Cloud Bridge: a Data-driven Immersive Audio-Visual Software Interface

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ABSTRACT
Cloud Bridge is an immersive interactive audiovisual software interface for both data exploration and artistic creation. It explores how information sonification and visualization can facilitate findings, by creating interactive visual/musical compositions. Cloud Bridge is a multi-user, multimodal instrument based on a data set representing the history of items checked out by patrons of the Seattle Public Library. A single user or a group of users functioning as a performance ensemble participates in the piece by interactively querying the database using iOS devices. Each device is associated with a unique timbre and color for contributing to the piece, which appears on large shared screens and a surround-sound system for all participants and observers. Cloud Bridge leads to a new media interactive interface utilizing audio synthesis, visualization and real-time interaction.

Keywords
Data Sonification, Data Visualization, Sonification, User Interface, Sonic Interaction Design, Open Sound Control

1. INTRODUCTION
In this era of big data, the analysis and use of data with various digital tools has become paramount for knowledge discovery and also as a new medium for artistic expression. These data come from everywhere: the stock market, climate information, cell phone GPS signals, posts to social media websites, etc. There are myriad opportunities to uncover insights by examining data and content in new ways, looking for patterns in the information that may lead to new discoveries, as well as inspire new questions. For these reasons, data visualization has been increasingly developed in computer science, digital media art, and social science. One issue is that visualization excludes the visually impaired from knowledge discovery and artistic creation. Also, there are often problems with visual occlusion when the data becomes too large and cumbersome. Rather than relying solely on visual modality, multimodal representation can provide multiple sensory cues and may be more efficient for parsing voluminous amounts of data and complex information.

Thus, data sonification is an important technique for presenting data in a variety of contexts. Auditory Display and sonification researchers examine how the human auditory system can be used as the primary interface channel for communicating and transmitting information [1]. A goal of Auditory Display is to enable a better understanding for finding structures in data that may not be obvious through visualization. This is especially the case for structures that unfold in time.

Considering these aspects of sonification, we propose a new data sonification/visualization project, Cloud Bridge. This project is a proof of concept for an interactive multi-user software instrument that utilizes data as the driver for visual/audio content. Cloud Bridge uses data from the Seattle Public Library database acquired through George Legrady's "Making Visible the Invisible" artwork [2], a permanent art commission that receives approximately 30000 data records per day representing books, CDs and DVDs checked-out by library patrons [3]. The project began in September 2005 and will be operational until 2019. There are at this time over 70 million recorded transactions available that can be studied in detail to map how topics of interest to the patrons have changed over time during the past decade. A keyword search pulls data from the database to be sonified as different timbres, frequencies and durations, and visualized in different colors and formats, creating an interactive visual/audio composition. The audience becomes an interactive performance ensemble by entering the keywords via iOS devices.

Cloud Bridge provides an innovative way to compose and perform multi-user data-driven audiovisual works. The data serves as the fundamental layer, with the audience playing an essential role of creating their own collective visual/audio composition. The development of Cloud Bridge began with the desire to explore creative ways of mapping and using data. The development led to a combination of data sonification, data visualization, and multi-user interaction, which makes it an innovative approach to data-driven multimedia composition, as well as a unique data-mining tool.

In this paper, we discuss related work in data sonification, visualization, and dynamic query in Section 2. Section 3 describes the concept and system of Cloud Bridge, and Section 4 discusses data sonification. Visualization and interaction are presented in Section 5 and 6, and Section 7 features audiovisual results of examples and an installation in the AlloSphere [4], a unique multi-user, multimodal facility. Finally, Section 8 concludes with results and suggestions for future work.

2. RELATED WORK

2.1 Data Sonification
Much data sonification research has had the goal of allowing visually impaired people to explore data with auditory input. For example, Heuten, Wichmann, and Boll created an interactive 3D sonification for visually impaired people to explore city maps [5]. Geographic objects and landmarks are represented by sound areas, which are placed within a sound

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Table 1. Visualization Tasks and Influence on Cloud Bridge

Task	Influence on our work
Gain an **overview** of the entire collection.	The overall "time tunnel" display provides the viewers with general information about the database at weekly scale. Audiences would be able to compare the volume changes, major item types, dewey and non-dewey items through this mode.
Zoom in on items of interest	Camera navigation allows users to fly around the space as they wish.
Details-on-demand: Select an item or group and get details when needed.	Cloud Bridge attempted another method, which is to bring in a separate display mode just target for detail-on-demand.
Relate: View relationships among items.	Our general mode compares item types, weekly check-out volumes, etc.; detail mode allows the users to comparison in between single item's check-out histories.

room. Each type of object is associated with a different sound and can therefore be identified. This research is novel in practical and experimental ways, however users need to learn how to recognize auditory characteristics and predetermined rules, so there may be a learning curve.

