California Drought Impact: Multimodal Data Representation to Predict the Water Cycle

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Figure 1: Six data sculptures of California drought from 2011 to 2016 (left) and an interactive audiovisual installation (right)

ABSTRACT

We present our approach for visualizing and sonifying multivariate data describing California's drought using physical data sculptures and projection-mapping images with user interactions. We provide an interaction tool to depict the causes and impact of the drought and promote awareness of water consumption. It offers an opportunity to experience a metamorphosis of water and its impact on the drought. Prototypes of an interactive multimodal data visualization and sonification depict the past, present, and future of the drought by altering water morphology (water metamorphosis) which occurs as a result of climate changes. Thus, this multimodal data representation not only provides an aesthetically meaningful visualization but also encourages good environmental stewardship using the hybrid practices of art and design. This data representation also leads to a new media interactive interface utilizing audio synthesis, visualization, and real-time interaction. In this paper, we describe the design process and illustrate how this interface was developed based on environmental issues and can also be applied to other interactive media artwork to visually reveal informative patterns.

Keywords: Multimodal data visualization, california drought data, data art, data visualization, data sonification, data sculpture

Index Terms: [Arts and Humanities]: Fine Arts, Literature; H.5.m. [Information interfaces and presentation (e.g., HCI)]: Miscellaneous. H.5.2 [Information interfaces and presentation (e.g., HCI)]: User Interfaces.

1 INTRODUCTION

California has been experiencing its most severe drought in the past five years [1]. Drought has affected water changes and the ecosystem, which has become an inspiration and great resource to artists and designers because it had a significant impact on the environment. Previous data visualizations using California drought data primarily depicted its impact on the purpose of predictive analysis and scientific investigations (Section 2.2 for more details); however, it has been hard to find aesthetically meaningful visualizations/sonfications or artistic visualizations yet. Because the California drought has been driven from many types of physical data in nature, such as water, soil, or snow records, a new way of data representations might be necessary to deliver the narratives of the data and reflect the our environment much closer. Furthermore, although visual data is capable of surpassing other senses, the eyes are not the only sensory organs to induce perception. Diverse materials, fabrication techniques and multi-sensory interpretations have been used in the field of data visualization in these days. New aesthetics of visualizations driven from the various materials and techniques will have great potential to raise the environmental issues by shifting the data over multiple sensory organs. The primary roles of conventional data visualization are to facilitate the understanding of the data, predict future outcomes, suggest possible solutions for improving the problems, and to raise awareness among the public. Interactive multimodal data representation using user interactions may enhance the roles of the conventional data visualization by developing the complex of environmental data in an innovative perspective. It may also lead to more active participations in taking actions to the drought from the public. These questions and

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issues have been our inspirations, and here we propose an interactive multimodal data artwork that explores new ways of visualizing and sonifying the California drought dataset with user interactions. This work aims not only to explore new aesthetically meaningful visualizations but also to allow users to learn about the causes of drought by examining the past and present and predicting the future of the California water system as both an art installation and an educational application.

Because we used temporal data and time-based exploration (past, present, and future) of the California drought data, this research focused on creating both a non-interactive sculptural representation and a proactive spatial portrait using visualization and sonification to create an interactive art experience. The engagement of users and a proactive mode to transform the data will enhance communication through the interface so that they can understand the potential impact implied by the updated data.

By adopting multimodality into physical forms, we aimed to create an interactive artwork that explores the artistic experience and engagement with the audience, which is critical because the audience is a part of the artwork, and the artwork evolves based on their input and interaction. In this paper, we will explore how the past, present, and future drought data can be represented in both physical and virtual forms and how they can smoothly mingle to create aesthetically pleasing artwork. We will also present an implementation of our prototypes based on these ideas through data visualization and sonification.

2 BACKGROUND

This section will explore the causes, impact and mitigation of the drought in California. Furthermore, previous visualizations based on a variety of topics related to this research will be investigated. The topics include drought data visualization, water and stream visualization, physical interaction-driven data visualization, data sculptures, and multimodality in data representations.

