Visualizing Causes and Effects of California Sea Lion Unusual Mortality Event (UME)

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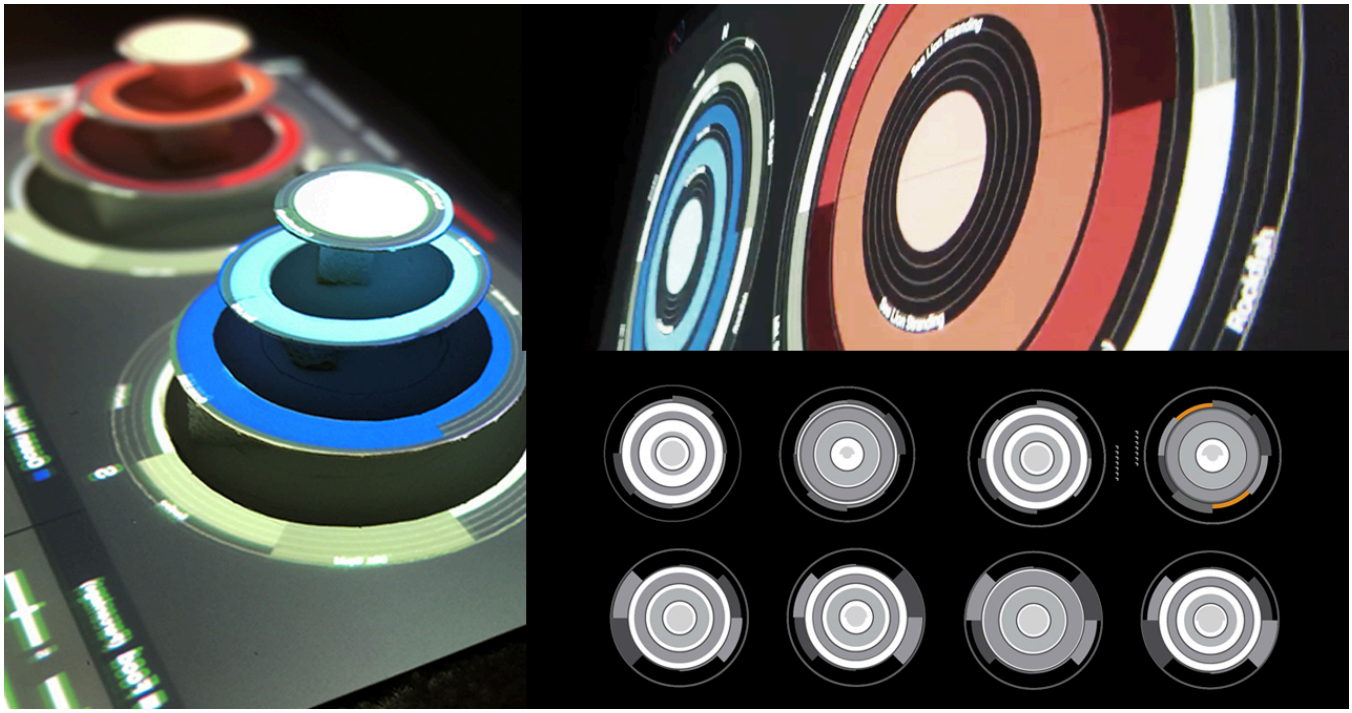

Figure 1: Visualizations and a Prototype of the Data-driven artwork "Causes and Effects"

ABSTRACT

This paper introduces our project *Causes and Effects*, which visualizes California sea lion unusual mortality events (UME) to create a new layer of understanding of the situation as an important environmental issue. It examines the causes of and impacts on sea lion UME by controlling multivariate factors that impact sea lions' health and stranding. Previous visualizations for sea lion mortality only captured temporal data and the relationship between causes and effects using simple graphs. However, sea lion UME results from multiple causes and it requires multivariate visualization to establish clear solutions for future results. The resulting images of our visualization allow users to explore how environmental factors impact the lives and situations of sea lions.

Keywords: Data art, multimodal data visualization, California sea lion mortality, interactive art

Index Terms: K.6.1 J.5 [Arts and Humanity]: Architecture; I.3.m: [Computer Graphics]: Miscellaneous: H.5.m. [Information interfaces and presentation (e.g., HCI)].

1 INTRODUCTION

Various visualization techniques have depicted cause-effect relationships. The best example is the cause-effect diagram—also called the fishbone or Ishikawa diagram [1]—developed in Japan in the 1940s. The Ishikawa diagram provides a structure through which to understand the relationships between many possible causes of a problem. However, the diagram uses many numbers and lines of text, which prevents examiners from reading data easily, due to its complexity. Furthermore, it has been hard to find aesthetically or artistically meaningful visualizations/sonification indicating cause and effect. A more effective method of visualizing the cause-and-effect relationship is undoubtedly necessary for readers.

