# *An Elemental Approach*
# to Animation and Sound in Information Graphics

*Along with an Apologia For Doing It*

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## Introduction

The growing availability of relatively low cost computer hardware and software has opened up new options for information graphics design and production. Static graphics have been the primary focus of attention as well as the primary medium for representing information. The static graphic will continue to dominate information graphics because it is economical, easy to distribute, and the most appropriate and powerful medium for much of the information that we want to represent. However, several new media are emerging as viable *additions* to more traditional representational forms.[1] These new media are broadening the toolbox of representational options available to information graphics designers. This paper will discuss two of these new media: animation and sound. Both media will be discussed in the context of cartography, but the ideas should transfer over into the broader realm of information graphics in general.

## Approaches to Information Graphics

An evolution of sorts can be traced in the changing approaches to information graphics in general and cartography in specific. The earliest approach to the construction of visual representations of information could be called the "craftsman" approach. Simply put, the craftsman approach consisted of individuals producing maps and graphics within a craft-based, individualistic setting: techniques and methods were learned through practice or from more experienced masters of the trade. A more methodical approach to information graphics developed when either outsiders (such as psychologists) or insiders (such as cartographers) began to attempt to understand how graphics worked, were used, and how they could be better. This approach borrowed the notion of the scientific method as a basic guiding principle, and thus can be called the scientific approach to graphics. The approaches gathered under this heading are

1 "New" here is meant only in the sense that these media are now viable choices for information graphics designers.

broad: visual psychophysics,[2] perceptual studies,[3] cognitive studies,[4] and representation.[5] This approach to information graphics has produced a large body of information which suffers from the lack of any general synthesis; this has resulted in repetitious studies and a general lack of appreciation for what has been achieved. Recently this scientific approach to information graphics has been questioned at various levels.

One set of critiques has been from actual graphics practitioners. Michael Macdonald-Ross, in an attempt at synthesizing some of the research on information graphics, has pointed out some failings of the scientific approach: the failure to take into account the practical time and cost constraints of creating graphics; the horrible quality of stimulus material used in many experiments; and the inappropriate and sometimes goofy nature of the tasks which subjects in tests are often asked to perform.[6] Barbara Petchenik, a practicing cartographer, has taken the critique a step further and stated unequivocally that the scientific approach to information graphics as it stands is at best limited and at worst a research dead end.[7] While the practicing information graphicist can undoubtedly learn something from scientific research on graphics, the critique by Macdonald-Ross and Petchenik is important to consider: information graphics practitioners may just ignore the research of individuals who never make information

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[2] For example, see: I. Spence. "Visual Psychophysics of Simple Graphical Elements." *Journal of Experimental Psychology: Human Perception and Performance.* 16, 1990. pp. 683-692.

[3] For example, see: Michael Dobson. "The Future of Perceptual Cartography." *Cartographica.* 22:2, 1985. pp. 27-43.

[4] For example, see: Steven Kossyln. "Graphics and Human Information Processing." *Applied Cognitive Psychology.* 3, 1989. pp. 499-512.

[5] For example, see: D.E. Rumelhart and D.A. Norman. "Representation in Memory." In: R.C. Atkinson, R.J. Herrnstein, G. Lindzey, and R.D. Luce (eds.). *Steven's Handbook of Experimental Psychology.* New York: John Wiley and Sons, 1988. pp. 511-587.

[6] Michael Macdonald-Ross. "How Numbers are Shown: A Review of Research on the Presentation of Quantitative Data in Texts." *Audio-Visual Communication Review.* 25:4, 1977. pp. 359-409.

[7] Barbara Bartz Petchenik. "A Map Maker's Perspective on Map Design Research 1950-1980." In D.R.F. Taylor. *Graphic Communication and Design in Contemporary Cartography.* New York: Wiley and Sons, 1983. pp. 37-68. Michael Dobson's reaction to Petchenik's article (his "The Future of Perceptual Cartography") in effect argued that Petchenik was wrong because being "anti-scientific" is not scientific.

graphics because the findings do not seem to relate to real world problems and applications of information graphics.

A more "academic" critique of the scientific approach to information graphics has come from various "postmodern" and "postobjectivist" perspectives. Brian Harley, for example, has questioned the positivistic, objectivist notion of the map as an unproblematical representation of reality and has argued for cartographers to admit the social, political, and human issues bound up with the map. While Harley's attack on "scientific cartography" is based, arguably, on a notion of cartography that is somewhat of a straw-man, his general gist is important. Harley has in effect attempted to get at some notion of what maps "actually are" as opposed to what they ideally "should be."[8] A related approach is that of the "ethnomethodologists" who have instigated a series of scientific lab studies which have begun to reveal how the scientific process works in practice. The ethnomethodological approach has also looked carefully at the use of representations in the scientific process, including text and graphics.[9] Harley and the ethnomethodologists are, like Macdonald-Ross and Petchenik, critiquing the scientific approach to graphics as too detached from application and practice and too dependent on assumptions of objectivity and scientific rigor.

A final critique of the scientific approach to information graphics can be derived from the literature dealing with appropriate technology. This literature arose from the realization that the third world was being caught up in a cycle of first world technological colonialism followed by technological fixes used to solve the problems caused by the initial technologies. Recent work has started to question, in a more general sense, the

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8 John B. Krygier. "Visualization in a PostObjectivist World." Paper presented at the 1991 Annual Meeting of the Association of American Geographers. p. 2. J.B. Harley. "Maps, Knowledge, and Power." In: Denis Cosgrove and Stephen Daniels. *The Iconography of the Landscape: Essays on the Symbolic Representation, Design and Use of Past Environments.* Cambridge: Cambridge University Press, 1987. pp. 277-312. J. B. Harley. "Deconstructing the Map." *Cartographica.* 26:2, 1989. pp. 1-20.