2.1 Causes, Impact and Mitigation of Drought

Drought is a deficiency in precipitation over an extended period, usually one or more seasons, resulting in a water shortage that has an adverse impact on vegetation, animals, and/or people [2]. Drought is a temporary aberration from normal climatic conditions; thus, its severity can vary significantly from one region to another. Water supply, whether atmospheric water, surface water, or ground water, significantly affects a drought. Water cycle is the most significant cause of a drought since water moves from oceans, lakes, rivers, and streams to the atmosphere based on weather patterns, such as precipitation and temperature. An insufficient amount of rain or snow over a long period of time impacts the water cycle, which causes drought. A drought has an economic impact on a variety of areas, including agricultural businesses, livestock businesses, and hydroelectric power companies. Its environmental impacts include losses or destruction of fish and wildlife habitat and lower water levels in reservoirs, lakes, and ponds. Its social impacts include health problems related to low water flows and poor water quality, loss of human life, and the threat to public safety from wild fires. Water-saving systems and water recycling are the most common and important ways to protect nature and humans from the impact of a drought. In this study, the California drought data will be narrowed down because, in that state, the drought has been severe for the previous 50 years [3]. Moreover, this study will use the water cycle as the main resource of the data visualization that will impact and predict the future of the California drought data.

2.2 Visualizing Drought Data and Water System

Previous approaches for visualizing the drought data are based, primarily, on geographical maps and simple two-dimensional charts to show the changes and spread of the data. The New York Times mapped the spread of drought across the U.S using simple map-based visualization and charts. [4] The United States Geological Survey (USGS) reported on the severe California drought data using simple visualization on a map with graphs and scroll interaction. [5] That map guides users as they read about the various aspects that caused the drought in California. Urban water systems [6], designed by Greg More, provides circular visualization of 10 years of urban water in Melbourne, Australia. That visualization, which tells a story about water over time, is an intriguing way to show data using interactions that might require a more metaphorical approach. Water Reservoir Data Visualization [7], designed by the Southern Regional Climate Center in at Louisiana State University, Baton Rouge, LA, uses various plots to show maps of reservoirs, reservoir levels over time, and elevation vs. capacity. Even though this tool shows up-to-date data visualization, it only does so for three states. Thus, it does not provide detailed drought information for all 50 states.

Several visualizations have used three-dimensional (3D) animated visuals and more active user interactions. NASA's Groundwater Visualization System [8] measures the world's ground water reserves from space using Gravity Recovery and Climate Experiment (GRACE) satellite data to show the yearly cycle of depletion and replenishment. The 3D visualization based on water data is intriguing. Deltares shows a demonstration of various data visualizations on top of the OpenEarth toolbox and Google Earth [9].

Most of the previous data visualizations are based on a geographic visualizing system and simple plots, such as line graphs, 2D plots, and bar graphs. It is difficult to find a predictive visualization to show the future of upcoming environmental data and how that information will impact our society, the environment, culture, and nature.

Since the drought data and its related water data are the main interests of and resources used in this study, previous visualizations of water and stream data should be investigated. Economics & Statistics Administration (ESA) created a visualization technique for Atmospheric Rivers (ARs) [10]. ARs are narrow regions in the atmosphere that transport water across the world. Like a river suspended in the air, these phenomena carry moisture from the humid tropics to temperate areas where it has the potential to fall as rain or snow. The complex swirling and eddying patterns bring atmospheric processes to life; they are a beautiful liquid analog to the more esoteric variable that they describe. Combining this data with reference information, such as coastlines, political borders, and terrain, helps paint a clearer picture of the Earth's surface and the atmospheric interactions on our planet. This open source enables designers and developers to access weather data visualization tools to create aesthetically pleasing visualizations. The NOAA/GLERL Great Lakes Surface Currents Map [11] flow patterns depict visualizations of grand lake currents. The visualization technique is similar to the wind map visualization [12], which is an intriguing visual representation of actual environment data.

2.3 Digital Fabrication: From Data Mining to Physical Data sculptures

Previous data visualization techniques have been created in digital fabricated forms using laser cut, 3D printing, CNC milling and/or other fabrication techniques. The sculptural visualizations are tactile representation of data and they clearly deliver information to users using 3D physicality and touchable materials that enable users to understand multivariate data in 3D space.

Water works [13] is a data sculpture and mapping tool that depicts the water infrastructure of San Francisco, CA. The project detects the water system of the city using 3D-printed sculptures, each paired with an interactive web map. Laser cut sculptures of California water [14] show a 3D model that maps population and water usage by county. The Snow Water Equivalent Cabinet [15] shows how the data can be sculpted using three different axes, based on a 3D graph of the amount of water in the snow pack. CNC milling techniques are used to create 3D sculptures, which can be examined in examples, such as Wind cuts [16], Emote [17], and 46°41'58.365" lat. -91°59'49.0128" long. @ 30m [18]. Other unique fabrication techniques, such as a waterjet machine, are applied to generate a physical data sculpture, as seen in the Bad data example [19].