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However, not all the issues have clear causes and its effects. Some issues have unclear causes and effects. For example, elevated stranding of California sea lion pups have occurred in Southern California since January 2013 for unknown reasons. This event has been declared an unusual mortality event (UME). [2] The number of California sea lions has been decreasing due to many factors, and the exact mechanism behind this trend is still under investigation. According to the National Oceanic and Atmospheric Administration (NOAA), various influences have impacted these sea lion pups. Sardine spawning grounds shifted further offshore in 2012 and 2013, and while other prey was available (market squid and rockfish), they may not have provided adequate nutrition for the milk of sea lion mothers supporting pups or for newly weaned pups foraging on their own. Findings indicate a lack of high-quality, nearby food sources for nursing mothers. How can we visualize the multivariate, unclear reasons effectively?

These questions have been our inspiration to determine how we can address this issue to the public using clear, effective, and innovative visualization to depict its complicated causes and effects. Furthermore, we explored what methods would be most appropriate to visualize causes and effects and enhance our understanding of the infinite loop of those relationships. We first researched the history of visualization of causes and effects and examined any effectiveness and shortfall within that body. Based on the research, we attempted to find a meaningful visualization that can lead to more active participation from the public in actions to save the sea lion.

We aimed to create an interactive data-driven work that explores artistic experience and engagement with the audience, which is critical because the audience is part of the artwork and the artwork evolves based on their input. This paper explores research on, experimentation with, and analysis of a new way of visualizing the cause-effect relationship using California sea lion UME data. It also presents the implementation of our prototypes based on these ideas through data visualization and installation art.

2 Background

This section will explore various types of cause-impact visualization, circular data visualizations, and investigation on the California Sea lion Unusual Mortality Event (UME). Furthermore, previous visualizations based on a variety of topics related to this research will be presented.

2.1 Cause and Effect Visualization

Most of data visualizations aim to find cause (event) and effect (what happened because of the event) through various techniques. The most commonly used technique is Cause-effect diagram (fishbone or Ishikawa diagram), which is the simplest way to visualize data to examine causes and effects directly. Common uses of the Ishikawa diagram are for product design to identify potential factors causing an overall effect. [1] Each cause or reason for imperfection is a source of variation. Causes are usually grouped into major categories to identify and classify these sources of variation. It is a very direct way to visualize the cause-effect relationship, but the complicated system might be overwhelmed. Using visual maps or graphical representations might be helpful to enhance readability. To do so, Edward R. Tufte used graphical representations in a map system. He researched life-and-death situation: the cholera epidemic in

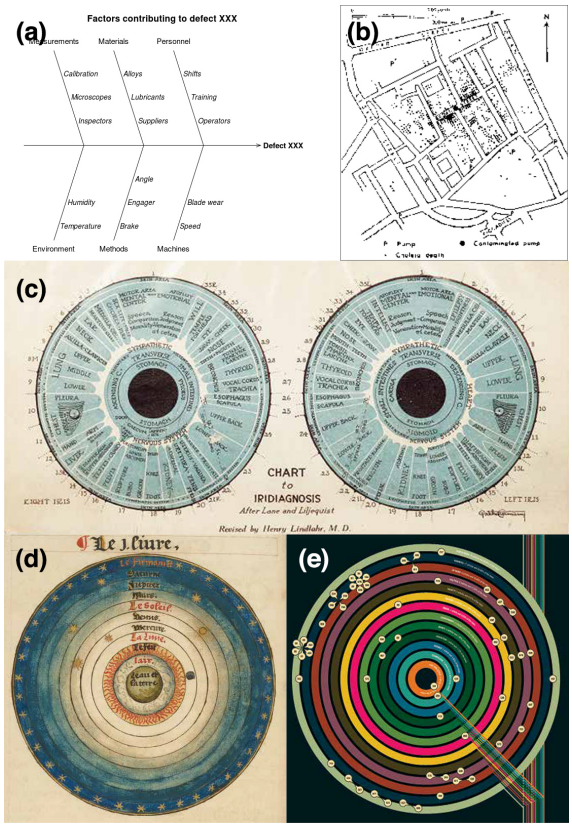

Figure 2: (a) Ishikawa diagram, (b) Edward R. Tufte, the choleraepidemic in London, (c) Henry Lindlahr. Chart to Iridiagnosis, (d) Oronce Fine, Geocentric model, (e) Dave Bowker. One Week of the Guardian: Wednesday.

London [3] He concerned the cholera epidemic in London, and tried to use a dot map showing both where deaths from the disease occurred and the location of eleven water pumps in the area. Tufts used this case to illustrate instead of using visual representations. It was very intuitive way to understand the narratives.