9 See the series of articles collected in Michael Lynch and Steve Woolgar (eds.) *Representation in Scientific Practice.* Cambridge: The MIT Press, 1990.

usefulness of research performed out of the context in which it is to be applied, and has argued that there is not any one generic solution to a problem – that solutions are context dependent and vary from once context to another.[10] This position supports and is supported by the position of Macdonald-Ross, Petchenik, Harley, and the ethnomethodologists, and, again, is an important consideration for individuals interested in research involving information graphics.

The various approaches to information graphics and the current debate concerning the scientific approach serve to frame the topic of this paper: the elements of cartographic animation and the elements of sound maps. My approach to both of these new media has been detached, context-free, and generic in obvious affront to the (in my opinion) viable objections that such an approach is problematical. However, the scientific, elemental, objectivist approach is only problematical if it is seen as providing strict rules and regulations for information graphic construction and use. That is not my intention. Instead, the following discussion only claims to be providing a loose body of notions which will toss the aspiring information graphics animator or sound mapper into the ballpark of adequate information design. What follows are some ideas which provide a place to start and, possibly, a useful way of beginning to think about how animation and sound can be applied to information graphics. What follows, hopefully, will also serve as a source of more interesting questions and applications. If truth is that which works itself out in practice, then, by god, it is time to get to work.[11]

## Animated Maps and the Dynamic Visual Variables

### Introduction

Animated maps have recently been re-attracting attention. A small barrage of

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10 I have yet to find any literature specifically applying the notion of appropriate technology to information graphics. My paper "Visualization in a NonObjective World" discusses the idea. The closest published literature is Lakshman Yapa. "Is GIS Appropriate Technology." *International Journal of Geographical Information Systems.* 5:1, 1991. pp. 41-58.

11 Thanks to Charles Peirce and William James for pointing this out.

articles and animated map videos have appeared in the last year, primarily due to the recent availability of relatively low cost and high power animation software.[12] The attraction of animation is in its ability to *dynamically* represent phenomena which vary in space and time, phenomena which is of interest to many geographers. This revitalized interest has served to raise a series of questions about cartographic animation.

First, what does animation provide as a cartographic medium? The most obvious answer would be the visualization of change through time and space. Yet it is obvious that we can have temporal change represented quite well with static graphics, as on the famous Minard graphic illustrating Napoleon's march to and retreat from Moscow. However, as is evident with Minard's graphic, time in static graphics is mapped onto space whereas with animation *time is mapped onto time.* When is animation appropriate? What are the advantages and disadvantages of mapping time onto time? A review of the literature on the temporal aspects of spatial phenomena may be a fruitful approach to understanding when animation is appropriate, when it can reveal more than a static graphic. Obviously the static graphic is not going to go away: at this point in the development of animated information graphics we need to be careful about demeaning the power and cost-effectiveness of static graphics. The question of when animation is appropriate is, then, tied closely to the nature of spatio-temporal phenomena and to the capabilities of static maps to represent change over time.

Second, the question of how to design an animated map is one of critical importance. Completed animation sequences have revealed to us the fact that many traditional cartographic design principles have to be rethought for animated maps. Current work in progress is revealing new design approaches for TV quality output and its limitations of resolution and color. Strict color standards have been set and they limit

[12] Philip J. Gersmehl. "Choosing Tools: Nine Metaphors of Four-Dimensional Cartography." *Cartographic Perspectives.* 5: Spring 1990. pp. 3-16. Alan MacEachren and David DiBiase. "Animated Maps of Aggregate Data: Conceptual and Practical Problems." forthcoming in *Cartography and Geographical Information Systems.*

design freedom and choices. Defining the limits of this "headroom" is an important task if we are to learn the design constraints of cartographic animation.[13] Further, the nature of the graphic representation, according to graphics semiotician Jacques Bertin, changes drastically when time is mapped onto time. Bertin is primarily known for his matrix of visual variables which have been influential in cartographic design. The semiology of graphics that Bertin devised, he warns, only holds for static graphics: "the intervention of real movement...would make us pass from the graphic system...into film, whose laws are very different."[14] The approach we have taken is to attempt to transform Bertin's semiology of static graphics into a "semiology of dynamic graphics," to ask if his contentions about the drastic changes "real movement" imposes on his visual variables are actually viable. The justification for attempting this modification of Bertin's matrix is simple: the visual variables have served as a useful way of thinking about graphics at a basic, elementary level for graphics practitioners. Obviously one can argue about what should or should not be included in the matrix, or argue that some of the variables are based on other variables. This line of argument misses the point. The matrix of visual variables cannot be ultimately specified and is somewhat arbitrary, an imposition of order on a complicated topic. Obviously something need not be "true" to be useful, and the visual variables have been useful, especially in teaching graphics.

**Previous Studies**

Interest in animated maps is not new. In an article published in 1942 Heinz Soffner detailed the possibilities of map animation:

> In the motion picture lies a highly essential but much neglected field for pictorial

[13] NTSC standards must be followed for television broadcasting; the standards help prevent such graphic nightmares as "chroma crawl" which smears high saturation colors. These standards should be followed whenever video is to be the presentational medium. See Don Pirius and Phil Gersmehl. "Tips and Techniques for Maintaining Visual 'Headroom' on Animated Maps." Abstract of paper presented and 10th Annual meeting of NACIS. *Cartographic Perspectives,* 7, 1991, p. 27.

