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Project-Team ILDA

Interacting with Large Data

IN COLLABORATION WITH: Laboratoire de recherche en informatique (LRI)

RESEARCH CENTER
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THEME
Interaction and visualization

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2. Overall Objectives

2.1. Overall Objectives

In an increasing number of domains, computer users are faced with large datasets, that are often interlinked and organized according to elaborate structures thanks to new data models such as those that are arising with the development of, e.g., the Web of Data. Rather than seeing the inherent complexity of those data models as a hindrance, we aim at leveraging it to design new interactive systems that can better assist users in their data understanding and processing tasks.

These "Data-centric Interactive Systems" aim at providing users with the right information at the right time, presenting it in the most meaningful manner, and letting users efficiently manipulate, edit and share these data with others. This entails minimizing the effort required to retrieve and relate data from relevant sources; displaying data using visual presentation techniques that match the data's characteristics and the users' tasks; and providing users with means of interacting with the data that effectively support their train of thought.

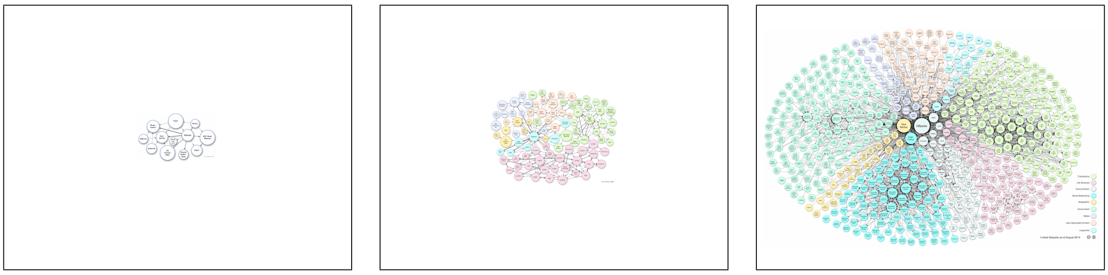
Our approach is based on the idea of bringing the fields of Web data management [29] and Human-computer interaction [52], [73] closer together, based on the strong belief that they have the potential to cross-fertilize one another. User interface design is essential to the management and understanding of large, interlinked datasets. Interlinked datasets enriched with even a small amount of semantics have the potential to help create interfaces that let users analyze and manipulate data in a more efficient manner by providing them with, e.g, more relevant query results and giving them efficient means to navigate and relate those results. Our ultimate, long-term goal is to design interactive systems that make it as straightforward to manipulate large webs of data as spreadsheets do for tabular data.

3. Research Program

3.1. Introduction

Our ability to acquire or generate, store, process, interlink and query data has increased spectacularly over the last few years. The corresponding advances are commonly grouped under the umbrella of so called *Big Data*. Even if the latter has become a buzzword, these advances are real, and they are having a profound impact in domains as varied as scientific research, commerce, social media, industrial processes or e-government. Yet, looking ahead, emerging technologies related to what we now call the *Web of Data* (a.k.a the Semantic Web) have the potential to create an even larger revolution in data-driven activities, by making information accessible to machines as semistructured data [28] that eventually becomes actionable knowledge. Indeed, novel Web data models considerably ease the interlinking of semi-structured data originating from multiple independent sources. They make it possible to associate machine-processable semantics with the data. This in turn means that heterogeneous systems can exchange data, infer new data using reasoning engines, and that software agents can cross data sources, resolving ambiguities and conflicts between them [71]. Datasets are becoming very rich and very large. They are gradually being made even larger and more heterogeneous, but also much more useful, by interlinking them, as exemplified by the Linked Data initiative [47].

These advances raise research questions and technological challenges that span numerous fields of computer science research: databases, communication networks, security and trust, data mining, as well as human-computer interaction. Our research is based on the conviction that interactive systems play a central role in many data-driven activity domains. Indeed, no matter how elaborate the data acquisition, processing and storage pipelines are, data eventually get processed or consumed one way or another by users. The latter are faced with large, increasingly interlinked heterogeneous datasets (see, e.g., Figure 1) that are organized according to complex structures, resulting in overwhelming amounts of both raw data and structured information. Users thus require effective tools to make sense of their data and manipulate them.



2007: 12 linked datasets   2009: 93 linked datasets   2014: 570 linked datasets

Figure 1. Linking Open Data cloud diagram from 2007 to 2014 – http://lod-cloud.net

We approach this problem from the perspective of the Human-Computer Interaction (HCI) field of research, whose goal is to study how humans interact with computers and inspire novel hardware and software designs aimed at optimizing properties such as efficiency, ease of use and learnability, in single-user or cooperative work contexts. More formally, HCI is about designing systems that lower the barrier between users' cognitive model of what they want to accomplish, and computers' understanding of this model. HCI is about the design, implementation and evaluation of computing systems that humans interact with [52], [73]. It is a highly multidisciplinary field, with experts from computer science, cognitive psychology, design, engineering, ethnography, human factors and sociology.

In this broad context, ILDA aims at designing interactive systems that display [37], [59], [80] the data and let users interact with them, aiming to help users better *navigate* and *comprehend* large webs of data represented visually, as well as *relate* and *manipulate* them.

Our research agenda consists of the three complementary axes detailed in the following subsections. Designing systems that consider interaction in close conjunction with data semantics is pivotal to all three axes. Those semantics will help drive navigation in, and manipulation of, the data, so as to optimize the communication bandwidth between users and data.

3.2. Semantics-driven Data Manipulation

Participants: Emmanuel Pietriga, Caroline Appert, Hande Ozaygen, Hugo Romat.

The Web of Data has been maturing for the last fifteen years and is starting to gain adoption across numerous application domains (Figure 1). Now that most foundational building blocks are in place, from knowledge representation, inference mechanisms and query languages [48], all the way up to the expression of data presentation knowledge [66] and to mechanisms like look-up services [79] or spreading activation [43], we need to pay significant attention to how human beings are going to interact with this new Web, if it is to *"reach its full potential"* [44].

Most efforts in terms of user interface design and development for the Web of data have essentially focused on tools for software developers or subject-matter experts who create ontologies and populate them [54], [42]. Tools more oriented towards end-users are starting to appear [34], [36], [49], [50], [53], [61], including the so-called *linked data browsers* [47]. However, those browsers are in most cases based on quite conventional point-and-click hypertext interfaces that present data to users in a very page-centric, web-of-documents manner that is ill-suited to navigating in, and manipulating, webs of data.

