Application of Gestalt Principles to Multimodal Data Representation

Muhammad Hafiz Wan Rosli * Andrés Cabrera†

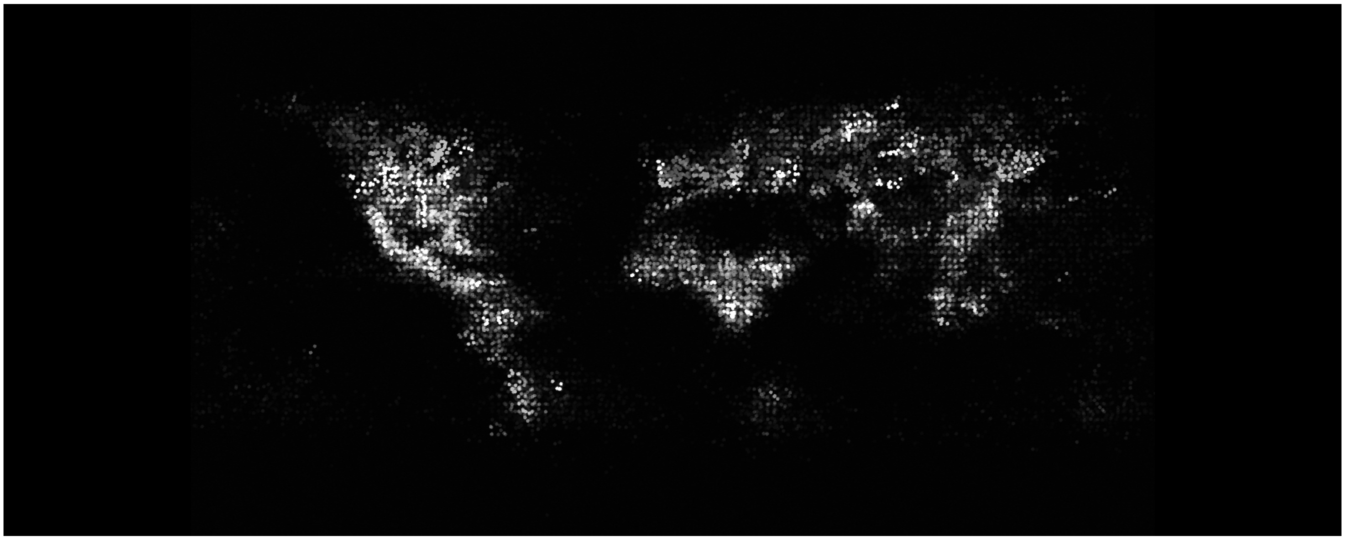

Figure 1: Still image from *Point Cloud* - visualization of lightning occurences over the course of a single year (day 333)

Abstract

Data visualization is a powerful tool to communicate data in a clear, digestible format through graphical means. But in order to be effective, form and function need to work in tandem, filtering layers of noise to reveal the key aspects of the analyzed data. Indeed, this could prove to be sufficient in discovering already known patterns. However, the search for undiscovered patterns would require the full dataset to be presented as a whole, which bears the risk of sensory overload. Our sensory systems function as a systemic unit, in relation to one another, dynamically sampling the signals around us to give a concise scene analysis. In order to decipher a complex, multidimensional dataset, a representational system that is able to reproduce the layers of information through different stimulations would be required. This paper explores the possibilities of using multimodal data representation as a method to communicate multidimensional data, guided by the principles of Gestalt Psychology. *Point Cloud*, an artwork that implements such explorations through the visualization and sonification of lightning data is presented as an application of this research.

Index Terms: Gestalt psychology, Multimodal, Visualization, Sonification, Pointillism, Granular synthesis.

1 Introduction

Scientific data visualization typically relies on clearly identifiable imagery, through unambiguous representations of the data. Any interpretation or preprocessing is designed to extract and enhance patterns and structures in the data. In contrast, artistic projects that use data to drive the generation and behavior of visual elements, rely on the artists' vision to drive interpretation, structure and mapping of the data to image. The goals are not only to transmit information about the data, but also to use the data as a means for aesthetic exploration.

Gestalt psychology describes the ways in which our perception groups and segregates elements in an effort to make sense of what we perceive. In the simplest sense, Gestalt theory describes how separate elements can be fused into a cognitive unit, and this idea can be used to drive the design of data visualization. Because these processes occur at a subconscious level, they always guide, to some extent any creative and design decisions in both scientific and artistic visualization.

