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John H. Flowers
University of Nebraska-Lincoln, jflowers1@unl.edu

Laura E. Whitwer
University of Nebraska-Lincoln

Douglas C. Grafel
University of Nebraska-Lincoln

Cheryl A. Kotan
University of Nebraska-Lincoln

SONIFICATION OF DAILY WEATHER RECORDS: ISSUES OF PERCEPTION, ATTENTION AND MEMORY IN DESIGN CHOICES

John H. Flowers, Laura E. Whitwer, Douglas C. Grafel & Cheryl A. Kotan

Department of Psychology
University of Nebraska -- Lincoln
P.O. Box 880308
Lincoln, NE 68588-0308
USA
jflowers1@unl.edu

ABSTRACT

Daily climate records that include temperature and precipitation observations, along with other optional "event" records (such as a severe storm occurrence or the highlighting of record high or low temperatures) are a form of multivariate time series data that is well suited to sonification. Our project describes and demonstrates sonification of historical monthly weather records from Lincoln, Nebraska that allow perceptual comparisons between corresponding monthly records from different years for illustration of climatic trends and fluctuations. Choices of data-sound mapping schemes and temporal properties of the display will be related to basic principles of auditory perception, attention and cognition.

1. INTRODUCTION

Recent concern about global climate change has heightened both public and scholarly interest in present and historical weather records. Within the folk culture of the United States, and particularly within regions (such as the Great Plains) that experience large fluctuations in weather conditions across seasons and between years, one hears many verbal accounts of memory of historical weather events. For example, long time residents of the Central Plains region, in response to complaints about the summer heat by members of a younger generation may say something like "This is *nothing!* Back in the '30's it was so hot and dry that…" Unlike retrospective reports of other social or historical events, it is relatively easy to assess accuracy of weather related recollections. Historical climatic data is typically well documented (from the late 19th century in the central US and even further back in other regions). Weather records, are now becoming increasingly accessible to both the public and to researchers through on-line resources. For example, daily weather records for Nebraska can be examined or downloaded from the High Plains Regional Climate Center (www.hprcc.unl.edu). Such data are crucial component of climate research, a valuable educational resource, and they can be used by the general public to verify Uncle Louie's recollection of July, 1936.

Raw listings of daily observations are highly useful for many research purposes. However, for making quick overall comparisons between two or more weather data samples (e.g, comparing July, 1936 with July, 2000), or for purposes of teaching about such differences in the classroom, tabular listings of high and low temperatures and rainfall amounts for each of 31 days are not very efficient. Graphic representations of various designs are one useful way of providing summaries of weather data for illustrating trends and comparisons. We would argue, however, that the use of auditory representation of sequential weather records offer potentially compelling display format, that, in addition to providing a means for access to blind and visually impaired individuals, may be useful to individuals with normal vision -- and may even be "fun" to listen to.

There are several features of sequential weather observations, particularly daily records of temperature and precipitation that make it particularly amenable to sonic display. First, the data are themselves sequential observations across time, and sound displays can directly represent the temporal relationships. Secondly, weather events are often metaphorically represented in music (e.g. Beethoven's Sixth Symphony, William Tell Overture, and countless movie scores) suggesting that assignment of effective mappings of weather data to sound will be feasible. Perhaps most importantly however, the data domain is a highly familiar one for which internal schemas are well established in memory.

2. PERCEPTUAL & COGNITIVE FACTORS IN DESIGN

Our initial goal was to develop an effective auditory format for representing a monthly period of weather data, initially consisting of daily high and low temperatures and daily rainfall amounts. We also wished to provide a flexible format that could be supplemented with other event markers such as snowfall amounts during winter months, and possible markers or beacons for severe weather events or extreme temperatures. While we envision applications in which several months of data could be joined to produce a musical representation of a year or longer, our primary interest was to provide a compact but compelling sound description of a monthly period that allow efficient perceptual comparisons with other monthly data records. Our initial "bare-bones" prototype design thus required representation of three variables: High temperature, Low Temperature and Precipitation. Based on our experience with studying other types of auditory data displays [1,2] two major cognitive/perceptual design constraints shaped our choice of auditory data mappings. First it is necessary to select pitch, timbre and temporal properties of the streams that would allow attention to be efficiently divided among them, while avoiding having one stream mask another. Secondly, the temporal length of monthly should be optimized to fit the constraints of working and auditory sensory memory, given the specific task for which the displays are being used. For making sequential comparisons between monthly samples of monthly observations, the optimal display duration should be relatively short without being so compact that important data features cannot be accurately perceived. Given what is known about the effective duration of human auditory sensory memory (echoic memory), display durations of less than 10 seconds might be preferable for making such comparisons. However, for other tasks such as searching a single longer data record for presence or density of critical features (like heavy rainfall events), a slower presentation rate of sonified data might prove optimal. Temporal optimization of auditory data displays is thus likely to be dependent upon both the complexity of the data, and the specific task of the user. Real world applications of such displays should therefore be implemented with options for control of presentation rate.