[14] Jacques Bertin. *The Semiology of Graphics.* Madison: University of Wisconsin Press, 1983.

statistics. . . . the screen offers the best imaginable opportunities for "dynamic" visual information. On the screen arrows can really move as opposing armies advance or retreat, statistical columns can grow or shrink, frontiers can be violated and empires can literally "crumble." The effect created by such "living" maps and graphs can be further heightened by an effective accompaniment of words or music. One could both see and hear a "frontier" "break down," the tramping "men" in the statistical column "join the army," "the whistling ships" slide down the ways and the like.

Why not include such a map feature, dynamically illustrating current war events, in the newsreels? Why not visualize the growth of line-lease aid, the progress of the war-bonds campaign, in pictorial statistics that move? Why not portray Germany's exploitation of the occupied countries by maps on which the confiscated goods actually march into the Reich? Or depict the effect of air raids, swarms of planes (in symbols) dropping bombs across a map of strategic and key industrial points? Why not dramatize the unrest in Nazi-occupied Europe by flashing on a map those places where hostages have been executed, troop trains have been derailed, underground papers have been secretly edited and printed.

These few suggestions indicate how great can be the improvement in the techniques and therefore the effectiveness of visual means for conveying information about the war.[15]

For what it's worth, the first cartographer to formally discuss map animation was Norman Thrower in 1959.[16] His article contemplated ideas of time and sound in cartography, and saw map animation as a way to appeal to an audience conditioned by television and movies. The first investigation of computer cartographic animation is in an article by Cornwell and Robinson in 1966.[17] The point is made that the computer will make cartographic animation easier and more applicable, and interactive maps (via "electro-mechanical gloves for object control") will become common. Tobler (1970) created a cartographic animation of a population model,[18] and this wedding of geographical models and map animation influenced Moellering who turned out a series of computer animated maps over the next decade.[19] Moellering's later work was

15 Heinz Soffner. "War on the Visual Front." *The American Scholar* 11:4, 1942. pp. 476-77.

16 Norman J.W. Thrower. "Animated Cartography." *The Professional Geographer.* 11:6, 1959. pp. 9-12. Also see: Norman J.W. Thrower. "Animated Cartography in the United States." *International Yearbook of Cartography.* 1:1, 1961. pp. 20-30.

17 Bruce Cornwell and Arthur H. Robinson. "Possibilities for Computer Animated Films in Cartography." *The Cartographic Journal.* 3:2, 1966. pp. 79-82.

18 Waldo R. Tobler. "A Computer Movie Simulating Urban Growth in the Detroit Region." *Economic Geography.* 46:2 (supplement), 1970. pp. 234-40.

based on animation software available on a super computer at Ohio State University. Real interest in cartographic animation did not surface again until microcomputer based animation software packages became available in the late 1980's.

## Approaching Animation in Information Graphics

A three tiered approach to cartographic animation will be detailed below.[20] First, we sought to evaluate Bertin's visual variables in the context of animation. Second, we sought to define any additional variables which animation added to the visual variables. Finally, we derived four basic applications of cartographic animation. These ideas are illustrated in the video "An Elementary Approach to Cartographic Animation."[21] The video is meant to be a first step in deriving some basic understanding of the elements of cartographic animation.

## The Visual Variables in a Dynamic Setting

We chose to create a matrix of visual variables adapted from Bertin's original matrix.

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[19] Harold Moellering. "Mapping Traffic Crashes in Washtenaw County by Computer." *HIT LAB Reports, Highway Safety Research Institute,* March 1972. pp. 1-5. Harold Moellering. "The Computer Animated Film: A Dynamic Cartography." *Association for Computing Machinery,* 1973. pp. 64-69. Harold Moellering. "A Journey to Death: A Spatial Analysis of Fatal Traffic Crashes in Michigan, 1969. *Michigan Geographical Publications,* #13, Department of Geography, University of Michigan, Ann Arbor, 1974. Harold Moellering. "At the Interface of Cartography and Computer Graphics." *Computer Graphics,* 9:1, 1975. pp. 256-59. Harold Moellering. "The Potential Uses of a Computer Animated Film in the Analysis of Geographical Patterns of Traffic Crashes." *Accident Analysis and Prevention,* 8:4, 1976. pp. 215-27. Harold Moellering. "A Preliminary Report on the Real Time Cartographic Animation of Three-Dimensional Objects." *Applied Geography Conference I,* 1978. pp. 51-61. Harold Moellering. "A Demonstration of the Real-Time Display of Three Dimensional Objects." *Computer Animated Videotape: Department of Geography, Ohio State University,* 1978. Harold Moellering. "The Real-Time Animation of Three-Dimensional Maps." *American Cartographer,* 7:1, 1980. pp. 67-75. Harold Moellering. "Real Maps, Virtual Maps and Interactive Cartography." In: Gary L. Gaile and Cort J. Willmott. *Spatial Statistics and Models.* Hingham: Reidel Publishing Company, 1984. pp. 109-32.

[20] The following discussion is in part based on the script for the video *An Elementary Approach to Cartographic Animation.* Created and written by David DiBiase, John Krygier, Catherine Reeves, Alan MacEachren, and Alan Brenner. Video: Penn State Department of Geography, 1991.

[21] The following discussion varies a bit from the video. We have already revised a few of the video topics, and I have changed a few things where my opinions differed from the group's opinion.

