Technical Brief

Data visualization in AR / VR

DISSEMINATION LEVEL PUBLIC

PARTNER

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This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement No. 883293. The content of this document represents the view of the authors only and is their sole responsibility. The European Commission does not accept any responsibilty for any use that may be made of the information it contains.

1. Data Visualisation - from paper to immersion[1]

We are a visual species and, as such, visualization is a natural way for us to get a better understanding of data. In his 2016 book, Alberto Cairo[2] defines visualization as "any kind of visual representation of information designed to enable communication, analysis, discovery, exploration".

In the case of data visualizations, they also serve one or many of these functions. They may help us to explore a dataset, to understand its implications, to discover new phenomena, and to communicate our findings to others. Instead of just going over raw data, creating graphical representations allows us to benefit from our innate capacity to detect visual patterns. Immersive technologies, such as AR or VR, open new alternatives for visualization of data. For these reasons, organizations that carry out knowledge work use data visualizations as a tool and are looking into the new possibilities of immersion. LEAs are no exception.

Originally, data visualizations were static prints on paper. Computers enable interaction with data, and as a consequence people could dynamically analyse data. However, interaction added one extra layer of complexity in the design of visualizations, and the need to find guidelines to simplify it emerged. The information seeking mantra: "overview first, zoom and filter, then details-on-demand" is a good starting point for those designing data analysis systems. This mantra is elaborated by Shneiderman[3] with the definition of task by data type taxonomy. Shneiderman identifies seven basic data types: 1-dimensional, 2-dimensional, 3-dimensional, temporal, multidimensional, tree, and network data. For each of these types he also discusses seven interactive tasks: overview, zoom, filter, details-on-demand, relate, history and extract. This taxonomy is a useful reference point to design, evaluate and compare interactive data visualization systems, although it is not the only one.

About this topic, Wong[4] said:

"*A genuine visual data mining system must not impose knowledge on its users, but instead guide them through the mining process to draw conclusions. Humans should study the visual abstractions and gain insight instead of accepting an automated decision.*"

After static, and then interactive visualizations, we are now experiencing the emergence of immersive data visualizations. Although some experiments were already carried out in the early 90's, e.g. by Bryson and Levit,[5] it is now when devices are mature to see widespread progress. The field of immersive analytics[6] is really emerging. The body of knowledge generated by research in non-immersive data visualization needs to be validated for this novel environment, where new concepts will be possible. For example, the concept of visual mapping can also be extended to sensory mapping, as Nesbitt discusses: data can be mapped as space, visual, sound, or haptics.

Immersive technologies like Augmented and Virtual Reality offer an exceptional medium for data visualization. In AR, data can be visualized embedded in the physical context where it comes from. For example, imagine revisiting a crime scene but augmented with all the knowledge generated by the investigation. VR allows the creation of alternative digital environments with an infinite canvas to work in a virtual replica of a physical setting or in any imaginable space configuration. Imagine now visiting that same crime scene, but now from the office, because it was previously captured. The possibilities of immersive technology are not limited to new visual experiences. Immersion, communication, and collaboration go hand in hand. As INFINITY has demonstrated, socialization and collaboration in VR are feasible through avatars, audio communication, or, in the future, holoportation. This applies also to AR environments, or to environments that are cross-platform with different users accessing to the same experience using different means (a headset, a phone, or a laptop). That same crime scene you visited first augmented with data, and then virtually from your office, you could now show to a colleague who is connected through a VR headset or a mobile phone.

2. State of the Art

This state-of-the-art section aims to answer to key questions in the development of immersive data visualization tools for LEAs. The first question is what interesting work has been done in this area that someone can use as inspiration and foundation of future tools. The second question is what technologies (tools and/or software libraries) are available to build these then.

During the last decades, there has been a dramatic increase of data sources, both in their complexity as well as their dimensionality. Multi-dimensional datasets often combine multiple modalities to convey information such as numerical measurements, images, time-series, categorical labels, or text to name a few. This escalation in data complexity and dimensionality introduces new challenges in data processing and investigation for finding data connections or data patterns, as well as in visualizing and providing meaningful information to the observer.