COMPath [6] also sonifies geographic data by transforming it into musical parameters, showing the potential of an interactive online map service as a musical interface. Polli [7] 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 for artists to more easily work with scientific data [8]. Our project uses similar techniques of passing scaled data to Max/MSP for synthesis, but goes further by providing methods of altering and sorting the data in real time based on the user's intention, by querying a database.

Other recent sonification research includes Physicist Jatila van der Veen's and Ryan McGee's sonification of the cosmic microwave background radiation [9]. Sonification research on seismic data includes artist David Rogers' and Ryan McGee's Inner Earth Interpreter [10].

2.2 Data Visualization

Ben Shneiderman, one of the pioneers of data visualization, described seven basic tasks of data visualization [10], four of which deeply influenced our work as Table 1.

Wattenberg [12] introduced a two-dimensional arc diagram to represent repeating patterns over time, which we adopted as a key visual element to represent patterns of checked-out items.

2.3 Dynamic Query and Multi-user Instruments

Dynamic query enables the possibility of customizing results based on interests. Following Shneiderman's [13] analysis, the dynamic query approach should allow users to explore a dataset rapidly, safely, and even playfully, which may also facilitate rapid discovery of patterns and areas of interest in a multidimensional search space. In our work, dynamic query is key to the user's control of the resulting soundscape.

Jordà [14] defined a "multi-user instrument" as one that can be played by a variable number of performers, with each performer able to take a different role upon various performances of a work. These ideas became the foundation of transforming a database to a playful multi-user instrument.

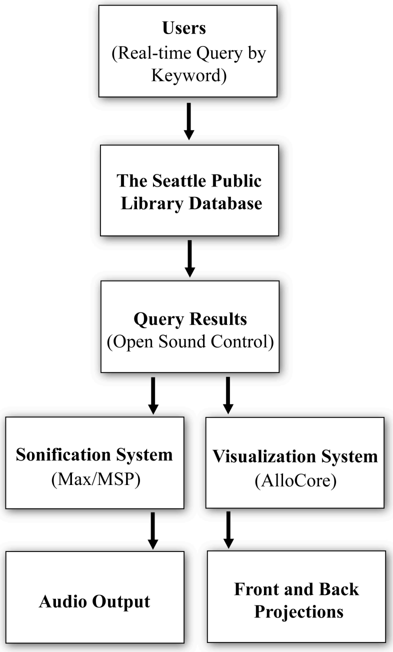

Figure 1. Cloud Bridge System Integration

The TweetDreams project [15] visualizes and sonifies Tweets from both local participants and worldwide Twitter users. Users participate in the performance in real time by Tweeting, but only if they have an Internet-connected device and a Twitter account. Cloud Bridge, in contrast, provides the users with devices and guarantees all the participants can interact with the project.

3. SYSTEM OVERVIEW

Figure 1 shows the overall system architecture. There are four major components: a MySQL database, an iOS interface implemented using Charlie Robert's mobile device interface software Control [16], data sonification written in Max/MSP, and a data visualization application written in C++ using AlloCore [17], a cross-platform suite of C++ components designed for UCSB's AlloSphere instrument. All communication among these components uses Open Sound Control [18].

The Seattle Public Library artwork database acquired through "Making Visible the Invisible" artwork contains fourteen fields, of which this project uses a subset: check-out and check-in date/time (year, month, day, hour, minute, and second), count (the total number of times this item has been checked out), title, subject, keywords, and whether the item has a code in the classical Dewey Decimal system [19]. (Generally non-fiction items have a Dewey code and fiction items do not.) We extract all words from the title, subject, and keyword fields into a separate *keyword* index table that allows for efficient search and retrieval by keyword.