We added several additional visual variables which seemed to merit inclusion, and chose appropriate "cells" in the matrix to animate. The animations are basic, and were chosen to illustrate how the static visual variables are affected by animation. The illustrated variables include: the x, y dimensions of the plane, size, value, hue, saturation, orientation, shape, arrangement, texture, and focus. It is hoped that such basic elements will be useful in selecting graphic techniques for cartographic animation. The addition of examples of animated maps which incorporate the illustrated visual variables would make the video more useful; as it stands, suggestions as to some applications of the various animated visual variables are mentioned in the script of the video.

Our conclusion with regard to the first part of this work is that it is obvious that Bertin's visual variables are applicable to animated maps, contrary to what he implies. While the addition of time to the visual variables extends the application of the variables, in essence they remain similar to their static counterparts.

**The Dynamic Variables**

Bertin's visual variables do, then, transfer over to the realm of animated graphics. However, the original variables are not dynamic in and of themselves. The second part of our research sought to define what (if any) variables were added by the dynamic nature of animated graphics. After much argument and wrangling we decided that two basic dynamic variables are distinguishable. To provide a setting for these variables, we defined a conceptual framework which included a distinction between "representational objects" and "representational devices."[22] The representational object is the object that one seeks to represent; the representational device is the graphic means, in this case, by which the representational object is represented.[23] (see

[22] Terms from: Paul Tibbetts. "Representation and the Realist-Constructivist Controversy." In: Michael Lynch and Steve Woolgar. *Representation in Scientific Practice.* Cambridge: The MIT Press, 1990. pp. 69-84.

[23] Yes, the notion of representational objects and devices and their implications are problematical upon reflection; alas, remember that something need not be "true" to be useful.

figure one).

Our first dynamic variable is **duration**. A single, static instant in time (the RO) is called a "situation" and its representation (the RD) is a "scene."[24] A scene is analogous to a static map. Duration is "the number of units of time which a scene is shown."[25] The cartographic animator controls the duration of a scene, a situation which is not applicable in the realm of static graphics.[26] Any other aspects of a scene are related to variation in the visual variables.

Our second dynamic variable is **rate of change.** An "event" is a "coherent sequence of two or more situations" (in the realm of the RO) and its representation (the RD) is, likewise, comprised of at least two scenes.[27] A scene, remember, is analogous to a static map; therefore the representation of an event can be best accomplished with an animated map.[28] Two basic changes can be represented by cartographic animation: change in **position** and change in **attribute**. Change in position is a variation of the x, y dimensions of the plane variable in Bertin's matrix. Change in attribute is a variation in the size, value, hue, saturation, orientation, shape, arrangement, texture, and focus variables. The rate of these two types of change is defined by the relationship between the scenes in the cartographic animation: the **duration** of each scene and the **magnitude** of change in position and/or attribute. The variation of duration and magnitude are illustrated in the video. Thus rate of change, with its two "sub-variables" duration of scene and magnitude of change in position and/or attribute comprises a second dynamic variable.

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[24] Terminology borrowed from Janos Svego. *Human Cartography.* Swedish Council for Building Research, 1987.

[25] David DiBiase, et. al. *An Elementary Approach to Cartographic Animation.*

[26] Duration in the static realm is determined by the individual viewing the map.

[27] David DiBiase, et. al. *An Elementary Approach to Cartographic Animation.*

[28] It is possible to represent an event with a static map via superimposition; however, as the number of scenes increases, so does the usefulness of animation.

**Basic Applications of Cartographic Animation**

Cartographic animation, as mentioned above, gives us the option of mapping time onto time. The visual variables and the dynamic variables together comprise the basic variables available for cartographic animation. The last segment of our research sought to define the way in which the temporal dimension can be applied. We suggest four basic applications: temporal symbols, time series animation, spatial touring, and reexpression. These applications were illustrated with a data set of actual and predicted temperature and precipitation values for various sites in Mexico.[29]

Temporal symbols are the most basic use of time in animation. A temporal symbol is a symbol which uses some type of temporal transformation to attain an effect, but the symbol is not really tied to any temporal aspect of the referent. A perfect example is the color cycle which is often used as a symbol for the jet stream in TV weather forecasts. While the referent in this case, the jet stream, does have a temporal dimension, the symbol, the color cycle, has an arbitrary temporal dimension which is not mapped to the temporal dimension of the jet stream. Time, in other words, is used as a symbol.[30]

Time series animation is by far the most typical use of cartographic animation. Time, in this case, is mapped to time. For example, a isorithmic map of precipitation data for the United States over the past several decades could be animated. Our video animates histograms which represent monthly precipitation and temperature data for twelve sites in Mexico along with predicted values from five different climate models.

Spatial touring refers to such effects as fly-bys and zooms where some object is viewed from different perspectives or at different scales. Time, in this case, is part of the mode of viewing some object as opposed to a dimension of the object itself. Of course, the object itself can have a temporal dimension, and spatial touring can be used with an object which is, for example, a time series animation.[31]

29 Predicted values were from five different climate models.

30 This application of time was not thought of until after the video was created.

31 Again, this application of time was changed from the video where the term used was data touring.

Our final application is the least obvious of the three we suggest. Reexpression, a term borrowed from John Tukey, refers to "the systematic reordering of chronological sequences of scenes by a data variable other than time"[32] – in English, to map some variable other than time onto time.[33] For example, one could map crimes committed in a city, located at points. The animation could take place over a one month period, with points being highlighted when the crime was reported. The length of time that the crime location is highlighted would be a function of the severity of the crime. Thus, this example combines the more typical time series with a reexpression where the severity of a crime is mapped onto the temporal dimension. Our example in the video represents a reexpression of months from least divergent predictions to most divergent predictions of temperatures in Puebla, Mexico. The duration that a month is shown increases as the divergence increases, focussing attention on the most divergent months. Divergence, in this case, is mapped onto the temporal dimension. The animation reveals greatest variation in the spring months. Our second example illustrates the observed and predicted January temperatures for the twelve Mexican sites, reexpressed in terms of increasing divergence of the observed and predicted temperatures.[34]

## Conclusions

In sum, our research has comprised of a three tiered approach to cartographic

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The first problem with "data touring" as presented in the video is that it is really a form of reexpression, for which a discussion follows. In addition, the term "touring" has a specific meaning in statistics which does not fit with our definition.

