evry, Institut Mines-Télécom Business School, LITEM)*.
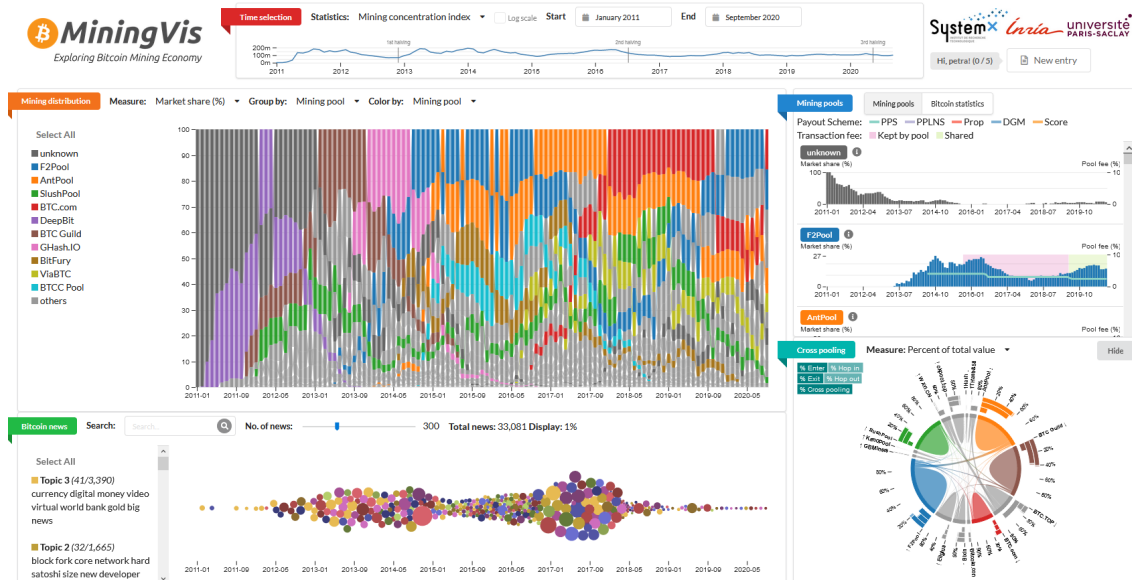

Figure 7: The MiningVis system developed for the exploratory analysis of Bitcoin mining pool evolution.

In the last year we actively worked on visual analytics tools to support the analysis of the Bitcoin blockchain. We focused on Bitcoin mining. Mining blocks is a critical component of the Bitcoin ecosystem, helping to keep the system secure, valid, and stable. At the same time, mining is a resource-intensive activity that continues to get more and more difficult. Mining pools have emerged to address this issue and to ensure a more stable and predictable income by sharing computing power. Yet, increased centralization of the mining power is also not without dangers (e.g., the 51% attack), and, thus, it is important to better understand and analyze mining pool activities in Bitcoin. We made several contributions: an extensive data collection on Bitcoin mining pools, the development of two custom visualizations and a comprehensive tool called MiningVis [27], a first exploratory data analysis leading to hypotheses and documented activities about pools' main features such as market share, reward rules, or location [37]. One extended analysis paper received a best paper runner up award at IEEE ICBC [35] . Finally, our system BitConduite [17] was published in IEEE CG&A. It is a visual analytics approach for explorative analysis of financial activity within the Bitcoin network, offering a view on transactions aggregated by entities, i. e. by individuals, companies or other groups actively using Bitcoin.

8.6 Visualizations for promoting empathy and compassion

Participants: Luiz Morais *(Inria)*, Yvonne Jansen *(CNRS)*, Nazareno Andrade *(Universidade Federal de Campina Grande)*, Pierre Dragicevic *(correspondant)*.

When showing data about people, visualization designers and data journalists often use design strategies that presumably help the audience relate to those people. The term "*anthropographics*" has been recently coined to refer to this practice and the resulting visualizations. Anthropographics is a rich and growing area, but the work so far has remained scattered. Despite preliminary empirical work and a few web essays written by practitioners, there is a lack of clear language for thinking about and communicating about anthropographics. In an article recently published at IEEE TVCG [126], we
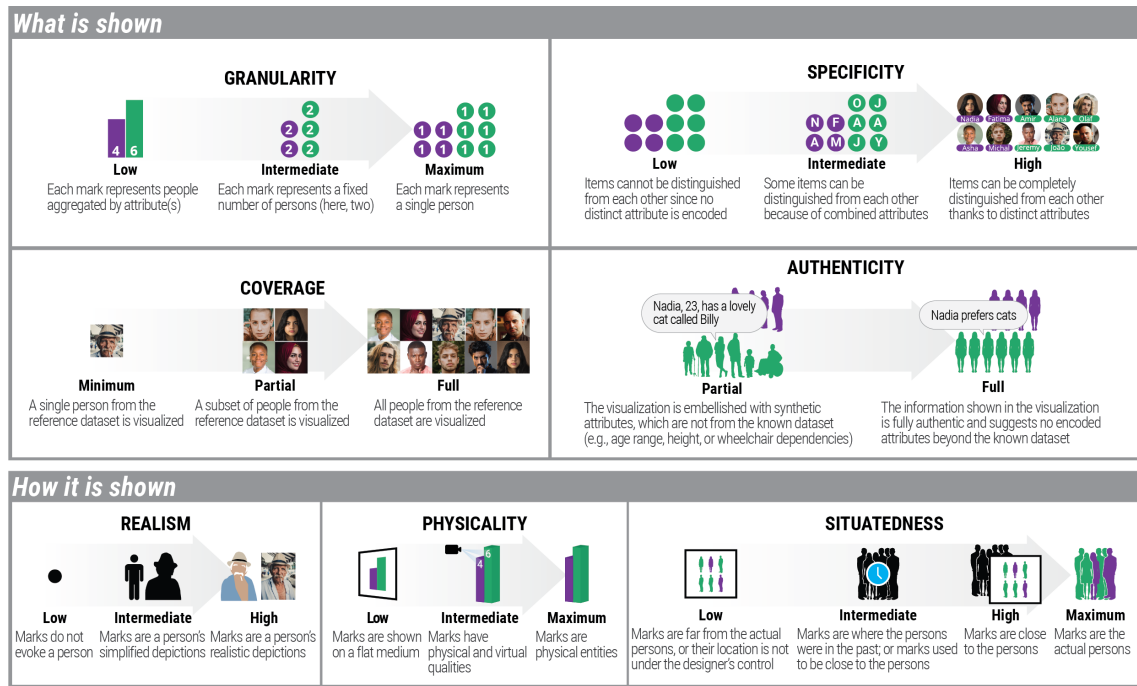
Figure 8: The seven dimensions of the anthropographics design space.

