Theme Article

A Walk Among the Data

Exploration and Anthropomorphism in Immersive Unit Visualizations

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***Abstract*—We examine the potential for immersive unit visualizations—interactive virtual environments populated with objects representing individual items in a dataset. Our virtual reality prototype highlights how immersive unit visualizations can allow viewers to examine data at multiple scales, support immersive exploration, and create affective personal experiences with data.**

As part of artist Paul Cummins' piece, *Blood Swept Lands and Seas of Red*, 888,246 ceramic poppies surrounded the Tower of London to mark the 100th anniversary of Britain's first day of involvement in the First World War. Over the course of two weeks, each poppy was hand planted by 17,500 volunteers to represent a British military fatality resulting from the war, then sold for charitable causes during its exhibition. The sheer scale of the project made this visualization an unforgettable experience for millions of visitors. From above, viewers observed a sea of red poppies engulfing the tower, emphasizing the overall magnitude of British war deaths. However, when walking through the grounds below the tower, viewers could examine each individual poppy in the field, establishing a personal and emotional connection to individual fallen soldiers. Each of these perspectives created a different experience for the viewer, and the unique staging of this art piece in a large public space with multiple points of view made it possible to explore both in an immersive way.

Digital Object Identifier 10.1109/MCG.2019.2898941
Date of publication 12 February 2019; date of current version 24 April 2019.

Designers and visualization researchers regularly use two-dimensional (2-D) unit visualizations—in which each visual mark directly corresponds to one element in a dataset—to represent data onscreen. Meanwhile, artists have long employed similar unit-based techniques to communicate and elicit emotional impact by representing data via large physical installations (see Figure 1). In Michel Tauriac's *Mazamet Ville Morte,* the artist asked the entire population of Mazamet, France, to lie on the pavement, evoking the total number of French motor vehicle deaths in 1972. The recent travelling stage performance series *100% City* also uses humans to visualize a variety of statistics. During each live performance, 100 participants selected from the city's local population organize themselves on stage in response to questions about their age, political leanings, and other topics. When viewed from an

Figure 1. Large art pieces like Paul Cummins' 2014 *Blood Swept Lands and Seas of Red* (left, image Ian Capper [CC BY-SA 2.0]), Yves Mourousi and Michel Tauriac's 1973 *Mazamet Ville Morte* (middle, André Cros [CC BY-SA 4.0]), or Rimini Protokoll's ongoing *100% City* stage (right, Arnold Pöschl) show use of physical objects and people to visualize data in real-world environments.

overhead camera, clear patterns and groupings can be observed. During the sessions, participants also discuss their choices with one another, creating a social visualization experience that sparks discussion.

Limited screen sizes and input modalities of traditional desktop computers have made it difficult to create dynamic visualizations that support these same kinds of embodied experiences. Taking inspiration from large and visually dramatic art pieces like these, we examine how virtual reality (VR) tools can be used to create *immersive unit visualizations* that represent data points as objects in virtual space. While this design space is vast, we focus on three unique properties of immersive systems: 1) enabling new experiences with visualizations that span multiple scales; 2) supporting data exploration using physical locomotion and interaction; and 3) using anthropomorphic techniques to prompt affective responses and encourage storytelling.

BACKGROUND

The practice of using physical objects and visual marks to represent, count, and reason about referents in the world has a rich history that far predates contemporary data visualization. Throughout the 20th century, designers have frequently employed more systematic techniques like *ISOTYPE* which uses pictographs to visually encode counts and quantities.[1] Pictorial encodings like these, while sometimes controversial, may support decoding and enhance memorability, and empirical studies have suggested that they can be effective when applied judiciously.[2] More recently, tools like *SandDance* and *Kinetica*[3,4] have illustrated the potential of dynamic interactive unit visualizations, which support the examination of much larger datasets by creating visual groupings made up of many individual marks. Meanwhile, unifying grammars like ATOM[5] now provide consistent mechanisms for expressing a diverse range of unit visualization designs. Data artists and journalists have also used unit visualizations to create interactive experiences (like those in Figure 2) that use unique marks to highlight data about individual people.