Most of the physical data sculptures capture multivariate data and map it into various dimensions using length, height, size, and colors, as well as other visual features. Even though the aesthetic value and physical forms of the sculptures are pleasing, and they allow users to easily portrait complex data at a glance, users might not be able to explore a broader dataset due to the limited scope of the existing dataset. Some of these data sculptures only capture a specific area of the dataset without any active user interactions. Few of these works combine projection images on top of the sculptures with user interactions; however, due to their limited content these works cannot predict more extended information or present meaningful stories from the previous data.

2.4 Multimodality and Data Representation

Although human perception is stronger in visualization, other sensory experiences cannot be ignored since our input sensors receive and analyze all the data, and work to understand the meaning of the information. Due to the complex process needed to analyze the information, the use of multimodality is significant. The multimodality between sight and hearing is an especially important aspect of improving how to capture data and information since it enhances the perception and judgment of simultaneity and causality [20].

It is well known, and many studies have verified [35], that sonification can improve the perception and understanding of a visualization. Most geographic and environmental data sonification research has only explored data with auditory input. For example, Heuten, Wichmann, and Boll created an interactive 3D sonification that visually-impaired people can use to explore city maps [21]. Geographic objects and landmarks are represented by sound areas, which are placed within a sound room. Each type of object is associated with a different sound; therefore, it can be identified. Although this research is experimentally novel as well as practical, users need to learn how to recognize the auditory characteristics and predetermined rules so they could be faced with a learning curve. COMPath [22] also sonifies geographic data by transforming it into musical parameters, showing the potential of an interactive online map service as a musical interface. Polli [23] explored the sonification of a highly detailed weather model by transforming the spatial meteorological data, dynamically, into parameters for various synthesis techniques. In addition, she developed 'datareader', a custom Max/MSP object designed to enable artists to more easily work with scientific data [24]. Our project uses similar techniques of passing scaled data to Max/MSP for synthesis; however, it goes further by providing multimodal ways of altering and sorting the data in real-time based on the user's intention.

3 DATASET

USGS has access to all the environmental data related to droughts [1]. The key USGS datasets we retrieved for our prototypes are reservoir, stream, and snow pack data, which mainly affect a drought. The size of the reservoirs changes dramatically over time when a drought becomes severe. Snow pack data is also another significant parameter used to examine the intensity of a drought. Streams that flow near reservoirs also affect to the size of the reservoir. The Trinity Lake and Trinity River data from Trinity County, California (Figure 2) shows that the average water volume of Trinity Lake was reduced by about 48% in 2014 in comparison to 2011, resulting in severe drought conditions. The river flow rate was relatively consistent from 2013 to 2015 (around 5,00,000 as seen in Figure 2) in comparison to other years. Generally, a reduction in the water volume of Trinity Lake was noticed with a decrease in the Trinity River flow rate. However, further statistical analysis of the data will provide an understanding as to whether or not the river flow rate had a significant effect on the lake volume. Since there are too many rivers and streams, we narrowed down to the significant rivers that are relatively longer and deeper than others.

The California drought monitor map [25] shows drought conditions from previous years (2000-2016) depicted as various percentage areas on the map. Due to the severe drought in California from 2011 to 2016, we extracted data from the previous six years and created average drought percentage data. This includes six drought conditions based on the intensity of drought: D0, D1, D2, D3, D4, D5, and D6. We retrieved reservoir data based on station ID numbers from the USGS Center for Integrated Data Analytics (CIDA) data [5], which has monthly and yearly storage (acre-feet) information from 2000-2014.

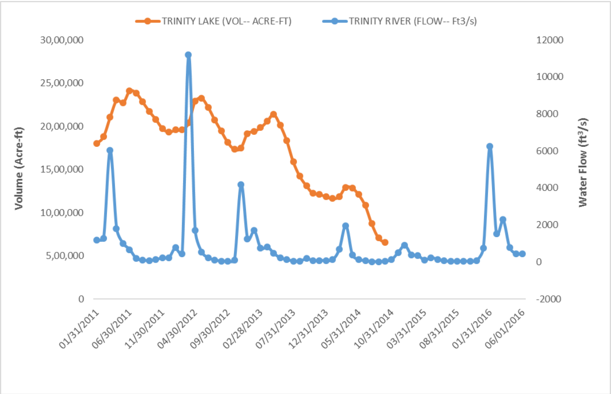

Figure 2: Two Changes and correlation between the Trinity Lake and Trinity River water volume, over time.