addressed this gap by introducing a conceptual framework and a design space for anthropographics. Our design space consists of seven elementary design dimensions that can be reasonably hypothesized to have some effect on prosocial feelings or behavior (Figure 8). It extends a previous design space and is informed by an analysis of 105 visualizations collected from newspapers, websites, and research papers. We used our conceptual framework and design space to discuss trade-offs, common design strategies, as well as future opportunities for design and research in the area of anthropographics. Our corpus of anthropographic visualizations can be explored at luizaugustomm.github.io/anthropographics/.
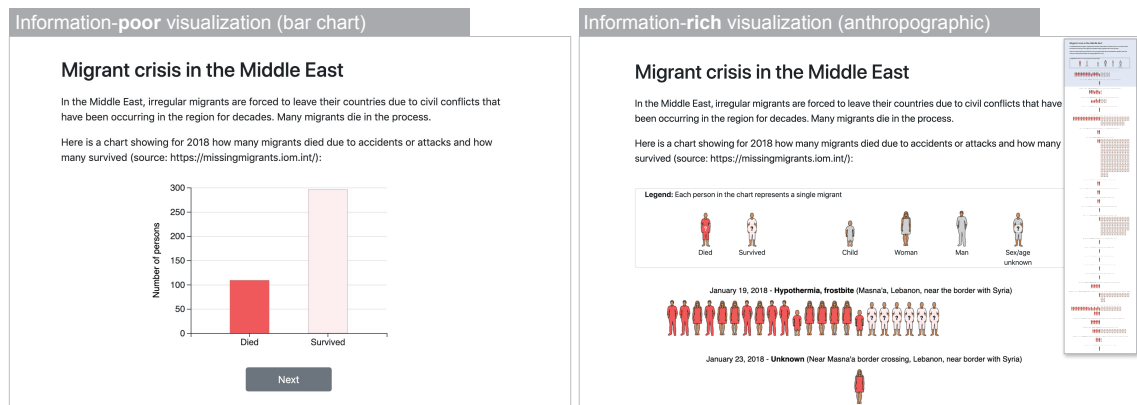

Figure 9: Two stimuli used in experiment 1, showing data from the Missing Migrants Project (missingmigrants.iom.int). On the left is the information-poor baseline condition, and on the right is the information-rich anthropographic condition (participants had to scroll to see the entire visualization – see overview on the right).

Empirical studies have recently examined whether anthropographics promote empathy, compassion, or the likelihood of prosocial behavior, but findings have been inconclusive so far. In an article recently published at ACM CHI [34], we contributed a detailed overview of past experiments, and two new

experiments that use large samples and a combination of design strategies to maximize the possibility of finding an effect. We tested an information-rich anthropographic against a simple bar chart (Figure 9), asking participants to allocate hypothetical money in a crowdsourcing study. We found that the anthropographic had, at best, a small effect on money allocation. Such a small effect may be relevant for large-scale donation campaigns, but the large sample sizes required to observe an effect and the noise involved in measuring it make it very difficult to study in more depth. We discussed implications for our findings, such as the importance of testing alternative anthropographic design strategies as well as using alternative methodologies, such as real money donation tasks or observations in the field, for example, by testing alternative designs on the website of a real charity. Data and code are available at osf.io/xqae2.

8.7 Mobile Data Visualization

Participants: Petra Isenberg *(Inria, correspondant)*, Alaul Islam *(Inria, Paris-Saclay)*, Tanja Blascheck *(University of Stuttgart)*, Anastasia Bezerianos *(Paris-Saclay)*, Bongshin Lee *(Microsoft Research)*, Eun Kyoung Choe *(University of Maryland)*.

Figure 10: Visualizations for Smartwatches with increasing complexity. On the right, visualization of study results that show which types of information are commonly displayed on watchfaces.