Three-dimensional and immersive approaches to information visualization are a more recent phenomenon. Examples of 3-D information visualization tools date back to at least the early 1990s[6] and showed promise for some specific applications. However, 3-D visualizations on the desktop have generally been regarded as problematic, since they can introduce occlusion and "extraneous" depth cues that can make visualizations more difficult to read and manipulate.[7]

Today, the widespread adoption of consumer VR hardware has triggered a resurgence of interest in 3-D and immersive visualization tools. A variety of commercial and research examples have begun to appear, often porting existing 2-D visualizations into 3-D virtual worlds. However, the inherent immersive quality of VR has the potential to also create new visualization experiences that were not feasible in the past due to the technical and usability constraints of 2-D displays. For example, recent VR visualization systems such as *ImAxes* have demonstrated the potential for immersive tools to enable new kinds of spatial exploration and comparison.[8]

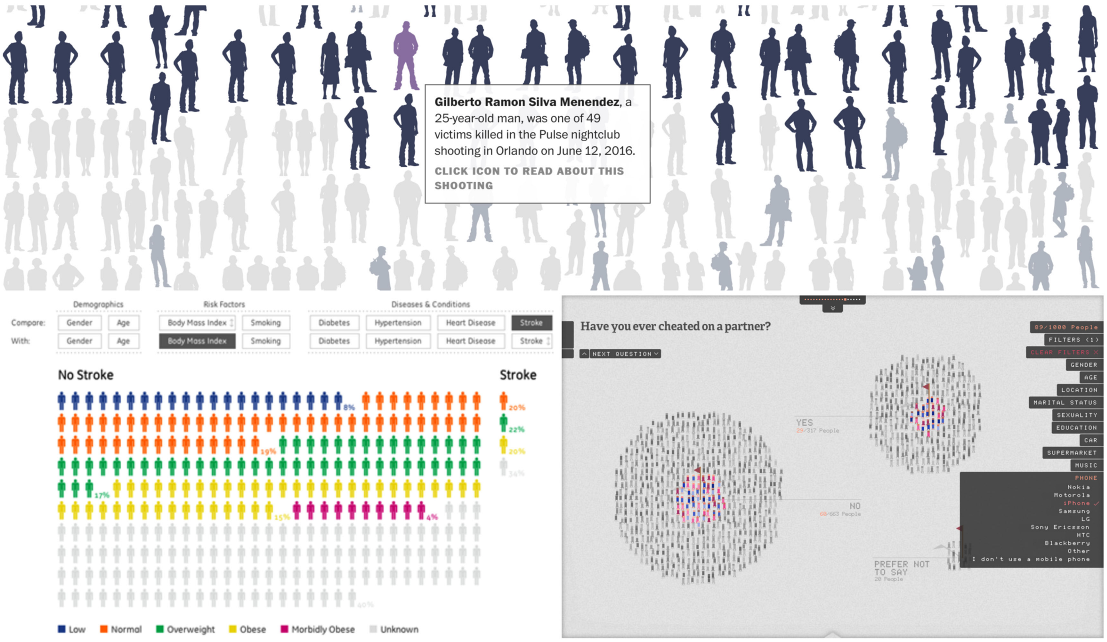

Figure 2. Examples of anthropomorphic 2-D unit visualizations. The *Washington Post's* 2017 interactive *The Math of Mass Shootings* (top, the *Washington Post),* Ben Fry's 2009 *GE Health Visualizer* (bottom left, Ben Fry), and Mint Digital and Lingobee's 2011 animated interactive *Sexperience 1000* (Producer: Adam Gee) for Channel 4 (bottom right, Adam Gee).