4 CALIFORNIA DROUGHT DATA REPRESENTATION

Based on the retrieved data we gathered, various approaches for visualizing drought data were considered. First, the intensity of the drought data from the previous six years was manipulated and polished into 3D layers and projected as visualizations. Figure 3 shows the dramatic changes in the California drought over the previous six years. In 2011, only the southern region of the state was impacted by the drought. However, in 2014 and 2015, the drought became more severe as the darkest layers (D6) in 2014 and 2015 grew and become more dominant (Figure 3).

4.1 Design

The overall design of the California Drought Impact visualization tool can be divided in three categories:

- Past (2000-2016)
- Present (real-time analysis)
- Future (predictive analysis)

Past data collected from 2000 to 2016 cannot be changed because the events and conditions depicted in that data have already occurred. However, we can observe a pattern and learn about a story through the previous temporal data over time. Due to the non-changeable aspect of the previous data, laser cut data sculptures are used to represent past drought data. Different intensities of the drought data are represented in various layers of the laser cut wooden plates. As an artistic material, the wood was carefully chosen to physically represent different water conditions based on the dryness, color, and the number of cracks in the material. The darkest wood was originally from Southern California where the water shortage directly affected the growth of the trees, which resulted in creating the darkest color with dramatic tree ring patterns. The lowest layer has the finest quality wood plate to represent the lowest level of the drought. Therefore, users can learn about and understand how various intensities of drought in each of the regions of the California were recreated with different types of wood, and then transformed into a 3D layered sculpture. Moreover, water data (reservoir, stream, snow pack) is added on top of the wooden sculptures as virtual projected images. Eventually, this creates a 2.5D topographical visualization as 2D visualization images are projected onto the 3D layered surface of the sculptures.

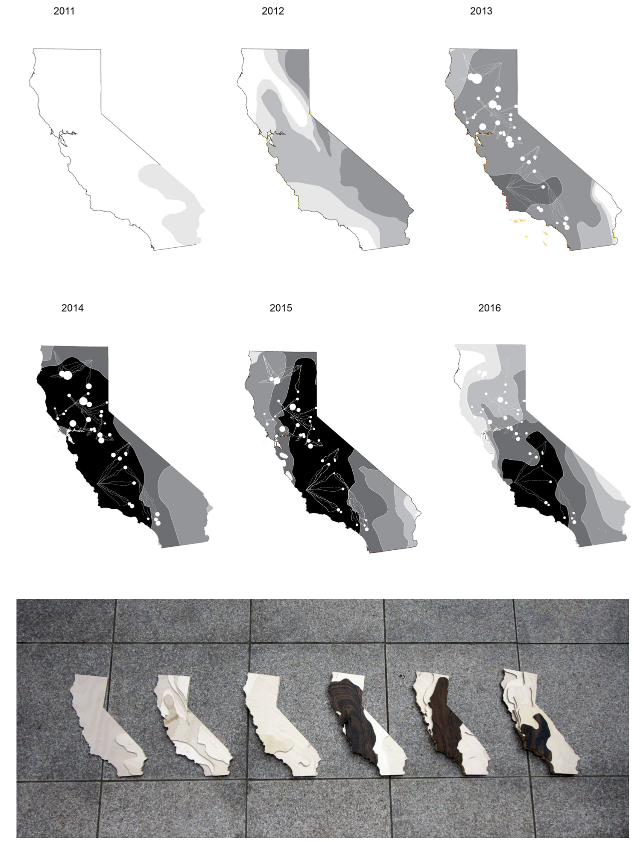

Figure 3: California drought data from the previous six years (top); the laser cut wooden sculptures represent the intensity of the drought data (bottom)

The present data is real-time drought data and the related environmental data. Since the present data is gathered from events and conditions that are happening now, the information should be played directly on a screen so users can see it in real-time instead of sculpting it using physical materials, as was done for the past data. Using the open data system on the web, real-time data are visualized and sonified. To examine future data, users can transform the real-time data; for example, in the prototype, the visualization is projected onto a physical landscape constructed of wooden layers, and users can use hand gestures to alter the data in real-time. The digital visualization installation also includes an audio/sound component that is directly manipulated by the water data controlled by hand gestures. Thus, the entire art installation consists of physical (sculptures), digital (water visualizations), and audio (water sound) components that work together to make a cohesive whole and amass a broad range of knowledge on environmental sciences, engineering and humanities.

