

Immersive Environmental Dashboard: Speculative Immersive Visual Analytics for Environmental Decision Making

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Figure 1: From dashboard-centered environmental analysis to spatial dashboard. The figure was designed by the author with assistance from Figure Labs [10].

ABSTRACT

Multivariate, heterogeneous data integration through large-scale simulations is becoming an increasingly critical component in modern environmental decision-making. Despite dashboard-based visual analytics systems now being the primary way to explore these datasets, they frequently separate spatial context, temporal progression, uncertainty, and analytical interaction across various coordinated views. Science fiction has frequently envisioned immersive environments in which experts collaboratively explore complex planetary systems through intuitive spatial interfaces. Although they prioritize storytelling over precise accuracy, these imaginative interfaces serve as a valuable source of inspiration for enhancing visualization research. This position paper argues that immersive visual analytics should re-imagine dashboards as immersive analytical spaces, as an add-on to the dashboard metaphor toward spatial reasoning environments that support exploration, comparison, communication of uncertainty, and collaborative interpretation. Using examples from science fiction together with recent advances in immersive environmental visualization, this paper out-

lines a speculative vision of a **Spatial Dashboard** and identifies the research challenges that must be addressed to transform speculative interfaces into practical systems for environmental decision-making.

Index Terms: Visual Analytics, Virtual Reality, 3D data visualization, Sci-Fi, Design Fiction, Decision Support.

1 INTRODUCTION

In many cases, environmental scientists and decision makers are expected to interpret simulations that are both computationally demanding and visually complex [2] [11]. Whether exploring future flood scenarios [8], understanding extreme weather events [13], or analyzing atmospheric simulations [17], the challenge is rarely a lack of data. Instead, the difficulty lies in making sense of large, uncertain, and interconnected datasets while comparing multiple possible futures.

Visual analytics dashboards have become the dominant solution for these tasks [23]. Maps, charts, timelines, and statistical summaries provide complementary perspectives that help analysts examine different aspects of the data. These systems have proven extremely valuable and will undoubtedly remain central to many analytical workflows.

Environmental processes unfold in space and time. Flood water follows the terrain, wind develops as a three-dimensional flow, and

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weather systems continuously change as they move across a region. When analyzing these phenomena, experts often switch between maps, timelines, statistical plots, and other coordinated views, gradually building a mental picture of how these pieces relate. While this workflow is effective, much of the spatial reasoning still happens in the analyst's head rather than through direct interaction with the data.

Science fiction has long imagined ways of interacting with complex information that differ from today's analytical tools. Interfaces shown in works such as *StarTrek* [22], *Interstellar* [12], *Avatar* (2009) [1], *Prometheus* (2012) [20] and *Minority Report* [18] allow users to explore dynamic environments through direct, spatial interaction rather than through conventional desktop applications. Although these interfaces are created to support fictional narratives [3] rather than scientific workflows, they encourage us to rethink how immersive technologies might support environmental analysis.

Instead of asking **how to recreate these interfaces, a more useful question is whether they can inspire new ways of exploring, interpreting, and discussing complex environmental data.**

This position paper argues that they can. Instead of presenting another immersive visualization system, we use this question as a starting point for discussing how future immersive environments might better support environmental exploration, scenario comparison, uncertainty interpretation, and collaborative reasoning. Our goal is not to predict future interfaces, but to identify research directions that could help move immersive visual analytics beyond the traditional dashboard paradigm.

2 FROM DASHBOARDS TO IMMERSIVE ANALYTICAL WORKSPACES

Most visual analytics systems are built around the dashboard paradigm, where multiple coordinated views support different aspects of the analytical process. Maps, charts, timelines, and interactive controls work together to help users explore complex datasets from complementary perspectives.

Dashboards have proven highly effective for analytical reasoning. However, environmental analysis often requires analysts to continuously relate information across spatial views, statistical summaries, temporal trends, and uncertainty representations. Environmental analysis has the following open problems:

- spatial reasoning happens separately
- comparison happens separately
- annotations happen separately
- collaboration happens separately

This concept paper argues that immersive environments provide an opportunity to reorganize, rather than replace, these coordinated views around the environmental phenomenon itself.