IMMERSIVE UNIT VISUALIZATION

Unlike traditional visualizations, which often aggregate multiple values into a smaller number of visual marks, unit visualizations ensure that every data point is represented by a separate visual mark. Extending this concept, we define an *immersive unit visualization* as a 3-D unit visualization created for exploration in an immersive environment. Bringing unit visualizations into immersive virtual spaces presents a number of unique properties, including the ability to transition between different scales, explore datasets using physical locomotion, and invoke affective responses through the use of anthropomorphism.

Scale and Transitions

With physical installations, like *Blood Swept Lands and Seas of Red*, people must move to another location to change their perspective from detail view to overview. By contrast, viewers in an immersive environment can quickly change perspectives and can dynamically adjust the distance between themselves and the visualization. This makes it possible to quickly examine the unit visualization from different viewpoints and levels of visual aggregation. Virtual environments also make it possible to view data from scales and perspectives that are not possible in the physical world. For example, by interactively scaling a visualization up or down, a viewer can experience a visualization both from a helicopter view and from the perspective of an ant in a matter of seconds. Viewers can also jump quickly from place to place in a virtual environment, using teleportation, portals, and other nonlinear movement strategies that might permit much larger and elaborate virtual installations.

Immersive Exploration

While immersed in virtual worlds, data exploration has the potential to become much more casual and exploratory than on traditional platforms. Compared to on-screen displays, immersive VR can greatly increase a viewer's sense of *presence* (their sense of being in an environment) as well as their perceived *embodiment* within a scene.[9] This increased level of *presence* and *embodiment* allows immersive visualization systems to emulate the exploratory experiences intrinsic to many physical unit visualizations and art pieces. In these environments, viewers can explore data via physical locomotion and leverage their spatial memory and spatial reasoning to build an understanding of it. Even with simple VR setups, the sense of *presence* can be profound, and we expect this sense of *presence* can be used to create visualizations that evoke a stronger awareness of scale and space, making it possible to create large virtual environments that reward the same kinds of physical exploration as large art installations without the overhead of physically producing the piece.

Yet, despite wide discussion in the context of VR generally, little work has specifically examined the impact of presence and embodiment on immersive data visualizations. However, preliminary experiments in both *CAVE* environments and using head-mounted displays suggest that more immersive environments may indeed impact viewers' sense of engagement as well as their data exploration strategies.[10] Recent systems like *ImAxes*,[8] which allows viewers to create complex multiaxis plots in virtual space, also highlight the potential for new visualization techniques, which more actively use 3-D space, and rely more explicitly on movement and exploration within the virtual environment. Immersive unit visualizations, which can be composed of large numbers of individual elements, lend themselves particularly well to these kinds of exploration—especially as the number and complexity of those elements increases.

Anthropomorphism

While human-like forms are only one of many possible building blocks for immersive unit visualizations, they introduce a number of promising traits for data-driven storytelling. Anthropomorphism has a long history in human art and culture, and research in a variety of fields suggests that the presence or assertion of anthropomorphic characteristics in objects and animals tends to be associated with emotional and empathetic responses.[11]

From a visualization perspective, humanoid unit representations are interesting because, like anthropomorphic *ISOTYPE* symbols,[1] they are highly recognizable and immediately suggest that the underlying data correspond to individual people. Moreover, visualization designers can vary the appearance of individual models based on data, altering attributes like height, clothing, gender cues, and posture to create recognizable individuals or groups. Viewers' sensitivity to differences in human appearance, style, and motion also makes it possible to encode data about individuals in subtle ways—for example, indicating the presence of an attribute with a fashion accessory or via changes in body language.

