Pelli, D. G. (2001). 47.1: Invited paper: How we see letters: Implications for making better displays. SID Symposium Digest of Technical Papers, 32(1), 1194-1195. http://dx.doi.org/10.1889/1.1831773

47.1: *Invited Paper:* How We See Letters: Implications for Making Better Displays

Denis G. Pelli

Psychology and Neural Science, New York University, New York, NY 10003, USA

Abstract

Recent research reveals that letter identification and reading use only an octave-wide band of spatial frequencies, which depends on letter size. Display design should optimize this band and may ignore errors outside it.

Review

With my students and colleagues, I have been studying letter recognition, how we identify a letter, like a–z, in order to understand the general process of object recognition. We haven't solved the big problem yet, but we have learned some things about letter identification that should be useful to display designers, including designers of software for text display.

The key result is that letter identification is mediated by a spatial frequency channel. This means that observers identifying letters (or reading) use only a certain part of the spatial frequency spectrum of the display. A demonstration will help. Fig. 1, reproduced from Solomon and Pelli [1], is a special kind of eye chart. Successive rows show letters at lower and lower contrast. The letters are obscured by a background of visual noise. The noise is coarse (low frequency) at the left and sweeps smoothly to fine (high frequency) at the right. You'll notice that very fine and very coarse noise have relatively little effect. Try to trace out the faintest (lowest) letter you can read in each column. You'll see that it forms an inverted U function, peaking at a middle frequency. This measures the noise-sensitivity of your eye (when identifying letters), as a function of frequency. More elaborate measurements show that this function is identical to that for detecting a simple grating pattern, has a standard shape (parabolic when plotted as log power gain as a function of log frequency), and a bandwidth (full width at half height) of about 1.5 octaves.[1]

This one-channel finding had been foreseen by Legge et al. [2] in experiments on reading, using simpler text manipulations that couldn't characterize the channel so definitely. The parallel results are important because Solomon and Pelli studied only identification of single letters, whereas Legge et al. were measuring reading rate as their dependent measure, so the two combined allow us to conclude that reading is based on the information that passes through a single spatial frequency channel.

The fact that reading is unaffected by noise frequencies beyond the channel's passband should be useful to display design. Make sure your display is right inside the critical band, and you may ignore errors outside that band. (Our research, e.g. Fig. 1, show that reading is unaffected by what's displayed outside the critical band, but observers may still be aware of it, even though it doesn't affect their reading.)

Where is that band, exactly? Surprisingly, this depends strongly on letter size. By repeating the experiments of Solomon and Pelli at many different letter sizes (and many different fonts), Majaj et al. [3] discovered that we use a different part of the letter spectrum at each letter size, and that the channel frequency follows a universal power law that applies to all fonts. To express that law we need a way to characterize the spatial frequency of a letter.

Spatial frequency is most usefully specified as cycles per degree of visual angle. We define an alphabet's *line (or stroke) frequency* as the average number of lines (strokes) crossed by a slice through a letter, divided by the letter width. We find that line frequency completely determines channel frequency, independent of alphabet, font, and size. We thought shape would be processed similarly at all sizes. For sinewave gratings, as expected, channel frequency equals sinewave frequency. For letters, however, channel frequency is not proportional to line frequency, rising with a log-log slope of 2/3, not 1,

$$\frac{f_{\text{channel}}}{10\ \text{c/deg}} = \left(\frac{f_{\text{line}}}{10\ \text{c/deg}}\right)^{\frac{2}{3}}.$$

Thus, large letters are identified by their edges; small letters are identified by their gross strokes.

This result is based on tests with letters in a wide range of fonts (Sloan, Bookman, Künstler), alphabets (Roman and Chinese), and sizes (0.07 to 24 deg).

Conclusion

Reading is mediated by a single spatial frequency channel with a center frequency that depends solely on the stroke frequency of the text. When presenting text for reading, this critical band should be displayed accurately. Errors outside this band do not affect reading.

References

[1] Solomon, J. A. and Pelli, D. G. (1994) The visual filter mediating letter identification. *Nature*, 369, 395-397.

[2] Legge, G. E., Pelli, D. G., Rubin, G. S., and Schleske, M. M. (1985) Psychophysics of reading--I. Normal vision. *Vision Res*, 25, 239-52.

[3] Majaj, N. J., Pelli, D. G., Kurshan, P., and Palomares, M. (2001) The role of spatial-frequency channels in letter identification. *Vision Research*, In press.