To be successful, interaction paradigms that let users navigate and manipulate data on the Web have to be tailored to the radically different way of browsing information enabled by it, where users directly interact with the data rather than with monolithic documents. The general research question addressed in this part of our research program is how to design novel interaction techniques that help users manipulate their data more efficiently. By data manipulation, we mean all low-level tasks related to manually creating new content, modifying and cleaning existing content, merging data from different sources, establishing connections between datasets, categorizing data, and eventually sharing the end results with other users; tasks that are currently considered quite tedious because of the sheer complexity of the concepts, data models and syntax, and the interplay between all of them.

Our approach is based on the conviction that there is a strong potential for cross-fertilization, as mentioned earlier: on the one hand, user interface design is essential to the management and understanding of webs of data; on the other hand, interlinked datasets enriched with even a small amount of semantics can help create more powerful user interfaces, that provide users with the right information at the right time.

We envision systems that focus on the data themselves, exploiting the underlying *semantics and structure* in the background rather than exposing them – which is what current user interfaces for the Web of Data often do. We envision interactive systems in which the semantics and structure are not exposed directly to users, but serve as input to the system to generate interactive representations that convey information relevant to the task at hand and best afford the possible manipulation actions.

3.3. Generalized Multi-scale Navigation

Participants: Olivier Chapuis, Emmanuel Pietriga, Caroline Appert, Anastasia Bezerianos, Olivier Gladin, Anna Gogolou, Maria Jesus Lobo Gunther, Arnaud Prouzeau.

The foundational question addressed here is what to display when, where and how, so as to provide effective support to users in their data understanding and manipulation tasks. ILDA targets contexts in which workers have to interact with complementary views on the same data, or with views on different-but-related datasets, possibly at different levels of abstraction. Being able to combine or switch between representations of the data at different levels of detail and merge data from multiple sources in a single representation is central to many scenarios. This is especially true in both of the application domains we consider: mission-critical systems (e.g., natural disaster crisis management) and the exploratory analysis of scientific data (e.g., correlate theories and heterogeneous observational data for an analysis of a given celestial body in Astrophysics).

A significant part of our research over the last ten years has focused on multi-scale interfaces. We designed and evaluated novel interaction techniques, but also worked actively on the development of open-source UI toolkits for multi-scale interfaces (see Section 6.2). These interfaces let users navigate large but relatively homogeneous datasets at different levels of detail, on both workstations [69], [31], [65], [64], [63], [32], [68], [30], [70] and wall-sized displays [5], [55], [67], [60], [33], [39], [38]. This part of the ILDA research program is about extending multi-scale navigation in two directions: 1. Enabling the representation of multiple, spatially-registered but widely varying, multi-scale data layers in Geographical Information Systems (GIS); 2. Generalizing the multi-scale navigation paradigm to interconnected, heterogeneous datasets as found on the Web of Data.

The first research problem is mainly investigated in collaboration with IGN in the context of ANR project MapMuxing (Section 9.2.1), which stands for *multi-dimensional map multiplexing*. Project MapMuxing aims at going beyond the traditional pan & zoom and overview+detail interface schemes, and at designing and evaluating novel cartographic visualizations that rely on high-quality generalization, *i.e.*, the simplification of geographic data to make it legible at a given map scale [76], [77], and symbol specification. Beyond project MapMuxing, we are also investigating multi-scale multiplexing techniques for geo-localized data in the specific context of ultra-high-resolution wall-sized displays, where the combination of a very high pixel density and large physical surface (Figure 2) enable us to explore designs that involve collaborative interaction and physical navigation in front of the workspace. This is work done in cooperation with team Massive Data at Inria Chile.

The second research problem is about the extension of multi-scale navigation to interconnected, heterogeneous datasets. Generalization has a rather straightforward definition in the specific domain of geographical information systems, where data items are geographical entities that naturally aggregate as scale increases. But it is unclear how generalization could work for representations of the more heterogeneous webs of data that we consider in the first axis of our research program. Those data form complex networks of resources with multiple and quite varied relationships between them, that cannot rely on a single, unified type of representation (a role played by maps in GIS applications).

Addressing the limits of current generalization processes is a longer-term, more exploratory endeavor. Here again, the machine-processable semantics and structure of the data give us an opportunity to rethink how users navigate interconnected heterogeneous datasets. Using these additional data, we investigate ways to generalize the multi-scale navigation paradigm to datasets whose layout and spatial relationships can be much richer and much more diverse than what can be encoded with static linear hierarchies as typically found today in interfaces for browsing maps or large imagery. Our goal is thus to design and develop highly dynamic and versatile multi-scale information spaces for heterogeneous data whose structure and semantics are not known in advance, but discovered incrementally.

3.4. Novel Forms of Input for Groups and Individuals

Participants: Caroline Appert, Anastasia Bezerianos, Olivier Chapuis, Emmanuel Pietriga, André Spritzer, Rafael Morales Gonzalez, Bruno Fruchard.

Analyzing and manipulating large datasets can involve multiple users working together in a coordinated manner in multi-display environments: workstations, handheld devices, wall-sized displays [33]. Those users work towards a common goal, navigating and manipulating data displayed on various hardware surfaces in a coordinated manner. Group awareness [46], [27] is central in these situations, as users, who may or may not be co-located in the same room, can have an optimal individual behavior only if they have a clear picture of what their collaborators have done and are currently doing in the global context. We work on the design and implementation of interactive systems that improve group awareness in co-located situations [56], making individual users able to figure out what other users are doing without breaking the flow of their own actions.

In addition, users need a rich interaction vocabulary to handle large, structured datasets in a flexible and powerful way, regardless of the context of work. Input devices such as mice and trackpads provide a limited number of input actions, thus requiring users to switch between modes to perform different types of data manipulation and navigation actions. The action semantics of these input devices are also often too much dependent on the display output. For instance, a mouse movement and click can only be interpreted according to the graphical controller (widget) above which it is moved. We focus on designing powerful input techniques based upon technologies such as tactile surfaces (supported by UI toolkits developed in-house), 3D motion tracking systems, or custom-built controllers [58] *to complement (rather than replace) traditional input devices* such as keyboards, that remain the best method so far for text entry, and indirect input devices such as mice or trackpads for pixel-precise pointing actions.