When a user enters text on the iPad interface, the database is queried for that keyword and the results are sent to both Max/MSP and the AlloCore application. The resulting sounds occur at the same time as the moving visual representations.

The following example SQL query selects records matching to the keyword "happy", with results shown in Figure 2:

```
select week(o), year(o), hour(o), week(i),
year(i), hour(i), count, title, dewey
 from count, act, word, dewey, title
 where count.bib = word.bib and
        count.bib = act.bib and
        count.bib = title.bib and
       word = 'happy' and
       (year(o) > 2005) limit 250;
```

checkoutweek	checkoutyear	checkouthour	checkinweek	checkinyear	checkinhour	floor(deweyClass)
48	2005	17	1	2006	9	613
49	2005	10	1	2006	10	NULL
17	2004	0	1	2006	11	NULL
45	2005	15	1	2006	12	158
50	2005	18	1	2006	13	782
1	2006	13	1	2006	13	NULL
49	2005	10	1	2006	14	782
49	2005	13	1	2006	14	394
49	2005	13	1	2006	14	745
49	2005	13	1	2006	14	394
47	2005	17	1	2006	15	636
1	2006	15	1	2006	15	NULL
50	2005	15	1	2006	15	152
45	2005	13	1	2006	15	NULL
50	2005	16	1	2006	15	NULL
48	2005	17	1	2006	15	NULL
49	2005	15	1	2006	16	636
51	2005	17	1	2006	16	782
47	2005	13	1	2006	16	NULL
28	2004	0	1	2006	16	NULL
47	2005	13	1	2006	16	NULL
28	2004	0	1	2006	16	NULL
52	2005	14	1	2006	16	NULL
50	2005	15	1	2006	17	NULL
48	2005	13	1	2006	17	NULL
52	2005	18	1	2006	17	NULL
49	2005	16	1	2006	17	NULL
52	2005	15	1	2006	17	NULL

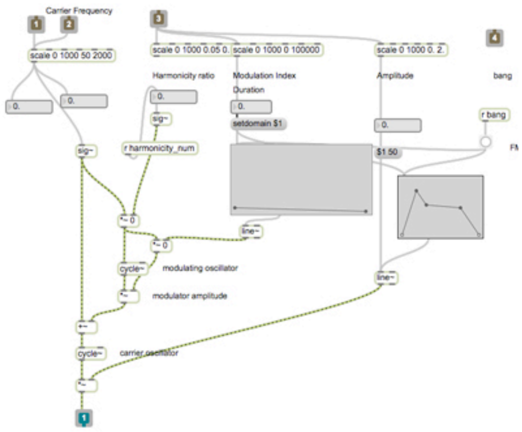

Figure 2. Query results for keyword "happy" (above) and FM synthesis in Max/MSP (below)

4. SONIFICATION

This section describes sound synthesis and data mapping.

4.1 FM Synthesis

FM Synthesis, discovered by Chowning in 1973 [20], 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 it 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 ears" audio experts, so we used a simple but effective sound engine providing obvious and distinct control parameters rather than subtle detail. This project uses two-operator FM with five parameters: fundamental (carrier) frequency, amplitude, duration, modulation index (modulator amplitude over modulator frequency), and harmonicity ratio (modulator frequency over carrier frequency). Modulation index affects the spectral brightness: higher values increase the number of sidebands. We use MSP's graphical "function" object to produce time-varying envelopes to control the modulation index.

Table 2. Mapping data to FM synthesis

Data type	*Variables of FM synthesis*
User ID	Selection of envelope for modulation index
Loan duration	Amplitude, duration
Check-in hour minus check-out hour	Harmonicity ratio
Check out week	Fundamental carrier frequency