By consciously using Gestalt theory to drive the design process, we can somewhat bridge these two approaches, and adjust visualization and sonification techniques to make the spectator a more active participant in the evaluation of data characteristics. In other words, by allowing the human cognitive system to pick up the patterns and behaviors, we leverage one of the tasks at which it excels. This might make a visualization more ambiguous and open to interpretation but it can also assist data discovery and understanding, as structures of data might be discovered by the spectator. In this paper we will discuss the application of Gestalt theories to multimodal displays, and present an implementation of these ideas through the visualization and sonification of lightning data; *Point Cloud*.

2 Gestalt Psychology and Data Visualization

2.1 Gestalt Psychology

Gestalt psychology, which has provided the foundation to the modern study of perception, proposes that the mind strives to grasp the big picture; a global whole. It does this through self-organizing tendencies, in parallel to when the details are perceived. It constantly

*Muhammad Hafiz Wan Rosli, Media Arts & Technology @ UC Santa Barbara, e-mail: hafiz@muhammadhafiz.com

†Andrés Cabrera, Media Arts & Technology @ UC Santa Barbara, e-mail: andres@mat.ucsb.edu

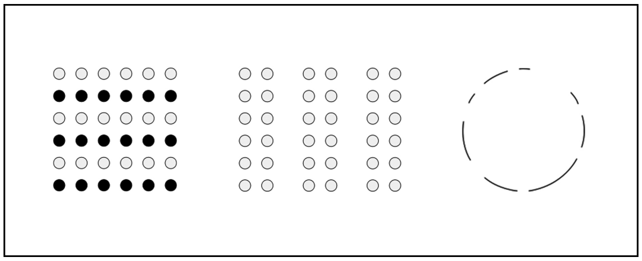

Figure 2: Gestalt laws of grouping: (a) similarity, (b) proximity, (c) closure

tries to extract patterns from a seemingly noisy, chaotic environment.

This articulation might seem rather obvious, for we simply take for granted how our brain organizes stimuli in the physical world. The idea that the mind is able to construct narratives and patterns from a spatial distribution of a set of individual visible points is remarkable to say the least (Fig. 2). Therein lie various principles that are derived from this particular school of psychology, to describe the effects of perception. The principles that seem useful in our context –which are only a subset of the whole Gestalt theory– are explored in this paper and are discussed in section 2.3.

Artists have long explored –both consciouscly and unconsciously– the impact of Gestalt psychology principles and how they affect perception of an artwork. Some artists that were deeply interested in Gestalt psychology, in particular those from the Bauhaus school of thought, include László Moholy-Nagy, Wassily Kandinsky and Josef Albers. The pertinent impact of this mode of thinking is clearly seen in their artwork. Josef Albers, for example championed the idea of "simultaneous contrast", which was also part of von Dürckheim's discussions. In essence, he questioned the true appearance of color, for we never see figures (or colors) by themselves, rather we see them based on their contrast to other elements in the same composition [6]. This is similar to the idea that a melodic line can be transposed into different keys, yet still retain it's overall structure, and convey the same abstract forms and attributes.

Even though these principles are easily evidenced through visual studies, we now know that it is the mind that organizes these patterns, and the visual senses are simply sensors that gather the information. These principles traverse other physiological capacities, working with one another to create a unified "perception".

2.2 Multimodality and Data visualization

Data visualization techniques are excellent at reducing n-dimensional datasets into a more digestible represenation, enabling us to dissect the gist out of the verbatim. However, human perception is much more complex in parsing information. Our input sensors work in tandem with each other, gathering information in the most detailed, complex of ways, whilst the brain receives the information and processes all this data to give us a concise analysis of the surrounding.

It is well known and studied that information from one sense can in fact alter the way events from another are perceived. In particular, multimodality between sight and hearing can affect the perception and judgement of simultaneity and causality [12]. It can also affect the subjective perception of quality and other aesthetic judgements [21]. It is clear that sonification can significantly affect the perception and judgement of a visualization.