The input vocabularies we investigate enable users to navigate and manipulate large and structured datasets in environments that involve multiple users and displays that vary in their size, position and orientation [33], [45], each having their own characteristics and affordances: wall displays [5], [81], workstations, tabletops [62], [41], tablets [6], [78], smartphones [10], [40], [74], [75], and combinations thereof [2], [9], [60], [33].

We aim at designing rich interaction vocabularies that go far beyond what current touch interfaces offer, which rarely exceeds five gestures such as simple slides and pinches. Designing larger gesture vocabularies requires identifying discriminating dimensions (e.g., the presence or absence of anchor points and the distinction between internal and external frames of reference [6]) in order to structure a space of gestures that interface designers can use as a dictionary for choosing a coherent set of controls. These dimensions should be few and simple, so as to provide users with gestures that are easy to memorize and execute. Beyond gesture complexity, the scalability of vocabularies also depends on our ability to design robust gesture recognizers that will allow users to fluidly chain simple gestures that make it possible to interlace navigation and manipulation actions.

We also plan to study how to further extend input vocabularies by combining touch [10], [6], [62] and mid-air gestures [5] with physical objects [51], [72], [58] and classical input devices such as keyboards to enable users to input commands to the system or to involve other users in their workflow (request for help, delegation, communication of personal findings, etc.) [35], [57]. Gestures and objects encode a lot of information in their shape, dynamics and direction, that can be directly interpreted in relation with the user, independently from the display output. Physical objects can also greatly improve coordination among actors for, e.g., handling priorities or assigning specific roles.

4. Application Domains

4.1. Mission-critical systems

Mission-critical contexts of use include emergency response & management, and critical infrastructure operations, such as public transportation systems, communications and power distribution networks, or the operations of large scientific instruments such as particle accelerators and astronomical observatories. Central to these contexts of work is the notion of situation awareness [27], i.e., how workers perceive and understand elements of the environment with respect to time and space, such as maps and geolocated data feeds from the field, and how they form mental models that help them predict future states of those elements. One of the main challenges is how to best assist subject-matter experts in constructing correct mental models and making informed decisions, often under time pressure. This can be achieved by providing them with, or helping them efficiently identify and correlate, relevant and timely information extracted from large amounts of raw data, taking into account the often cooperative nature of their work and the need for task coordination. With this application area, our goal is to investigate novel ways of interacting with computing systems that improve collaborative data analysis capabilities and decision support assistance in a mission-critical, often time-constrained, work context.

Relevant publications by team members this year: [22], [24].

4.2. Exploratory analysis of scientific data

Many scientific disciplines are increasingly data-driven, including astronomy, molecular biology, particle physics, or neuroanatomy. While making the right decision under time pressure is often less of critical issue when analyzing scientific data, at least not on the same temporal scale as truly time-critical systems, scientists are still faced with large-to-huge amounts of data. No matter their origin (experiments, remote observations, large-scale simulations), these data are difficult to understand and analyze in depth because of their sheer size and complexity. Challenges include how to help scientists freely-yet-efficiently explore their data, keep a trace of the multiple data processing paths they considered to verify their hypotheses and make it easy to backtrack, and how to relate observations made on different parts of the data and insights gained at different moments during the exploration process. With this application area, our goal is to investigate how data-centric interactive systems can improve collaborative scientific data exploration, where users' goals are more open-ended, and where roles, collaboration and coordination patterns [46] differ from those observed in mission-critical contexts of work.

Relevant publications by team members this year: [7].

5. Highlights of the Year

5.1. Highlights of the Year

5.1.1. Awards

- ACM CHI 2016 Honorable mention for **TouchTokens: Guiding Touch Patterns with Passive Tokens** [4], awarded to the top 5% of all 2325 paper submissions.
- IEEE InfoVis 2016 Honorable mention for **The Attraction Effect in Information Visualization** [13].

6. New Software and Platforms

6.1. Smarties

FUNCTIONAL DESCRIPTION

The Smarties system provides an easy way to add mobile interactive support to collaborative applications for wall displays.

It consists of (i) a mobile interface that runs on mobile devices for input, (ii) a communication protocol between the mobiles and the wall application, and (iii) libraries that implement the protocol and handle synchronization, locking and input conflicts. The library presents the input as an event loop with callback functions and handles all communication between mobiles and wall application. Developers can customize the mobile interface from the wall application without modifying the mobile interface code.

On each mobile we find a set of cursor controllers associated with keyboards, widgets and clipboards. These controllers (pucks) can be shared by multiple collaborating users. They can control simple cursors on the wall application, or specific content (objects or groups of them). The developer can decide the types of widgets associated to pucks from the wall application side.

- Contact: Olivier Chapuis
- URL: http://smarties.lri.fr/

Smarties was used in the projects that led to the following publications this year: [7], [8], [22].

6.2. ZVTM

Zoomable Visual Transformation Machine
KEYWORDS: Information visualization - Data visualization - Visualization - Big data - Graph visualization
FUNCTIONAL DESCRIPTION

ZVTM is a toolkit enabling the implementation of multi-scale interfaces for interactively navigating in large datasets displayed as 2D graphics.

ZVTM is used for browsing large databases in multiple domains: geographical information systems, control rooms of complex facilities, astronomy, power distribution systems.

The toolkit also enables the development of applications running on ultra-high-resolution wall-sized displays.

- Participants: Caroline Appert, Maria Jesus Lobo Gunther, Arnaud Prouzeau, Hande Ozaygen, Can Liu and Olivier Chapuis
- Contact: Emmanuel Pietriga
- URL: http://zvtm.sf.net

Smarties was used in the projects that led to the following publications this year: [7], [8], [22], [19], [21].

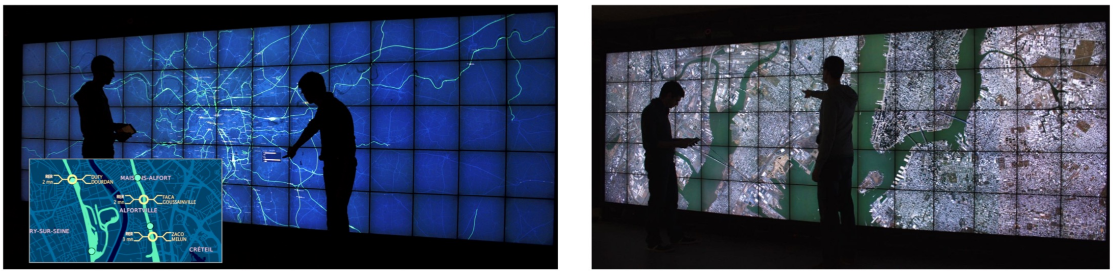


Figure 2. Geovisualization applications running on the WILDER platform. Real-time monitoring of railroad traffic in France (left), large-scale high-resolution orthoimagery visualization (right).