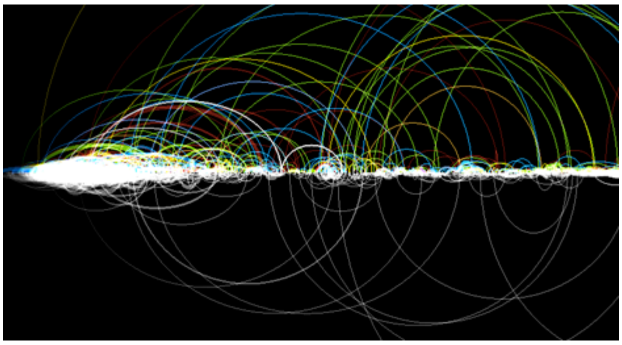

Figure 3. Cloud Bridge Visualization

4.2 Mapping data to sound

Table 1 shows the overall mapping of data to sound; the sonification depicts only the check-out and check-in dates and times. The time difference between check-out and check-in (i.e., the duration of the loan) controls the amplitude (linear from 0-1) and duration (0-10s) of sound: longer transactions correspond to longer and louder sounds. Check-out date determines the fundamental frequency within the range 50-2000 Hz such that a transaction in 2006 has a lower frequency than one in 2012. We subtract the check-out hour from the check-in hour to determine the harmonicity ratio: if a patron returns an item at the same time of day as the checkout then the sound will be perfectly harmonic, if the return is earlier in the day than the checkout then the overtone frequencies will be compressed, and if the return is later in the day than the checkout the overtone frequencies will be stretched.

Finally, each user is assigned a unique ID, which determines one of the predetermined envelope functions for modulation index. This allows users to recognize their query results by hearing their own characteristic sound.

5. VISUALIZATION

Cloud Bridge uses stereographic video projection to create a 3D visual space where visual cues unfold in time in synchronization with the audio.

5.1 Conceptual Design

Cloud Bridge's design was inspired by the physical infrastructure of the AlloSphere immersive instrument, which has a desktop configuration that provides two large windows on either side of a group of viewers. The audience is visually and sonically immersed in the time tunnel of data. Cloud Bridge links a check-out point and its corresponding check-in point with an arc (as in Wattenberg's Arc Diagrams [12]); compared to overlapping straight lines we believe the arcs provide more visual clarity and also beauty.

5.2 Visual Mapping

The visualization is based on the metaphor of "traveling in time." The spatial Z axis (depth) represents the time period from 2006 to 2012–the years for which the database contains transactions–with a grid spatialization subdivided into weeks.

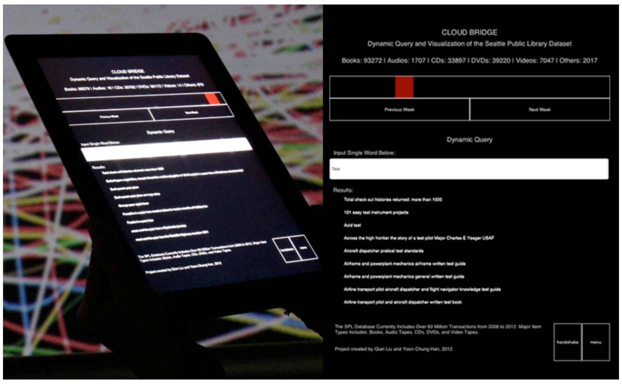

Figure 4. User Interface with a Keyword Search Result

The X axis (horizontal) represents the hour (0 to 24). The Y (vertical) axis is the dimension through which the arcs pass, thereby representing the duration of each transaction.

Each user (each iPad) has a unique ID that not only determines a unique timbre for sonification (as described in Section 4.2), but also corresponds to a unique color for visual output. A transaction of a Dewey item appears as an arc through positive Y in the color of the user who selected the transaction; a non-Dewey transaction appears as an arc through negative Y with the same user-specific color but a very small saturation value. Figure 3 depicts this visualization.

6. INTERACTION

Instead of contributing passively to the piece, users can treat their iOS devices as instruments and proactively create a real-time musical and visual conversation.

6.1 iOS Interface

Cloud Bridge uses the mobile device interface software Control [15] for interaction because it allows greater customization of interfaces than many interface apps and enables the use of HTML elements. The project requires interface elements for text entry and text display that were not available in other mobile interface applications. Control provides flexible control over text input and display using standard HTML, CSS and JavaScript technologies while also enabling OSC input and output.

There is a customized Control interface specifically designed for Cloud Bridge, shown in Figure 4. When this interface loads on a given iPad, it sends an OSC message to the visualization application that indicates its IP address. The visualization application then sends an OSC message back to the device providing a unique ID number and color. This process is called a "handshake."