There are interactions and relationships between sound elements that allow us to segregate or fuse elements, analogous to visual separation and grouping. Although these auditory interactions were not expressly codified in Gestalt theory, they seem to fit very well with it and pursue the Gestalt principle of wholeness. Multimodal data representations, e.g. combining sonification and visualization of data, can become more effective and clear if these Gestalt principles are applied comprehensively. For example, Auditory Scene Analysis is a model for studying how the human auditory system organizes sounds into groups of coherent patterns which relates to the principles of perceptual organization, explored by the school of Gestalt psychology [8].

2.3 Gestalt as a strategy for data visualization

Gestalt theory has been discussed previously as part of data visualization strategies, particulary in high-dimensional data projections [9]. There is awareness in the data visualization community of the need to incorporate perceptual and cognitive elements in the design of data visualizations to ensure important features in the data are not obscured or confused with others.

Additionally, awareness of Gestalt theories and the impact of multimodal stimuli on perception can inform decisions during the process of constructing data visualization and sonification, to enhance not only its technical, but also its aesthetic aspects.

In this paper we present the artwork *Point Cloud*, which was constructed using this approach. *Point Cloud* is a visualization and sonification of lightning data, presented as a time sequence of occurrences over the course of a single year. This artwork is further discussed in detail in section 3. Pointillism and granular synthesis were chosen as the two techniques for visualization and sonification, as they exploit Gestalt theories of pattern organization and shape discrimination. Both of these techniques rely on some sort of perceptual fusion to achieve a large image made up of microscopic structure. The identity of the micro elements are not perceived, but their composition define the macro structure.

The Gestalt laws that are discussed within this paper pertain to the ability of a specific stimuli to be perceived multimodally. Specifically, the principles that are explored and implemented as part of the visualization, and sonification are as follows:

2.3.1 Figure-ground relationships

A homogenous visual composition creates a mundane space where the perception of depth is unresolved, leading to complications in grouping objects. Without a consistent internal organization, a visual construct is perceived as lacking stratification, resulting in the inability to partition the figure (foreground) and the background. As a system of field organization is introduced, a figure would be perceived to posses an object-like character, whereas the ground with less perceptual saliency. This leads to the tendency to perceive the ground as a mere platform for the figure to be projected on, and the borders between the two to belong to the figure, rather than a separation between the two [20].

Apart from the famous faces-vace drawing described by Edgar Rubin, this principle has been explored in various artistic fields. Two dimensional compositions in art and graphic design use this relationship as a fundamental visual tool to create stratification, and grouping of elements. Negative and white spaces are also concrete examples of how this technique is widely used, for example in the realm of typography. In Japanese culture, the concept of space, or intervals, known as *Ma*, is integral as a structural element that binds the form and the surrounding. Compositions in the auditory domain also adheres to such principles. For example, the temporal hierarchy of structure in music compositions and the management of the structures is thoroughly dissected in *Microsound* [18].

In aesthetic explorations, these relationships help delineate the boundaries between an entity and emptiness. Emptiness, after all, defines the boundary of things. By exploiting patterns or colors that encourage or discourage these relationships, the design of a visualization can point the viewer towards specific structures or groups.

2.3.2 Proximity and similarity

In relation to the previous principle, assuming that the ground is a static, non transforming surface, we are now able to separate the figure from the ground. However, this separation is merely a fundamental backbone in the study of perception. What needs to follow is the grouping of elements as a function of distance. Gestalt theory states that the integration of individual components into a whole can be achieved through the use of the proximity principle: perception tends to group stimuli that are close together as part of the same object (Fig. 2b).

This principle complements the principle of similarity, which states that elements also tend to be integrated into groups if they are similar to each other. Though these two principles work together hand in hand, and can strengthen the organization of elements, they can also be varied independently, to investigate their joint effects on perceived grouping (Fig. 2a) [22].

Interestingly, a new style of painting started to emerge, around the same time Gestalt psychology started to take its shape, with great resemblance between one another. Pointillism is a painting technique derived from impressionism. It relies on the brain's ability to construct forms from disconnected points, even in the absence of clear, definite borders and shapes. By manipulating density, size, the use of color or various other qualities, one is able to elicit onto the viewer the segregation of certain elements in the composition to suggest shapes and forms.

This proximity principle can be exploited in data visualization to encourage perceptual grouping and clustering.

2.3.3 The principle of closure

"Human beings are symbolic animals; confronted with a trace they will seek to interpret it to give it meaning"[19][16]. This is precisely how the principle of closure works. Literally speaking, it's about drawing conclusions. When we are presented with an "incomplete" stimuli, our brain tends to make sense of it, and by making assumptions, we are applying the principle of closure to our perception (Fig. 2c).