6.3. Platforms

6.3.1. Platform: WILDER

Ultra-high-resolution wall-sized displays [33] feature a very high pixel density over a large physical surface. Such platforms have properties that make them well-suited to the visualization of very large datasets. They can represent the data with a high level of detail while at the same time retaining context: users can transition from an overview of the data to a detailed view simply by physically moving in front of the wall display. Wall displays also offer good support for collaborative work, enabling multiple users to simultaneously visualize and interact with the displayed data. To make them interactive, wall-sized displays are increasingly coupled with input devices such as touch frames, motion-tracking systems and wireless multitouch devices, in order to enable multi-device and multi-user interaction with the displayed data. Application areas for such visualization platforms range from the monitoring of complex infrastructures and crisis management situations to tools for the exploratory visualization of scientific data.

WILDER is the latest ultra-high-resolution wall-sized display set up at Inria Saclay, and is one of the nodes of the Digiscope EquipEx. We use this platform for multiple projects, both fundamental HCI research, and research and development activities for specific application areas such as geographical informations systems (Figure 2) and astronomy (see Figure 3).

WILDER was used in the projects that led to the following publications this year: [7], [8], [22], [19], [23].

6.3.2. Platform: ANDES

ANDES is a platform similar to WILDER, set up at Inria in Santiago de Chile, that we use both as a research platform and as a showroom of our research and development activities. ANDES is the main platform used for our collaborative research project with the Millenium Institute of Astrophysics on the visualization of large FITS images (see Figure 3).

ANDES was used in the projects that led to the following publications this year: [7].

7. New Results

7.1. Wall Displays

Ultra-high-resolution wall displays feature a very high pixel density over a large physical surface, which makes them well-suited to the collaborative, exploratory visualization of large datasets (see Sections 6.3.1 and 6.3.2). We have continued working on the design, implementation and evaluation of interactive visualization

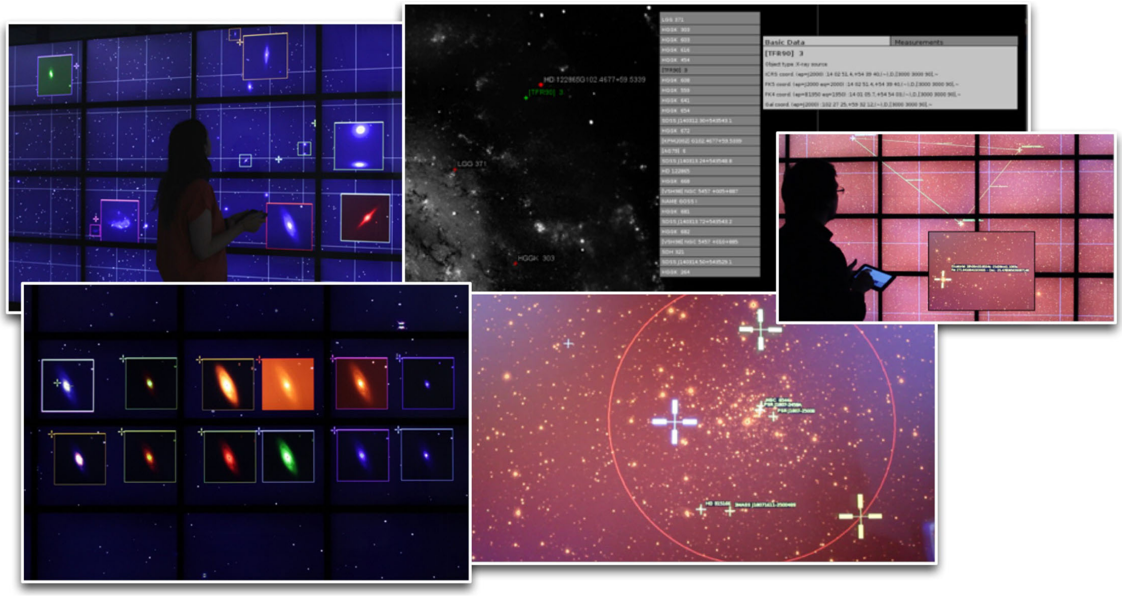


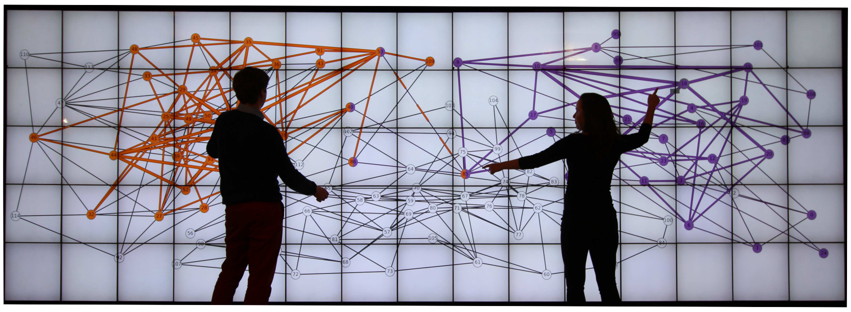
Figure 3. Visualization of high-dynamic-range FITS images and associated data catalogs in the domain of Astronomy on ANDES (collaboration with Inria Chile, Millenium Institute of Astrophysics, and Institut d'Astrophysique Spatiale).

Figure 4. ***Left:*** *FITS-OW running on the WILDER platform, showing: multiple FITS images, (a) M31 on the left side, (b) three juxtaposed images that show observations of the Eagle nebula at different wavelengths, and (c) a much larger FITS image (86,499 × 13,474 pixels) used as a zoomable background over the entire wall; (d) the result-set of a SIMBAD query restricted to observations about galaxies; (e) basic measurements for galaxy M31; (e) a page of a research paper (PDF) discussing that particular galaxy; (f) the color map selector.* ***Right:*** *Results of a SIMBAD query superimposed on the corresponding FITS image, along with a sorted list of all items in the result-set. Selecting an element in this list updates the detailed info in the lower right window and highlights the source in the image. All windows can be freely repositioned on the wall.*

techniques for such ultra-high-resolution wall-sized displays, focusing, in some of these projects, on the collaboration between users who perform different data manipulation and analysis tasks.