Environmental analysis introduces challenges that are not always well served by traditional dashboards, creating room for improvement. Analysts often need to understand how environmental processes evolve in space, compare several simulation scenarios simultaneously, and evaluate regions where different models disagree. These activities require constant movement between views and considerable cognitive effort to combine spatial, temporal, and statistical information into a coherent mental model.

Immersive visual analytics offers an opportunity to rethink this interaction paradigm. The goal should not be to recreate existing dashboards inside a virtual environment, nor to replace carefully designed visualizations with visually impressive three-dimensional scenes. Instead, immersion should enable analysts to experience environmental phenomena directly within their spatial context

while retaining the analytical capabilities that make visual analytics effective.

In other words, the immersive environment becomes a workspace for reasoning rather than a larger display for existing interface components. A concept comparing the current dashboard and potential future Immersive Reasoning Environments is shown in Figure 1.

3 ENVIRONMENTAL REASONING ROOM: SPATIAL DASHBOARD

To illustrate this idea, we propose the concept of an Environmental Reasoning Room (ERM) aka Spatial Dashboard.

Imagine entering the ERM. Instead of a monitor, the room itself is the dashboard. The center contains city terrain, flood, heat-wave, heavy rainfall, strong wind, heavy snow, or other simulations. Around the wall: timeline, scenario selector, weather variables, ensemble overview, and historical observation. The floor contains spatial navigation. Ceiling, uncertainty layer, and side panels contain annotations, reasoning history, and discussion. In this room, everything becomes spatially organized. To keep the interaction seamless without increasing interaction complexity, ERM keeps timelines, legends, charts, and parameter controls, and places them around the immersive scene, almost like a cockpit. A visual comparison with the current dashboard and the proposed spatial dashboard concept is shown in Figure 2.

Now imagine a multidisciplinary team evaluating future flood adaptation strategies for a coastal city. Instead of switching among maps, reports, and charts displayed across multiple monitors, participants enter a ERM that represents the affected region.

Within this environment, users can move between regional, city, and neighborhood perspectives depending on the question they are investigating. Multiple heavy rainfall and flood scenarios, heat-waves (depending on the time of year), strong winds, heavy snow, and other extreme weather events can be examined side by side, making it easier to understand where different simulation models agree and where they diverge. Instead of presenting uncertainty as a separate graph or statistical summary, it is embedded directly into the spatial representation, allowing analysts to see both the predicted outcomes and the confidence associated with them as part of the same exploration process. The proposed workflow for the spatial dashboard is shown in Figure 3.

Rather than supporting a single analyst, the proposed environment assumes that environmental decision-making is often a collaborative process involving experts with different backgrounds. It provides a shared workspace where participants can annotate locations, compare alternative scenarios, discuss observations, and capture the rationale behind their interpretations. The emphasis is not on producing a recommendation but on making the analytical process more transparent and enabling experts to reason together about the available evidence.

The ERM should be viewed as a speculative research vision rather than a blueprint for a future system. Many of its individual components already exist within immersive visual analytics, including techniques for exploring large-scale environmental simulations [7], representing uncertainty [5], and interacting with volumetric data [16]. We frame the ERM as a design fiction: a speculative artifact intended to provoke discussion about possible immersive analytical practices and expose research questions, rather than predict a future interface. The contribution of this concept lies in considering how these capabilities could be combined into a single analytical environment that better supports environmental reasoning as a spatial dashboard, an add-on to the current dashboard-based workflows. In the spatial dashboard, dashboards will be wrapped around the environment instead of dashboards being replaced by immersive reality.