6.2 Dynamic Query/Multi-User Interaction

The interface for dynamic queries consists of a text field and an html field located at the bottom half of the iOS interface. The user can type a single word into the text field, at which point the program will query the database for all transactions involving items matching the keyword, as described in Section 3. Cloud Bridge will then visualize and sonify these transactions. Meanwhile, the iPad will display the total number of transactions found and several titles that contain the keyword. When the user enters a new word the html field refreshes itself, and displays the latest feedback.

Cloud Bridge allows multiple participants to query the database from their devices and visually and sonically "plays" the data they have mined interactively together as an ensemble.

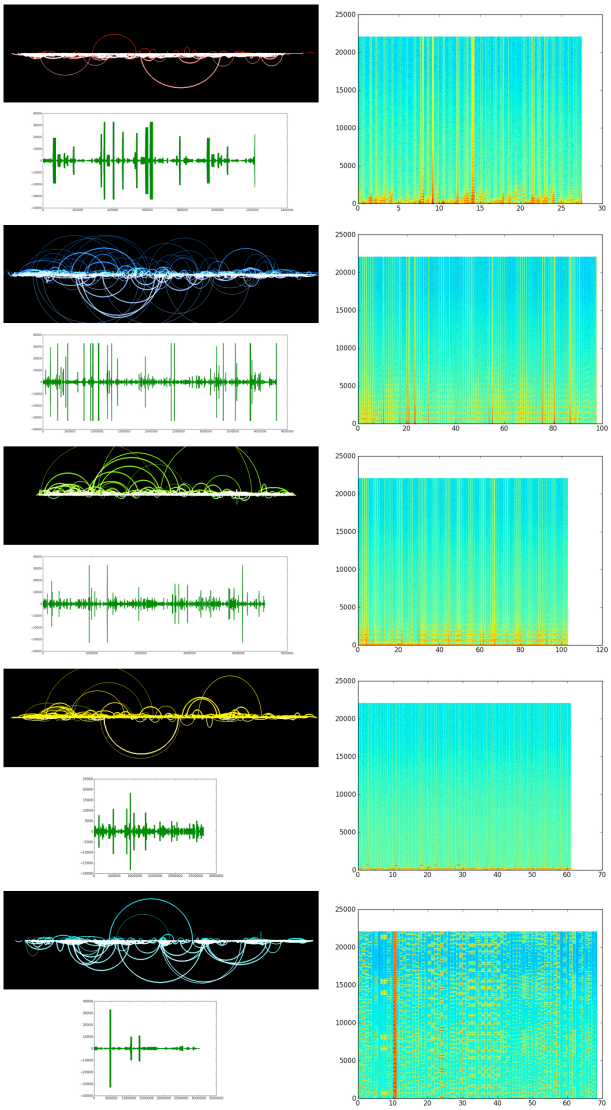

Figure 5. Five examples of arcs, waveforms and generated magnitude spectrograms from five keywords (from top to bottom: happy, love, Seattle, coffee, Christmas)

Participants can improvise with one another, querying data that may have some connection from a previous request.

7. RESULTS

In our case studies we tried five different keywords and query data. Each result had a different length, and user ID, which altered the overall duration and timbre of sound, as shown in Figure 5. One interesting aspect of the audiovisual results was hearing the different durations of check-out items; the longest duration was 2555 days, resulting in a long-playing time with increasing amplitude. Overall, the audio and visuals were coherent with each other, and enhanced the real-time query data results.

The first installation of Cloud Bridge took place in the UCSB AlloSphere, allowing us to represent this large data set immersively front and back on a large screen and in full surround sound, with enough distance to view and hear the information unfold. The AlloSphere, one of the largest scientific/artistic instruments in the world for immersive visualization, sonification, and multimodal data manipulation, is a 10m diameter metal sphere finely tuned for perceptual experiences with a 360-degree, super-black, non-reflective screen surrounded by a multi-channel loudspeaker array, all housed in an echo-free chamber (see Figures 7 and 8). Multiple users standing on the 2m-wide central bridge can interact through myriad multimodal devices as they experience stereographic projections and spatial audio. The AlloSphere was conceived by JoAnn Kuchera-Morin as a general-purpose eye- and ear-limited multimedia instrument both for new modes of artistic expression and for scientific discovery. It provides a common meeting ground where diverse researchers can share insights and pursue similar fundamental questions about symmetry, beauty, pattern formation, and emergence. Our attitude to this unique opportunity is to establish a frontier of research that is grounded in both art and science, but not constrained to either one. This has required a holistic rethinking of the fundamental aspects of our medium: computation, data, process, perception, interaction, immersion, and evaluation.