By internally breaking up figures, and perceptually subdividing a stimuli into multiple individual parts, it is possible to reverse engineer this effect and cause the disintegration of the whole. This is similar to the camouflage effect used by certain animals in their struggle for survival [11]. Therefore, a presence of a figure in space is not necessarily true whether or not we perceive it, rather it depends on the relationships between the stimuli. Generally speaking, we are extremely competent at figuring out the bigger picture, so long as there is enough information for the principle of closure to take effect.

An excellent visual example of this principle could be found in the works of Oscar Munóz. In his series of works "Re/trato", the artist explores the boundaries of form and the dissipation of form by painting on a hot stone. As new lines are drawn, the previous sections of the painting evaporates. However, albeit the painting is "incomplete", our mind seems to draw conclusions, and sees the full image as though it was still there. The impermanent nature of perception can also be seen in the traditional practice of *Taoism* water calligraphy.

3 Application

Following the ideas presented above, an artistic exploration called *Point Cloud* was developed. This artwork presents the data of lightning occurrences across the world via visual and auditory stimuli. Multimodality in data representation is explored as part of the artwork by carefully *tuning* the excitation for each sense (sight and hearing) in order to exploit the discussed Gestalt principles.

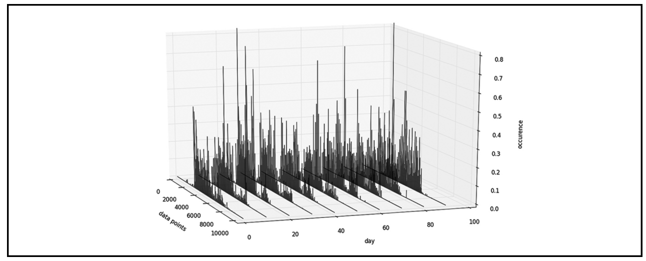

Figure 3: Lightning occurences for flattened (720 x 360) data points over series of days

3.1 Data Source

The data was gathered from the NASA Marshall Space Flight Center (MSFC) [2]. This data was generated by 2 of their spaceborne optical sensors; The Optical Transient Detector (OTD) and the Lightning Imaging Sensor (LIS). The actual data spans over 16 years of lightning information, but for the purpose of this project, only a single year's worth of data was used [10].

The LIS and OTD sensors monitor the 777.4 nm atomic oxygen multiplet, detecting pulses of illumination (produced by lightning) above background levels. Both are onboard satellites in low earth orbit, viewing an earth location for about 3 minutes as OTD passed overhead or 1.5 minutes as LIS passed overhead. Lightning flash times and locations are recorded with approximately 10 km resolution from OTD and 5 km resolution from LIS.

The data takes the form of an annual cycle of flash rates with a product dimension of 720 x 360 x 365 (bin size of 0.5 degree x 0.5 degree) (Fig. 3).

3.1.1 Data management and preprocessing

The MSFC dataset takes the form of Hierarchical Data Format (HDF), which is a data model, library, and file format for storing and managing data. It is designed for flexible and efficient Input/Output, and for volume and complex data [1]. The dataset was parsed using the python *pyhdf* library. The data was resampled and exported as a XML file for visualization purposes, whilst a different sampling factor was used for the purpose of downsampling for the audio synthesis engine.

For the purpose of visualization, and due to computational limitations, the data for each time slice (day) is resampled from 720 x 360 bins to 144 x 72 bins. The resulting bins take the maximum value of the neighboring bins in the original dataset.

3.2 Visualization

3.2.1 Data mapping and aesthetic decisions

There are 365 time slices corresponding to the the number of days in a year. The flash rate (rate of occurrence) values for each bin (144 x 72) is directly mapped to a grid of the same size in the visual domain. If an algorithm is set to draw a single element at each data point, the result would be a mundane repeating cycle, akin to looping a video file (with the length of 365 frames). Instead, the visualization algorithm renders a sequence of points for each data point on the grid. As such, the density of occurrences at a particular location in time retains its overall weight every cycle. However, it does not appear to be an exact repetition of the previous cycle as a result of the algorithm generating random new points every time the data point is updated.