- We continued working on FITS-OW, an application designed for such wall displays, that enables astronomers to navigate in large collections of FITS images, query astronomical databases, and display detailed, complementary data and documents about multiple sources simultaneously. We published a paper about FITS-OW [7], in which we describe the system, reporting on the technical challenges we addressed in terms of distributed graphics rendering and data sharing over the computer clusters that drive wall displays. The article also describes how astronomers interact with their data using both the wall's touch-sensitive surface and handheld devices. This work was also featured as a short article in the SPIE Newsroom (see Section 10.3).
- Wall-sized displays support small groups of users working together on large amounts of data. Observational studies of such settings have shown that users adopt a range of collaboration styles, from loosely to closely coupled. Shared interaction techniques, in which multiple users perform a command collaboratively, have also been introduced to support co-located collaborative work. In [19], we operationalized five collaborative situations with increasing levels of coupling, and tested the effects of providing shared interaction support for a data manipulation task in each situation. The results show the benefits of shared interaction for close collaboration: it encourages collaborative manipulation, it is more efficient and preferred by users, and it reduces physical navigation and fatigue. We also identify the time costs caused by disruption and communication in loose collaboration and analyze the trade-offs between parallelization and close collaboration. These findings inform the design of shared interaction techniques to support collaboration on wall-sized displays.
- We also studied how pairs explore graphs on a touch enabled wall-display [16], using two selection techniques adapted for collaboration: a basic localized selection, and a propagation selection technique that uses the idea of diffusion/transmission from an origin node. We assessed in a controlled experiment the impact of selection technique on a shortest path identification task. Pairs consistently divided space even though the task is not spatially divisible. The basic selection technique, that has a localized visual effect, led to parallel work that negatively impacted accuracy. The large visual footprint of the propagation technique led to close coordination, improving speed and accuracy for complex graphs only. We then observed the use of propagation on additional graph topology tasks, confirming pair strategies on spatial division and coordination.
- In [22], we focused on road traffic control center. Road traffic control centers are of vital importance to modern cities. Interviews with controllers in two such centers identified the need to incorporate the visualization of results from predictive traffic models with real traffic, to help operators choose among different interventions on the network. We explore this idea in a prototype that runs on a wall display, and supports direct touch and input from workstations and mobile devices. Apart from basic functionality to manage the current traffic such as changing traffic light duration or speed limits, the prototype incorporates traffic simulations for forecasting results of possible actions, highlighting their differences to current traffic. Based on needs identified in our interviews, we offered two techniques that visually combine simulated and real situations, taking advantage of the large display space: multiple independent views and DragMagic, a variation of magic lenses. A preliminary laboratory experiment suggests that both techniques are viable design options, even for monitoring several simulations and areas of interest, contrary to expectations from previous work. However DragMagics are easier to master.
- Immersion is the subjective impression of being deeply involved in a specific situation, and can be sensory or cognitive. In a position paper [23], we used a basic model of visual perception to study how ultra-high resolution wall displays can provide visual immersion. With their large size, depending on the position of viewers in front of them, wall displays can provide a surrounding and vivid environment. Users close to the wall can have their visual field filled by the wall and they are able to see clearly a large amount information with a fine resolution. However, when close to the wall, visual distortion due to large possible viewing angles, can affect the viewing of data. On the

contrary, from far away, distortion is no longer an issue, but the viewers' visual field is not fully contained inside the wall, and the information details seen are less fine.



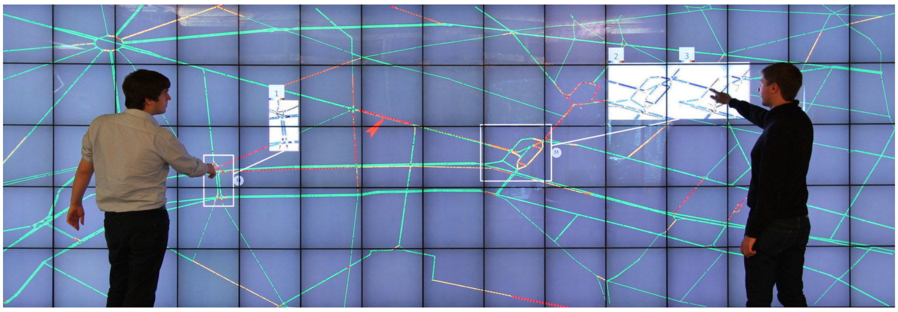


*Figure 5. **Top:** A pair using the propagation technique described in [16] to explore a graph. They discuss two communities, in orange and purple, selected using the propagation technique. The communities are linked by a specific node shown by the right user. The remaining 3 orange-purple nodes show how by propagating the purple community, it flows into the orange one through this node. **Bottom:** Visualization from [22] of traffic in a city with two "DragMagics" (white rectangles) showing one (left) and two (right) simulations associated with different possible interventions on the traffic. The simulation visualizations use difference color maps to highlight differences with the real traffic.*

7.2. Gestures, Tangibles and Sound

- We designed a new way of implementing tangible interfaces with TouchTokens [4]. The approach requires only passive tokens and a regular multi-touch surface. The tokens constrain users' grasp, and thus, the relative spatial configuration of fingers on the surface, theoretically making it possible to design algorithms that can recognize the resulting touch patterns. We performed a formative user study to collect and analyze touch patterns with tokens of varying shape and size. The analysis of this pattern collection showed that individual users have a consistent grasp for each token, but that this grasp is user-dependent and that different grasp strategies can lead to confounding patterns. We thus designed a second set of tokens featuring notches that constrain users' grasp. Our recognition algorithm can classify the resulting patterns with a high level of accuracy (>95%) without any training, enabling application designers to associate rich touch input vocabularies with command triggers and parameter controls.