With an increasing use of mobile devices in everyday life, it is important to understand how to design data visualizations for small displays. A nuanced understanding is especially important since existing guidelines for visualization and data interaction design do not transfer well to mobile devices. Throughout the year several projects of the team contributed to an increased understanding of mobile data visualization design.

We co-edited a book on Mobile Data Visualization [39] and contributed to four chapters in the book. Specifically an introduction to the topic [46], a chapter on glanceable interactions for mobile visualization [41], an ideation methodology for novel representations for mobile devices [44], and a chapter on 3D mobile interaction [40].

We also published a replication study on our previous work in which we tested differences in visualization size [31].

MobileVisFixer [30] was a collaboration with the University of HongKong, Microsoft Research, and Monash University on how to automatically suggest problems and solutions with mobile friendly visualizations.

9 Partnerships and cooperations

9.1 International research visitors

9.1.1 Visits of international scientists
Inria International Chair

Participants: Jean-Daniel Fekete, Petra Isenberg, Pierre Dragicevic, Tobias Isenberg.

IIC PLAISANT Catherine

Name of the chair: Catherine Plaisant

Institution of origin: University of Maryland

Country: USA

Dates: From Mon Jan 01 2018 to Sat Dec 31 2022

Title: Visual Analytics for Exploratory Data Analysis

Other international visits to the team

Sara Di Bartolomeo

Participants: Jean-Daniel Fekete, Alexis Pister.

Status PhD

Institution of origin: Northeastern University

Country: USA

Dates: From June 15 2021 to September 15 2021

Context of the visit: Collaboration on dynamic hypergraph visualization

Mobility program/type of mobility: internship

Ameya Patil

Participants: Jean-Daniel Fekete, Gaëlle Richer.

Status PhD

Institution of origin: University of Maryland

Country: USA

Dates: From June 15 2021 to September 15 2021

Context of the visit: Collaboration on progressive visualization

Mobility program/type of mobility: internship

Raimund Dachselt

> **Participants:**   Petra Isenberg, Alaul Islam.

Status Professor

Institution of origin: Technische Universität Dresden

Country: Germany

Dates: From October 11 - November 5. 2021

Context of the visit: Collaboration on mobile data visualization and visualization aesthetics

Mobility program/type of mobility: invited researcher

9.2   International Initiatives

Program: ANR PRCI (ANR-18-CE92-0059-01)

Project acronym: MicroVis

Project title: Micro visualizations for pervasive and mobile data exploration

Duration: Until 2/28/2023

Coordinator: Petra Isenberg

Other partners: University of Stuttgart, Germany

Abstract: The goal of this joint Franco-German project is to study very small data visualizations, micro visualizations, in display contexts that can only dedicate minimal rendering space for data representations. We will study human perception of and interaction with micro visualizations given small as well as complex data. The increasing demand for data visualizations on small mobile devices such as fitness tracking armbands, smart watches, or mobile phones drives our research. Specifically, we define micro visualizations as small-scale visualizations that lack or have a limited set of reference structures such as labels, data axes, or grid lines and have a small physical footprint of a few square centimeters. Micro visualizations can be as simple as small unit-based visualizations such as a battery indicator but also include multi-dimensional visualizations such as star glyphs, small geographic visualizations or even small network visualizations. Although micro visualizations are essential to mobile visualization contexts, we know surprisingly little about their general visual and interaction design space or people's ability in interpreting micro visualizations. We will address this gap by proposing a common framework, conducting empirical studies to understand people's abilities to interpret these visualizations while in motion, and by developing a software toolkit to aid practitioners in developing micro visualizations for emerging mobile and wearable displays.

9.3   National initiatives

Program: ANR PRC (ANR-19-CE33-0012)

Project acronym: EMBER

Project title: Situated Visualizations for Personal Analytics

Duration: 2020 – 2023. Total funding: 712 k€

Coordinator: Pierre Dragicevic

Other partners: Inria Bordeaux, Sorbonne Université

Abstract: The Ember project will study how situated data visualization systems can help people use their personal data (e.g., fitness and physiological data, energy consumption, banking transactions, online social activity,…) for their own benefit. Although personal data is generated in many areas of daily life, it remains underused by individuals. Rarely is personal data subjected to an in-depth analysis and used to inform daily decisions. This research aims to empower individuals to improve their lives by helping them become advanced consumers of their own data. This research builds on the area of personal visual analytics, which focuses on giving the general public effective and accessible tools to get insights from their own data. Personal visual analytics is a nascent area of research, but has so far focused on scenarios where the data visualization is far removed from the source of the data it refers to. The goal of this project is to address the limitations of traditional platforms of personal data analytics by exploring the potential of situated data visualizations. In a situated data visualization, the data is directly visualized near the physical space, object, or person it refers to. Situated data visualizations have many potential benefits: they can surface information in the physical environment and allow viewers to interpret data in-context; they can be tailored to highlight spatial connections between data and the physical environment, making it easier to make decisions and act on the physical world in response to the insights gained; and they can embed data into physical environments so that it remains visible over time, making it easier to monitor changes, observe patterns over time and collaborate with other people. Website: ember.inria.fr/.

Other projects:

- DATAIA project HistorIA "Computational social sciences and information visualization join forces to explore and analyze large historical databases". Duration: 36 months. Total funding: 240k€. Partners: Inria Saclay, Telecom Paris. Coordinators: Jean-Daniel Fekete, Christophe Prieur.