These rendered points are stochastically spread around it's corresponding data point, which serves as the median for a probability density function. The shape of this function's curve determines how far away the rendered points are spread from it's respective origin. The density of points in a particular location corresponds to it's flash rate value. Thus, if a data point contains a value of 0, there will be no rendered points in that region. Consequently, if a data point contains a value of 1.0 (normalized), then the rendered points on that particular data point will have a high rate of appearance. The opacity of rendered points are also correlated to the values of it's corresponding data point, enhancing the perception of density, and proximity.

By using equal sized, monochromatic points, we enable the similarity principle to take effect, grouping them together as an entity, while allowing the figure-ground relationship to take place. A few other visual experimentations included segregating continents/ countries using different sized points, and/ or different colors. However, the usage of colors somehow tends to shy away from the idea of lightning occurrences, making it less of a prominent cue. It also tends to not bridge the connection between the visual and the aural stimuli. Moreover, the usage of different elements in grouping deeper structures lacks the aesthetic simplicity. This is an important aspect of the algorithm, as it allows the participants to focus on other details of the data, rather than be fed with information that occludes the macro structures.

This technique borrows some elements from the Op-Art technique proposed by Marchese [14], as points are represented in a monochromatic grid. However, the addition of randomness in position and the time variation adds a new dimension and proposes a different, more organic aesthetic.

Initial viewing of the piece does not unravel any distinct pattern or configuration. However, as the mind slowly grasps the bigger picture via categorization of forms, the viewer is able to decipher the shape of land masses. In other words, the attributes of the whole are not deducible from analysis of the parts in isolation (Fig. 4). All three Gestalt principles discussed in section 2.3 work in collusion, as empty space helps define boundaries through figure-ground relationships and the principles of proximity and closure help establish the shapes over time.

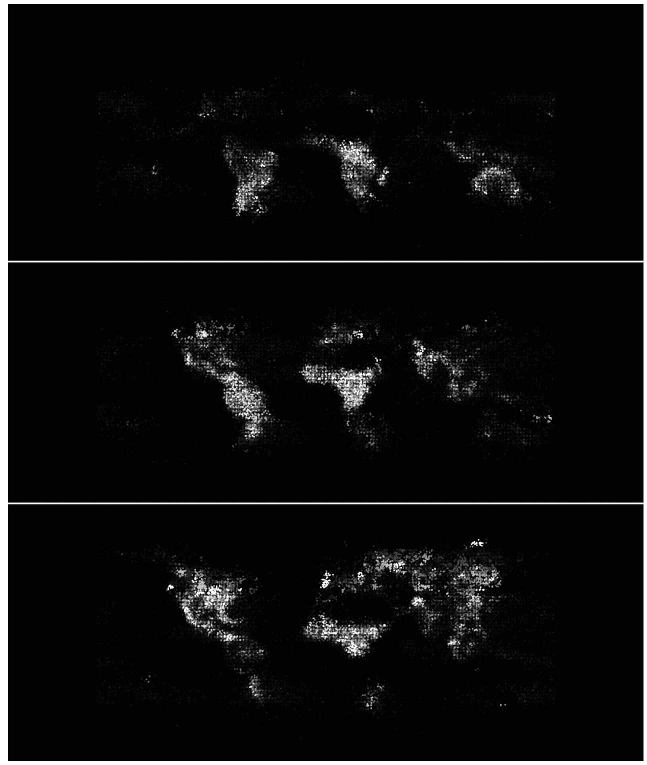

Figure 4: Categorization of forms through time

3.2.2 Ambiguity in data representation

One of the fundamental functions of data visualization lies in its ability to use spatial representation in cohesively enabling the parsing of information. However, as this particular implementation not only functions as a direct visualization, but also as an artistic exploration, formal rules that are otherwise applied to visualization practices are not necessarily adhered to. Such an example can be seen in the ambiguity of representing spatial information.

Indeed, a more direct, logical approach would be in clearly defining the boundaries of continents, or countries so as to clearly identify the occurrences within that particular geographic location. On the other hand, the piece attempts to allow audiences to extract information that is not clearly available from the dataset. By not clearly defining such boundaries, we explore the possibilities of extracting unknown patterns in the dataset. The need to not suggest obvious patterns, in this case the geographic separations, is important so as to allow the audience to not drive obvious conclusions, and instead open to interpretation, enabling other non-obvious patterns to be revealed.