Figure 4: A detail view of a wooden data sculpture showing 2014 California drought data.

The installation design of both the data sculptures and the interactive data visualization is shown in Figure 5. As seen, six data sculptures are attached to the wall. Each data sculpture represents previous drought data from each of the years ranging from 2011 to 2016. The range of years was selected to represent the recent period of severe drought in California. A camera-tracking system with a Microsoft Kinect camera is used to project the interactive data visualization onto a plain wooden sculpture that represents an outline of the map of California. The digital visualization and sonification is updated when a user moves his/her hand towards a specific region. More details on the transformed data will be discussed in the Section 4.3.

4.2 User Interaction in the Data Visualization

A water cycle is a loop between evaporations and water streams. In order to create a simple way for users to interact with the water cycle, we first used a mouse interaction technique with a web-based application, and we applied a Microsoft Kinect camera, which will be installed in a gallery space. We decided to develop a handy, compact, and easily-accessible application with a low-cost depth sensing camera device (Microsoft Kinect).

Users can move their hands to add water to specific regions and impact the water cycle there by changing the capacity and shapes of the reservoirs and streams. This means that one hand will be placed in the closest position to the Kinect camera and the projection to determine where to input the water supply and reduce the water consumption. To obtain the best results, a user should stand in the same position and at the same distance from the Kinect camera, and then stare straight at the projection and camera (as shown in Figure 5). The Kinect camera has raw depth data (11 bit numbers between 0 and 2048) and a practical ranging limit of 3.9–11 ft. (1.2–3.5 m) However, considering the distance between a user and the camera, we only need more accurate results within 3.9–8 ft. (1.2–2 m) In that area, the X, Y, and depth values of the detected hand motion are sent to the system, and then mapped as X, Y, and Z coordinates into the web applet.

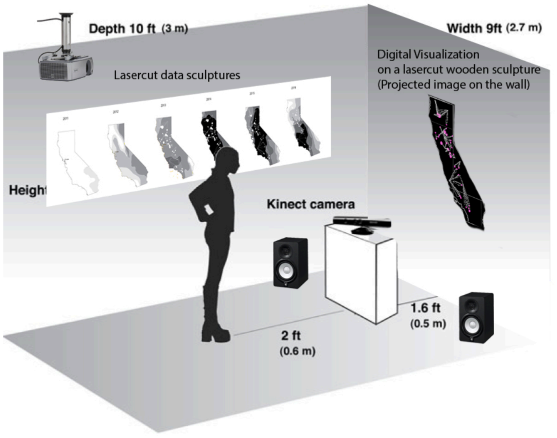

Figure 5: Installation design plan for the interactive data visualization and the data sculptures.

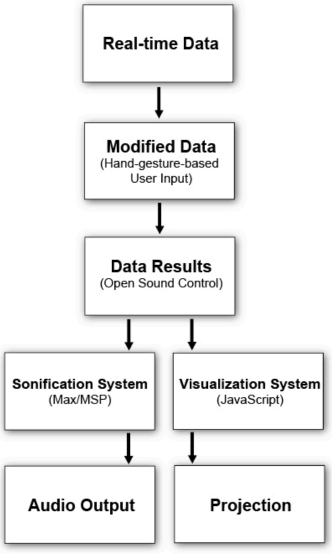

Figure 6: California drought impact system integration.

Figure 6 shows the California drought impact system integration. First, real-time data (present data) is used as the default data. Once users add hand gesture-based input data, the water data is modified and delivered to both the sonification and visualization systems. The audio output has a stereo system and the images are projected onto a screen.

