Immersive narrative visualisation for understanding autonomous maritime vessels

It is clear that autonomous systems (AS), and in particular swarms of Autonomous Underwater Vehicles (AUV), will play a significant part in future maritime defence force design. Human oversight and control of such systems can be a complex challenge; the swarms may be composed of a large number of AUVs and communication links can be unreliable, requiring the human operator to understand a significant amount of information when communication links are re-established. This challenge is compounded by the fact that 1) unexpected events may have occurred that must be reported and, 2) that the information is highly spatial in nature. These compounding factors create situations that place operators under high cognitive-load.

Narrative visualisation combines narrative techniques and information visualisation to communicate a consistent and coherent view of the information that builds upon the user's mental model of the situation being explained. Applying narrative visualisation to the AS maritime use-case can address the challenge of communicating decisive events from swarm information. Furthermore, the spatial nature of the maritime data is ideally suited to *immersive visualisation* and analytics, leveraging the perceptual affordances of virtual reality (VR) to accurately represent spatial relationships. The combination of narrative visualisation and immersive analytics—immersive narrative visualisation—can provide seamless mission-report summaries to human operators.

Aim

This PhD will focus on Human Machine Interfaces (HMI) and dialog management to more effectively support an operator in understanding a complex situation involving a team of AS (AUVs or robots), where *effective* is considered faster, more accurate, and contributing less cognitive load. To achieve this aim, this PhD will develop novel narrative visualisation (Segel & Heer, 2010) techniques and exemplar systems using immersive technologies (virtual and augmented reality) to explain to a user unexpected or anomalous behaviour of the team of AS. The narrative visualisation techniques will be implemented in immersive environments (both VR and AR), as these technologies provide an interface approaching the human sphere of perception ideally suited to visualising complex spatial scenarios.

The work will be undertaken in two stages. In the **first stage**, techniques for visually communicating historical simulated swarm data will be developed and evaluated, supporting a scenario of explanation in post-action review. Through interaction, the user will distinguish different levels of detail for each agent in the zone, causal relationships amongst the events, and explanations about the anomaly. The **second stage** of this PhD will explore techniques to support real-time scenarios where the explanation may evolve over time, and decisive events occur while using the system. A novel cognitive model will be developed that considers physiological sensors in the VR headsets (e.g. eye-tracking) and presents relevant narratives to the operator's current task. Through embodied interaction in the immersive environment, the user will be able to explore the situation and intervene with automated assistance about the action to be triggered. The techniques developed throughout this PhD will be validated through controlled user studies that will compare users' cognitive load and situational awareness between the new methods developed and current approaches.

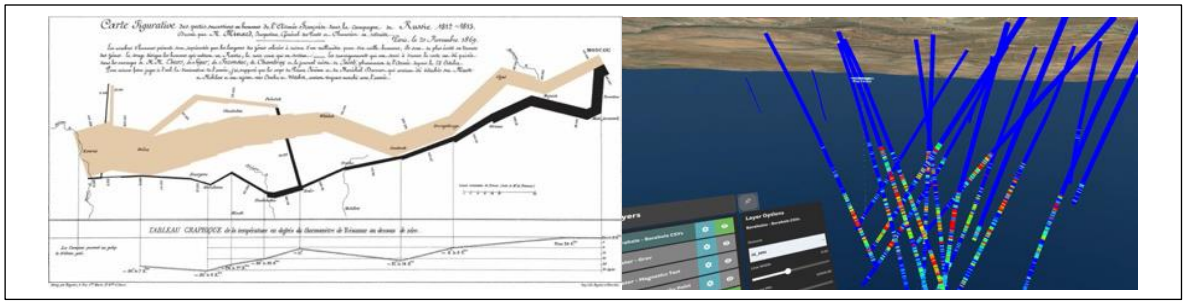

Figure 1: Left: *Charles Joseph Minard's diagram of Napoleon's failed Russian campaign of 1812. The diagram integrates multiple aspects of data to convey a cohesive story, including the size of Napoleon's army at different stages of the campaign and the dropping temperature.* ***Right:*** *An example of an immersive analytics system we developed for OzMineral of sub-surface mining data. This PhD project will seek to develop the equivalent of Minard's diagram for explaining Autonomous systems swarm behaviour in immersive environments.*

Background

Narrative Visualisation applies narrative techniques to visualisation in order to communicate insights within data by representing information as *stories* rather than discrete data points. Stories link events to achieve coherence and cohesion, making them effective frameworks for integrating multiple dimensions of data—including space, time, and causality—and thereby better supports the user's mental model of a complex situation (Zwaan and Radvansky 1998). To illustrate, Figure 1, left, represents Charles Joseph Minard's classic diagram of Napoleon's Moscow Campaign of 1812. This diagram, posthumously referred to as Narrative Visualisation, integrates multiple aspects of data to convey a cohesive story, including the dwindling size of Napoleon's army at different stages of the campaign and the dropping temperature over time.

Immersive Analytics (Chandler, Cordeil et al. 2015) is the use of embodied data analysis tools in immersive environments to understand the data and make informed decisions. Immersive Analytics removes the physical barrier of the computer screen and mouse that exists between people and their data. The key motivators for immersive analytics are embodied interaction, space-to-think, and 3D visualisation (Dwyer, Marriott et al. 2018). For highly spatial data, such as subsurface AUV behaviour, 3D stereoscopic visualisation is ideally suited (Figure 1, right). However, most spatial data visualisation to-date has focused on accurately representing the individual target tracks, rather than using more recent general visualisation approaches such as bundling to reduce the number individual marks presented on screen.

There is broad opportunity to explore narrative visualisation in immersive environments. We have previously explored immersive narrative visualisation for supporting law enforcement agents with complex spatial investigative data (Cunningham, Walsh et al. 2018). GeoTime (Eccles, Kapler et al. 2008) explored three-dimensional geo-temporal event visualization tool to allow exploration, analysis and communication of data. Since time-based data is an excellent fit for storytelling, authors developed the tool with a story system which lets analysts operate with a higher level of data abstraction.

Methodology and outcomes

This PhD will follow a user-centred design methodology. The concept demonstrator's and techniques developed during PhD will be evaluated both objectively and subjectively based on performance and feedback from participants in a series of user study based experiments (Lazar, Feng et al. 2017), through an iterative evaluation-based design life cycle involving: 1) Identify the users tasks, requirements and environment. 2) Produce conceptual design of solutions addressing the needs. 3) Prototyping solutions. 4) evaluate the prototypes using objective measures and feedback and get insights that will drive the next iteration.

The outcomes of this research will be:

- A novel approach for presenting complex AUV swarm data as immersive narrative visualisations that reduce the cognitive load of human operators.
- A real-time cognitive model of an operator that accounts for attention and task when presenting information.
- Visualisation and interaction techniques to support real-time analysis of AUV swarm data.

References

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