The other most common visualization technique for causal relationship is the Hasse diagram. It represents causal relationship in a very intuitive way, but it does not convey much about the information flow in the system [4]. Hasse diagram fails to visualize systems with complex granularity. In [5], authors discuss about another interesting visualization technique called as Growing Squares. This technique uses color-coded square to indicate the influence it has received from the other event. So, the visualization clarifies the event, which got effected due to certain causes. [5] The squares grow and shrink to denote causality over time. However, Growing Square technique does not link the timing of the events. The timing is manually deduced by the color-coding and by the animation of the system. Also, each color denotes an event in the system. Therefore, it is very difficult to distinguish the event in the large complex system [4]. Sankey diagrams are also commonly used to depict flows from one set of values to another using nodes connected through links. It is an effective system to show mapping between two or more categories. Most of Sankey diagrams start from left and move toward right, which makes uni-directional relationships effectively for reading topics such as water system or energy flow. However, if data has a complicated feedback loop system with multi-directions, it would be hard to visualize connections concisely through this system.

Cause-effect visualization should increase abilities of *comprehension* for readers. More visually appealing and effective methods are necessary to lead to immediate identification of major causes and point to the potential remedial actions. Our proposed sunburst diagram addresses the discussed limitation of other techniques. The sunburst diagram has arcs, which denotes the various causes or effects. Our proposed technique has flexibility in denoting level of granularity. The granularity level can be denoted either by representing it on outer circle or either by splitting the arcs. We will discuss more details of our design in section. 4.

2.2 Circle Data Visualization

Circle is a universal symbol of unity, and since the ancient time, it has been regarded as metaphors of perfection and infinity. Due to the aspects, circle has been popularly used in the fields of infographics and data visualizations to depict the continuousness and endless contexts. Manuel Lima mentioned that circle used to represent a wide range of ideas and phenomena pertaining to almost every domain of knowledge. The circle became a universal metaphor embraced by virtually every civilization that has ever existed. [6] Wheel of the year and ancient calendars show annual cycles through its circular visualizations. [7] Many diagrams and illustrations combine multiple circles in order to express a stronger sense of unity or various types of relationships. Many data visualizations use multiple circles and arcs such as Henry Lindlahr's Chart to Iridiagnosis, Oronce Fine, Geocentric model, Dave Bowker. One Week of the Guardian: Wednesday [6], the first pi chart by Florence Nightingale [8] and Brandon Dawes's EE - Digital City Portraits [9].

Another related visual metaphor is *infinity* (symbol: ∞) When trying to think of visual representations of never-ending cycles, the infinity symbol is the first one to come up. It shows a continuous cycle, while at the same time being more visually appealing than a simple circle. John Wallis first designed the symbol the notation for infinite numbers and calculations in 17th century. [10]

The other iconography that came to mind when thinking about infinity is the hour-glass. An hour-glass not only represents time, but it also looks similar to a vertical infinity symbol. (Figure 3) Based on these ideas, we considered circles, infinite, and the hour glass as visual metaphors and effective shapes as it not only has aesthetically powerful imageries, but deliver narratives and detailed information based on the continuous line formation.

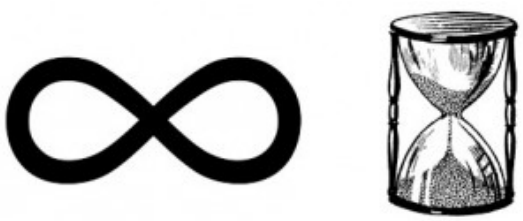

Figure 3: Infinite symbol (left) and hour-glass (right)

2.3 California Sea Lion Unusual Mortality Event (UME)

According to NOAA [2], the large number of stranded, malnourished California sea lion pups was a change in the availability of sea lion prey, especially sardines, a high value food source for nursing mothers. Current data show changes in availability of sea lion prey in Southern California waters was likely a contributor to the UME, the exact mechanism is still under investigation. Sardine spawning grounds shifted further offshore in 2012 and 2013, and while other prey were available (market squid and rockfish), these may not have provided

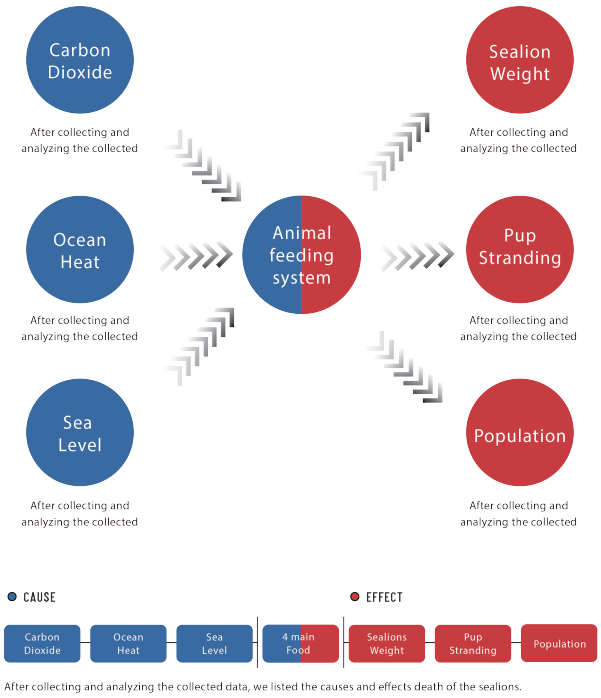

Figure 4: Data Analysis – Causes and Effects of California Sea Lion UME.