The subtle correlation between lightning occurrence and the angular axial tilt of the earth, and the effect that poles has on lightning occurrences are examples of the patterns that may be extracted. Another association that might be derived is the relationship between a particular geographic location and its direct neighboring (adjacent) locations (data points). This is the case of micro relationships, while the overall macro structure might also contain information that is not necessarily easily parsed otherwise.

The lack of clearly defined boundaries makes it harder for audiences to easily parse the main components of the dataset, causing the sense of scale and landmarks to be hidden from the viewer (at first). Moreover, by resampling the dataset into sparse approximations (Fig 5(a)), we are able to view the structure (trend) of the data as a whole, albeit not necessarily the actual precise values. While the actual values could be obtained from a direct mapping of the dataset (Fig 5(b)), the "blurring" of data could potentially give rise to different *hidden* structures.

3.2.3 The function of negative space

As discussed in 2.3.1, the use of negative space plays a crucial role in the realization of this project. This effect renders itself to be an important component, as it acts as the fundamental backbone, supporting other Gestalt principles. Not only does it assist in giving clarity to the figure-ground relationship by providing a *clear* background, it also implicitly aids the perception of "the absence of boundaries". For example, if the apparent use of negative space is not taken into account, such as in the case of a noisy/ complex background, then the lack of separated elements might not be perceived, and ultimately disables the effectiveness of the figure-ground relationship, and the grouping of meaningful patterns.

It also assists in the perception of the ephemeral temporal domain. By allowing the fading out of previous frames to give rise to newly rendered frames, the negative space of the previous frame is perceptually carried over to the next. This results in an effect much similar to what can be seen in Oscar Munóz's "Re/trato", as discussed in 2.3.3.

3.2.4 Persistence of vision and the time domain

The use of certain qualities (in this case, the use of proximity/ density) to group forms together would not be sufficient to suggest the overall formations, as lightning occurrences do not constantly happen at every data point for each time slice. What this means in the context of this exploration, is that the time domain would need to be exploited in order for the occurrences in the previous time slice to remain in one's perception as the next time slice is visualized. This is crucial because each time slice on its own does not contain

Figure 5: (a) Top: Probability distribution for each data point
(b) Bottom: Direct mapping of each data point

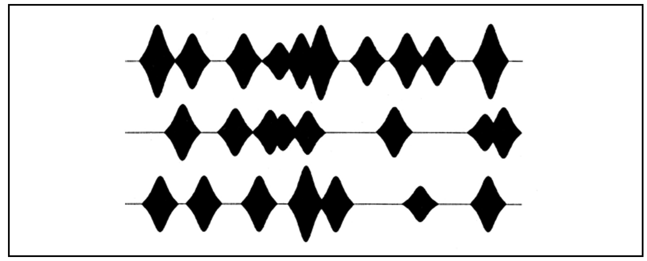

Figure 6: Varying density of 3 granular streams mapped to flash rate [4]

enough information for the brain to deduce the shape of the Earth's solid surface.

Persistence of vision [15] (eye centered) is the phenomenon where an afterimage lingers on for approximately one twenty-fifth of a second (40 ms). This effect, combined with persistence of motion (brain centered), is used to provide a structural basis. The implementation is much simpler than the concept, but the problem statement and solution is pivotal to the realization of the piece. By simply creating individual smooth fade outs for every single rendered visual point (occurrences) over a number of frames, the dataset in the previous time slice is able to be carried forward to the next time slice. In effect, it provides us with a history of the previous occurrences to be juxtaposed with the current ones. The translucency of each point shows how far away (in time) it was from the current (opaque) point. As a result, the overall form becomes more comprehensible, but the form rhythmically moves in and out of ambiguity depending on the density of occurrences in a certain time frame (seasonal transitions).

3.2.5 Data manipulation

In order for the audience to navigate freely through the time domain, an OSC [23] controller is used to define the playback rate of the dataset (365 time slices). The rate could vary from a rate of 1 time slice per second, to 30 time slices per second (approx. 12.2 seconds to complete the annual cycle). At its maximum speed, the rate of change (time slice) is greater than the length of the fade outs, causing the complete image to be formed, before the disintegration of the previously rendered points. The controller allows subtle dynamic time domain changes to enable the audience to view various levels of structure that is present in the dataset. This level of control effects both the visualization, and sonification, thus creating a different textural effect for each time structure.