[32] David DiBiase, et. al. *An Elementary Approach to Cartographic Animation.*

[33] Or to rearrange time into another order. See the next footnote.

[34] The video example of "data touring" is really a kind of reexpression where time is reordered. Our example refers to the Merida station on the Yucatan peninsula, and displays the months in which the mean model predictions for temperature are the most divergent – in this case the winter months. A similar reexpression of the precipitation data reveals that the summer months yield the most divergent predictions. This pattern was not immediately obvious from the original time series data, and the researcher who provided the data was surprised to see the pattern. One could construct additional data reexpressions: the months with the least divergence of model predictions or the months with the best predictions. One could select any one of the five models and perform the same type of data reexpressions.

animation. First, we applied animation to Bertin's original visual variables matrix and concluded that in essence the visual variables can be brought over into the realm of cartographic animation. This is not to say that nothing changes; certain emergent properties of animating some of the variables are evident, for example the apparent movement in the line/texture variable. Actual applications of these techniques will undoubtedly reveal more questions and complications.

Second, we defined two dynamic variables which cartographic animation provides: the duration of one scene and the rate of change between multiple scenes. These dynamic variables are not available in the realm of static graphics.

Finally, we identified four basic applications of the temporal dimension: temporal symbols, time series animation, spatial touring, and reexpression. All four of these applications arise from the integration of the temporal dimension into cartographic representations.

To stress a point made earlier: the approach we have taken to animated maps is elementary and cannot be exhaustive. There are emergent and higher level structures which operate in the context of cartographic animation. What we are claiming is that we have taken the initial steps toward providing a basic tool box of techniques from which actual applied cartographic animation can start. At minimum this project provides a basic educational tool with which to introduce the idea of cartographic animation to students. At best, it may provide an approximate but useful way of thinking about cartographic animation, much as Bertin's original matrix has served as a useful basis for thinking about static cartographic design.

## Sound Maps and the Audio Variables

### Introduction

A second "new" dimension available for data representation is sound. Again, as with animation, the presentation of information via sound is nothing really new. However, it is increasingly easy to integrate sound into data exploration and presentation systems. With the increasing desire to have more channels of information available sound is certain to play an important role in future information graphics.

Obviously our sense of vision is much more dominant and sharp than our sense of sound, or at least it seems to be. Yet one only has to think about the environment of sound which surrounds us in our day to day existence to realize that the sonic aspects of space have been severely undervalued in comparison to the visual.[35] Sound plays an important but often unrecognized role in our lives. We can look to the experience of the blind to see how important sound is and how it serves as an important element in understanding and navigating through our environment.

The ability of sound to communicate information is obvious. Human communication is primarily carried out via speech and we are quite used to using audio cues in our day to day lives – from the honk of a car horn to the beep of a computer to the snarl of a cranky dog as we approach it.[36] In bringing sound into the context of information "graphics," then, we need to be aware of the way in which sound is perceived and used to communicate information. We must also be aware of the problem of "cognitive overload," of barraging the user with too many different dimensions of sound.[37] Finally, we have to gain an understanding of how people deal with sound in a conscious manner – what training is needed to make people able to successfully use sound as a data exploration and presentation technique.

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[35] See Diane Ackerman. "Hearing." in *A Natural History of the Senses.* New York: Random House, 1990. pp. 173-226.

[36] Ronald Baecker and William Buxton. "The Audio Channel." In: Ronald Baecker and William Buxton. *Readings in Human-Computer Interaction.* Los Altos: Morgan Kaufman Publishers, 1987. pp. 393-99.

[37] Meera M. Blattner, Denise A. Sunikawa and Robert M. Greenberg. "Earcons and Icons: Their Structure and Common Design Principles." *Human-Computer Interaction,* 4:1989. pp. 12. Also See: "Workers in Close Quarters May Not Be Ready for Noisy Computers." In: *Centre Daily Times,* State College, PA. Monday, March 18, 1991, 1991. pp. 9E.

## Previous Studies

Previous studies which have approached the question of sound as a data exploration and presentation tool have generally found sound to be a valuable addition to more traditional visual techniques.[38] Yeung mapped seven dimensions of information (relating to a specific chemical) with sound and found that test subjects were able to correctly classify the chemicals with a 90% accuracy rate before training and with a 98% accuracy rate after training.[39] Lunney and Morrison used high/low pitches and pitch duration to map out "sound graphs" and found that users were able to comprehend the graphs with relative ease.[40] Bly presented subjects with six dimensional data, two dimensions in visual form and four dimensions in sonic form. She found that subjects were able to deal with information presented in sonic form as well as they could with information presented in visual form. Using sound and visual forms together slightly increased the ability to perform the task.[41] Mezrich, Frysinger, and Slivjanovski presented subjects with redundant visual/sonic information and found that sound added to the test task success.[42] Mansur, Blattner, and Joy compared tactile graphs to sound graphs and found comparable accuracy of information communication capabilities. However, sound graphs were found to be a quicker way of communicating information

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[38] Reviews of this literature and current applications can be found in: Ivars Peterson. "Some Labs are Alive with the Sound of Data." Science News, 127:June 1, 1985. pp. 348-350. Ronald Baecker and William Buxton. "The Audio Channel." William Buxton. "Introduction to This Special Issue on Nonspeech Audio." *Human-Computer Interfaces,* 4:1989. pp. 1-9. S. Joy Mountford and William Gaver. "Talking and Listening to Computers." In: Brenda Laurel. *The Art of Human Computer Interface Design.* Reading: Addison-Wesley, 1990. pp. 319-334.