Data visualization, if done well, can help LEAs in the analysis and understanding of more complex, or just more, data. The goal of a good visualization is to connect the quantitative meaning of data with human intuition. Creating useful and appealing visualizations is part art and design, and part science and engineering. As such, theory, use cases or guidelines come from different perspectives. They are based on the experience in 2D, but knowing them will also do good to developers of immersive visualizations. An interesting argument is that the key to data visualization is visual mapping. The prototypical form of data visualization, a chart, encodes data magnitudes with shapes, colours or proportions. However, there are a myriad of other forms: such as maps that represent geo-located data, network graphs that represent a relationship among entities, or digital twins of objects and places. As one can imagine, there are plenty of options for visual mapping to choose from when creating a visualization. Cleveland and McGill[7] identified the ten elementary perceptual tasks depicted in the figure that follows. This theory is useful and inspiring for visualization design and most data visualizations result from combining one or many of these properties:

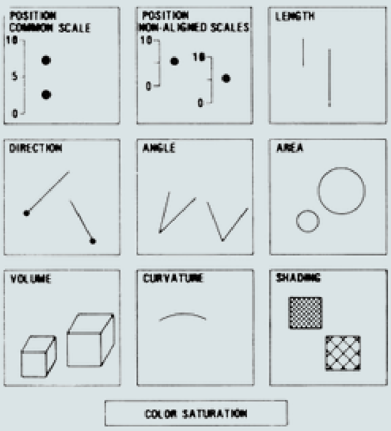

Figure 1: 10 elementary perceptual tasks. Source: Cleveland and McGill, 1984

These perceptual tasks that Cleveland and McGill studied for 2D visualizations are also relevant for immersive environments. Nonetheless, they must be used with care. A characteristic of immersive visualizations, which most 2D visualization lack, is the possibility to change one's perspective. As a result, the perception of physical properties, such as volume, angle or length can change. Two lines of the same length may look different when observed from different perspectives in a 3D space. Other guidelines are worthy of being inherited from the traditional data visualization field, such as Cairo's visualization wheel,[8] Wilke's classification of visualization properties,[9] or Tufte's[10] seminal work. But analogously to the 10 perceptual tasks mentioned, their translation to immersive spaces is not always straight forward. The emerging field of Immersive Analytics tries to adapt the lessons from traditional data visualization to immersive technology.

Beyond the theoretical and practical body of work by the academic community, practitioners must understand the technology, the tools and the frameworks used to build visualizations. Since the field is young, not a lot of off-the-shelf technology exists to build visualizations in AR or VR. Developers will likely need to combine different libraries or tools to achieve the desired visualization or tool. For that reason, in the following table we enumerate and reference popular visualization libraries. We provide a brief description, and we mention the relevant related technologies, i.e. if they provide 2D or 3D visualizations, if they are for web, AR or VR environments, and on top of what language or framework they have been built upon.

Tool	Description	Technologies
D3.js	https://d3js.org/ - D3.js is a popular JavaScript library for manipulating documents based on data.	2D/3D, Web based, Javascript
Pixi.js	https://pixijs.io/ - PixiJS is a rendering library that allows to create rich, interactive graphics and cross platform applications.	2D/3D, Web based, Javascript
Vis.js	https://visjs.org/ - A dynamic browser-based visualization library to create network visualizations, timelines, and 2D/3D graphs	2D/3D, Web based, Javascript
Chart.js	https://www.chartjs.org/ - A javascript library to create 2D animated charts.	2D/3D, Web based, Javascript
Plotly.js	https://plotly.com/javascript/ - Built on top of d3.js and stack.gl, Plotly.js is a high-level, declarative charting library. plotly.js ships with over 40 chart types, including 3D charts, statistical graphs, and SVG maps.	2D/3D, Web based, Javascript
raphael.js	https://dmitrybaranovskiy.github.io/raphael/ - Built on top of d3.js, raphael.js is a small JavaScript library that allows to create charts visualizations.	2D/3D, Web based, Javascript
Recharts.js	https://recharts.org/ - Built on top of d3.js and React.js. This library eases the integration of charts in React applications.	2D/3D, Web based, Javascript
Victory	https://formidable.com/open-source/victory/ - Similar to the previous library, it also helps to add charts in React applications.	2D/3D, Web based, Javascript
React-vis	https://uber.github.io/react-vis/ - Built by Uber on top of d3.js and React.js. It supports the creation of a great number of charts.	2D/3D, Web based, Javascript
Echart	https://echarts.apache.org/en/index.html - Built by Apache on top of d3.js and three.js, it allows to create 2D/3D visualizations in SVG and Canvas.	2D/3D, Web/WebGL, Javascript
Frappe Charts	https://frappe.io/charts - Simple library to build SVG charts for the web. The powerful of this library is that it has not subdependencies.	2D/3D, Web based, Javascript
Nvio	https://nivo.rocks/ - Built on top of d3.js and React.js. Provides server-side rendering (SSR) ability to build data visualizations apps.	2D/3D, Web based, Javascript
Google charts	https://developers.google.com/chart - A library that provides multiple pre-built charts types, such as bar, line, area, calendar, geo charts and many more.	2D/3D, Web based, Javascript
Highcharts	https://www.highcharts.com/ - Provides multiple data visualizations and interfaces to interact with them.	2D/3D, Web based, Javascript
C3.js	https://c3js.org/ - Provides multiple data visualizations in 2D based in d3.js	2D/3D, Web based, Javascript
Mermaid	https://mermaid-js.github.io/mermaid/#/ - It is a Javascript based diagramming and charting tool that renders markdown-inspired text definitions to create and modify diagrams dynamically.	2D/3D, Web based, Javascript
DXR	https://sites.google.com/view/dxr-vis - A toolkit for building immersive data visualizations based on the Unity development platform developed by (Sicat et al., 2019).	3D, VR/AR, Unity
IATK	https://github.com/MaximeCordeil/IATK - A Unity toolkit for interactive authoring and exploration of data visualization in immersive environments developed by (Cordeil et al., 2019).	3D, VR/AR, Unity
VRIA	https://vriajs.github.io/vria/#/docs - Web-based framework for creating Immersive Analytics experiences in VR/AR. Built on top of three.js and React.js (Butcher et al., 2021).	3D, WebXR, Javascript
VR-viz	https://github.com/mustafasaifee42/VR-Viz - Generate 3D visualizations in VR using WebVR and a combination of D3, React and A-Frame.	3D, WebXR, Javascript
HiruXR	A library built on top of three.js to create immersive collaborative data visualizations - https://dl.acm.org/doi/abs/10.1145/3505284.3532981. A result of the INFINITY project.	3D, WebXR, Javascript