Data journalism pieces like the *Washington Post's The Math of Mass Shootings* have used human forms along with playful animation to represent data as a way of humanizing the data and anchoring individualized stories (see Figure 2).[12] However, the efficacy of these approaches remains unclear. Some members of the visualization community have advocated strongly for using humanizing graphics as part of a broader agenda of *empathetic design*.[13] Yet, recent work by Boy et al., which examined the impact of a variety of different anthropomorphic data graphics (or "anthropographics") in 2-D charts, found that they had little to no impact of viewers' level of empathy or willingness to donate to a charitable cause.[14]

In contrast to 2-D unit visualizations like these, which typically represent individuals or groups of people using small graphical marks, immersive virtual unit visualizations offer the potential for much more lifelike representations. Rather than representing people using small marks on a page or screen, an immersive unit visualization can render them as a detailed character at the same scale as the viewer. This increase in size and detail may make it possible to more easily humanize and create empathetic feelings toward individuals represented in a dataset. It also enables more cinematic and game-like interactions with these characters. In a virtual environment, character models can exhibit life-like animations and human-like interactions allowing viewers to interact by asking questions or reaching out and touching them directly. As a result, these interactions have the potential to enable a kind of direct "face-to-face" relationship with visualizations that simply is not possible in other settings.

BUILDING AN IMMERSIVE MATH OF MASS SHOOTINGS

To explore the potential of these three properties of immersive unit visualizations, we

Figure 3. Immersive unit visualization showing mass shooting victims grouped by gender. Viewers can examine the visualization from different perspectives, observing groupings and patterns from above (A), then zooming in to a human scale to see details for individual victims (C).

constructed a series of prototypes inspired by the *Washington Post's The Math of Mass Shootings* (see Figures 3, 4, and 5).[12] These prototypes, which we implemented using Unity and the HTC Vive VR headset, allowed us to examine the impact of scale transitions, immersive exploration, and anthropomorphism in a visualization of 130 mass shooting incidents in the United States (incidents where four or more people were killed by a shooter) from 1966 to 2017. The use of digital tools also allowed us to create large-scale visualization designs, similar to Paul Cummin's *Blood Swept Lands and Seas of Red*, without the overhead of a physical installation setup and tear down process.

We treated our design and development as an exercise in *research-through-design*,[15] in which we constructed three iterations of the system over a four-month period, using each as an opportunity to explore alternative visual representations, control schemes, and layouts. During each iteration, we used the visualization extensively ourselves and also deployed it with a set of three colleagues from whom we elicited initial responses and feedback to help guide subsequent iterations. We also demonstrated the final version of the visualization at a public on-campus event, eliciting feedback from a diverse range of viewers.

Visualization Design

In our prototype, we represented each civilian death (excluding the shooters themselves) in the dataset with a 3-D avatar model. To provide more visual differentiation between individuals, we used demographic data to select representative models based on the person's gender and age. In total, we used six unique character models to represent five age groupings and two gender categories. Because we lacked character models for very young children, we used the same model for infants, children, and teens. Our initial version of the system used more detailed character models. However, in later iterations, we applied a flat gray shading to the scene to render all human figures as silhouettes—creating a ghostly appearance similar to the original *Math of Mass Shootings* article.[12] Due to a lack of data about each person's identity, this approach also ensured that we did not misrepresent the visual appearance of the victims. We arranged these models in a fractal phyllotaxis pattern (see Figure 4). This layout ensured even spacing among models, allowing viewers to move between them while minimizing the need to travel vast distances.

Interaction

Across three prototype iterations, we examined several different direct and indirect mechanisms for interacting with the visualization. To control scale and position, we explored a mix of physical locomotion and gestures. Our final implementation used a two-handed pinch-to-scale gesture to quickly change the scale of the world, allowing viewers to transition smoothly between high-level overviews and more detailed unit-level perspectives (see Figure 3). This pinch-to-scale gesture is ubiquitous on multitouch devices today and is also widely used in VR applications, making it quick for the majority of testers to grasp. When the world is scaled