2.1. Choice of MIDI Format

Since relatively high quality MIDI synthesizers are now available with most personal computers, the MIDI format seemed to offer a useful platform for implementing weather sonification. Furthermore, the "track" structure of a MIDI file, allowed the separate assignment of different data streams (temperature, rainfall, snowfall, etc.) to separate tracks that were easily hand edited for initial design exploration and testing. Our current sonification procedure consists of a Visual Basic Routine that transforms text files of temperature and precipitation daily values into text versions of MIDI commands that can be compiled by MF2T/T2MF software.

2.2 Sonification of Temperature (MIDI Track #1)

High and low temperature values constitute separate data variables – however we chose to integrate them into a four note alternating "motif" that "framed" the temperature range for each month using synthetic strings (General Midi Instrument #50). The note number was scaled to temperature in order to provide a five octave pitch range (from C4 to C9; MIDI notes 36 to 96) across the temperature range in Lincoln, Nebraska daily observations (-36C to +46C or –33F to 115F). The four-note motif (high-low-high-low) provides a redundant presentation of the temperature range for each day. Since our presentation of precipitation information is placed in the last half of the time period used for a given day, this format assured that at least one presentation of the high and the low would occur on each day without risk of masking by events in the precipitation track. A similar strategy appears to have guided the temporal separation of midi events, and the use of coherent motifs as opposed to single pitch representations in the far more complex multivariate ice core data recently sonified by Quinn [3].

2.3 Sonification of Rainfall (MIDI Track #2)

To allow perceptual segregation of rainfall information from the temperature screen, a very different timbre (Grand Piano, Instrument #1) was chosen. Daily precipitation amounts contained in the weather records we are investigating, range from zero on most days, a "trace" (meaning less than 0.01 inches or 0.025 cm) on some days, to a maximum value of 5.42 inches (13.77 cm). Since agricultural and other consequences of rainfall are not linearly related to daily amounts, we elected to use a partially categorical scheme for representation of rain. No precipitation sound occurs on days without precipitation. Amounts of less than 0.05 inches are indicated by a sixteenth note C9 (note 96), that produced brief, single "plink". For amounts between 0.05 and 0.5 inches, two sixteenth notes are played. C9 is followed by a second note, for which the pitch *decrease* from C9 is scaled to the precipitation amount. The scaling equation is represented by the following equation:

$$N = Int(96-(8.8*P(i))) \quad (1)$$

Where N is the MIDI note value, and $P(i)$ is the precipitation amount in inches on the ith day of the month.

The second note is also played at a greater MIDI volume (velocity=80) as compared with the first note (velcocity=64). Thus amounts in this range are heard as "double plinks" with the second note slightly louder than the first. Rainfall amounts greater than 0.12 inches produced a pitch drop in the second note (ranging up to 4 semitones for a 0.49 inches rainfall).

For precipitation amounts in excess of 0.5 inches, a sequence of three consecutive sixteenth notes is played. The pitch drop from the first to third is scaled to amount by equation (1) and the pitch value of the second note was the integer value of the mean of the MIDI note numbers of the first and third notes. Three-note sequences, representing these larger precipitation values, also increase in loudness. Velocity values are 64. 80, and 96 respectively. With this mapping scheme, the heaviest daily rainfall in our Lincoln, Nebraska records, a 5.42 inch amount on July 25, 1990, is represented a three-note sequence dropping over a four octave range.

The choice of a "pitch drop" representation was made for metaphorical reasons. Light rain is indicated by single very high plinks (analogous to single raindrops), and heavier rain "comes down harder." Rainfall amount is thus redundantly represented by the specification of one, two, or three note sequences for categorically different amounts, and by pitch drop from the starting note of C9.