Table 1: Tools and frameworks to create visualizations

Among all tools analysed, only the last five provide capabilities for immersive visualizations. The five of them are products of research activity in an early stage of their development. The last one, HiruXR was developed during INFINITY and was used to create immersive collaborative visualizations related to INFINITY use cases.

HiruXR has been used in INFINITY to create visualizations of results of AI tasks, such as object recognition, trend and event analysis, or text detection and extraction. These AI tasks analyse videos, images, or text, and as output they generate all types of multimedia data from cropped video sequences to text labels. The visualizations created for INFINITY use cases help investigators to analyse and explore these data results in a collaborative and immersive environment. They have been developed with the following features in mind

- **Web based:** The platform is web-based, and it can be accessed from any device with a web browser.
- **Multiplatform:** Web applications can be accessed from different platforms such as desktop computers, VR headsets or mobile devices can all use the tool.
- **Interactive:** Users can interact with the data displayed in the visualization. Actions such as pointing/hovering the data points, clicking, scrolling and rotating whole visualizations are possible.
- **Multimedia:** The platform is heavily focused on visualization of video files, images and text data.
- **Collaborative:** There is an audio chat where users in the same session can communicate while exploring the visualization. Some of the actions performed on the data can also be shared between users, for example, a user can highlight a data point, displaying its detail panel, and other users can see it happen in real time.

The following figures present some screenshots of the environment created with HiruXR for INFINITY:

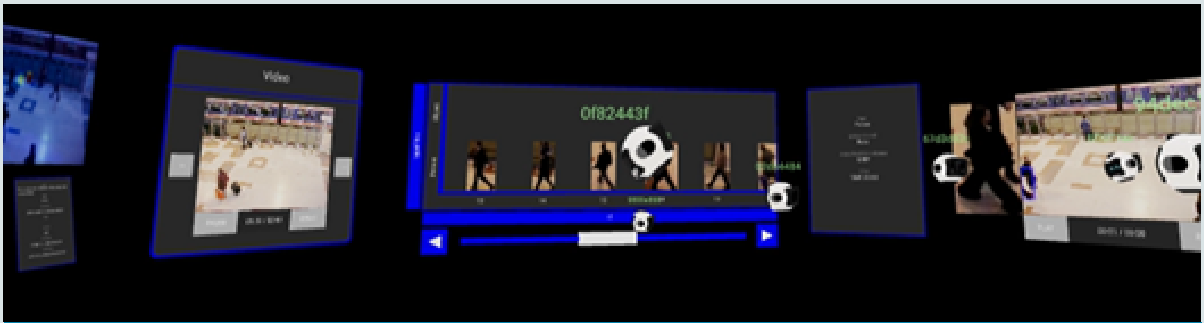

Figure 2: Users looking for an abandoned suitcase in HiruXR. The video analysed comes from a staged scenario in a public dataset.

Figure 3: Results of a text extraction analysis rendered in a 2D web interface.