- Naviscope Inria Project Lab on Image-guided NAvigation and VIsualization of large data sets in live cell imaging and microSCOPy; collaboration with several Inria project teams and external collaborators; this grant supports a PhD position and funds travel and equipment.

10   Dissemination

10.1   Promoting scientific activities

10.1.1   Scientific events: organisation

General chair, scientific chair

- Tobias Isenberg: Eurographics workshop on Visual Computing for Biology and Medicine (VCBM 2021)

Member of the organizing committees

- Pierre Dragicevic: alt.chi co-chair at ACM CHI 2021.

10.1.2   Scientific events: selection

Chair of conference program committees

- Petra Isenberg: Paper Co-Chair for ACM Interactive Surfaces and Spaces (ISS)

Member of the conference program committees

- Pierre Dragicevic: IEEE VIS 2021

- Jean-Daniel Fekete: IEEE VIS 2021, EuroVis 2021, BigVis 2021

- Petra Isenberg: EuroVis Star Reports 2021, EuroVis Short Papers, IEEE VIS 2021

- Tobias Isenberg: IEEE VIS 2021, EuroVis 2021 short papers

10.1.3   Journal

Member of the editorial boards

- Pierre Dragicevic: Member of the editorial board of the Journal of Perceptual Imaging (JPI)

- Pierre Dragicevic: Member of the editorial board of the Springer Human–Computer Interaction Series (HCIS).

- Jean-Daniel Fekete: Associate Editor in Chief of IEEE Transactions of Visualization and Computer Graphics (TVCG)

- Petra Isenberg: Associate Editor for Transaction on Visualization and Computer Graphics (TVCG), Associate Editor in Chief at IEEE Computer Graphics & Applications (CG&A)

- Tobias Isenberg: Associate Editor for Elsevier Computers & Graphics

10.1.4   Invited talks

- Jean-Daniel Fekete: Panel at 5eme journée Interaction Humain-Machine et Intelligence Artificielle: "Analyser, comprendre le monde : Complémentarité entre apprentissage et visualisation" with Michèle Sebag, Mar. 11, 2021

- Petra Isenberg: Keynote at VIZBI 2021 (virtual): "Interactive visual analytics & storytelling", March 2021

- Steve Haroz:

    - Invited talk at European Conference on Visual Perception (virtual): "The Salience Bias in Ensemble Coding", August 2021

    - Panel at IEEE VIS (virtual): "Compensate subjects well. Compensate participants optionally.", October 2021

10.1.5   Leadership within the scientific community

- Jean-Daniel Fekete: Member of the Scientific Committee of the French journal "humanités numériques"

- Jean-Daniel Fekete: Chair of the EuroVis Best PhD Award

- Jean-Daniel Fekete: Committee member of the Prix de Thèse Gilles Kahn (French best CS PhD dissertation award)

- Petra Isenberg: Vice-Chair of the IEEE VIS Steering Committee

- Tobias Isenberg: Steering Committee for ACM/EG Expressive; Steering Committee for BELIV workshop series

10.1.6   Research administration

- Pierre Dragicevic: member of the CCSU (Commission Consultative de Spécialistes de l'Université Paris-Saclay)

- Pierre Dragicevic: member of the Conseil de Labo LISN

- Pierre Dragicevic: co-chair of the IID axis of the Labex Digicosme

- Pierre Dragicevic: member of the CER (Comité d'Éthique de la Recherche) Paris-Saclay

- Petra Isenberg: Member of the Commission de Developpement Technologique (Inria)

- Petra Isenberg: Commission formation de la GS ISN (Paris-Saclay)

- Frédéric Vernier : Conseil d'Administration de l'Université Paris-Saclay (membre du bureau du CA)

- Frédéric Vernier : Commission Electorale de l'Université Paris-Saclay

- Frédéric Vernier : Commission des Carrières des Enseignants-Chercheur (CCEC= equiv. Conseil ACadémique en formation restreinte) de l'Université Paris-Saclay

- Frédéric Vernier : Membre élu du conseil du departemewnt d'informatique de l'Université Paris-Saclay

10.2   Teaching - Supervision - Juries

10.2.1   Teaching

- Master: Petra Isenberg, "Interactive Information Visualization", 36.5h equivalent TD (total, co-taught with Anastasia Bezerianos), M1/M2, Université Paris-Saclay.

- Master: Petra Isenberg, "Visual Analytics", 60h equivalent TD (co-taught with Natkamon Tovanich), M2, Centrale Supelec.

- Licence: Tobias Isenberg, "Introduction to Computer Graphics", 18h en équivalent TD, L3, Polytech Paris-Saclay, France.

- Master: Tobias Isenberg, "Photorealistic Rendering/Advanced Computer Graphics", 28h en équivalent TD, M2, Polytech Paris-Saclay, France.

- Master: Tobias Isenberg, "Illustrative Visualization", 6h en équivalent TD, M2, ENSTA, France.

- Master: Frederic Vernier, class and lab class. "Information visualization", 24h en équivalent TD, M2 ISC, Faculté des sciences d'Orsay. Univ. Paris-Saclay, France.