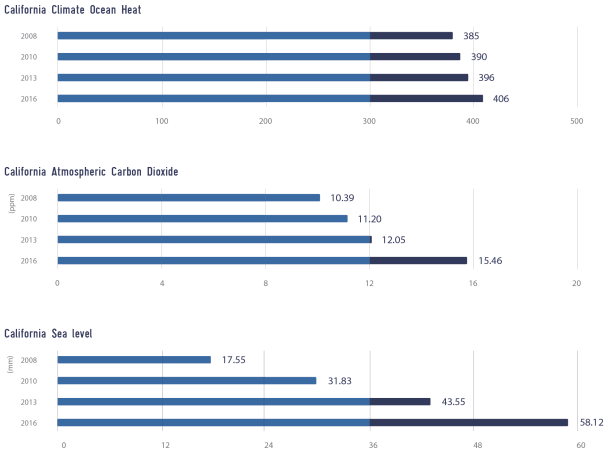

Figure 5: Three graphs to show changes of a) Ocean Heat, b) Carbon Dioxide and c) Sea Level data in the past 7 years.

adequate nutrition in the milk of sea lion mothers supporting pups or for newly-weaned pups foraging on their own. The research also depicted that the sea lion prey has been controlled by the California climate changes; ocean heat, carbon dioxide, and sea levels have been changed their spawning grounds. Thus, multiple causes have resulted in various effects as summarized in Figure 4. When Carbon dioxide, ocean heat and sea level are increased, the weight and population of sea lion decrease, and the strandings increase. As artists/designers living in California, we realized that this is a major issue to be addressed, and decided to use them as data materials.

3 Design Goals

The main goal of this project was to examine new ways of visualizing causes and effects within California sea lion data in

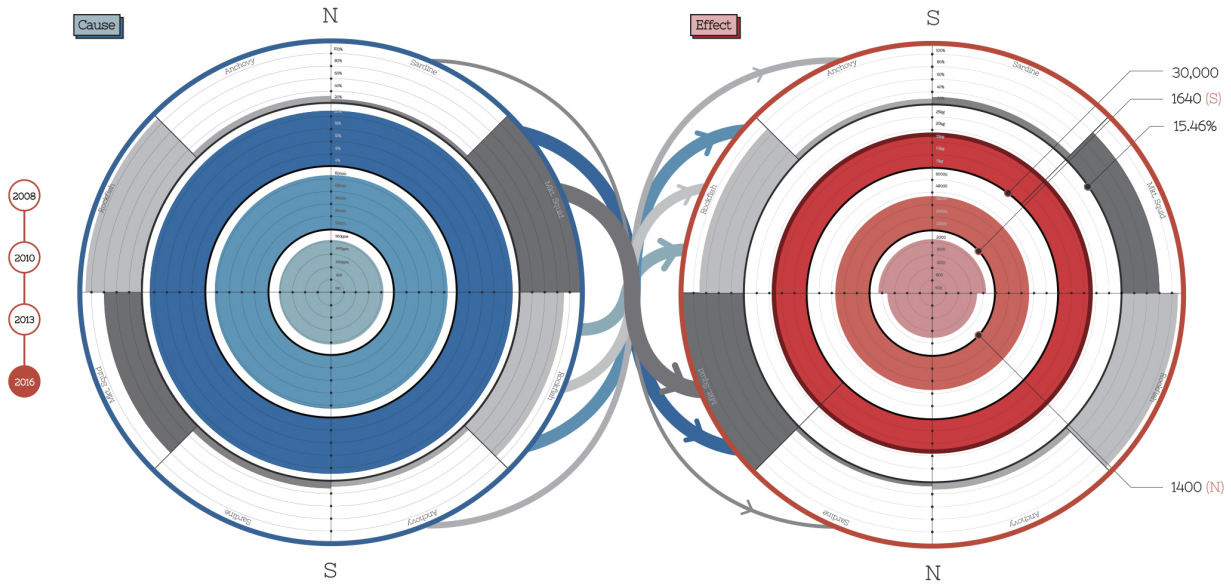

Figure 6: A basic shape and structure of Cause and Effect – California Sea Lion UME Data Visualization.

order to allow the relationships among nature, animals, and the impacts of global warming to be understood. To achieve this goal, several detailed approaches were used in this project:

- **Infinity loop as a visual metaphor to represent cause-effect relationship**
- **Screen-based visualization vs. Physical installation**
- **Interactivity for both overview and details on demand**

Infinity loop as a visual metaphor to represent cause-effect relationship
As mentioned, multiple causes can eventually become effects within circular cycles. To visualize this concept, we used two main circles that were connected to form an infinity loop.