3.3 Sonification

3.3.1 Synthesis

The technique of sonification is equivalent to visualization for the auditory system. By integrating both approaches in a coherent manner, more information is able to be presented at a given moment without the risk of sensory overload. This is not an easy task, for most implementations risk having each respective sensory stimulus not correlating with each other, causing the stimulation to be perceived as two separate events, i.e: failure to self-organize the grouping of patterns. Another common problem occurs when the data is not resampled into a more suitable format for the respective senses, causing a superfluous flow of information, disabling the data to be parsed.

3.3.2 Granular Reverberation

Thunder is the result of a shock wave caused by a sudden thermal expansion as lightning passes through the air. A typical lightning bolt lasts for about approximately 20 μs. As the mass of energy is introduced into the cumulus cloud enclosure, it's impulse response takes the shape of irregularly spaced delays as a result of the spectral reflections in the cloud formation.

This continuous "rolling" effect can be synthesized using a technique known as granular reverberation. The foundation for granular reverberation is *Asynchronous granular synthesis*, which scatters grains statistically within a region defined on the time/ frequency plane [17]. Each cloud of sound particles' density is effected by the number of grains in a particular region.

By mapping the value (flash rate) of each point in the dataset to the density of grains (Fig. 6), we are able to simulate the frequency of lightning occurrences in that specific location. The maximum amplitude and the duration of the grains in a particular cloud (region) is also mapped to the values of each point in the dataset, as a means to intensify the data mapping.

The usage of synthetic grains with sharp attack and decays, and a lifespan in between 10 ms to 50 ms enables us to evoke the idea of individual bursts of lightning bolts. The short barrage of energy also results in a very strong association with the rendered points in the visualization. This results in the tendency for these two different stimuli to be grouped together as an interconnected event.

3.3.3 Spatialization

For this iteration of the sonification, every dataset point on the same longitudinal plane is clamped down to it's corresponding point on the equator, transforming the 2d dataset of 720 x 360 points into a single dimensional array of 720 values. Depending on the speaker configuration of the art space, the artwork could function in a multichannel setup, or simply in stereo.

The granular textures are mixed together so that all the signals in each longitudinal distance of 5 degrees corresponds to a unique bandpass filter with different upper and lower cutoff frequencies. By doing so, we are able to (theoretically) differentiate the occurrences from one geographic coordinate and the other.

3.3.4 Multimodal principle of past experience

As discussed in previous sections, Gestalt theory functions for various senses, and could be used together to strengthen perceptual attributes. Here, we are exploring "past experience" as a multimodal principle and how two senses merges separate stimuli into a single event. When the auditory perception is fed with a familiar stimulus, it tends to bias the whole perceptual image to the direction that is of known origins. Although this principle is regarded to be lacking in importance compared to the other principles of Gestalt psychology, it plays an extremely important role in our exploration. In this case, the modeling of sounds of thunder elicits that particular phenomena, which then serves as an accompaniment to the visualization. The visual stimulus could not function by itself in providing the context of the whole, and the auditory stimulus would not suffice as a means to provide the full information. However, when fused together, they form a more concise, overall representation of the dataset.

3.4 Tools

The initial version of the piece was realized using a heterogeneous setup to allow fast prototyping. The data parsing, handling and processing was done using python, in particular the interactive ipython notebook. The visuals were done using processing [3], and the sonification was done using Csound [7] within the ipython notebook. The synchronization and data interchange between aplications was done using Open Sound Control [23].

3.4.1 Materials

Source material can be downloaded from:
http://muhammadhafiz.com/downloads/pointCloud/materials.zip

4 Conclusion and Future Work

Explorative methods on the possibilities of the applications of Gestalt psychology towards multimodal data representations have been presented within this paper. However, much work needs to be done in exploring what the limits are for our different senses in receiving separate stimuli for data representations, how our different perceptions react to different stimuli, and how they interact with one another.

We are currently in the process of porting the work for the Allosphere [13]. The Allosphere is a 3-story facility that contains a 10 meter diameter sphere that provides 360^o realtime stereographic visualization using a cluster of servers driving 26 high-resolution projectors. Audio is projected by 54 loudspeakers positioned along three rings of the sphere. Porting to the Allosphere will require using AlloSystem, the software that allows synchronization and blending of the projectors for surround rendering. The challenge ahead is porting from high level and domain specific languages to a single C++ code base.