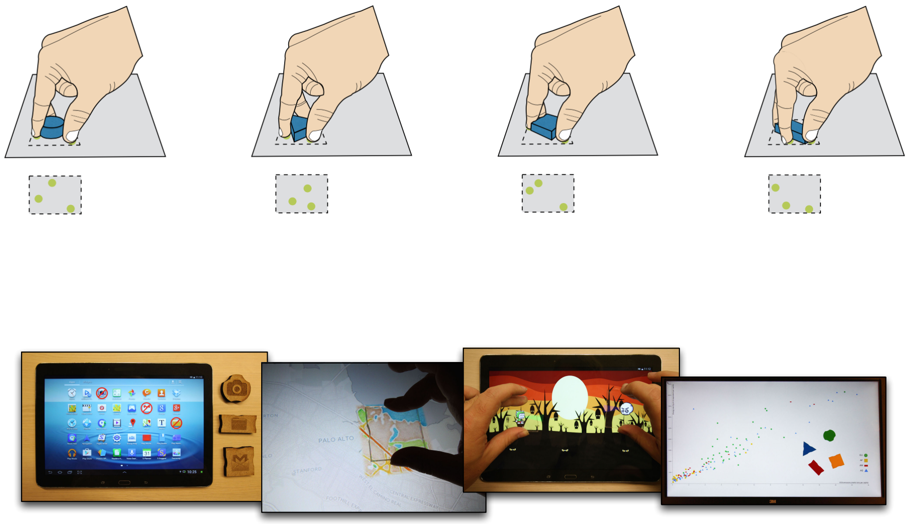


*Figure 6. **Top:** TouchTokens are passive tokens that guide users' fingers to specific spatial configurations, resulting in distinguishable touch patterns. **Bottom:** Proof-of-concept applications: access control, tangible magic lenses, character controllers in a game, data visualization.*

- In collaboration with IRCAM, we introduced SoundGuides [17], a user adaptable tool for auditory feedback on movement. The system is based on a interactive machine learning approach, where both gestures and sounds are first conjointly designed and conjointly learned by the system. The system can then automatically adapt the auditory feedback to any new user, taking into account the particular way each user performs a given gesture. SoundGuides is suitable for the design of continuous auditory feedback aimed at guiding users' movements and helping them to perform a specific movement consistently over time. Applications span from movement-based interaction techniques to auditory-guided rehabilitation. We first describe our system and report a study that demonstrates a "stabilizing effect" of our adaptive auditory feedback method.

7.3. Interacting with Linked Data

As part of the team's novel research theme on Semantics-Driven Data Manipulation 3.2, and in collaboration with Aba-Sah Dadzie from the Open University, Emmanuel Pietriga coordinated a special issue of the Semantic Web Journal and wrote a follow-up [12] to the 2011 survey about Approaches to Visualizing Linked Data [42]. Linked Data promises to serve as a disruptor of traditional approaches to data management and use, promoting the push from the traditional Web of documents to a Web of data. The ability for data consumers to adopt a follow your nose approach, traversing links defined within a dataset or across independently-curated datasets, is an essential feature of this new Web of Data, enabling richer knowledge retrieval thanks to synthesis across multiple sources of, and views on, interrelated datasets. But for the Web of Data to be successful, we must design novel ways of interacting with the corresponding very large amounts of complex, interlinked, multi-dimensional data throughout its management cycle. The design of user interfaces for Linked Data, and more specifically interfaces that represent the data visually, play a central role in this respect. Contributions to this special issue on Linked Data visualization investigate different approaches to harnessing visualization as a tool for exploratory discovery and basic-to-advanced analysis. The papers in this volume illustrate the design and construction of intuitive means for end-users to obtain new insight and gather more knowledge, as they follow links defined across datasets over the Web of Data.

7.4. Visualization

- The attraction effect is a well-studied cognitive bias in decision making research, where one's choice between two alternatives is influenced by the presence of an irrelevant (dominated) third alternative. In collaboration with EPI Aviz, we examined in [13] whether this cognitive bias, so far only tested with three alternatives and simple presentation formats such as numerical tables, text and pictures, also appears in visualizations. In a series of crowdsource experiments, we observed this cognitive bias in visualizations (namely scatterplots), even in larger sets of alternatives, never considered before, where the number of alternatives is too large for numerical tables to be practical. We discussed implications for future research on how to further study and possibly alleviate the attraction effect.
- With colleagues from the University of Konstanz [14] we concluded previous work on data glyphs, i.e., visual marks that encode multiple dimensions to one or more visual variables. We provided a systematic review of experimental studies on data glyphs from the past 60 years, describing the types of glyphs and design variations tested, the tasks under which they were analyzed, and study results. Based on our meta analysis of all results, we further contributed a set of design implications and a discussion on open research directions.
- In [11], with colleagues from INRA, we provided an overview of a framework for Evolutionary Visual Exploration (EVE) that guides users in exploring large search spaces. EVE uses an interactive evolutionary algorithm to steer the exploration of multidimensional datasets towards two-dimensional projections that are interesting to the analyst. Our method smoothly combines automatically calculated metrics and user input in order to propose pertinent views to the user. While previously we showed that using EVE, domain experts were able to formulate interesting hypothesis and reach new insights when exploring freely, our new findings indicate that users, guided by the interactive evolutionary algorithm, are able to converge quickly to an interesting view of their data when a clear task is specified. Our work aims at building a bridge between the domains of visual analytics and interactive evolution.

8. Bilateral Contracts and Grants with Industry

8.1. Bilateral Contracts with Industry

- Tecknowmetrix (TKM): ANRT/CIFRE PhD (Hugo Romat), 3 years, starting June 2016.

9. Partnerships and Cooperations

9.1. Regional Initiatives

ScaleGest. Surface Gestures for Advanced Graphical Interfaces: Which Gesture for What. (2014-2017) Funded by Digiteo. In collaboration with Telecom ParisTech: **109Keuros**. Participants: Caroline Appert (PI), Rafael Morales Gonzalez, Emmanuel Pietriga.

The project aims at designing gesture-based interaction for expert users who navigate and manipulate large datasets. In the context of advanced graphical applications, the number of gestures should be large-enough to cover the set of controls (*i.e.*, commands and parameter settings) but remain simple-enough to avoid exceeding human abilities. Making gesture-based interaction scale with graphical applications' growing complexity can be achieved only by understanding the foundational aspects of this input modality. This project is about characterizing and structuring both the space of application controls and the space of surface gestures in order to establish guidelines for appropriate control-gesture mappings. It is also about the definition of a sound and systematic evaluation methodology that will serve as a reference benchmark for evaluating these mappings. The resulting control-gesture mappings are demonstrated in the specific application domains of cartography and astronomy.

