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Animated Visual Vibrations as an Uncertainty Visualisation Technique

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Abstract

Research into the visualisation of imprecise data is a relatively new field in visualisation. Work is beginning to appear detailing the process of visualising uncertainty in data. Continuing previous work by the author, this paper seeks to extend techniques used to visualise uncertainty from the spatial to the temporal domain, by using visual vibrations to indicate the level of imprecision at a visualised data point. The paper contains an analysis of the present visual features used to indicate imprecision, and then details a methodology for using visual vibrations to display the uncertainty contained in visualised data. Novel additions include addressing chart junk issues outlined by Tufte, additions of perceptual factors and extension to stereo vision applications.

CR Categories: I.3.8 [Computer Graphics] – Applications; I.3.3 [Computer Graphics] Picture/Image Generation – Viewing algorithms; [Computer Graphics] Methodology and Techniques – Interaction techniques.

Keywords: Uncertainty Visualisation, Vibrating Textures, Visual Features, Stereo Vision.

1 Introduction

Data does not exist at an infinite precision, and as such, visualisation schemes should include approaches to highlight the amount of error attached to the data. This is a relatively new field within data visualisation, and work has been carried out into the appropriate representation of such error values [Lodha et al. 1996] [Gershon 1992], [Johnson and Sanderson 2003] and the related area of Fuzzy set representations [Pham and Brown 2003].

Analysis of the present state of the art in visualisation shows that a number of visual features have been suggested and used for the visualisation of uncertainty. A precise of the possible features used is shown below [Gershon 1998; Johnson and Sanderson 2003; Pham and Brown 2003]:

- Intrinsic representations – position, size, brightness, texture, color, orientation and shape;
- Further related representations – boundary (thickness, texture, and colour), blur, transparency and extra dimensionality;
- Extrinsic representations – dials, thermometers, arrows, bars, different shapes and complex objects – pie charts, graphs, bars, or complex error bars;

While these features are an effective metaphor of imprecision, there are two things to note. They may not have a direct perceptual connection to the concept of uncertainty and they do not include the temporal domain as a possible method for uncertainty representation.

The term *uncertainty* refers to such dictionary words as accuracy, sureness, precise determination and dependability [Hanks 1989]. However, in order to map an appropriate set of features to the human concept of uncertainty, a tighter definition is required. Pang notes, that there is no real consensus on the definition of uncertainty and its related terms [Pang 2001]. To further obfuscate the issue, there is another set of terms used by the Fuzzy set community for the definition of precision in data [Berkan and Trubatch 1997; Pham and Brown 2003].

This paper will focus on the concept of uncertainty and avoid the other related terms: error, accuracy, validity, quality and noise. In particular, the technique in this paper will deal with mapping the term uncertainty to a visual vibration feature. Figure 1 illustrates this mapping from a *task-oriented* viewpoint, and is derived from a visualisation data ontology outlined in previous work [Brown and Pham 2003].

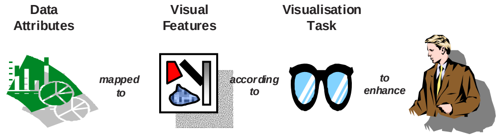

Figure 1 Illustration of the process of mapping attributes of the data to visual features which are then viewed through a task filter as a perception of the information.

The diagram outlines the major components needing to be considered before creating a visualisation. The mapping begins with the choice of *data attributes* to be represented: relationships, resemblances, order and proportion [Gershon 1998]. These attributes are mapped to *visual features* depending on the *visualisation task* to be performed. The visualisation task is chosen to enhance the perception of the

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information required by the viewer. The knowledge required for such a task-oriented approach is encapsulated in an agent-based visualisation architecture that has been developed in previous work [Brown and Pham 2003].

With regards to the perception of the uncertainty of segments of a data set, some of the features mentioned previously do not map intuitively. For example, mapping the uncertainty in data to a color map as a feature does not produce an immediate perception of uncertainty in the data, it has to be interpreted via a higher level cognitive process.

However, of the visual features listed, blurring has the most immediate and intuitive mapping to uncertainty, as it simulates the visual percept caused by an incorrectly focused visual system. Thus, the viewer is presented with a direct perception of the accuracy of the data, without needing to resort to a mapping requiring more cognition. Therefore, it can be argued that it is a very effective metaphor for the concept of uncertainty. This blurring metaphor is now investigated in detail.