4.3 Predictive Analysis using Hand Motions

Users can control both the digital visualization and sonification using hand motions detected by the Kinect camera. If no user is interacting with the digital visualization, real drought data (2011-2016) loops across the screen so that only past data is displayed. However, if a user interrupts that data loop by moving his/her hand in front of a wooden sculpture and holds that hand on a specific region on the California map, current data on the water cycle and the river system of the chosen region will be shown. If the user keeps holding his/her hand on the same region for a while, the water keeps flooding until it reaches the maximum amount, and the lines of the river streams become thicker, thereby representing the increasing amount of water. This represents a prediction of a possible scenario that would result if increased water supplies, such as heavy rainfall in the region (as an act of God) or other forms of water irrigation, were released into the area. Users can understand how their input can increase the water supply to change the severity of the drought in real time. This part of the digital visualization also shows a pop-up user interface (UI) design that includes the approximate amount of the water input created by the hand motion, and the decreased rate of the drought. Therefore, the user can, presumably, compare the current drought data and the predictive data, and see how the water supply could, eventually, impact the drought. After the user experiences this interaction with the screen, and then moves his/her hand a certain distance away from it, the screen reverts back into loop mode, shows the original real data, and then loops the past data visualization. The visualization is also accompanied by an audio effect. When a user interacts with the visualization, changed streamlines and reservoirs start to create a unique sound that has different timbre, frequencies and volume. The audio effect not only provides ambient sound, it also directly maps the data into sonification, which supports the user's ability to read the visualization more easily. More details on the sound will be described in the next section. Figure 9 shows how the hand motions alter the level of drought and the amount of water in the river streams and reservoirs.

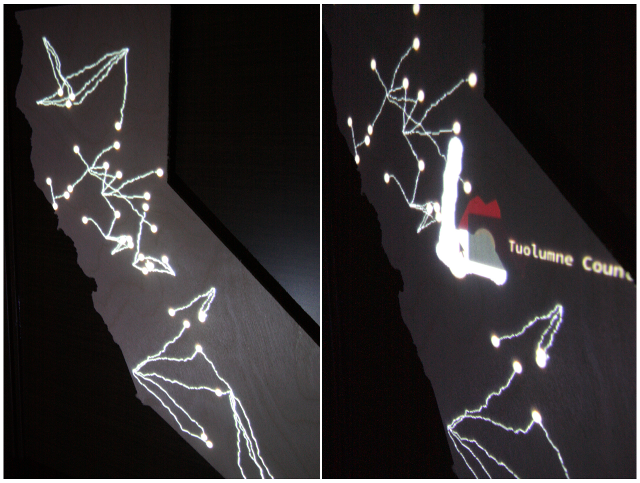

Figure 7: A prototype of the interactive visualization tool on a wooden data sculpture, ranging from present data (left) to impacted future data with water input (right).

4.4 Data Sonification

This section describes the sound synthesis and data mapping used in the proposed visualization tool.

4.4.1 FM synthesis and AM synthesis

Frequency modulation (FM) synthesis, discovered by Chowning in 1973 [26], is an effective way to change the timbre of a simple waveform by modulating its frequency with another waveform to create side bands. We chose this technique for this project because it allows easy control and manipulation of a wide range of sounds with a few perceptually salient parameters, such as loudness, pitch, and harmonicity. Our target is a general audience, not "golden ear" audio experts. Thus, we used a simple, but effective, sound engine that provides obvious and distinct control parameters rather than subtle detail. This project uses a two-operator FM transmitter with five parameters: fundamental (carrier) frequency, amplitude, duration, modulation index (modulator amplitude over modulator frequency), and harmonicity ratio (modulator frequency over carrier frequency). The following additional modules were also added: amplitude modulation (AM) and a classical Attack Decay Sustain Release (ADSR). The modulation index affects the spectral brightness: higher values increase the number of sidebands. We used Max/MSP's graphical "function" object to produce time-varying envelopes to control the modulation index.

Table 1. Mapping data to the FM and AM synthesis

Data type	**Variables of FM synthesis and other modules**
Positions of the reservoirs	Fundamental carrier frequency
Radius of the reservoirs	Amplitude/intensity of carrier frequency
Intensity of the streams	Harmonicity ratio and duration
Intensity of the drought (average)	Total amplitude
Water input	Frequency shift

4.4.2 Mapping data to sound

Table 1 shows the overall mapping of data to sound; the sonification primarily depicts data on reservoirs, streams, drought intensity, and water input. Overall, the drought intensity (average data) controls the main amplitude (linear from 0-1); severe drought corresponds to louder sounds. The positions of the reservoirs determine the fundamental frequency within the range of 50-2000 Hz, such that a reservoir in Southern California has a lower frequency than one in Northern California. The radius of the reservoirs controls the amplitude/intensity of the carrier frequency. The intensity of the streams determines the harmonicity ratio. If a stream is steady, overall, without any dramatic changes, the sound will be perfectly harmonic. If the stream becomes dynamic and its patterns or shapes are changed, the overtone frequencies will be compressed. If the streams get longer and stay changeable for a while, the overtone frequencies will be stretched. Finally, the water input determines one of the predetermined envelope functions for the modulation index and the frequency shift. This allows users to recognize their input by hearing the changed frequency.