Screen-based visualization vs. Physical installation
Screen-based visualizations and physical installations were both used, as these have different functionalities. To provide easier access to more users, web-based interfaces are effective, as they allow users to explore visualizations and to interact with data via web browsers. We created and published a web-based prototype. We are planning to conduct user studies in the near future with this prototype to examine how users explore the web interface. We also built a prototype for physical installation. To create greater awareness, a public installation is thus being considered for this project. For this physical installation, we used a 3D sculptural system for the projection of the infinity loop and an iPad as an input device. Section 4.4 explains the physical installation in greater detail.

Interactivity for both giving an overview and details on demand
This approach was reliant on the use of a web-based framework and technology. Based on Ben Schneiderman's theories on the fundamentals of data visualization [11][12], this effort attempted to interactively show users an overview as well as detailed information on demand. Users can first see the big picture of cause-effect relationships, which are depicted with colors within the two main circles. Then, users can hover over each arc to examine more detailed numbers and indicators and to manipulate data in order to view how results would change, enabling them to better understand the context. Thus, this design aims to deliver both an overview and detailed information on demand.

4 Design

Based on design research and background and retrieved data, we considered various approaches for visualizing data. In this section, details on the design of the cause and the effect networks are described. These networks can be depicted in two ways: through a 1) screen-based design or a 2) projection-based physical installation. Each format has different interactivity and user experiences.

4.1 Mapping Data into Visuals and Sound

Figure 7 shows the overall mapping of data to each arc and different ranges of numbers and units. The data associated with causes include carbon dioxide levels in the ocean, sea levels, ocean heat, and availability of four foods (anchovies, sardines, rockfish, and mountain squids), whereas effect data was associated with sea lion stranding, populations, and weights (female and male) in addition to the four foods. The positions of each dataset are determined based on their significance and order of impact. For example, the carbon dioxide levels in the ocean first impact sea levels. The sea level then increases or decreases as the ocean heats, which impacts the quantity of the four foods. This serial order is represented through the positioning of these data along the arcs and the cause and effect circles. The thickness of each arc represents the quantity/levels of inputted data. Full thickness indicates a large range of data, whereas zero thickness means no range in the data. Finally, the data has either a north or south orientation and correspond with one half of each circle. The top half of a circle on the left can be associated with the bottom half of the other circle on the right, as these are connected diagonally to create an infinity loop symbol.

4.2 Screen-based Interaction

Web browsers are the main platform for the screen-based design, enabling easy and widespread access and allowing users to explore the information. Users can control multiple sliders to