Blurring is removal of spatial high frequency details from information [Russ 1992]. This high frequency information is used to represent fine detail, and its removal reduces the ability of the viewer to recognise fine features, producing uncertainty as to its contents. Within the context of visualisation of uncertainty, this effectively smears the boundary between two values, inducing a sense of uncertainty as to what value occupies a particular spatial location. A number of visual features may be used in a similar manner, for example, *hue* and *luminance*.

Hue can be used to represent uncertainty by a smearing of its values, for example, between green and red passing through the colour yellow, as well as the smearing of luminance between black and white. Blurring can also be seen as an interpolation scheme, inserting values between two positions along a data dimension. Thus, other features may be blurred, including: hue *saturation*, glyph *sizes*, *opacity*, to reduce the sharpness of the boundaries between the values in spatial regions.

This blurring metaphor can be extended to the temporal domain via animation [Gershon 1992; Lodha et al. 1996]. While animation has been used before to represent error values, no one has analysed these animations in the light of the chart-junk described by Tufte and the overuse of visual vibrations in visualisations [Tufte 1983]. Furthermore, no-one has fully investigated its applicability, especially within the context of perceptual constraints, when applied to the visualisation of uncertainty.

Most animations described in the literature highlight uncertainty, but do not use the period of the animation to create a blurring effect. Finally, this work extends the blurring metaphor to stereo visualisation of data, via the spatial disruption of binocular fusion.

2 Temporal Extension to Blurring

The previously described blurring principle can be extended to the temporal domain. A way to represent uncertainty would be to allow two values to exist in the same spatial location, with a vibration animation between the two values, to indicate uncertainty. This represents a competition between the two values within a region, and provides a temporal mapping to uncertainty for visualisation animations.

It has been noted by Tufte that a visualisation should not use vibrating textures, as it is annoying to the viewer, as shown in Figure 2 [Tufte 1983]. However, this was noted for cases where the vibrations in the graph are both *inappropriate* and *confusing*. Inappropriate, in that the textures are not used to encode appropriate information, and confusing, in that the overuse of such textures causes low level perceptual effects giving a noisy appearance [Tufte 1983].

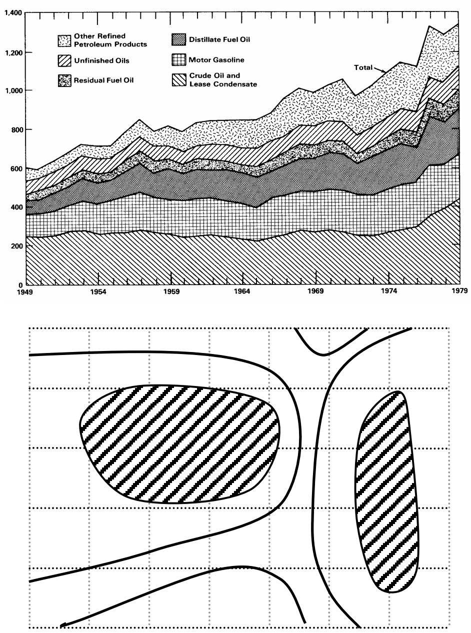

Figure 2 An illustration from Tufte of the inappropriate use of vibrating textures in the presentation of data, top figure. Note how the different textures vibrate and confuse the viewing of the graph [Tufte 1983]. The bottom figure indicates the *location* of uncertainty in the height field grid viewed from above, by highlighting the uncertain locations with textures that vibrate, which is appropriate to the task of finding the most uncertain areas.

Irrelevancy is a major factor in the use of such effects; the vibrations are often used to indicate a category or value by marking with a texture. Unfortunately, effects occur with spatial frequencies being juxtaposed together that are not visually divergent enough to avoid interference. A better way is to use the vibrations to indicate the location of uncertainty within a region, not the actual value of the uncertainty, refer to Figure 2.

Confusion occurs in the examples shown by Tufte, due to the indiscriminate use of such textural vibrations, and therefore indicate a lack of consideration in the application of such spatial frequencies. However, judicial use of such vibrations can be used to highlight important regions in subtle manner. The lesson learnt here is that part of the *art* of visualisation is the considered use of restraint when using any rendering technique. Therefore, an argument can be constructed supporting vibrations as a valid visualisation technique, when used to specify uncertainty location and only when applied sparingly.

