Illusions of Infinity: Feedback for Infinite Worlds

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ABSTRACT

Sensory feedback for user actions in arbitrarily large information worlds can exhaust the limited dynamic range of human sensation. Two well-known illusions, one optical and one auditory, can be used to give arbitrarily large ranges of feedback.

KEYWORDS: Zoom views, multiscale interfaces, interface feedback, ZUI, sensory illusions

INTRODUCTION.

Interactive user interface design typically tries to give users direct feedback about the consequences of their actions. Scrollbars for example, indicate the current window's position in a document and the direction of its movement during scrolling. New *Zoomable User Interfaces* (ZUIs), like Pad++[1], however, allow access to virtually infinite information spaces, presenting new feedback challenges. The pitch of a tone, for example, could be used as auditory feedback for how much the virtual space is currently magnified (a rising/falling pitch indicating zooming out/in). However, since the virtual space can be zoomed-in almost arbitrary amounts, the required range of pitches could easily be much larger than the capacity of both physical output media and human senses. Current ZUIs, for example, change scale by more than a factor of 10^{12}, quickly reaching tones too high or too low to be audible.

To render such infinite interaction ranges with finite perceptual media, we used two known perceptual illusions, both analogs of M. C. Escher's famous woodcut of the paradoxical spiral staircase where walkers seem to go endlessly up or down but never get anywhere.

AUDITORY FEEDBACK - TONES FOR ZOOMING

Feedback about how magnification is changing during a zoom is especially important since empty regions [5] and certain special effects (e.g., sticky-Z, anti-zooming[4]) can give poor or contradictory visual cues.

To give unlimited indication of arbitrarily large zooms, we used Shepard Tones [2], notes that seem to rise (or descend) endlessly yet never get higher (or lower) in pitch. They are created by synthesizing many octaves of the same note (say C), with amplitudes given by a bell-shaped envelope (Figure 1). Each complex tone sounds like a note on an organ, with a dominant pitch in the mid-range, but over- and under-tones fading away in the high and low registers. A sequence is generated by moving the individual octave pitches up slightly, while the envelope stays the same. This sounds like the organ note is moving upward. However, when the components have moved up a whole octave, the signal is exactly as it started. By tying zooming-in to descending Shepard Tones and zooming-out to ascending ones, zoom direction and magnitude could be auditorally distinguished, yet pitches never got too high or too low to be heard.

VISUAL FEEDBACK – NESTED BOXES

A common visualization technique used in ZUI's involves showing hierarchical structure (e.g., file system hierarchies[1]) with nested boxes. If the boxes appear only in outline (current practice), partial views in a window can be quite ambiguous and disorienting (Figure 2a). The visual ambiguity is easily resolved by shading the boxes, say coloring inner boxes successively more darkly (Figure 2b). After a few nestings, however, the boxes would all be indistinguishably dark. The vast range of ZUI's has again swamped the range of the perceptual system.

Using the Cornsweet illusion[3], however, one can make a series of steps that seem to move from lighter to darker at each step, yet the overall brightness does not change. This is done by what is called "high pass filtering" – suppressing the gradual changes in brightness that correspond to differences in overall lightness or darkness in larger regions of an image. (You can produce this in Photoshop®, for example, by subtracting, from an image, a blurred version of itself.) This leaves only the fast, local changes in brightness that happen at edges (Figures 3a & b). The eye is to some extent fooled by these so-called "edge transients" into erroneously reconstructing, i.e., "seeing," overall level differences that were in fact subtracted out. By drawing boxes with just these edge transients, we obtained seemingly darker boxes inside brighter ones (Figure 4a), but the nesting could go on forever. Even partial views were unambiguous (Figure 4b).

The illusion seemed to be fairly forgiving, working for edge transients in the range of 1-5 degrees of visual angle (about 2-9 mm wide per 10 cm viewing distance). To keep the transients within this range, however, the boxes cannot be zoomed geometrically – the edge transients must be explicitly recalculated at different magnifications. In our code we tried to keep them a constant pixel width on the screen. This had the useful side effect that, when a box was small, its internal edge transients started to overlap, with

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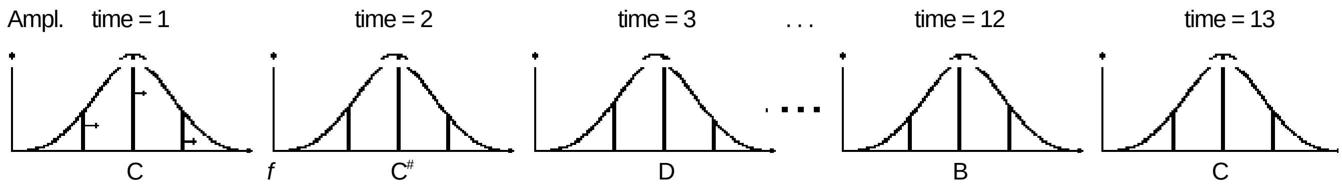