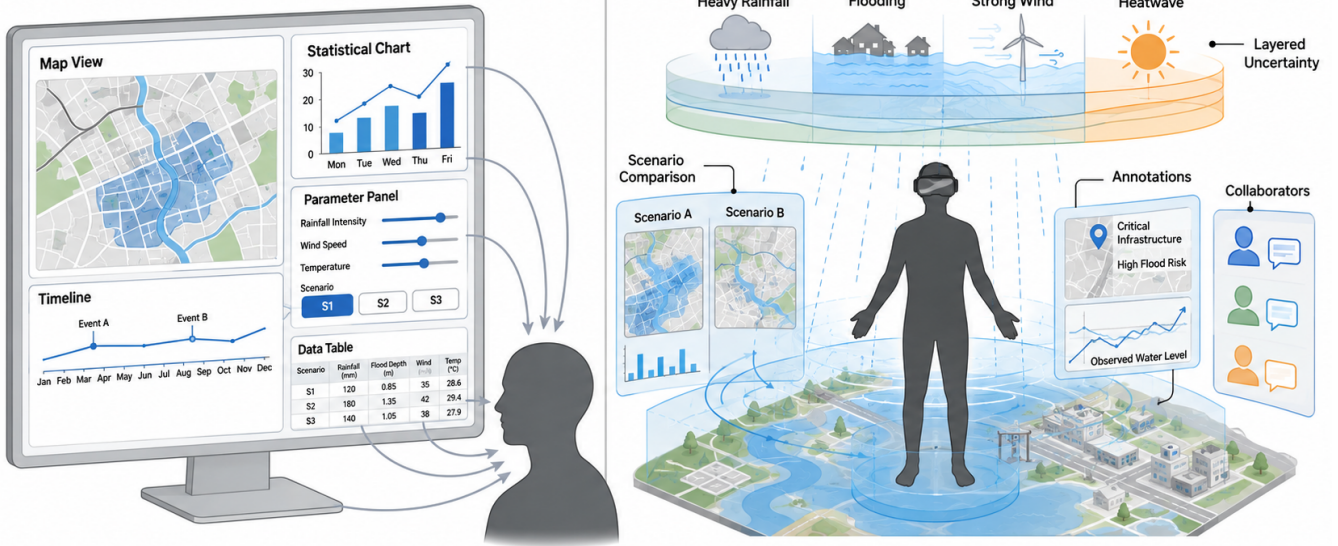


Figure 2: Traditional dashboard VS spatial dashboard. Conceptual view of an Environmental Reasoning Room. The figure was designed by the author with assistance from Figure Labs [10].

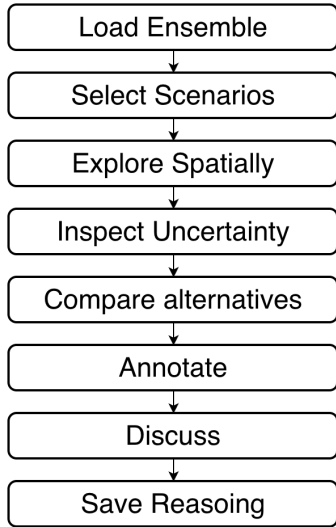


Figure 3: Spatial Dashboard workflow.

4 FROM SCIENCE FICTION TO RESEARCH CHALLENGES

Science fiction rarely acknowledges the limitations that visualization researchers encounter. Data loads promptly, and experiences are consistently seamless. Immersive visual analytics addresses questions raised by these fictional interfaces, even though they are not real.

In environmental simulations, handling large datasets presents a challenge because they can't be fully loaded into memory or easily visualized in immersive reality. Maintaining performance necessitates interactive exploration, data streaming, and rendering techniques based on multiresolution representations. The tile-based rendering technique offered by Oyshi et al. [14] can be utilized to address real-time large dataset handling issues.

Science fiction usually fails to accurately depict the data. Analysis of the environment rarely leads to a single conclusion. Experts work with ensembles, multiple scenarios, and uncertain model out-

puts. A significant portion of the examination is dedicated to contrasting these options and grasping their differences. Therefore, an immersive system should facilitate users' exploration of these differences instead of projecting a single future outcome.