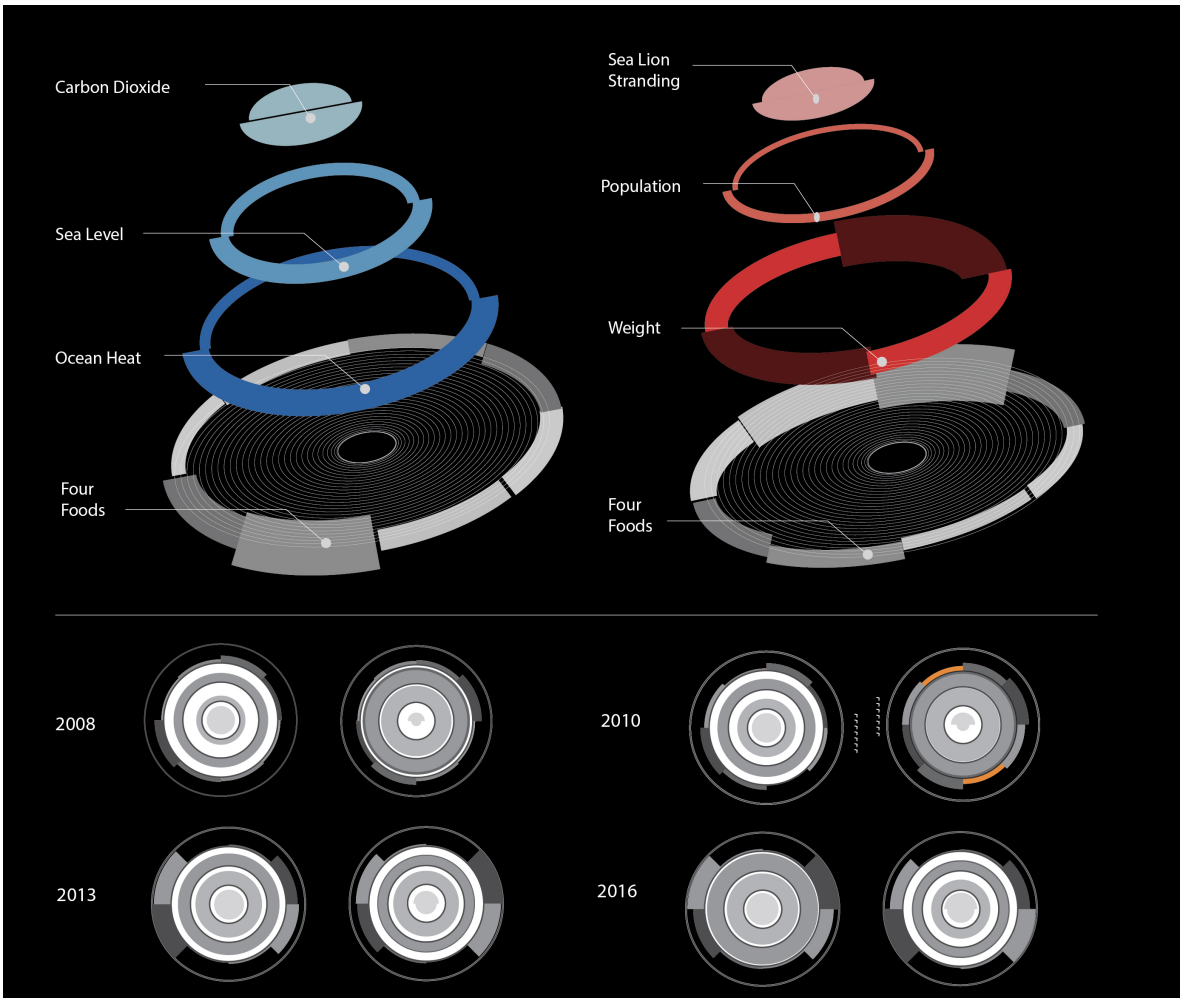

Figure 7: Data Mapping of each arc lines (top), and visualizations of four key years (bottom)

change different variables or the extent of each cause in order to observe the resulting impacts on the right side of the circle. Preset data also allow users to observe the data for key years.

4.3 Physical-Installation based Interaction

In a public space, this visualization can be exhibited as artwork as part of a physical installation. Two circular forms are projected on multiple layers of circular forms, wherein either an iPad screen or analog slider sensors can be used as input devices. Users would thus be able to directly control and manipulate each arc. The use of three-dimensional depth can be used to emphasize different details of the visualization and to make the two circular shapes more dynamic. Figure 8 shows the projected visualization on a flat screen and a 3D prototype of the installation. This physical installation will be exhibited at the PUMP art show in Long Beach, California, in October 2017. Currently, prototypes of this installation have been made to test user interactions and to ensure that the physical setup works effectively. Figure 9 shows a floor plan of the physical installation in a public space and projected images on a circular screen.

5 Implementation

We used web-based technologies and frameworks for this project. A simple interactive design was created with HTML, CSS and JavaScript libraries such as D3.js [13], node.js, and web audio. The project website displays the web-based interactive version [14].

6 Results and Analysis

We tested the infinity loop visualization in various scenarios using suggested parameters and controlling the input data. Figure 10 shows how variance in the input data impacts sea lion weight, populations, and stranding as well as the availability of four different foods. The resulting effects on sea lions can become the causes of other effects, further affecting for example, the availability of the four food sources. Thus, users can see the correlation of different factors with one another. Users can easily observe dramatic changes in the data over the previous 8 years from 2008 to 2016 through selecting the preset options. Four presets show variance in the data for key several years (2008, 2010, 2013, and 2016). Users will be able to experience the prototype in a short amount of time and quickly view these four presets. However, longer interactions are also possible if users use the sliders to explore the causes and effects of sea lion mortality. Many scenarios can result from the manipulation of the input/output data, and these are displayed as an active simulation or as future predictions. In addition, sonification guides users through changes in the sea lion data.