5 IMPLEMENTATION

We relied on web-based technologies and frameworks for our prototype. A web-based application helps make it easy for the visualization to be explored on an external monitor. The front-end of the prototype was created using HTML5, CSS3, and jQuery. We implemented a map using a D3.js [27] information visualization library. It provides easy and fast methods for binding data to graphical elements. The application was executed using Python SimpleHttpServer [28]. The demo can be run on a Linux/Mac/Windows machine. The map of California was rendered on to the browser using library gdal [29] and topojson [30] files. A standard d3.geo.mercator function [31] projection was used to display the polygons. The map was developed from previous examples, such as those found in [32] and [33]. The geo-coordinates of the course and destination with latitude and longitude values, respectively, were projected onto the map using a d3.geo.mercator. [31] This implemented the path of the river lines between the geo-coordinates on the map. Similarly, reservoirs were displayed on the map as circles by projecting their coordinates (cx and cy) to the d3.geo.mercator projection. [31] The d3.scale.linear function [34] was used to update the radius and the stroke width of the river lines.

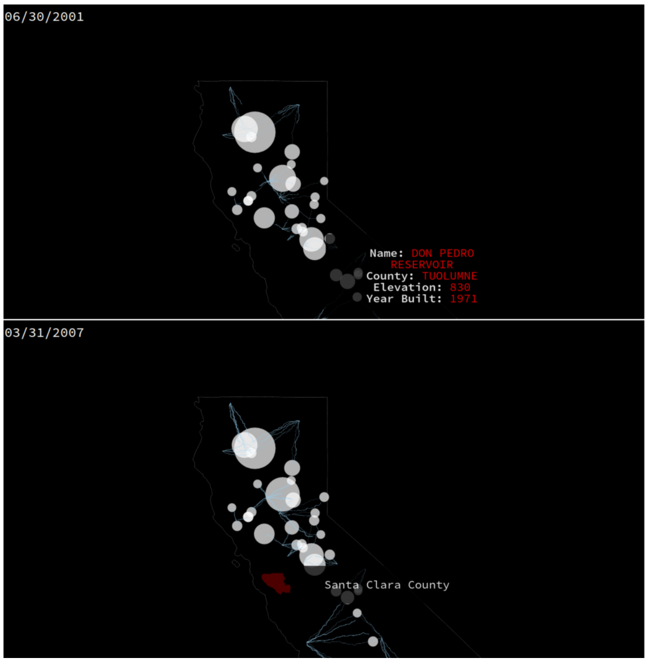

Figure 8: Screenshot images of the reservoirs and stream data visualization.

We used Max/MSP software [36] to sonify the reservoir, stream, and water system data. Max/MSP is a good way to import/export the data via a local host protocol at a fairly fast speed. As described in Section 4.3, FM synthesis and AM synthesis were implemented in Max/MSP using the parameter mapping method.

A Microsoft Kinect camera was used to track the hand motions and hand joints of users' skeletons. We used all the necessary SDKs and libraries to read the stream of the skeleton data inside Node.js with JavaScript. We used a Windows-based computer to communicate with the official Kinect SDK. All computational processes were calculated in JavaScript file, directly affected by the skeleton tracking based data from Kinect. The required data was simultaneously transmitted to Max/MSP through the Open Sound Control (OSC) protocol [37]. OSC received the X and Y coordinates of the hand motions and the geolocations to control the audio in a Max/MSP patch.

6 RESULTS AND DISCUSSION

In our case studies, we tested various situations using different locations, intensities of water input, and impacts of the data. Figure 9 shows how water input will impact drought in the selected county and nearby counties. The effect on drought is represented by various colors. The darker blue means sufficient water is created in the region. The circles(reservoirs) become bigger and stream lines get thicker as well. Depending on the length of time a region is held, the capacity of the water supply varies. Longer interactions result in greater water additions, simulating actively solving the water shortage for users. Once a certain time period passes, the water evaporates and disappears which results in the lack of water in the region. The last image shows the process of water evaporation and a beginning of drought effect. Since water circulates over the area, there is a maximum amount of water that users can access. Once exceeded, other regions or environmental factors are negatively affected. This rule is based on the natural water cycle, leading users to wisely approach how to irrigate the most critical regions. Sonification guides users through changes in the drought data.