- Licence: Mickaël Sereno, tutorial sessions for "Introduction to Computer Graphics", 24h en équivalent TD, ET3 (eq. L3), Polytech Paris-Saclay, France.

- Licence: Mickaël Sereno, tutorial sessions for "Introduction à l'Informatique ", 37h en équivalent TD, Peip1 (eq. L1), Polytech Paris-Saclay, France.

- Licence: Frederic Vernier, class and lab class. "Introduction to Computer Graphics", 42h en équivalent TD, L1-MI, Faculté des sciences d'Orsay. Univ. Paris-Saclay, France.

- Licence: Frederic Vernier, class and lab class. "Advanced Computer Graphics", 36h en équivalent TD, L2-MI, Faculté des sciences d'Orsay. Univ. Paris-Saclay, France.

- Licence: Frederic Vernier, class and lab class. "Web development", 42h en équivalent TD, L3 computer sciences, Faculté des sciences d'Orsay. Univ. Paris-Saclay, France.

- Master: Lijie Yao, "Interactive Information Visualization", 7h equivalent TD (total 36.5h, co-taught with Petra Isenberg and Anastasia Bezerianos), M1/M2, Université Paris-Saclay

- Licence: Alexis Pister, "Algorithmique", 16h equivalent TD, L2, Polytech Paris-Saclay, France.

- Licence: Alexis Pister, "Remise à niveau en informatique", 20h equivalent TD, L3, Polytech Paris-Saclay, France.

- Licence: Alexis Pister, "Algorithmique des graphes",12h equivalent TD, L3, Polytech Paris-Saclay, France.

- Licence: Alexis Pister, "Base de données", 12h equivalent TD, L3, Polytech Paris-Saclay, France.

10.2.2 Supervision

- PhD in progress: Tingying He, *A Design Space for Visual Data Mapping for Low-Color Displays*, Univ. Paris-Saclay, defense planned for December 2024, Tobias Isenberg

- PhD in progress: Jiayi Hong, *Interactive Visualization and Classification of Temporal Developments in 3D Datasets*, Univ. Paris-Saclay, defense planned for December 2022, Tobias Isenberg

- PhD in progress: Alaul Islam, *Micro Visualizations for Fitness Trackers*, Petra Isenberg

- PhD in progress: Alexis Pister, *Exploration, Analysis, Interpretability of Large Historical Networks*, Univ. Paris-Saclay, (co-supervision with Christophe Prieur), defense planned for December 2022, Jean-Daniel Fekete

- PhD in progress: Lijie Yao, *Situated Visualization in Motion*, Univ. Paris-Saclay, defense planned for December 2023, Petra Isenberg, Anastasia Bezerianos

- PhD in progress: Natkamon Tovanich, *Visualization and Visual Analytics of Blockchain*, Petra Isenberg and Jean-Daniel Fekete, defense planned for February 2022

- PhD completed: Mickaël Sereno, *Collaborative Data Exploration and Discussion Supported by AR*, Univ. Paris-Saclay, defended successfully on December 14, 2021, Tobias Isenberg.

- MSc thesis completed: Tingying He, *A Design Space for Watchface Micro Visualizations*, Petra Isenberg

- MSc thesis completed: Nathan van Hille, *Visualization of dynamic compounds involved in the life process of cells with the HoloLens*, Tobias Isenberg

10.2.3 Juries

- Jean-Daniel Fekete: member of the PhD committee of Benoît Colange, "Energy Systems Diagnosis through Intelligent Analysis of High Dimensional Data Structures", Université Savoie Mont Blanc, May, 2021

- Jean-Daniel Fekete: review of the HdR of Céline Coutrix, "Physically Flexible Control for Human-Computer Interaction", Université Grenoble Alpes, Feb. 24, 2021

- Pierre Dragicevic: member of the mid-term PhD committee of Martin Tricaud, UP-Saclay.

10.3 Popularization

10.3.1 Articles and contents

- Pierre Dragicevic and Yvonne Jansen: the data physicalization wiki (dataphys.org/) and the List of Physical Visualizations and Related Artefacts (dataphys.org/list/, 600 weekly visits) are continuously being updated.

10.3.2 Education

- Steve Haroz: A Succinct Intro to R (r-guide.steveharoz.com) used in multiple courses on data science and statistics. Over 10k visits in 4 months.

10.3.3 Interventions

- Jean-Daniel Fekete: Keynote at Datarama #6: "Visualisation des données de la recherche", Nantes, Sep. 17, 2021

- Alexis Pister: Talk at Junior Conference on Data Science And Engineering (JDSE): "PK-Clustering: Integrating Prior Knowledge in Mixed-Initiative Social Network Clustering", Online, Feb. 02, 2021

- Alexis Pister: Software demo at Historical Networks Conference: "PK-Clustering: Integrating Prior Knowledge in Mixed-Initiative Social Network Clustering", Online, Jul. 02, 2021

11 Scientific production

11.1 Major publications

[1] S. Halladjian, D. Kouřil, H. Miao, E. Gröller, I. Viola and T. Isenberg. 'Multiscale Unfolding: Illustratively Visualizing the Whole Genome at a Glance'. In: *IEEE Transactions on Visualization and Computer Graphics* (2022). DOI: 10.1109/TVCG.2021.3065443. URL: https://hal.inria.fr/hal-03163672.