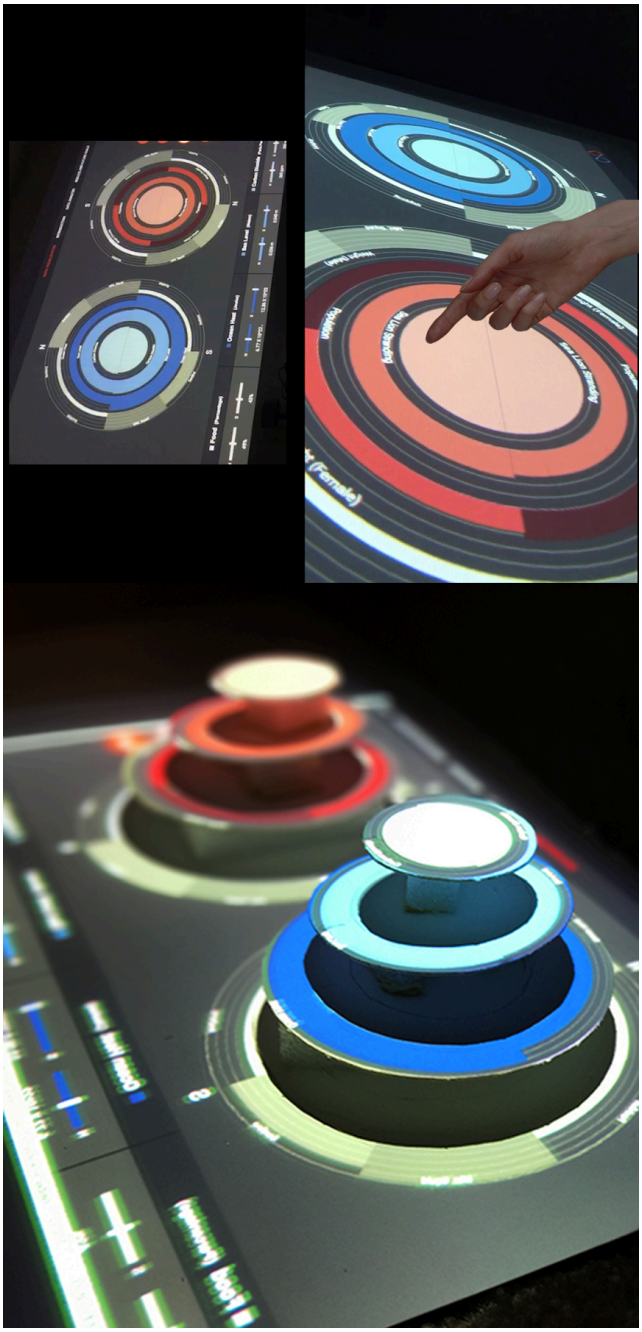

Figure 8: Projected visualizations on a flat screen and a 3D prototype of the installation.

This art installation could lead to more active participation in environmental issues and increased public awareness of sea lion mortality. As mentioned above, NOAA has tried to spread the word on sea lion UME; however, this topic has not yet received significant attention among the public. Both a web-based visualization and a public installation can raise awareness and eventually lead to more active approaches from the public to address this issue. More importantly, this project aims to outline a new and aesthetically different approach for delivering narratives about environmental topics through multimodal interaction. The

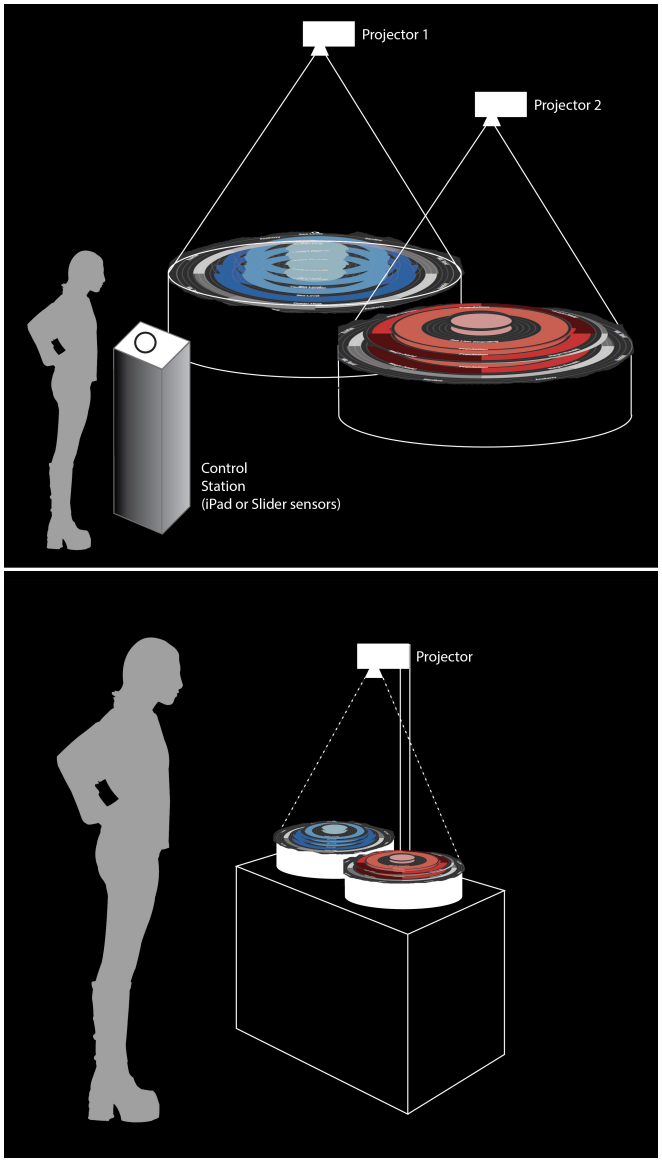

Figure 9: Two versions of Floor Plan using two circular sculptures/projections in a larger scale (top) and a smaller scale (bottom)