As we are exploring multimodality in data representations, it is only natural to find new ways in pursuing 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 enable better localization of sound sources, and to study how it correlates to a certain visual position in space.

For example, in the context of *Point Cloud*, it would then be possible for us to geographically localize occurrences based on the visual stimulus alone (mapped to geographic coordinates). In addition, it would also be possible for us to "tune-in" on the frequencies of a particular cloud of grain to listen to concurrent occurrences throughout the globe [5].

Acknowledgements

The authors wish to thank CREATE and the Allosphere Research Group for the usage of facilities during the prototyping phase. This work was supported in part by the Graduate Program in Media, Arts and Technology at the University of California, Santa Barbara. The AlloSphere infrastructure is based upon work supported by the National Science Foundation under Grant Numbers 0821858, 0855279,and IIS-1047678.

References

[1] The HDF group - information, support, and software. http://www.hdfgroup.org/. Accessed: 2014-06-28.
[2] Nasa marshall space flight center. http://www.nasa.gov/centers/marshall/. Accessed: 2014-06-28.
[3] Processing.org. https://www.processing.org/. Accessed: 2014-06-28.
[4] Truax, Barry (SFU). http://www.sfu.ca/ truax/. Accessed: 2014-06-28.
[5] X. Amatriain, J. Kuchera-Morin, T. Hollerer, and S. T. Pope. The allosphere: Immersive multimedia for scientific discovery and artistic exploration. *IEEE Multimedia*, 16(2):64–75, 2009.
[6] R. R. Behrens. Art, design and gestalt theory. *Leonardo*, pages 299–303, 1998.
[7] R. C. Boulanger. *The Csound book: perspectives in software synthesis, sound design, signal processing, and programming*. MIT press, 2000.
[8] A. S. Bregman. *Auditory Scene Analysis: The Perceptual Organization of Sound*. MIT Press, 1994.
[9] A. Buja, D. Cook, and D. F. Swayne. Interactive High-Dimensional Data Visualization. *Journal of Computational and Graphical Statistics*, 5(1):78–99, 1996.
[10] D. Cecil et al. Gridded lightning climatology from trmm-lis and otd: Dataset description. 2012. doi:10.1016/j.atmosres.2012.06.028. Accessed: 2014-06-28.
[11] K. Gottschaldt. *[Gestalt factors and repetition]. Psychologische Forschung [English translation and condensation in W. D. Ellis (1958). A source book of gestalt psychology]*. London, Routledge & Kegan Paul, 1926.
[12] M. Grassi and C. Casco. Audiovisual bounce-inducing effect: When sound congruence affects grouping in vision. *Attention, Perception, & Psychophysics*, 72(2):378–386, Feb 2010.
[13] J. Kuchera-Morin, M. Wright, et al. Immersive full-surround multi-user system design. *Computers & Graphics*, 40:10–21, May 2014.
[14] F. T. Marchese. Op-glyph: A tool for exploring op art representation of height and vector field data. In *Proceedings of the Working Conference on Advanced Visual Interfaces*, AVI '02, pages 103–107, New York, NY, USA, 2002. ACM.
[15] H. Münsterberg. *The Photoplay: A Psychological Study*. D. Appleton and Company, 1916.
[16] J.-J. Nattiez. *Music and discourse: Toward a semiology of music*. Princeton University Press, 1990.
[17] C. Roads. *The Computer Music Tutorial*. MIT Press, Jan. 1996.
[18] C. Roads. *Microsound*. MIT Press, 2004.
[19] C. Roads. *Composing Electronic Music: A New Aesthetic*. New York, Oxford University Press, Forthcoming.
[20] E. Rubin. *Figure-Ground Perception In: Readings in perception. Translated from German by M. Wertheimer.* Princeton, NJ: Van Nostrand. (Original work published 1915.), 1958.
[21] D. Västfjäll, M. A. GulbolL, M. Kleinier, and T. Gärling. Affective evaluations of and reactions to exterior and interior vehicle auditory quality. *Journal of Sound and Vibration*, 255(3):501–518, aug 2002.
[22] M. Wertheimer. *Laws of organization in perceptual forms*. Harcourt, Brace & Jovanovitch, London, 1938.
[23] M. Wright. Open sound control: an enabling technology for musical networking. *Organised Sound*, 2005.