2.1 Inducing Visual Vibrations

Before such vibrations can be used, there must be an examination of how this phenomena is induced, and what parameters there are within these effects that can be used to tailor the visual effect to each data visualisation application. This perceptual vibration effect can be induced by a number of stimuli, a display of edges that cause this vibration from *stationary* visual content, or a more explicitly *animated* spatial region.

Stationary visual content at certain spatial frequencies induces a visual vibration effect from the mosaic of cones within the retina of the eye [Wandell 1995]. Contributions to this effect also come from the eye movements of the viewer [Tufte 1983] and the simultaneous contrast produced by the juxtaposition of dark and light regions [Posner and Raichle 1997]. Whatever the physiological process, these vibrations have been used within the *OpArt* movement as a source of inspiration for geometric designs showing dynamic visual effects [Ouchi 1977].

These stationary vibrations are the inspiration behind the technique in this paper. Unfortunately, due to changes in viewing angles, the perceptual effect is hard to control over a 3D surface in an interactive viewing situation. Therefore, for the rest of this paper, explicitly animated forms of vibrations will be analysed and applied in detail.

Animated textures can induce a similar shimmering effect for an animated display. This occurs by the oscillation of a visual feature within a defined time period in a spatial area. Simplistically, these oscillations fuse at around a period of 0.015sec per cycle, which forms the basis of most frame rates for animation [Wandell 1995]. However, the visual sensitivity to such temporal frequencies is modulated by the *contrast sensitivity function* (CSF) [Wandell 1995]. This means that the fusion occurs at different temporal frequencies, depending on the spatial frequency and colour of the stimuli[1].

So a program can temporally oscillate the hue of a region between red and green, to illustrate the uncertainty of the values within an area. The main issue here is to cause the oscillations to be fast enough that the changes do not fuse, but shimmer between the two values to *preattentively*[2] [Treisman and Gelade 1980] indicate the location of uncertainty about values within a region.

Therefore, this vibrational technique should be considered as a low resolution method of finding uncertainties in data, not quantifying the amount of uncertainty. Other techniques should be utilised when seeking to quantify the amount of uncertainty with a fine granularity via colour codes or actual numeric values superimposed over the data [Tufte 1983].

2.2 Methodology

From this basic principle of vibrating textures, a framework is derived to implement this technique, with an appropriate set of visual features and parameters, to tailor this approach to different visualisation applications.

Each oscillation represents a change between lower and higher bounds of uncertainty values in the data set, represented by the visual feature change - the size of error in the data, or the membership value of a fuzzy set, for example. The animation is set out as a feature value V being an oscillating function O of time t, period p, floor value f and ceiling value c:

$$V = O(t, p, f, c) \tag{1}$$

where:

t is the point in time of the animation in seconds;
p is the number of cycles per second;
f is the floor value of the function;
c is the amplitude of the function;
O is a function of type step, linear or sinusoid.

The oscillation function thus determines the nature of the transitions between the two values of the features. The step function produces a hard change between functions, the linear function is a linear interpolation between the two values, and the sin function is a smooth sinusoidal change between the two values. The expressions for each form of oscillation are illustrated below:

Step:

$$V = \begin{cases} f & \text{if} \quad 0 \geq t < \dfrac{1}{4p} \\ f + c & \text{if} \quad \dfrac{1}{4p} \geq t < \dfrac{3}{4p} \\ f & \text{if} \quad \dfrac{3}{4p} \geq t < \dfrac{1}{p} \end{cases} \tag{2}$$

Linear:

$$V = \begin{cases} \dfrac{2c}{p}t + f & \text{if} \quad 0 \geq t < \dfrac{1}{2p} \\ -\dfrac{2c}{p}t - c + f & \text{if} \quad \dfrac{1}{2p} \geq t \leq \dfrac{1}{p} \end{cases} \tag{3}$$

Sinusoidal:

$$V = \frac{c \sin\left(2\pi pt + \dfrac{\pi}{2}\right) + f + 1}{2} \tag{4}$$

The functions are graphically defined below, in relation to their parameters, see Figure 3. Each of the functions has been implemented to investigate their perceptual effects, with

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[1] This issue is addressed in Section 4 Perceptual Issues.
[2] That is, before consciousness has had a chance to process the stimuli.

regards to the visualisation of uncertainty. While it has been the norm to use sin functions because of their visual acceptability, in this work it is still an open question about the utility of the various oscillation parameters. Therefore, all three oscillation functions will be investigated.