[2] B. Lee, R. Dachselt, P. Isenberg and E. K. Choe. *Mobile Data Visualization.* 0. Chapman and Hall/CRC, Dec. 2021, p. 346. DOI: 10.1201/9781003090823. URL: https://hal.inria.fr/hal-03524082.

[3] Y. Lu, L. Cheng, T. Isenberg, C.-W. Fu, G. Chen, H. Liu, O. Deussen and Y. Wang. 'Curve Complexity Heuristic KD-trees for Neighborhood-based Exploration of 3D Curves'. In: *Computer Graphics Forum* 40.2 (May 2021), pp. 461–474. DOI: 10.1111/cgf.142647. URL: https://hal.inria.fr/hal-03151998.

[4] A. Pister, P. Buono, J.-D. Fekete, C. Plaisant and P. Valdivia. 'Integrating Prior Knowledge in Mixed Initiative Social Network Clustering'. In: *IEEE Transactions on Visualization and Computer Graphics* 27.2 (Feb. 2021), pp. 1775–1785. DOI: 10.1109/TVCG.2020.3030347. URL: https://hal.inria.fr/hal-02566438.

[5] M. Sereno, X. Wang, L. Besançon, M. J. Mcguffin and T. Isenberg. 'Collaborative Work in Augmented Reality: A Survey'. In: *IEEE Transactions on Visualization and Computer Graphics* (2022). DOI: 10.1109/TVCG.2020.3032761. URL: https://hal.archives-ouvertes.fr/hal-02971697.

[6] N. Tovanich, N. Soulié, N. Heulot and P. Isenberg. 'MiningVis: Visual Analytics of the Bitcoin Mining Economy'. In: *IEEE Transactions on Visualization and Computer Graphics* 28.1 (Jan. 2022), pp. 868–878. DOI: 10.1109/TVCG.2021.3114821. URL: https://hal.archives-ouvertes.fr/hal-03348145.

[7] W. Willett, B. A. Aseniero, S. Carpendale, P. Dragicevic, Y. Jansen, L. Oehlberg and P. Isenberg. 'Perception! Immersion! Empowerment! Superpowers as Inspiration for Visualization'. In: *IEEE Transactions on Visualization and Computer Graphics* 28.1 (Jan. 2022), pp. 22–32. DOI: 10.1109/TVCG.2021.3114844. URL: https://hal.inria.fr/hal-03342677.

11.2 Publications of the year

International journals

[8] L. Besançon, A. Ynnerman, D. F. Keefe, L. Yu and T. Isenberg. 'The State of the Art of Spatial Interfaces for 3D Visualization'. In: *Computer Graphics Forum* 40.1 (Feb. 2021), pp. 293–326. DOI: 10.1111/cgf.14189. URL: https://hal.inria.fr/hal-03012861.

[9] P. Caillou, J. Renault, J.-D. Fekete, A.-C. Letournel and M. Sebag. 'Cartolabe: A Web-Based Scalable Visualization of Large Document Collections'. In: *IEEE Computer Graphics and Applications* 41.2 (Apr. 2021), pp. 76–88. DOI: 10.1109/MCG.2020.3033401. URL: https://hal.inria.fr/hal-02499006.

[10] J. Chen, M. Ling, R. Li, P. Isenberg, T. Isenberg, M. Sedlmair, T. Möller, R. S. Laramee, H.-W. Shen, K. Wünsche and Q. Wang. 'VIS30K: A Collection of Figures and Tables from IEEE Visualization Conference Publications'. In: *IEEE Transactions on Visualization and Computer Graphics* 27.9 (Sept. 2021), pp. 3826–3833. DOI: 10.1109/TVCG.2021.3054916. URL: https://hal.inria.fr/hal-03123279.

[11] X. Chen, J. Zhang, C.-W. Fu, J.-D. Fekete and Y. Wang. 'Pyramid-based Scatterplots Sampling for Progressive and Streaming Data Visualization'. In: *IEEE Transactions on Visualization and Computer Graphics* 28.1 (Jan. 2022), pp. 593–603. DOI: 10.1109/TVCG.2021.3114880. URL: https://hal.inria.fr/hal-03360776.

[12] M. Destandau and J.-D. Fekete. 'The Missing Path: Diagnosing Incompleteness in Linked Data'. In: *Information Visualization* 20.1 (22nd Feb. 2021), pp. 66–82. DOI: 10.1177/1473871621991539. URL: https://hal.archives-ouvertes.fr/hal-02612896.

[13] S. Halladjian, D. Kouřil, H. Miao, E. Gröller, I. Viola and T. Isenberg. 'Multiscale Unfolding: Illustratively Visualizing the Whole Genome at a Glance'. In: *IEEE Transactions on Visualization and Computer Graphics* (2022). DOI: 10.1109/TVCG.2021.3065443. URL: https://hal.inria.fr/hal-03163672.

[14] S. Haroz. 'The Set Salience Bias in Ensemble Decision-Making'. In: *Journal of Vision* 21.9 (27th Sept. 2021), p. 2844. DOI: 10.1167/jov.21.9.2844. URL: https://hal.inria.fr/hal-03334523.

[15] T. Isenberg. 'Special C&G and G&VC session at EuroVis'. In: *Computers and Graphics* 96 (May 2021), A3–A4. DOI: 10.1016/j.cag.2021.05.004. URL: https://hal.inria.fr/hal-03227524.