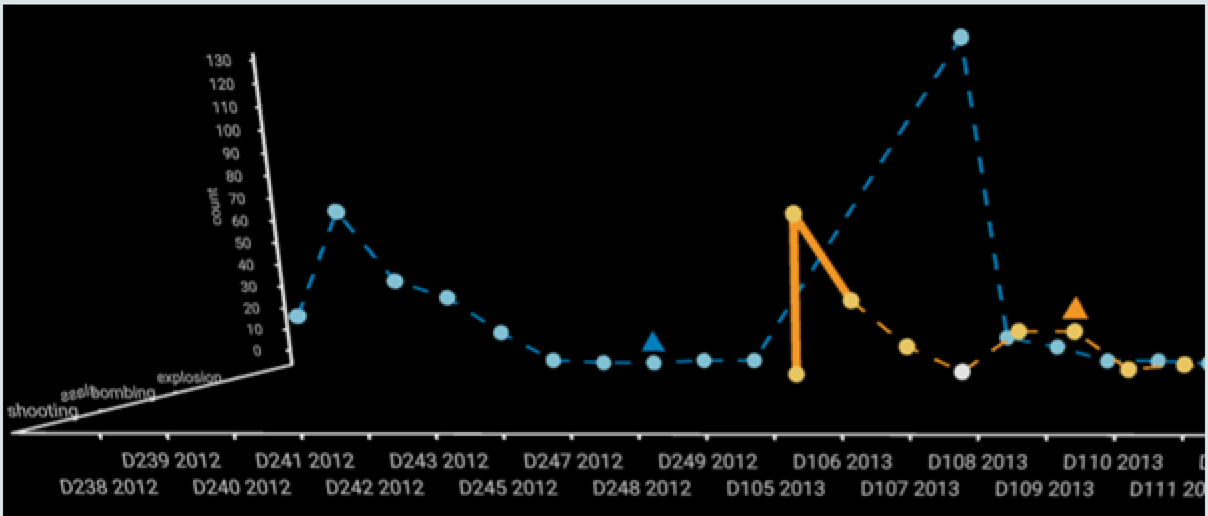

Figure 4: interactive and collaborative line plot showing trends and events in a public Twitter dataset used for security research.

3. LEAs

The application of immersive data visualization by LEAs can produce short, mid, and long-term benefits. Three of them are:

Immersive technologies will improve the productivity of current analytic and visualization tools. Like going from a printed chart to an interactive chart, making these tools immersive will facilitate investigations. Immersive dashboards, even if they contain the same types of visualizations used today, could be a first step. They would allow organising visualizations in space at user's will. Collaboration will also be crucial. Inviting other investigators to that immersive dashboard will be similar to walking with a colleague into a meeting room to discuss, but your colleague can be anywhere.

- Immersive technologies will merge the real and digital worlds. Scanning crime scenes and visiting them virtually is already an option. The proliferation of 3D scanning sensors and applications, now available even in high-end smartphones, makes this technology accessible to most. In addition, 3D scanning technology is also used to create 3D indoor and outdoor maps, which can be leveraged for tactical decisions. Creating digital representations of the physical world, link data to them, and interacting with them in a natural way, makes working with large amounts of data easier.

- Immersive technologies will create new ways of analysing and visualising data. It is not only about making current tools better, but also about new and better tools. Once investigators are used to immersive technologies, their workflows will change. New types of visualizations will appear, more tailored to the immersive space. Instead of working with data with a keyboard and a mouse, physical ways of interacting with it will appear. Combined with Artificial Intelligence, it will change the whole investigation process.

4. Future challenges and opportunities

As we have mentioned, immersion and the use of XR technologies gives many more opportunities than just adding a third dimension or an unlimited canvas. Immersive technology is good for remote collaboration, for working with digital replicas of objects and spaces, for placing data in a specific physical context with augmented reality, for interacting with it in new ways, and even for including other senses than sight. These opportunities come with their own challenges. Now it is not only about how data is placed or visually represented, but also how it is shared with others, how can be interacted, or contextualised in the physical or digital space. Recently, Ens et al.[11] have narrowed down these problems in a set of 17 research challenges around spatial distribution of data (5 challenges), interaction (4 challenges), collaboration (5 challenges), and evaluation (3 challenges). Many, if not all of them, will be relevant for tools used by LEAs:

1. Placing Visualisations accurately in space.
2. Extracting and representing semantic knowledge.
3. Designing guidelines for spatially situated visualization.
4. Understanding human perception and cognition in situated context.
5. Applying spatial visualization ethically.
6. Exploiting human senses for interactive immersive analytics.
7. Enabling multi-sensory feedback for immersive analytics.
8. Supporting transitions around immersive environments.
9. Coping with immersive analytics interaction complexity.
10. Supporting behaviour with collaborators.
11. Overcoming constraints of reality.
12. Supporting cross platform collaboration.
13. Integrating current collaboration practice.
14. Assessing collaborative work.
15. Defining application scenarios for immersive analytics.
16. Understanding users and contexts for evaluation of immersive analytics.
17. Establishing an evaluation framework for immersive analytics.

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