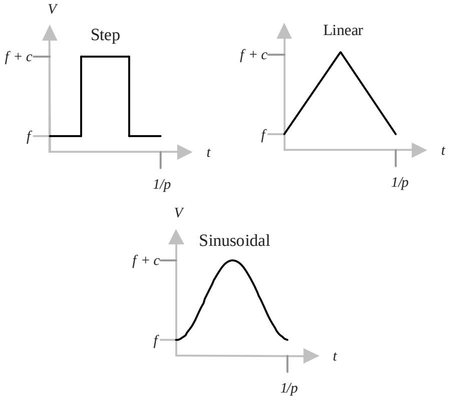


Figure 3 Diagram showing the three oscillation functions to be implemented.

This vibration technique should be viewed as a part of a larger toolbox of rendering methods, to be used in the visualisation of uncertain data. Therefore, a set of visual features needs to be chosen and analysed for their applicability to this technique. Based on previous work in the area [Pham and Brown 2003], there are a number of candidate visual features that can be mapped to the value *V* for this animation technique: hue, saturation, luminance, glyph size and geometry. For this paper we limit the scope of the visualisation to texture data projected onto a surface as a height field, varying the hue, luminance and geometry. This lends itself to applications displaying the spatial location of data in a region on the surface, often required for GIS systems [Pang 2001]. Other data geometry will be considered in future work.

Hue and luminance are a relatively straight forward set of features to use within this technique. They are one-dimensional in nature, and so only require two fixed points along the feature dimension, for example, red and green oscillations for the hue dimension. The above formula was applied to the surface hue and luminance of a data surface, with animations being developed at different amplitudes and thresholds.

Vertices in the data set can be oscillated via a translation along an arbitrary axis in space. In this paper, the oscillations are made perpendicular to the basis axes for the data – the x, y plane. For the purpose of this example, the grid data points translate up and down according to the present functions used. Other vertex manipulations will be considered in future work, for example, rotations, shears, twists etc.

3 Implementation

This visualisation technique has been implemented in the *Framework for Experimental Visualization in Education and Research* (FEVER), developed at the Faculty of Information Technology, QUT. This is an extension to *Open Scene Graph*, a scene graph viewing system [OSG 2003]. This is a free scene graph viewing system written using OpenGL that runs under Unix and Windows environments.

Terrain data has been used as a basis for the display of the oscillation techniques. This terrain data is arbitrary in nature, and is defined by a luminance height field drawn in a paint package. The data, though synthetic, will suffice for the display of the various techniques on a typical terrain surface that would appear in many visualisation systems.

The terrain data is formatted as a mesh of quads, with vertices at varying heights. Error data is attached to each vertex to indicate the amount of uncertainty contained in the values at each vertex. This is read in as an uncertainty data map image that is overlaid on the terrain.

The hue, luminance and vertex transform techniques were implemented and are shown running below[3]. Some of the views have highlight rectangles, as the still frames do not indicate the changes as strongly as the original videos.

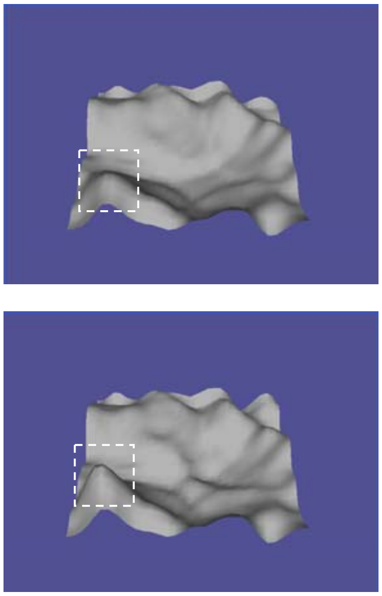
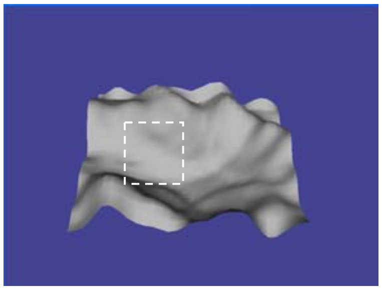


Figure 4 Frames from a movie of the vertex oscillation technique, with the changes in height values highlighted with the dashed rectangle.