[39] Edward S. Yeung. "Pattern Recognition by Audio Representation of Multivariate Analytical Data." *Analytical Chemistry,* 52:7, 1980. pp. 1120-1123.

[40] E. Lunney and R.C. Morrison. "High Technology Laboratory Aids for Visually Handicapped Chemistry Students." *Journal of Chemical Education,* 58:3, 1981. pp. 228-231.

[41] Sara Ann Bly. *Sound and Computer Information Presentation.* Unpublished PhD, University of California, Davis, 1982. Sara Ann Bly. "Presenting Information in Sound." *CHI '82 Conference on Human Factors in Computer Systems,* pp. 371-375.

[42] J.J. Mezrich, S. Frysinger and R. Slivjanovski. "Dynamic Representation of Multivariate Time Series Data." *Journal of the American Statistical Association,* 79:385, 1984. pp. 34-40.

and were easier to create.[43] Williams, Smith, and Pecelli asked subjects to match visual texture patches; the performance improved with the addition of a specific sound texture to each patch.[44] A data "visualization" system which integrates sound tools is currently under development at the University of Lowell.[45]

## Approaching Sound in Information Graphics

There are several ways to approach the implementation of sound for information graphics. First, it seems important to look to the nature of environmental sound and how we deal with it and use it to cope with day to day existence. Such an approach can look to the literature on the perception of sound,[46] the literature on the ecological approach to sound,[47] the literature on the cognition of sound,[48] the literature on acoustic communication,[49] and the literature on the geography of sound.[50]

A more basic level approach to sound as a dimension in information graphics

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43 D.L. Mansur, M.M. Blattner and K.I. Joy. "Sound Graphs: A Numerical Data Analysis Method for the Blind." *Journal of Medical Systems,* 9, 1985. pp. 163-174.

44 Marian G. Williams, Stuart Smith and Giampiero Pecelli. "Computer-Human Interface Issues in the Design of an Intelligent Workstation for Scientific Visualization." *SIGCHI Bulletin,* 21:4, 1990. pp. 44-49.

45 The "Exvis" system is detailed in Marian G. Williams, Stuart Smith and Giampiero Pecelli. "Computer-Human Interface Issues in the Design of an Intelligent Workstation for Scientific Visualization." Stuart Smith, R. Daniel Bergeron and Georges G. Grinstein. "Stereophonic and Surface Sound Generation for Exploratory Data Analysis." *Proceedings of the Association for Computing Machinery Special Interest Group on Computer Human Interfaces,* 1990. pp. 125-32. Stuart Smith and Marian Williams. "The Use of Sound in an Exploratory Visualization Environment." *Department of Computer Science University of Lowell Technical Report* No. R-89-002, 1989. 16 pp.

46 Albert Bregman. *Auditory Scene Analysis: The Perceptual Organization of Sound.* Cambridge: MIT Press, 1990. Stephen Handel. *Listening: An Introduction to the Perception of Auditory Events.* Cambridge: The MIT Press, 1989.

47 William W. Gaver. *Everyday Listening and Auditory Icons.* Unpublished PhD, University of California, San Diego, 1988.

48 William W. Gaver. *Everyday Listening and Auditory Icons.*

49 Barry Truax. *Acoustic Communication.* Norwood, NJ: Ablex Publishing Co., 1984.

50 Birger Ohlson. "Sound Fields and Sonic Landscapes in Rural Environments." *Fennia,* 148:1976. pp. 33-45. Douglas Pocock. "Sound and the Geographer." *Geography,* 74:3, 1989. pp. 193-200. J. Douglas Porteous and Jane F. Mastin. "SoundScape." *Journal of Architectural Planning Research,* 2:1985. pp. 169-186. R. Murray Schafer. *The Tuning of the World.* New York: Knopf, 1977. R. Murray Schafer. "Acoustic Space." In: D. Seamon and R. Mugerauer. *Dwelling, Place, and Environment.* Dordrecht: Martinus Nijhoff, 1985. pp. 87-98.

concerns the delineation of audio variables and symbols. As with the dynamic visual variables, a set of audio variables is not absolutely differentiatible; instead, a basic array of audio variables from which to start thinking about the use of sound can be derived.

The impetus to derive a series of audio variables is based upon two approaches to sound that can be found in the literature. First is the literature which seeks to build and define audio icons or "earcons" for computer interface uses.[51] Second is the literature which is focused on using sound as a data exploration tool.[52] Both of these approaches are based on a similar notion of audio variables which can be built up into audio symbols. The "earcon" literature tends to deal with one dimensional sound symbols. Such symbols can be generated with one speaker and are generally not located at any specific point. A simple example would be the common warning beep most computers are equipped with; another example would be a "thunk" sound when a document was successfully dragged into the trash can in the Macintosh interface. The data exploration literature, on the other hand, has pushed the use of sound into two and even three dimensions. Two dimensional sound "surfaces" are created with stereo speakers and sounds can be located left/right or up/down. Three dimensional sound "volumes" are created with the use of stereo headphones and add the effect of backward/forward to the effects found in two dimensional sound displays.[53]

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51 Meera M. Blattner, Denise A. Sunikawa and Robert M. Greenberg. "Earcons and Icons: Their Structure and Common Design Principles." William W. Gaver. "Auditory Icons: Using Sound in Computer Interfaces." *Human-Computer Interaction,* 2:1986. pp. 167-77. William W. Gaver. *Everyday Listening and Auditory Icons.* William Gaver. "The Sonic Finder." *Human-Computer Interaction,* 4:1989. pp. 67-94. S. Joy Mountford and William Gaver. "Talking and Listening to Computers."