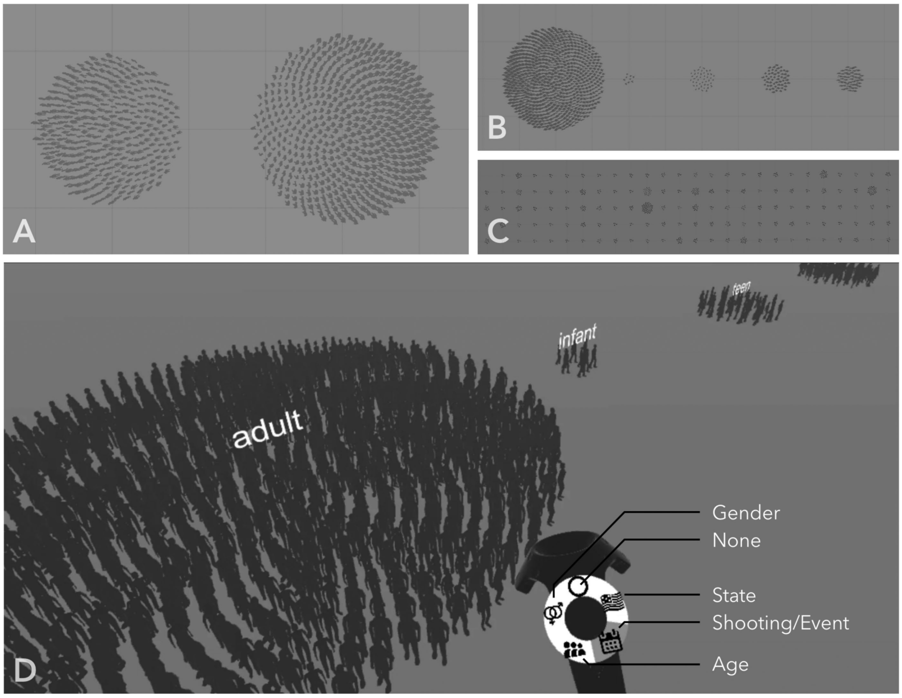

Figure 4. Using the radial menu (D), viewers can group shooting victims by gender (A), age group (B and D), or shooting event (C). Viewers can also group the victims by the U.S. state or choose to leave them ungrouped (not shown).

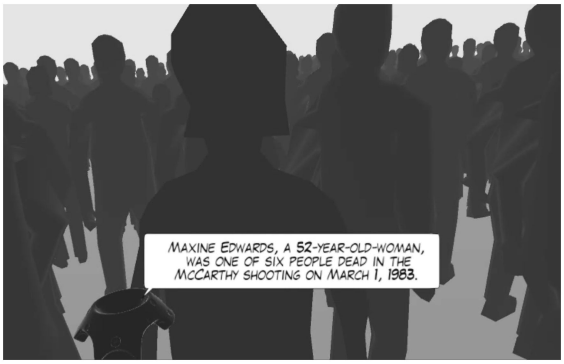

Figure 5. In our prototype, viewers can interact with avatars directly for additional details and personalized stories from the avatars.

down, viewers can observe general aggregated trends in the data from above (see Figure 4). When the world is scaled up, viewers can walk among the avatars and learn more about them.

For examining individual data points, we settled on a set of short-range interactions that required viewers to reach out and touch each avatar directly. This triggered a speech bubble describing the shooting victim (see Figure 5). Because attaching speech bubbles to the avatars themselves sometimes caused the message to be too small or occluded, we instead attached the bubbles to the controller to ensure that viewers could read the text clearly. While some testers did not initially see the speech bubble attached to the controller because it was outside of their field of view during the interaction, we found this to be a reasonable compromise given the display resolution.

To control the layout of the visualization, we designed a radial menu on the right controller which allowed viewers to cluster the victims according to their age, gender, shooting incident, or U.S. state. Viewers could also choose "no grouping" to explore the victims as a single large crowd. Each time a viewer selected a new group, the entire set of avatars would immediately turn and walk to their place in the new layout. We also included large 3-D labels above each cluster [see Figure 4(D)], which served as landmarks for navigating within the scene. When observing testers using the system, we found that these animated transitions were particularly effective when viewing the visualization in overview perspective, as it made it possible to track individual victims as they moved from group to group. However, reorganizing groups while viewing from a human-scale perspective was sometimes more disorienting for viewers as crowds of avatars moved past the viewer at a brisk pace, making them hard to track.