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[3] AVI videos of these movies are available at: www.fit.qut.edu.au/~brown8/uncertvis/uncertvis.html.

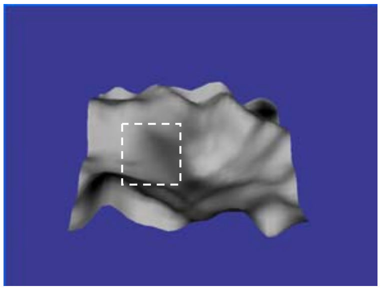

Figure 5 Frames from a movie of the luminance oscillation technique, with the changes in luminance values highlighted with the dashed rectangle.

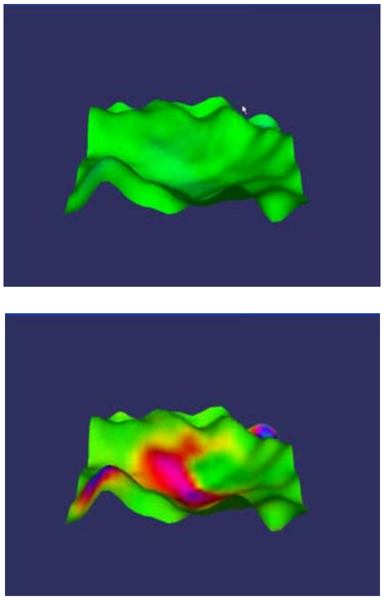

Figure 6 Frames from a movie of the hue oscillation technique, with the changes in hue values varying from green through to blue.

4 Perceptual Issues

Research into human visual perception can be applied to this technique to improve its efficacy in: choice of parameters, modes of delivery, and evaluation of its utility.

Parameters for the display of the data should be aligned with present knowledge of the capacities of the human visual system [Wandell 1995]. At present, the system is adjusted in an ad-hoc manner to ensure the vibrations are set to acceptable values in both period and amplitude for visually acceptable results. Using what is termed the *Temporal Contrast Sensitivity Function* (TCSF), the technique can be modified to adapt parameters to fit human perception characteristics. For example, the period of the animation depends on the size and shape of the region to be modified. This may be processed and modulated by the TCSF to maintain optimal cycles per second, no matter what the orientation of the data being viewed.

Furthermore, these techniques can be extended to stereo displays, with the following showing vertex perturbation presented as a stereo pair, refer to Figure 7.

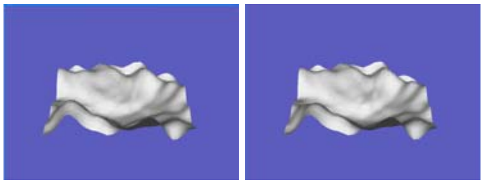

Figure 7 Stereo pair with uncertainty at the peaks and in the centre rendered with vertex vibrations. This appears as a blurred uncertainty region due to an absence of binocular fusion.

The centre region of the surface in Figure 7, upon being viewed, is blurred by lack of binocular fusion and therefore represents uncertainty with a stereo form of blurring. Again, the parameters within this mode of delivery can be modified according to visual perceptual constraints.

Finally, despite its promise as a technique, there is a lack of empirical evidence for the utility of using this technique in viewing uncertain data. Experiments should be performed to validate the technique with a cohort of viewers. This validation should include both subjective impressions of the utility of these vibrations as an uncertainty viewing technique, and task-based evaluation to ascertain its ability to aid a user in specific uncertainty visualisation tasks.

Conclusions

This paper has presented a visual vibrations technique for viewing uncertain data. An argument for its efficacy has been presented, a framework and methodology developed and test implementations have been displayed. It has shown promise as a visualisation technique for uncertainty in data in both mono and stereo modes.

This technique has opened up a number of questions about the perception of uncertainty in visualisation and they form the basis for future work in this area. The technique will be implemented using other visual features including hue saturation and glyph representations – both texture and geometric. The implementation will have a TCSF component installed to allow run-time adaptation to viewing parameters.

Finally, the technique should be evaluated to ascertain the usefulness of the three oscillation functions, and to indicate support for the mapping of uncertainty to vibrating phenomena and to test its automated adaptive ability under changing viewing conditions.

This technique is expected to find application is areas requiring visualisation of uncertainty in data, such as fuzzy systems, geographical information systems and design applications.

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