52 Marian G. Williams, Stuart Smith and Giampiero Pecelli. "Computer-Human Interface Issues in the Design of an Intelligent Workstation for Scientific Visualization." Stuart Smith, R. Daniel Bergeron and Georges G. Grinstein. "Stereophonic and Surface Sound Generation for Exploratory Data Analysis." Stuart Smith and Marian Williams. "The Use of Sound in an Exploratory Visualization Environment."

53 Durand R. Begault. "The Composition of Auditory Space: Recent Developments in Headphone Music." *Leonardo,* 23:1, 1990. pp. 45-52. Jens Blauert. *Spatial Hearing: The Psychophysics of Human Sound Localization.* Cambridge: MIT Press, 1983. Elizabeth Wenzel, Frederick Wightman and Scott Foster. "Development of a Three-Dimensional Auditory Display System." *SIGCHI Bulletin,* 20:2, 1988. pp. 52-57. Elizabeth Wenzel, Frederick Wightman and Scott Foster. "Development of a Three-Dimensional Auditory Display System." *SIGCHI Bulletin,* 20:2, 1988. pp. 52-57. William Yost and

The rest of this section will be concerned with a review of the audio variables and some of their possible uses. I will be concerned mainly with abstract audio variables, and will not deal directly with representational audio symbols which are digitized natural sounds. The advantage of such representational audio symbols is similar to the advantage of representational or pictorial cartographic symbols – they sound/look like what they represent. On the other hand, there is an obvious role for abstract audio variables since many of the things that could be mapped in sound have no natural aural counterpart. Further, it could be argued that even natural, representational sonic symbols have as their basis some abstract audio variables.

## The Audio Variables

One group of researchers argue that rhythm and pitch should be "fixed parameters" of basic sound symbols, or "motives."[54] Another name for a motive is a "sonic event."[55] I shall complicate the matter and call these "motives" and "sonic events" sound symbols. A sound symbol has one or both of two basic fixed elements, then, rhythm and pitch. To "extend" the meaning of this symbol one can engage additional variables which modify the sound of the symbol but do not change its basic characteristics. For example, "mary had a little lamb" is recognized as the essentially the same if played on different instruments or at a different level of loudness.

### *1. rhythm: The grouping and ordering of sounds*

Rhythm is one of the most effective and recognizable audio variables, and one of the primary means of distinguishing one sound symbol from another. It is temporal, as most audio variables, and has many elements: frequency, duration, intensity, meter, beats,

George Gourevitch. *Directional Hearing.* New York: Springer-Verlag, 1987.

54 Meera M. Blattner, Denise A. Sunikawa and Robert M. Greenberg. "Earcons and Icons: Their Structure and Common Design Principles." pp. 22-23.

55 Stuart Smith and Marian Williams. "The Use of Sound in an Exploratory Visualization Environment."

rate, and silence. Rhythm can represent qualitative and quantitative information.

*2. pitch: the frequency of a sound*

Pitch is highly distinguishable and is also a very effective way of differentiating sound symbols. There are eight octaves of twelve pitches each; extreme pitches, however, are hard to distinguish. The most obvious mapping of pitch is onto information which contains highs and lows: sound graphs can be created by varying the pitch to match the varying graphed curve. In addition, high pitches seem to represent high location or quantity; low pitches low location or quantity. Pitch, then, can represent quantitative information, primarily ordinal.

Several "variable parameters" of sound symbols can be specified. As mentioned above, these audio variables modify the sound of the symbol but do not change its basic characteristics. These variable parameters of sound symbols can be used alone for simpler sound symbols.

*3. timbre: The general or prevailing quality or characteristic of a sound*

Timbre describes the character of a sound and is best described by the sound of different instruments: the brassy sound of the trumpet, the warm sound of the cello, the bright sound of the flute, etc. As such, timbre denotes qualitative change.

*4. register: "The relative high/low of a pitch or set of pitches"*[56]

Register describes the location of a pitch or set of pitches within the range of available pitches. It can represent location in the vertical plane and direction.

*5. dynamics: The loudness or softness of a sound*

Dynamics can be manipulated to create various different effects: a constant pitch, a pitch which increases (crescendo) and a pitch which decreases (decrescendo). Dynamics

[56] Meera M. Blattner, Denise A. Sunikawa and Robert M. Greenberg. "Earcons and Icons: Their Structure and Common Design Principles." pp. 27.

can represent direction, location, scale change, distance, and intensity.

Other audio variables of interest can be distinguished. As with the dynamic visual variables, the audio variables are not easy to distinctly define, and some "variables" contain elements which themselves can be distinguished as variables.

*6. duration: the length a sound is heard*

On one level, duration can refer to the length of a single sound and can represent some quantity mapped to that duration. On another level, duration can refer to the length of a sound symbol comprising various audio variables. In the case of the latter, it is not clear how well humans can deal with complex sound symbols with long durations.