LESSONS LEARNED

Based on our extended and iterative experience with our prototypes, as well as preliminary reactions from colleagues and other viewers who used our prototype system, we identify a number of unique challenges and opportunities VR presents for immersive unit visualization.

Challenges for VR Unit Visualization

Orientation and Situational Awareness—The open-world nature of immersive visualizations like the one in our prototype gives viewers the freedom to casually explore data in a large virtual space. However, open environments like these also have the potential to become disorienting. For example, in our prototype visualizations, the high visual similarity between the low-poly avatar models often made it easy for viewers to lose track of individuals. Some of the early testers of our system also experienced difficultly maintaining a clear sense of their own position and orientation. Furthermore, zooming back and forth between overview and human-scale perspectives was sometimes confusing if the layout, orientation, or makeup of the visualization had changed since the last rescaling.

Orientation and awareness issues like these are common in other kinds of virtual environments, where prior work on orientation and wayfinding suggests that landmarks (such as flags, towers, physical terrain, labels, etc.) can make it easier for viewers to situate themselves.[16] Allowing viewers to place their own landmarks and displaying trails that highlight recent movement in the scene could also help preserve situational awareness during changes to the visualization. In addition, immersive visualizations could prioritize consistent default viewpoints that allow viewers to reset their perspective by quickly teleporting back to a known consistent overview.

Visual Fidelity and Unit Appearance—In early versions of the system, we added low-resolution textures on top of the models, giving them clothes, skin tones, and facial features that made them appear more lifelike. However, this created an unpleasant experience for some testers of the system, both because it produced a lifeless *uncanny valley* effect and because we could not produce textures that accurately reflected the appearance of the real individuals identified in the dataset. As a result, viewers were confronted by multiple model "clones", which appeared identical but were intended to represent different individuals. In our particular case, stylizing the scene and rendering the avatars as silhouettes addressed this concern, but also made it more difficult for viewers to identify specific victims, leaving testers often asking for more details about the victims and their personal identities. Techniques from crowd simulation could be used to create more detailed and diverse avatars, varying properties of the underlying models, textures, colors, etc., in systematic or data-driven ways.[17] However, caution is necessary in cases where these kinds of generative approaches might produce avatars or other units that do not visually reflect their real-world referents.

Personal Space—Users immersed in virtual environments try to abide by the same nonverbal social cues that exist in the physical world when encountering human-like models. In our prototype, changing the clustering often caused avatars to walk through the user's body and through one another which created an off-putting experience for some testers. Furthermore, avatars would often stand uncomfortably close to the viewer, breaking social conventions that humans generally abide by in the physical world. Although we observed some testers resolve these proxemic issues by maneuvering themselves out of uncomfortable situations, immersive application designers must account for these scenarios and decide explicitly what interactions users can perform and how personal space should be handled. Observations from proxemics, including Hall's *distance zones,* may provide useful templates for these decisions,[18] helping designers predict how a viewer will tolerate intrusions into personal space.

Opportunities for VR Unit Visualization

Dynamic and Personal Interactions—Although our visualizations used relatively minimalist 3-D models and animations, high-quality models like those used in many contemporary video games have the potential to support more dynamic interactions within avatar-based unit visualizations. In our implementation, viewers can approach individual models and touch them to view their personal stories. However, as in the original *Washington Post* article, these stories merely revealed details about each victim's death, which left some testers interested in uncovering more information about the individuals' identities. Adding more complex agent-based interactions via natural language could add another level of depth to the experience. For example, a viewer could use speech to initiate character-specific responses.