2.4 Snowfall Representation (MIDI Track #3)

During winter months, snowfall constitutes a third category of significant weather data for the Northern Plains Region of the United States. Like rainfall events, economic and social consequences of snowfall are not linear with amount. Snowfalls of less than one inch (2.54 cm) have relatively minor consequences. Amounts in the 1-3 inch range can become a minor issue for automobile travel. Amount of 3-6 inches can require substantial effort for road clearance and travel safety. Larger amounts, which are relatively infrequent events in eastern Nebraska, can create major travel problems and closures of business and schools. We thus chose to use the number of daily "snow" notes in a "snow event" to specify four "impact categories." Very light snow (<1 inch) is indicated by a single note, 1-3 inch amounts by two notes, 3-6 inch amounts by three notes, and amounts in excess of 6 inches by a four note sequence. The pitch range of these notes is also scaled to amount, in one-inch units. Each "inch bin" has a unique sequence of notes associated with it, with the pitch of the final (highest) note scaled the to amount range. For example, a snowfall of 2.-2.99 inches will be a two note sequence of MIDI notes 84 and 86 (C8, D8), while an 8-8.99 inch fall would be a four note octave "arpeggio" consisting of notes 84, 88, 91 and 96 (C8, E8, G8, C9). Hence snowfall is indicated by an *ascending* series of one to four sixteenth notes, categorized to the nearest inch. Whereas "rain comes down" in our representation, snow "piles up." As an additional means of emphasizing the perceptual distinction between rain and snow, we chose a different timbre for the "snow track" – dulcimer, or MIDI instrument #15. Of several choices available on our sound card synthesizer, this instrument was judged to be particularly "wintery" by a sample of faculty and graduate students who informally listened to several different options.

2.5 Performance Evaluation and Display Optimization

The major focus of the present report has been to describe the cognitive ergonomics of the design of a multivariate auditory time-series display. This design process constitutes the initial step in an ongoing research program that is investigating actual performance of users of such displays for a variety of simulated tasks. These include comparative judgment tasks, and tasks requiring direct judgment of quantitative and qualitative aspects of the displayed data. While a detailed description of this research plan is beyond the scope of this report, several specific research objectives should be mentioned. These are the issues of the efficiency of perception of the data patterns (including comparisons with visual table and graph displays), temporal optimization, and effects of adding additional data streams. The first two issues are being investigated jointly, since they are most likely not independent. The optimal display duration for rating specific dimensions of data in single samples may be quite different from the optimal duration for making comparisons between entire samples on several characteristics or in sorting them according to overall similarity. For both overall classification tasks employing comparative judgments and sortings of stimulus displays and attribute judgment tasks we are using displays of varying display rates. Multidimensional scaling and cluster analysis of comparative judgments can reveal overall perceptual structure of a set of stimuli, and such structures can be directly compared with the known quantitative and temporal distribution properties of monthly weather events. Will the behaviorally derived structures qualitatively differ for displays having different rates of presentation? Will display rates change the correspondence between perceptually derived structures and the actual properties of the original data -- and if so, what presentation rates maximize that correspondence? Since winter months in Nebraska tend be more complex than those of summer owing to joint presence of snow and rain, and wide fluctuations in temperatures, it seems possible that optimal presentation rates could differ for these seasons. Similar findings may also result with tasks involving direct attribute rating. Unfortunately, very little prior research on auditory display efficiency has directly addressed temporal optimization of multivariate displays. Our findings should thus be useful to development of other applications involving auditory display of multivariate information.

3. POSSIBLE FUTURE ENHANCEMENTS

3.1 Enhancing Extreme Temperature Values

In our present design, we have a partially categorical scheme for representing precipitation. In addition to using pitch to indicate amount, different "impact categories" have different amounts of notes. With temperature, our present displays use only analog pitch changes. It could be argued that extremely high or low temperatures represent meteorologically (or psychologically) important "impact categories" as well. For example temperatures above 100F have consequences for both humans and agriculture, as do temperatures below freezing. Our software is easily modifiable to add tracks to indicate or emphasize values in a critical range. For example instrument doubling such as adding a piccolo track for temperatures above 100F or a tuba track for temperatures below freezing could be employed. As an alternative to timbre shifts, significant temperature crossings or year "records" could be "beaconed" or "alarmed" by addition of unique instruments on added tracks (e.g., a bell to indicate first frost of the season). Such enhancements could be valuable when using monthly weather displays as "summary earcons" for searching archived records.

3.2 Indicating Other "Significant Events."

Markers of significant or severe weather events (e.g., tornado, hail, wind damage, etc.) might be useful. The addition of tracks that have particular "event motifs" could be added to our display format as additional tracks. For displays that portray an extended period of time (e.g. an annual display of daily weather records) markers indicating time intervals or month boundaries might also prove useful. The ability to write supplementary tracks that contain such additional information would be a desirable feature of future weather sonification software.

4. SUMMARY AND CONCLUSIONS

The sonification of daily weather observations provide an example of representing multivariate time series data by sound – a general scheme that could be applied to a variety of other time series data that includes both continuous and event-based information. Because of the familiarity of weather information to the general public, weather sonification has potential to introduce auditory display principles to a wide audience, and to alert developers of assistive and educational technology to the usefulness of sonification. In addition to conducting experimental research on the efficiency and optimization of these types of displays, linking sonic displays to public weather databases could provide a forum for evaluation by the general public.

5. REFERENCES

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