*8. location: the location of a sound in a two or three dimensional sound space*

Location as an audio variable is more important to stereo or three-dimensional sound although it can be roughly seen to work with, for example, a sound decreasing in pitch to represent something moving from higher to lower. Two- and three-dimensional sound would allow for more accurate mapping of left/right, up/down, forward/backward locations.

**Proposed Case Study**

In a 1987 paper, Ronald Abler delineated a plan for National Science Foundation research initiative called the National Center for Geographic Information and Analysis (NCGIA). Tucked away in the article is a brief mention that the NCGIA should investigate "non-cartographic techniques for visualizing spatial relationships."[57] Exactly what this means is unclear, but the use of sound as a way of dealing with data exploration and communication seems to fit the bill.

[57] Ronald Abler. "The National Science Foundation National Center for Geographic Information and Analysis." *International Journal of Geographical Information Systems.* 1:4, 1987. pp. 310.

I propose a simple prototype system which can demonstrate the use of sound for mapping information. This prototype should be sophisticated enough to be able to create and test the use of the audio variables as outlined above, and to determine if sound is a viable addition to information graphics.

Maps tend to be "totalizing" creatures; they impose strict lines and points and areas where no strict structures actually exist or where the certainty of their location is uncertain. On one hand, this is why maps are so useful, and it is obvious that maps enable us to deal with our uncertain and messy world by making it look more certain and tidy. Yet it seems important that some sense of the "quality" of the represented data be available. One method, currently being investigated by a graduate student in the geography department here at Penn State, is to design graphic representations of uncertainty. The advantage of such an approach is that it gives one a visual presentation of what uncertain data looks like. There is a rich history of such visual presentation of uncertainty – many historical atlases for example, show past migration of peoples in a manner which stresses that what is know about the migration is "fuzzy" and not well established. On the other hand, taken to its logical extreme, a map which visually displayed uncertainty would often become a blurred mess, looking more akin to a satellite photo than a map. The purpose of maps, remember, is to impose order on the chaos, not to accurately represent chaos.

I propose an alternative approach to "visualizing" uncertainty which uses the sound capabilities of the computer. Quite simply, one would construct a "sound map" which underlies the visual map and can be accessed if and when it is necessary. This sound should be constructed to represent some aspect of the data at that point, line, or area on the map.

Two levels of sound maps can be constructed. First, and simplest, is the one dimensional sound map. The click of a mouse at any position on the visual map would cause a specific sound symbol mapped to that specific point, line, or area to be "heard;"

dragging the mouse would reveal a variation of sound as the sound-mapped data varied. A sound representing the level of uncertainty could be represented by how "flat" a chord or series of pitches are. By dragging the mouse one could begin to move toward a representation of a two dimensional space; but the effect would be like having a small "window" with which you could only see a small portion of a map at one time. Can people build up an audio "image" of the entire sound map from these small glimpses? Possible applications of this technique are many: a click at a point could reveal a voice reading the elevation or a sound representing the relative highness or lowness of the crime rate in a county. In any case, a sound legend would be needed to help the user learn the symbols on the sound map.

A two dimensional sound map or sound texture can be created with special equipment. Such a sound map would be the next step beyond dragging the mouse over the surface of the map. A two-dimensional sound space is created in which the relationships of left/right and up/down are mappable. Stereo (and possibly headphones) would be necessary to create these effects. Smith, et. al., have created such a sound texture by turning on all of the sounds located on the two dimensional plane at once.[58] The sound space can be on all at once, or can be activated in a line that runs across or up and down the surface. One could speculate that an actual "all at once" sound map could be created using these techniques. The easiest application would be a quantitative map, for example the AIDS map in the following figure.[59] (see figure two). Sounds which use the pitch or dynamics variables could be used to create a two-dimensional map. It is also possible to add the third dimension – forward and backward

58 Marian G. Williams, Stuart Smith and Giampiero Pecelli. "Computer-Human Interface Issues in the Design of an Intelligent Workstation for Scientific Visualization." Stuart Smith, R. Daniel Bergeron and Georges G. Grinstein. "Stereophonic and Surface Sound Generation for Exploratory Data Analysis." Stuart Smith and Marian Williams. "The Use of Sound in an Exploratory Visualization Environment."

59 Where the top map represents the graphic representation of the data and the bottom map represents a "graphic" approximation of a sound representation of the same map. The squares are locations in a two dimensional sound space; the darker the square the louder the sound (dynamics) or higher the pitch.

located sounds – and to create in essence a sound space. It is unclear how well the locations of these two- and three-dimensional located sounds can be controlled and how well people could deal with them. We obviously deal quite well with three-dimensions of sound in our day to day lives; this ability may transfer over into the realm of sound maps.

**General Conclusion**

This paper began with a brief and general overview of the current setting in which research in information graphics is situated. I argue that a critique of generalizable and "context-free" research on information graphics is evident in the trenches of information graphics design and production as well as from the academic realm. I am not arguing that "scientific" research is irrelevant, but that it is time to take seriously the idea that there are interesting insights and questions that emerge in the process of solving real graphic problems. Once found, solutions to these problems can be evaluated "scientifically." This supposition does not mean that the individual interested in information graphics has to cow tow to the often inane and tedious graphic problems that are quite common in the "real world;" instead I would suggest that there are many interesting applications and topics upon which information graphics could make a major impact.

This paper offers two elemental investigations: the dynamic visual variables and audio variables. These two pieces of research must be taken for what they are, starting points. The next step is to apply these two "new" media to real problems and to see if the elemental approach taken in the research for this paper is viable and useful in practice – this is what I will be doing this summer. Application will undoubtedly suggest additional arenas of research and interesting graphic problems which need to be solved.