Figure 1: Shepard Tones – individual pitch components move up smoothly in frequency while envelope stays the same. Subjectively, the pitch seems to rise but ends up with time=13 identical to time=1.

the box's center never quite reaching neutral gray, thus remaining somewhat darker. That is, the nominally darker inner boxes in fact started off darker when they were small. Their centers gradually returned to the neutral gray as they were zoomed in. Since, by another optical effect, the eye is insensitive to temporally slow brightness changes, this was not at all disconcerting, and enhanced the illusion of nested darker boxes.

This visual example was implemented both under Pad++, and Jazz. Informal user tests show a marked improvement in comprehensibility of zooming.

FURTHER REFINEMENT

Both these techniques provided good feedback for local scale changes without using up dynamic range: a small zoom was easily heard, one box nested within another was unambiguously distinguished. However, we lost the capability to use the overall tone height, or the overall darkness, to signal absolute zoom or nesting level. We should be able to recover this to some extent, by re-introducing an attenuated version of the basic level changes (Figure 5). Thus for example, we can let the bell-shaped envelope of the Shepard Tones move slowly upwards at a rate that goes from low to high over the dozen orders of magnitude of the ZUI. For the nested boxes, in addition to the edge transients, we can let the boxes actually get slowly darker overall as we nest inwards.

ACKNOWLEDGMENTS

This research was supported by grants from DARPA (N66001-94-C-6039) and Microsoft.

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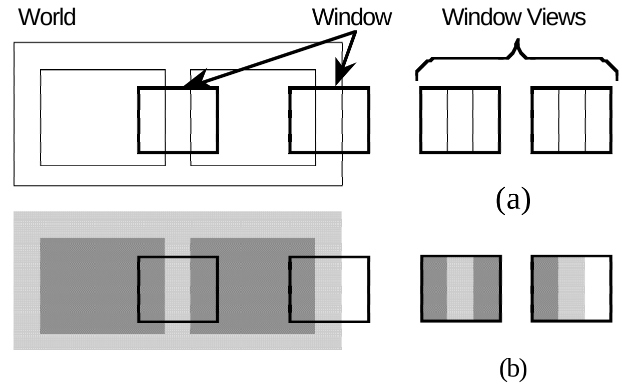

Figure 2: Visual ambiguity of partial views of nested box outlines(a) resolved by shading boxes(b)

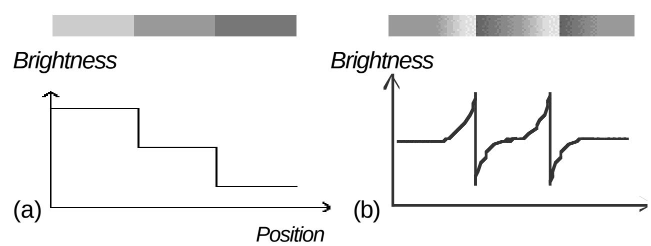

Figure 3: Cornsweet Illusion - Brightness steps in (a), suggested by edge transients in (b). [Note: Effects diminished in photocopying.]

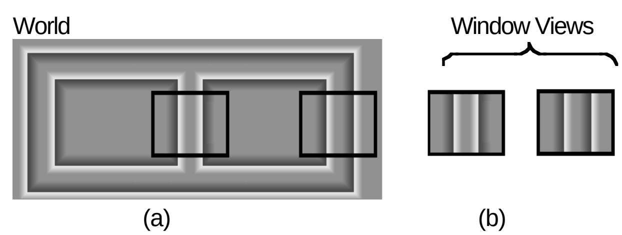

Figure 4: Boxes drawn with edge effects (a) show nesting even in partial views (b).

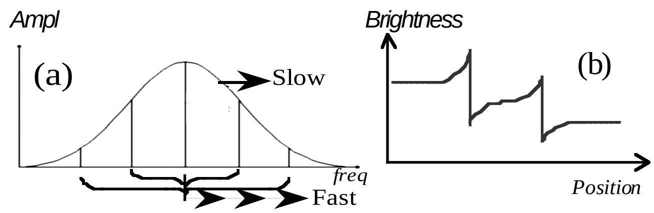

Figure 5: (a) Shepard tones modified so envelop rises slowly as individual pitch components rise quickly. (b) Cornsweet edge transients accompanied by gradual level changes