visual metaphor of an infinity loop is meaningful and appropriate, as it depicts the relationship or circulation of causes and effects in nature. For example, modification to nature and the environment can lead to higher levels of carbon dioxide in the ocean as well as higher sea levels and temperatures, resulting in global warming. Such phenomena often impact small creatures first. In this case, small fish may initially move to different environs, and sea lions would then experience greater difficulty in finding food. The mortality of sea lions will also have a negative impact on humans. Therefore, this multimodal data representation aims to effectively engage audiences with sea lion mortality. The circular formation references nature's infinite flow and feedback loops and also instantly depicts different results based on manipulation of the data. This model serves as a representation of the interaction of humans and nature and shows the effects of humans on nature. Ultimately, such visualizations may enhance users' connection with the information and increase the public's awareness of the sea lion UME. The ultimate goal would be for such awareness to

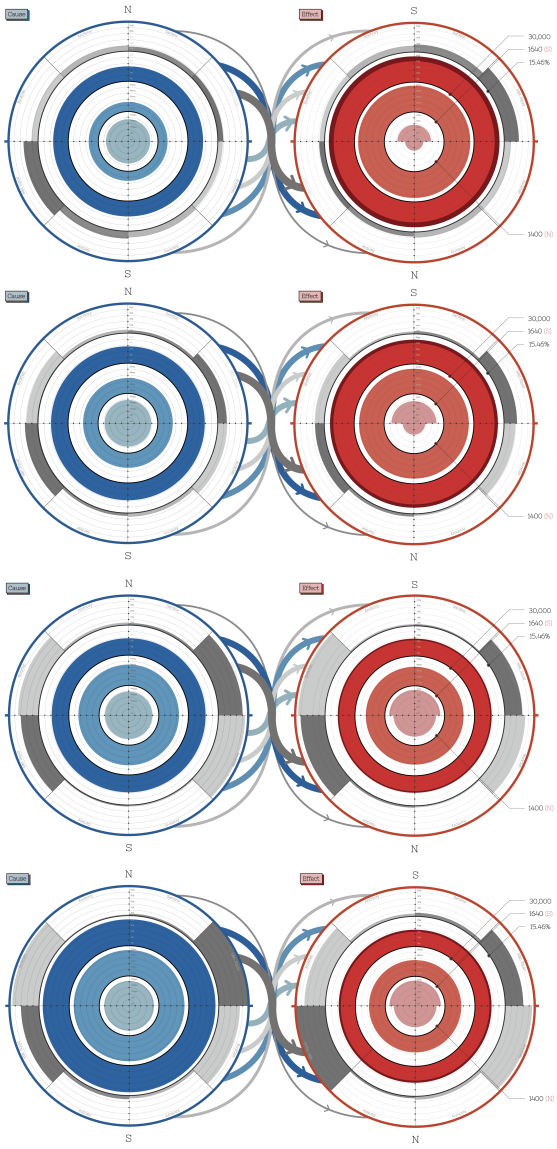

Figure 10: Four Key years to show dramatic changes of sea lion mortality (from top to bottom: 2008, 2010, 2013, 2016)

lead to actions necessary for halting negative outcomes in nature and for resolving current issues.

7 Conclusion and Future Work

This data-driven artwork was designed to raise awareness of a serious issue involving ocean environments and sea lions as well as to successfully implement a projection and visualization of related environmental data. This project draws attention to the issue through a simple and intuitive visualization that makes use of an infinity loop and that places emphasis on aesthetics. Users can observe and explore how the sea lion UME has been developed over time through simple interactive settings. Users can thus visualize various causes and effects. These visuals are also representative of natural flows and impacts to natural cycles as a result of global warming, which is one of the most critical environmental issues of modern times. This project combined past data representations through the implementation of preset options but also allows for future data manipulation. Both a screen-based visualization and a physical installation will allow users to gain a glimpse of past data as well the interactions between different causes and effects. The resulting visuals depict the effects of human activities on nature within a circular canvas, demonstrating the close relationship between humans and the fate of sea lions.

This is an on-going project. More interactive data-driven applications are continually being developed, and additional details and strategies should simultaneously be developed for future works. User studies are necessary to examine how users understand data related to the sea lion UME. We are also definitely considering developments of 3D visualizations for the next stage. The use of an additional axis for representing the dataset could also give more depth to the visualization. We are currently working on a public version of this prototype and will install this work at PUMP, an art event in Long Beach, California, on October 2017. This event will be a good opportunity to gather users' reactions and to conduct a user survey in order to subsequently improve the installation or to make it sturdier and more immersive. We are aiming to show this project at various places in California and also internationally to encourage greater awareness of this issue. We will also build physical sculptures to depict past information. The visual exploration of data in three dimensions could be an effective way of finding new meanings in datasets. Increasingly complex layers and visualization systems can be implemented in future developments in order to display multivariate datasets as well as to provide greater depth and understanding of this topic. More in-depth analyses and sonification techniques will also provide greater engagement for users.

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