[16] T. Isenberg, Z. Salazar, R. Blanco and C. Plaisant. 'Do you believe your (social media) data? A personal story on location data biases, errors, and plausibility as well as their visualization'. In: *IEEE Transactions on Visualization and Computer Graphics* (2022). DOI: 10.1109/TVCG.2022.3141605. URL: https://hal.inria.fr/hal-03516682.

[17] C. Kinkeldey, J.-D. Fekete, T. Blascheck and P. Isenberg. 'BitConduite: Exploratory Visual Analysis of Entity Activity on the Bitcoin Network'. In: *IEEE Computer Graphics and Applications* (2021). DOI: 10.1109/MCG.2021.3070303. URL: https://hal.inria.fr/hal-03199547.

[18] D. Kouřil, T. Isenberg, B. Kozlíková, M. Meyer, E. Gröller and I. Viola. 'HyperLabels—Browsing of Dense and Hierarchical Molecular 3D Models'. In: *IEEE Transactions on Visualization and Computer Graphics* 27.8 (1st Aug. 2021), pp. 3493–3504. DOI: 10.1109/TVCG.2020.2975583. URL: https://hal.inria.fr/hal-02493893.

[19] D. Kouřil, O. Strnad, P. Mindek, S. Halladjian, T. Isenberg, M. E. Gröller and I. Viola. 'Molecumentary: Adaptable Narrated Documentaries Using Molecular Visualization'. In: *IEEE Transactions on Visualization and Computer Graphics* (2022). DOI: 10.1109/TVCG.2021.3130670. URL: https://hal.inria.fr/hal-03451509.

[20] B. Lee, A. Srinivasan, P. Isenberg and J. Stasko. 'Post-WIMP Interaction for Information Visualization'. In: *Foundations and Trends in Human-Computer Interaction* 14.1 (2021), pp. 1–95. DOI: 10.1561/1100000081. URL: https://hal.inria.fr/hal-03261048.

[21] Y. Lu, L. Cheng, T. Isenberg, C.-W. Fu, G. Chen, H. Liu, O. Deussen and Y. Wang. 'Curve Complexity Heuristic KD-trees for Neighborhood-based Exploration of 3D Curves'. In: *Computer Graphics Forum* 40.2 (May 2021), pp. 461–474. DOI: 10.1111/cgf.142647. URL: https://hal.inria.fr/hal-03151998.

[22] A. Pister, P. Buono, J.-D. Fekete, C. Plaisant and P. Valdivia. 'Integrating Prior Knowledge in Mixed Initiative Social Network Clustering'. In: *IEEE Transactions on Visualization and Computer Graphics* 27.2 (Feb. 2021), pp. 1775–1785. DOI: 10.1109/TVCG.2020.3030347. URL: https://hal.inria.fr/hal-02566438.

[23] M. Sereno, L. Besançon and T. Isenberg. 'Point Specification in Collaborative Visualization for 3D Scalar Fields Using Augmented Reality'. In: *Virtual Reality* (2022). DOI: 10.1007/s10055-021-00614-2. URL: https://hal.inria.fr/hal-03512784.

[24] M. Sereno, X. Wang, L. Besançon, M. J. Mcguffin and T. Isenberg. 'Collaborative Work in Augmented Reality: A Survey'. In: *IEEE Transactions on Visualization and Computer Graphics* (2022). DOI: 10.1109/TVCG.2020.3032761. URL: https://hal.archives-ouvertes.fr/hal-02971697.

[25] N. Tovanich, P. Dragicevic and P. Isenberg. 'Gender in 30 Years of IEEE Visualization'. In: *IEEE Transactions on Visualization and Computer Graphics* 28.1 (Jan. 2022), pp. 497–507. DOI: 10.1109/TVCG.2021.3114787. URL: https://hal.archives-ouvertes.fr/hal-03348149.

[26] N. Tovanich, A. Pister, G. Richer, P. Valdivia, C. Prieur, J.-D. Fekete and P. Isenberg. 'VAST 2020 Contest Challenge: GraphMatchMaker: Visual Analytics for Graph Comparison and Matching'. In: *IEEE Computer Graphics and Applications* (23rd June 2021). DOI: 10.1109/mcg.2021.3091955. URL: https://hal.archives-ouvertes.fr/hal-03283200.

[27]   N. Tovanich, N. Soulié, N. Heulot and P. Isenberg. 'MiningVis: Visual Analytics of the Bitcoin Mining Economy'. In: *IEEE Transactions on Visualization and Computer Graphics* 28.1 (Jan. 2022), pp. 868–878. DOI: 10.1109/TVCG.2021.3114821. URL: https://hal.archives-ouvertes.fr/hal-03348145.

[28]   P. R. Valdivia, P. Buono, C. Plaisant, N. Dufournaud and J.-D. Fekete. 'Analyzing Dynamic Hypergraphs with Parallel Aggregated Ordered Hypergraph Visualization'. In: *IEEE Transactions on Visualization and Computer Graphics* 27.1 (Jan. 2021), pp. 1–13. DOI: 10.1109/TVCG.2019.2933196. URL: https://hal.inria.fr/hal-02264960.