Cloud Bridge ran on the AlloSphere's dual desktop configuration (as shown in Figure 6) with stereoscopic video on two large quasirectangular windows and with sound spatialized through a 34.1 channel surround system. About 30 people joined this installation and some of them participated in the interaction process. Experienced users generally gave positive feedback about this project, and commented on how well the sounds matched the visuals. Most users found being surrounded by the data and observing it from different perspectives important for gleaning more information as well creating an ensemble-style multimedia art work. The use of iPads and dynamic query also received positive feedback, and most users agreed that the two-way interaction, with keyword query results appearing as text on their iPads, helped them understand the dataset even better.

8. CONCLUSION

Cloud Bridge is an interactive audiovisual artwork using library transaction data, which represents a novel combination of data sonification, data visualization, and multi-user interaction. The sonification enhances the understanding of query results along with visualization in a large-scale immersive environment, the AlloSphere. The use of dynamic queries in real-time allows users to explore the diverse dataset, and to create a musical conversation. Participants are no longer restricted to a one-way communication, but able to interact with data, in an immersive audiovisual environment, and contribute to new query results expressed in a multimodal experience.

Cloud Bridge is not a typical NIME instrument in that it does not provide detailed realtime direct control of sound synthesis. User input consists solely of entering query text and choosing when to trigger the beginning of the unfolding of the audiovisual response to the query, enabling a performance practice more akin to interactive data mining. The content of the database defines the bounds of this unique instrument by determining all potential results, from which potentially many simultaneous users can select possibilities. Users can approach Cloud Bridge as a sonification tool for exploring patterns in the the data base, as an improvisatory, interactive audiovisual artwork, or by thinking in terms of linguistics such as by choosing keywords to form sentences and larger narratives, perhaps by creating a "tone poem" or a "play on words."

Another major challenge that Cloud Bridge attempts to address is to create an interactive audiovisual interface that works equally well regardless of venue, from laptops/desktops, to gallery-style installations with mobile device interaction, and even large-scale immersive stereoscopic environments such as the AlloSphere.

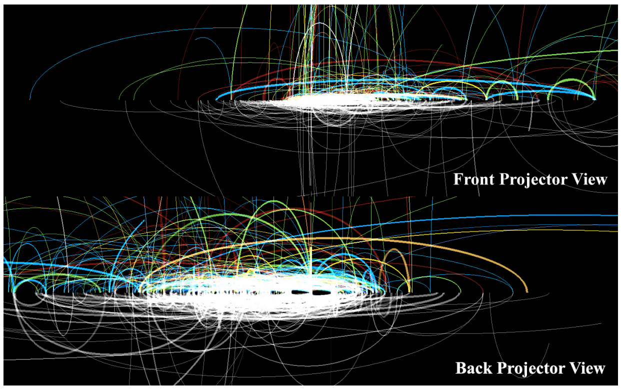

Figure 6. Front and Back Projections

Future work includes exploring other synthesis techniques and sonification methods including additive synthesis, IFFT synthesis and dynamic filters, looking for a greater variety of sound timbres.. It may be beneficial to map the change in frequency over the arcs and use the z axis as a spatial distance axis. The work could also take greater advantage of the AlloSphere's multichannel spatial sound system. Another important consideration is the need to normalize the data with the current sound representation since longer check-out times result in higher peak amplitudes.

Future interaction research will encompass adding more query techniques. This will facilitate building out the software infrastructure as a general-purpose data-driven multimodal instrument.