While our visualization is completely exploratory and viewer driven, characters in the environment could also provide a guided tour of a dataset, using storytelling techniques inspired by contemporary first and third-person games. In fact, past work on virtual learning environments suggests that using empathetic characters in narrative learning tools may indeed lead to heightened perceptions of presence, involvement, and control.[19] We hypothesize that this may create more personal, familiar, and empathetic connections to data. However, simply anthropomorphizing data elements may be insufficient, especially if those models or characters fail to conform to social norms or suggest a level of complexity or interactivity that the system cannot deliver.

Exploring Large Situated Datasets—Immersive environments may also be well suited for unit visualizations in which physical location and context are important. This includes representations like population dot maps, which visualize demographic data by plotting individual geolocated points either to represent population density or (at the extreme) each individual in a dataset.[20] In 2-D, these representations scale elegantly, allowing viewers to zoom in and examine individual points or zoom out to see those points visually aggregate. Immersive visualizations with these kinds of data, however, have the potential to scale even further, allowing viewers to examine and interact with individual data points at a human scale or perhaps displaying them in-context in virtual recreations of relevant physical environments or atop 3-D geospatial models.

Worlds-in-Miniature—Viewers in an immersive unit visualization have the potential to quickly and dynamically vary the scale of the visualization. These scale transitions make it possible to transition back and forth between *overview* perspectives, where the entire dataset is visible, and *detail* perspectives, where they can focus on individual units. However, as with traditional 2-D visualizations, it may often be useful to examine the data at both levels simultaneously, using *overview+detail* views that surface both high-level context and low-level detail. During early testing sessions of our prototype, there were times when individuals frequently changed scale of the environment to get a sense of their position relative to the groups of avatars.

In immersive visualization environments, developers might implement *overview+detail* views using virtual navigation techniques like *world-in-miniature*.[21] This approach places a miniature copy of the entire environment or visualization in the scene next to the viewer. Viewers could then use this miniature view as a sort of minimap, allowing them to examine the entire visualization and building a better understanding of their current position in it. These worlds-in-miniature could also serve as a navigation tool, allowing viewers to quickly jump to more distant locations in the visualization without changing their scale.

Nonanthropomorphic Units—Datasets that represent physical objects (museum collections, 3-D models, etc.) may also be excellent candidates for immersive unit visualizations, especially where detailed 3-D models exist. Here, units in the visualization might serve not just as visual marks that represent the data but instead as direct representations of the data itself. For example, a visitor might filter, sort, group, and explore an entire archival collection in single virtual space—comparing items that might be impossible to physically co-locate.

Sonification and Ambient Audio—In addition to creating convincing visual landscapes, modern immersive hardware also provides creators with precise control over the sonic characteristics of their environments. Unit visualizations could leverage this audio capacity, encoding data attributes via unique sounds, pitches, or speech that appear to originate directly from individual marks. Such approaches can leverage the high degree of presence in a virtual space to create strong spatial association between visual and audio elements. For example, when a viewer approaches an individual mark, ambient audio could provide *details-on-demand* or encode additional quantitative values. More interestingly, when a viewer enters an area occupied by multiple entities, the audio from all of them could be allowed to blend, creating a soundscape that helps the viewer understand the diversity of data points in their vicinity—including ones they might not be able to see. Much like immersive visualizations, the design of these audio experiences could also draw on examples from large multimedia installations that exist in the physical world.

CONCLUSION

Unit visualizations, while well established as a 2-D visualization technique, present a number of new opportunities in VR. Our initial prototypes highlight three interesting properties of these systems. Dynamic scale transitions support fluid pivots between overview and detail views within an immersive environment, building on intuition from the physical world. Immersive exploration affords new ways of spatially browsing datasets, while still supporting standard analysis techniques like sorting and clustering. Meanwhile, anthropomorphic interactions within immersive environments have the potential to emphasize human connections to the data and create new genres of data-driven storytelling. While immersive unit visualizations entail a unique set of design challenges, they also provide a variety of new and exciting ways for viewers to engage with data, and appreciate the people, places, and objects behind it.

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