9.2. National Initiatives

9.2.1. ANR

MapMuxing - Multi-dimensional Map Multiplexing. (2014-2018) Funded by the French National Research Agency (ANR). In collaboration with IGN (Institut National de l'Information Géographique et Forestière): **208Keuros**/499Keuros. Participants: Emmanuel Pietriga (PI), Caroline Appert, Olivier Chapuis, María-Jesús Lobo. http://mapmuxing.ign.fr

The project explores novel ways of combining different maps and data layers into a single cartographic representation, and investigates novel interaction techniques for navigating in it. The project aims at going beyond the traditional pan & zoom and overview+detail interface schemes, and at designing and evaluating novel cartographic visualizations that rely on high-quality generalization, *i.e.*, the simplification of geographic data to make it legible at a given map scale, and symbol specification.

9.2.2. Collaborations with other French Research Organizations

CorTextViz. (2015-2016) Funded by INRA (Institut National de la Recherche Agronomique). In collaboration with project-team Aviz at Inria Saclay (Jean-Daniel Fekete) and INRA (Jean-Philippe Cointet, Guy Riba). Interactive visualization of medium-scale multi-level networks, supporting data storytelling on wall displays. Participants: André Spritzer, Emmanuel Pietriga (PI), Anastasia Bezerianos.

9.3. European Initiatives

9.3.1. Collaborations with Major European Organizations

- European Southern Obseervatory (ESO)
- ALMA Operations Monitoring and Control - design and implementation of state-of-the-art interactive visualization components for the operations monitoring and control software that runs the ALMA radio-observatory in Chile.
- Deutsches Elektronen-Synchrotron (DESY)
- Scientific collaboration on the design and implementation of user interfaces for array operations monitoring and control for the Cherenkov Telescope Array (CTA) project [24], to be built in the Canary Islands (Spain) and in the Atacama desert (Chile).

9.4. International Initiatives

9.4.1. Inria International Labs

Inria Chile / CIRIC. From 2012 to 2015, Emmanuel Pietriga was the scientific leader of the Massive Data team at Inria Chile, working on projects in collaboration with the ALMA radio-telescope and the Millenium Institute of Astrophysics [15]. He is now scientific advisor to Inria Chile's visualization lab.

9.4.2. Inria International Partners

9.4.2.1. Informal International Partners

- University of Konstanz: Daniel Keim and Johannes Fuchs on mapping out the design space for visualization glyphs [14]. Participants: Anastasia Bezerianos.

9.5. International Research Visitors

9.5.1. Visits of International Scientists

- Shumin Zhai, Google, June 2016
- Iftach Sadeh, DESY/CTA Observatory, April 2016

9.5.1.1. Internships

- María Grazia Prato, Inria Chile, April 2016

10. Dissemination

10.1. Promoting Scientific Activities

10.1.1. Scientific events organisation

10.1.1.1. General chair, scientific chair

- CHI 2017, 35th ACM SIGCHI Conference on Human Factors in Computing Systems: Caroline Appert (papers and notes co-chair)

10.1.2. Scientific events selection

10.1.2.1. Chair of conference program committees

- CHI 2017, 35th ACM SIGCHI Conference on Human Factors in Computing Systems: Emmanuel Pietriga (SC - subcommittee chair)

10.1.2.2. Member of the conference program committees

- CHI 2017, 35th ACM SIGCHI Conference on Human Factors in Computing Systems: Anastasia Bezerianos (AC - associate chairs)
- CHI 2016, 34th ACM SIGCHI Conference on Human Factors in Computing Systems: Anastasia Bezerianos, Emmanuel Pietriga (AC - associate chairs)
- UIST 2016, 29th ACM ACM User Interface Software and Technologies Symposium: Caroline Appert, Anastasia Bezerianos (AC - associate chairs)
- InfoVis 2016, IEEE Information Visualization Conference: Anastasia Bezerianos (AC - associate chair)
- EICS 2016, 8th ACM SIGCHI Symposium on Engineering Interactive Computing Systems: Emmanuel Pietriga
- VOILA @ ISWC 2016, Visualizations and User Interfaces for Ontologies and Linked Data, workshop co-located with ISWC 2016: Emmanuel Pietriga
- SSDBM 2016: 28th International Conference on Scientific and Statistical Database Management: Emmanuel Pietriga
- Immersive Analytics @ ISS 2016: Exploring Future Interaction and Visualization Technologies for Data Analytics, workshop co-located with ACM ISS 2016: Emmanuel Pietriga
- IHM 2016 – Conference of the Association Francophone d'Interaction Homme-Machine: Olivier Chapuis (AC - associate chair)

10.1.2.3. Reviewer

- ACM CHI 2016, Conference on Human Factors in Computing Systems: Olivier Chapuis, María-Jesús Lobo, Arnaud Prouzeau
- ACM UIST 2016, Symposium on User Interface Software and Technology: Olivier Chapuis, Emmanuel Pietriga
- EuroVis EG/VGTC 2016, Conference on Data Visualization: Caroline Appert
- ACM ISS 2016, International Conference on Interactive Surfaces and Spaces: Caroline Appert, Olivier Chapuis
- ACM MobileHCI 2016, International Conference on Human-Computer Interaction with Mobile Devices and Services: Caroline Appert
- ACM IUI 2017, International Conference on Intelligent User Interfaces: Caroline Appert

- IEEE VR 2016, Virtual Reality: Olivier Chapuis
- ACM EICS 2016, Symposium on Engineering Interactive Computing Systems: Olivier Chapuis

10.1.3. Journal

10.1.3.1. Member of the editorial boards

- Semantic Web Journal: Emmanuel Pietriga (guest editor, special issue on Visual Exploration and Analysis of Linked Data)

10.1.3.2. Reviewer - Reviewing activities

- ACM ToCHI, Transactions on Computer-Human Interaction: Olivier Chapuis
- IJHCI, International Journal of Human-Computer Interaction: Olivier Chapuis, Emmanuel Pietriga
- IEEE TVCG, Transactions on Visualization and Computer Graphics: Anastasia Bezerianos

10.1.4. Invited talks

- Olivier Chapuis, L'équipement d'excellence Digiscope: un réseau de plateformes pour la visualisation interactive, CNRS Innovatives Big Data Forum, October 2016, Paris France.
- Anna Gogolou, Visualization and human-computer interaction methods: Challenges in Interactive Visual Exploration of Large Data Series, 2nd Interdisciplinary Time Series Workshop, December 2016, Paris France.
- Anastasia Bezerianos, Hands-on session on visualization and human-computer interaction methods: Designing interactive visualization techniques for large data series, 2nd Interdisciplinary Time Series Workshop, December 2016, Paris France.