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10. ACKNOWLEDGEMENT

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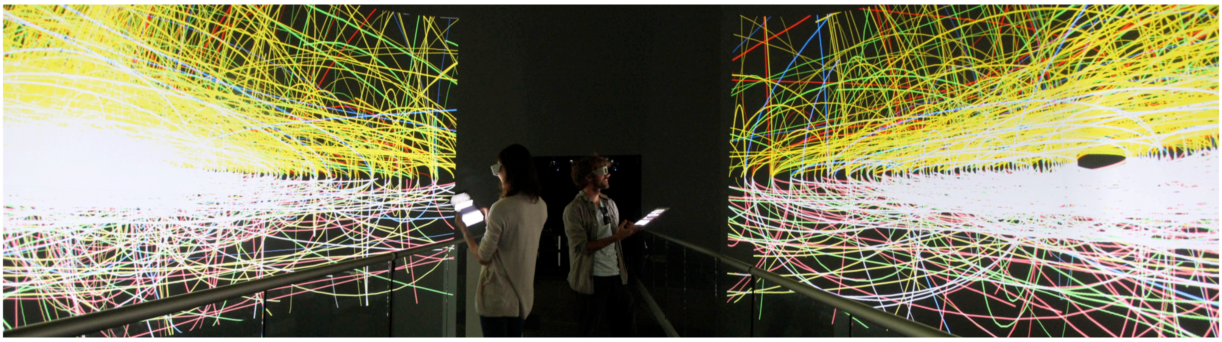

Figure 7. Cloud Bridge in the AlloSphere

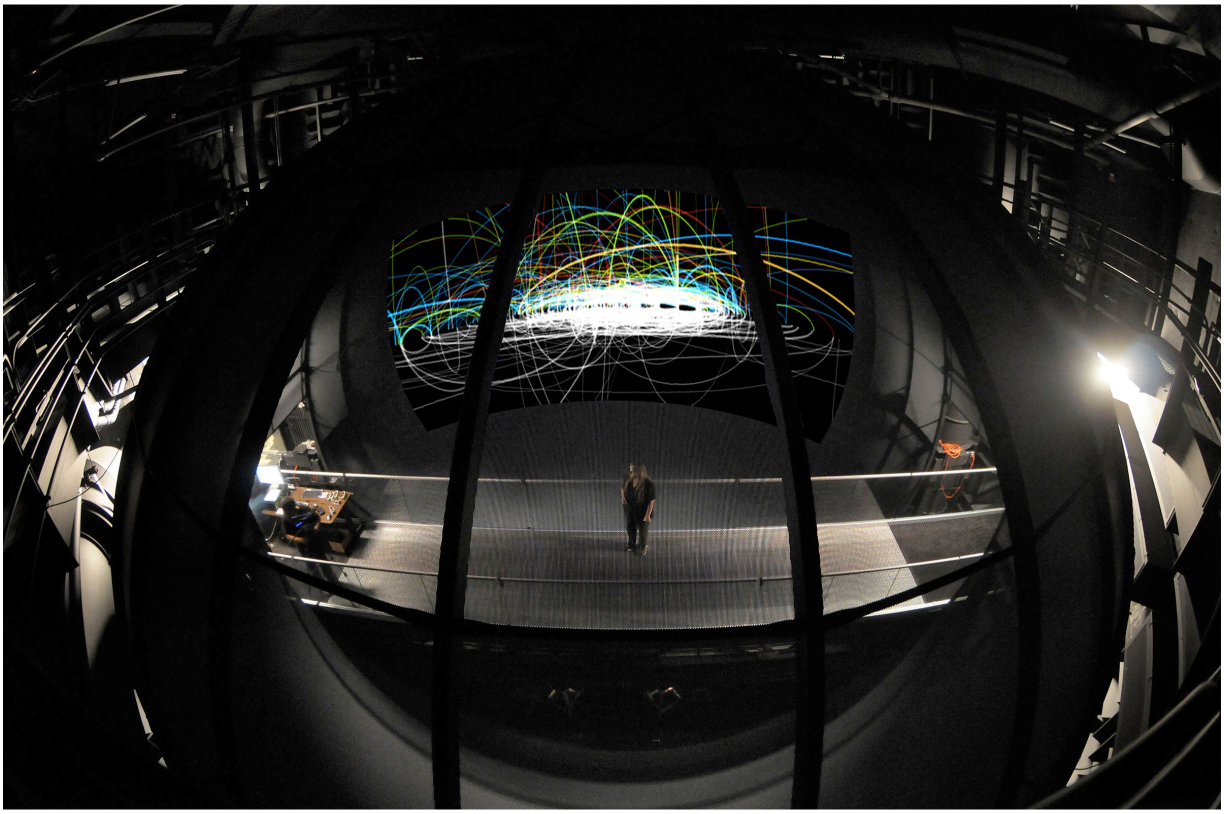

Figure 8. AlloSphere - View from Above