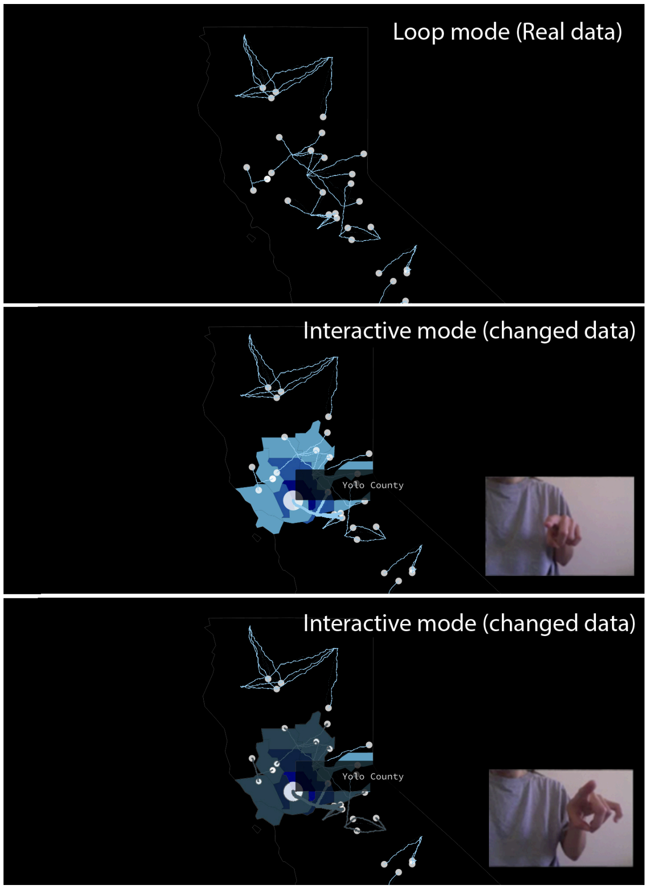

Figure 9: Screenshot images of interactive application that shows changed water cycle around the Yolo County and nearby counties in real time by hand motions

This art installation could lead to more active participation and increased public awareness about how to resolve the California drought. More importantly, it aims to create a new approach for representing information about a significant societal topic by using multimodal interaction. Representing the environmental data via multi-sensory experiences is appropriate because, in the natural world, materials undergo a variety of transformations; for example: water becomes snow, snow evaporates, and air becomes water. As we experience the different types of materials in different sensory ways, this multimodal approach for representing the environment may lead to an effective engagement for the audience. Furthermore, the output of this research is an interactive art installation that consists of both an analogic wood element and digital audiovisual components. Thus, it ties back to nature while also creating an artificial element, which represents how humans interact with nature. Ultimately, this may enhance the user's connection to the information and increase the public's awareness about drought and the actions needed to reduce or resolve it.

7 CONCLUSION AND FUTURE WORK

The impact of the California drought is used as an interactive multimodal data visualization and sonification that depicts the past, present, and future of the drought based on the water system. Users can observe and explore how the drought has been created over time using simple hand motion and how they can control it using water input. Furthermore, the combination between the past data representation as wooden data sculptures as physical representations, future data manipulation on screen-based visualization, and sonification give dynamic multimodal interactive experiences for users. This artwork attempts to expand a boundary of multi-sensory experiences for the users in a variety of aesthetic data representations. It can result in multiple perspectives, allowing for various interpretations, and shifting and developing innovative sensory representations. Thus, it can deliver spatial data representation using the theme of *Nature*, which represents the geographical and environmental changes. The users can touch the physical sculptures, and observe and manipulate the digital projection images in real time, which creates 2.5D topographical visualization as we experience in the nature. Sound is altered whenever the users modify the data. This full experience on mutated senses is important to understand and represent the multitude of the complicated data like this California Drought data.

This is an on-going project. In keeping with the development of a more stable interactive application, an important strategy for future work is to conduct user studies to examine how users understand the drought data visualization and sonification. They will also help us determine how users react to water consumption or shortage by exploring the changes in the water system that lead to correcting or exacerbating the drought and environment. We are currently working on a public version of this prototype and will install it in a public space. This will provide us the opportunity to improve the installation to be more sturdy and immersive.

Because we are exploring multimodality in data representations, it is only natural to find new ways to pursue more dimensions in depicting information. Visually exploring data in three dimensions could provide a more effective way to gather new meanings in a dataset. A more complex audio spatialization algorithm (ambisonics/wavefield synthesis) will be implemented in future iterations to better enable localization of sound sources and to study how this correlates with a certain visual position in space.

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