Acknowledgements

We thank Jim Larimer for the invitation. Supported by National Eye Institute grant EY04432 to Denis Pelli.

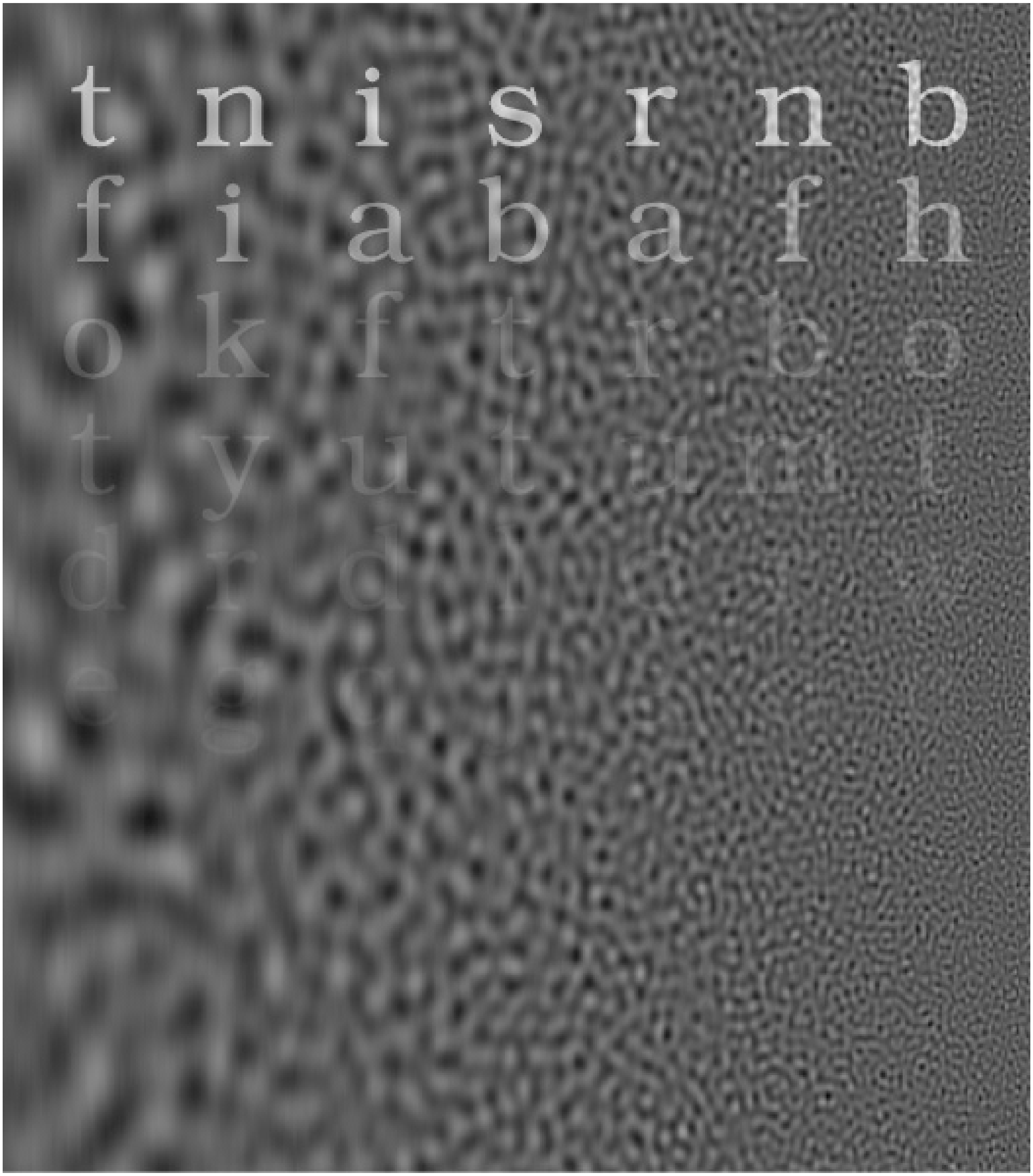

Fig. 1 A visual noise sensitivity test. Read down each column as far as you can; the positions of the faintest identifiable letters trace out the sensitivity of your eye's letter-identification channel as a function of spatial frequency, from coarse to fine. From Solomon and Pelli [1].