10.1.5. Scientific expertise

- Evaluator for the Sponsored Program for Industrial Data Science (EDF & Thales) - Fondation Mathématique Jacques Hadamard/IRSDI: Emmanuel Pietriga

10.1.6. Research administration

- Executive committee of the Laboratoire de Recherche en Informatique (LRI): Olivier Chapuis
- President of Inria Saclay - Île de France's Commission for Technological Development (CDT): Emmanuel Pietriga

10.1.7. Learned societies

- Association Francophone d'Interaction Homme-Machine (AFIHM): Olivier Chapuis (board member, vice-president).

10.1.8. Hiring committees

- Univ. Paris-Sud hiring committee, Commission Consultative des Spécialistes de l'Université 27ème section (computer science), members: Caroline Appert.
- Univ. Paris-Sud hiring committee, Comités de Sélection PRCE/PRAG 1195 (english language), members: Anastasia Bezerianos.

10.2. Teaching - Supervision - Juries

10.2.1. Teaching

Master: Anastasia Bezerianos, Co-Head of EIT masters M1 & M2 HCID, Univ. Paris-Sud

Master: Anastasia Bezerianos, Co-Head of M2 Interaction, Univ. Paris-Sud, Université Paris-Saclay

Master: Anastasia Bezerianos, Programming of Interactive Systems – 21h CM, M1/M2 HCID + M2R Interaction, Univ. Paris-Sud

Master: Anastasia Bezerianos, Mixed Reality and Tangible Interaction – 11h CM, M1/M2 HCID + M2R Interaction, Univ. Paris-Sud

Master: Anastasia Bezerianos, Career Seminar, – 12h CM, M2 HCID + M2R Interaction, Univ. Paris-Sud

Master: Anastasia Bezerianos, Design Project in HCI, – 21h CM, M1 HCID, Univ. Paris-Sud

Master: Anastasia Bezerianos, HCI Project, – 21h CM, M2 HCID + M2 Interaction, Univ. Paris-Sud

Master: Anastasia Bezerianos, Introduction to Java – 18h CM, M1/M2 HCID + M2R Interaction, Univ. Paris-Sud

Master: Caroline Appert, Evaluation of Interactive Systems – Intro, 21h CM, M1/M2 HCID + M2R Interaction, Univ. Paris-Sud

Master: Caroline Appert, Evaluation of Interactive Systems – Advanced, 21h CM, M1/M2 HCID + M2R Interaction, Univ. Paris-Sud

Master: Emmanuel Pietriga, Data Visualization, 24h CM, M2 Informatique Décisionelle, Univ. Paris-Dauphine.

Licence: María-Jesús Lobo, Informatique Graphique, 28h, L3 Univ. Paris-Sud

Licence: María-Jesús Lobo, Programmation d'Interfaces Interactives avancées, 29h, L3 Univ. Paris-Sud

Master: Arnaud Prouzeau, Programming of Interactive Systems: 27h, Univ. Paris-Sud.

Licence: Arnaud Prouzeau, Programmation Impérative en C++, 22.4h, Univ. Paris-Sud.

Licence: Arnaud Prouzeau, Programmation Impérative Avancée en C++, 16.5h, Univ. Paris-Sud.

Licence: Arnaud Prouzeau, Interaction Homme-Machine, 12h, olytech Paris-Sud.

Licence: Bruno Fruchard, Développement d'Applications Mobiles, 13h, Télécom Paristech.

Licence: Bruno Fruchard, Paradigmes de programmation, 24.5h, Télécom Paristech.

10.2.2. Supervision

PhD in progress : Anna Gogolou, Iterative and expressive querying for big data series, October 2016, Advisors: Anastasia Bezerianos, Themis Palpanas

PhD in progress : María-Jesús Lobo, Interaction Techniques for Map Multiplexing, since October 2014, Advisors: Caroline Appert, Emmanuel Pietriga

PhD in progress : Rafael Morales Gonzalez, Surface Gestures for Advanced Graphical Interfaces: Which Gesture for What, since November 2014, Advisors: Caroline Appert, Gilles Bailly, Emmanuel Pietriga

PhD in progress : Arnaud Prouzeau, Collaboration around Wall-Displays in Time Critical and Command and Control Contexts, since October 2014, Advisors: Anastasia Bezerianos, Olivier Chapuis

PhD in progress : Hugo Romat, Nouvelles techniques de visualisation et de manipulation interactive de collections de documents et données hétérogènes, since June 2016, Advisors: Caroline Appert, Emmanuel Pietriga

PhD in progress : Evanthia Dimara, Merging Interactive Visualization and Automated Analysis for Group Decision-Making Involving Large Datasets, since October 2014, Advisors: Pierre Dragicevic, Anastasia Bezerianos

PhD in progress : Bruno Fruchard, Techniques d'interaction exploitant la mémoire spatiale pour faciliter l'accès rapide aux commandes et aux données, since October 2015, Advisors: Eric Lecolinet, Olivier Chapuis

Master: Dylan Lebout, Indirect vs Direct surface gestures for wall-sized displays, May - August 2016, Advisors: Caroline Appert, Olivier Chapuis

10.2.3. Juries

PhD: Rémy Dautriche, Université Grenoble-Alpes: Emmanuel Pietriga (rapporteur)

PhD: Pascal Goffin, Inria / Université Paris-Saclay: Emmanuel Pietriga (président du jury)

10.3. Popularization

- SPIE Newsroom: E. Pietriga, F. del Campo, A. Ibsen, R. Primet, C. Appert, O. Chapuis, M. Hempel, R. Muñoz, S. Eyheramendy Duerr, A. Jordan, H. Dole, Ultra-high-resolution walls for visualizing very large datasets, May 2016. http://spie.org/newsroom/6505-ultra-high-resolution-walls-for-visualizing-very-large-datasets

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