Interaction is another aspect. Science fiction tends to rely on gestures because they look intuitive on screen. In practice, environmental analysis involves many other tasks, including selecting regions of interest, inspecting values, annotating findings, and switching between different levels of detail. Supporting these activities efficiently is likely to matter more than reproducing cinematic interaction techniques.

Spatial organization also introduces problems that desktop dashboards largely avoid. Analytical elements may occlude one another, annotations may obscure environmental features, and information distributed throughout a room may require physical navigation. In collaborative settings, participants themselves may further occlude views or movement. Spatial dashboards therefore require techniques for visibility management, adaptive placement, viewpoint coordination, and safe navigation. Occlusion handling method offered by Oyshi et al. [15] can be adapted to address this issue, although this method is offered for 2D video sequences. Further research can be done in this direction.

Many fictional command centers assume that all participants immediately reach the same conclusion after viewing the same information. Real environmental decision-making is collaborative and often involves diverse expertise, competing priorities, and alternative interpretations. Supporting discussion, annotation, provenance, and shared reasoning may therefore be just as important as improving visualization itself.

Seen from this perspective, science fiction becomes less a prediction of future technology and more a source of design provocations that help identify meaningful challenges for visualization research.

To move beyond science fiction as general inspiration, we examine specific fictional interface characteristics and the visualization research questions they raise. Table 1 connects selected science-fiction examples to features relevant to the proposed Spatial Dashboard. These examples highlight how science fiction can inspire research questions for immersive visual analytics. Shared spatial representations, gesture-based interaction, collaborative environments, and multi-scale navigation introduce opportunities as well as chal-

Table 1: From Science-Fiction Interfaces to Visualization Research Challenges

SciFi example	Interface characteristic	Research question for ERM
Avatar (2009)	Shared 3D terrain representation	How can multiple analysts inspect environmental data from different perspectives?
Minority Report	Gesture-based spatial interaction	Which immersive interactions remain efficient for analytical work?
Star Trek	Collaborative command environment	How should different expertise and interpretations be represented?
Prometheus (2012)	Multi-scale spatial and holographic mapping	How can large spatial datasets be navigated while maintaining context?
Interstellar	Spatial representation of complex phenomena	How can spatial representations preserve uncertainty and analytical context?

lenges related to interaction, scalability, visual complexity, uncertainty, and collaborative reasoning. These challenges provide concrete directions for developing and evaluating the proposed Spatial Dashboard.

5 A RESEARCH AGENDA FOR IMMERSIVE ENVIRONMENTAL ANALYTICS

A spatial dashboard requires more than new interaction techniques or more immersive displays. It requires rethinking how immersive environments support analytical reasoning.

Future systems should remain centered on the environmental phenomenon itself rather than the interface. They should communicate uncertainty as clearly as they present the underlying data. They should encourage exploration and discussion instead of presenting seemingly definitive answers. Finally, they must remain grounded in practical constraints such as scalability, rendering performance, and usability.

Many of these challenges are already being addressed within immersive visual analytics research. Work on large-scale environmental visualization [21][6], uncertainty-aware exploration [9], and immersive interaction [19], [4] provides important building blocks. The next step is to integrate these advances into coherent environments that support complete analytical workflows rather than isolated visualization techniques.

6 CONCLUSION

For decades, science fiction has depicted immersive interfaces that let readers dive into the complexities of systems. Even though these visions are frequently unrealistic from a technological standpoint, they inspire us to challenge assumptions that have long influenced visualization interfaces.

We believe that the future of immersive environmental visual analytics is more than just a virtual reality or immersive reality adaptation of a dashboard. Instead, immersive systems should become environments where analysts explore environmental phenomena, compare uncertain futures, discuss interpretations, and build an evidence-based understanding together.

The proposed Environmental Reasoning Room, aka Spatial Dashboard, is intentionally speculative. Its purpose is not to predict the future or replace traditional dashboards, but to frame a research agenda that connects speculative interface design with current challenges in immersive visual analytics for environmental decision-making. By treating science fiction as a source of research questions rather than technological blueprints, we hope to encourage

new conversations about the next generation of immersive visualization systems.

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