[29]   *Best Paper*
W. Willett, B. A. Aseniero, S. Carpendale, P. Dragicevic, Y. Jansen, L. Oehlberg and P. Isenberg. 'Perception! Immersion! Empowerment! Superpowers as Inspiration for Visualization'. In: *IEEE Transactions on Visualization and Computer Graphics* 28.1 (Jan. 2022), pp. 22–32. DOI: 10.1109/TVCG.2021.3114844. URL: https://hal.inria.fr/hal-03342677.

[30]   A. Wu, W. Tong, T. Dwyer, P. Isenberg, B. Lee and H. Qu. 'MobileVisFixer: Tailoring Web Visualizations for Mobile Phones Leveraging an Explainable Reinforcement Learning Framework'. In: *IEEE Transactions on Visualization and Computer Graphics* (2021). DOI: 10.1109/TVCG.2020.3030423. URL: https://hal.inria.fr/hal-03001709.

International peer-reviewed conferences

[31]   T. Blascheck and P. Isenberg. 'A Replication Study on Glanceable Visualizations: Comparing Different Stimulus Sizes on a Laptop Computer'. In: *Proceedings of the Conference on Computer Vision, Imaging and Computer Graphics Theory and Applications - Volume 3 IVAPP*. IVAPP 2021 - 12th International Conference on Computer Vision, Imaging and Computer Graphics Theory and Applications. Virtual, Austria: SCITEPRESS - Science and Technology Publications, 8th Feb. 2021, pp. 133–143. DOI: 10.5220/0010328501330143. URL: https://hal.inria.fr/hal-03151924.

[32]   J. Hong, F. Argelaguet Sanz, A. Trubuil and T. Isenberg. 'Design and Evaluation of Three Selection Techniques for Tightly Packed 3D Objects in Cell Lineage Specification in Botany'. In: GI 2021 - Graphics Interface. Mississauga, Canada, 27th May 2021, pp. 213–223. DOI: 10.20380/GI2021.33. URL: https://hal.inria.fr/hal-03127256.

[33]   M. Ling, J. Chen, T. Möller, P. Isenberg, T. Isenberg, M. Sedlmair, R. S. Laramee, H.-W. Shen, J. Wu and C. L. Giles. 'Document Domain Randomization for Deep Learning Document Layout Extraction'. In: Proceedings of the 16th International Conference on Document Analysis and Recognition (ICDAR, September 5–10, Lausanne, Switzerland). Lausanne, Switzerland, 2nd Sept. 2021, pp. 497–513. DOI: 10.1007/978-3-030-86549-8_32. URL: https://hal.inria.fr/hal-03336444.

[34]   L. Morais, Y. Jansen, N. Andrade and P. Dragicevic. 'Can Anthropographics Promote Prosociality? A Review and Large-Sample Study'. In: CHI 2021 - Conference on Human Factors in Computing Systems. Yokohama / Virtual, Japan, 8th May 2021. DOI: 10.1145/3411764.3445637. URL: https://hal.inria.fr/hal-03132731.

[35]   *Best Paper*
N. Tovanich, N. Soulié, N. Heulot and P. Isenberg. 'An Empirical Analysis of Pool Hopping Behavior in the Bitcoin Blockchain'. In: *2021 IEEE International Conference on Blockchain and Cryptocurrency (ICBC)*. 2021 IEEE International Conference on Blockchain and Cryptocurrency (ICBC). Sydney / Virtual, Australia, 24th June 2021. DOI: 10.1109/ICBC51069.2021.9461118. URL: https://hal.archives-ouvertes.fr/hal-03163006.

Conferences without proceedings

[36]   A. Rilliard, P. Boula De Mareüil and F. Vernier. 'Medida objetiva da variação prosódica entre línguas Românicas da França'. In: XIX CONGRESSO INTERNACIONAL DA ASSOCIAÇÃO DE LINGUÍSTICA E FILOLOGIA DA AMÉRICA LATINA. Online, Bolivia, 8th Aug. 2021. URL: https://hal.archives-ouvertes.fr/hal-03511305.

[37] N. Tovanich, N. Soulié and P. Isenberg. 'Visual analytics of bitcoin mining pool evolution : on the road toward stability?' In: BSC 2020-2021 - 3rd International Workshop on Blockchains and Smart Contracts held in conjunction with the 11th IFIP International Conference on New Technologies, Mobility and Security. Paris, France, 2021. DOI: 10.1109/NTMS49979.2021.9432675. URL: https://hal.archives-ouvertes.fr/hal-02902465.

Scientific books

[38] S. Haroz. *A Succinct Intro to R*. 2021. DOI: 10.5281/zenodo.5751924. URL: https://hal.inria.fr/hal-03464537.

[39] B. Lee, R. Dachselt, P. Isenberg and E. K. Choe. *Mobile Data Visualization*. 0. Chapman and Hall/CRC, Dec. 2021, p. 346. DOI: 10.1201/9781003090823. URL: https://hal.inria.fr/hal-03524082.

Scientific book chapters

[40] L. Besançon, W. Aigner, M. Boucher, T. Dwyer and T. Isenberg. '3D Mobile Data Visualization'. In: *Mobile Data Visualization*. Chapman and Hall/CRC, 23rd Dec. 2021, pp. 111–150. DOI: 10.1201/9781003090823-4. URL: https://hal.inria.fr/hal-03457378.

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