

### Intensity & Luminance

[Color Exploratory](#)

**Intensity**

- Integral of spectral distribution (power)
- Total light energy

**Luminance**

- Intensity modulated by wavelength sensitivity
- Integral of spectrum x luminous efficiency function
- Perceived brightness

Green and blue lights of equal intensity have different luminance values

### Luminance from Displays

For any RGB

- $Y = rY_R + gY_G + bY_B$
- $Y_R, Y_G, Y_B =$  Maximum luminance of the display red, green, blue
- $r, g, b$  are linear pixel values

**Pixels to linear luminance**

- $Y = F(\text{pixel})$
- $F$  often  $p^{1/\text{gamma}}$
- Macs: gamma typically 1.8
- PCs: gamma typically 2.2

### Uniform Lightness ( $L^*$ )

$L^*$  is a function of normalized luminance

- Perceptually uniform lightness scale
- Range 0 to 100
- Equal steps are equally different
- Relative to black & white

$$L^* = 116(Y/Y_n)^{1/3} - 16$$

About 18% luminance = 50%  $L^*$

### Value

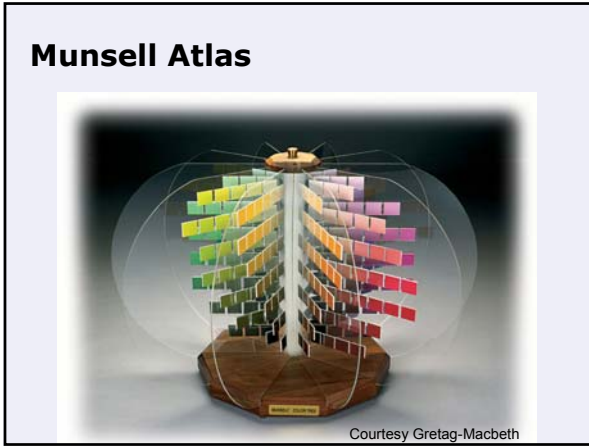
**Value**

- Perceived lightness (Munsell value,  $L^*$ )
- Term used by artists, designers

**Value differences**

- Define legibility
- Control attention
- Create layering

Contrast = metric for value difference



### Art & Design

Hue (color wheel)

- Opposites complement (contrast)
- Adjacent are analogous
- Many different color wheels\*

\*See [www.handprint.com](http://www.handprint.com) for examples

Chroma (saturation)

- Intensity or purity
- Distance from gray

Value (lightness)

- Dark to light
- Applies to all colors, not just gray

*Wucius Wong, Principles of Color Design*



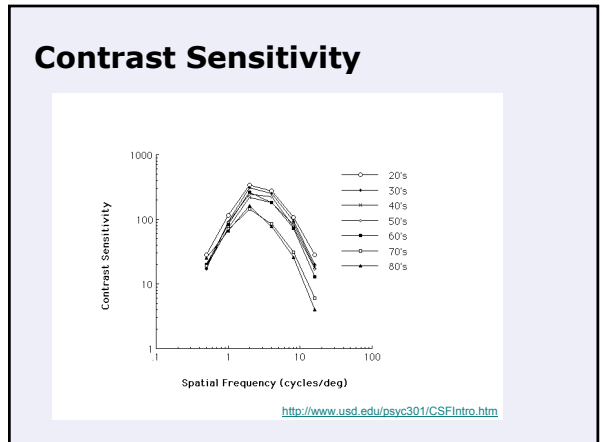
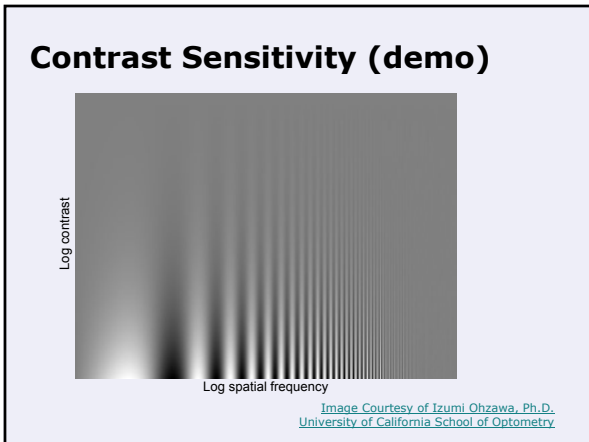
### Contrast

General formulation

- Luminance difference ( $Y_f, Y_b$ )
- Depends on size (spatial frequency)
- Depends on adaptation

Contrast sensitivity function

- Spatial frequency vs. luminance contrast
- Peak sensitivity around 1-3 cycles/degree
- Depends on age, acuity



### Computing Contrast

Small symbols, solid background (Weber)

- $C = (Y_f - Y_b) / Y_b$
- Adapted to background

Textures, high frequency patterns (Michelson)

- $C = (Y_f - Y_b) / (Y_f + Y_b)$
- Adapted to average

Contrast using  $\Delta L^*$  (my rules of thumb)

- 1 is ideally visible
- 10 is easily visible
- 20 is legible for text

### Summary

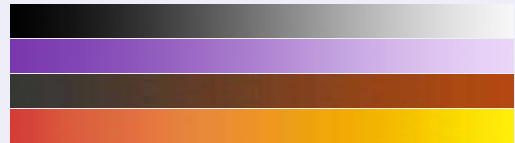
Value

- Perceived lightness (Munsell value, L\*)
- Computed from measured luminance

Contrast=value difference

- Different models based on luminance
- Depends on spatial frequency

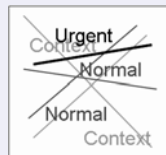
Independent of hue



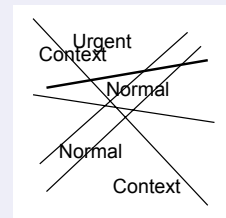
### Layering

Information "layers"

- Separable, legible
- Semantic
- Variable attention

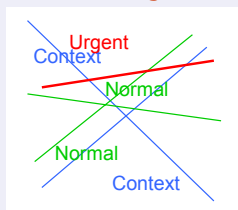


### How do we fix this?



### Luminance Contrast

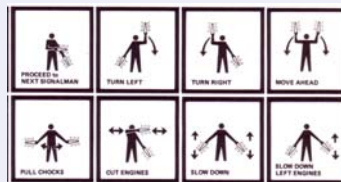
Wrong



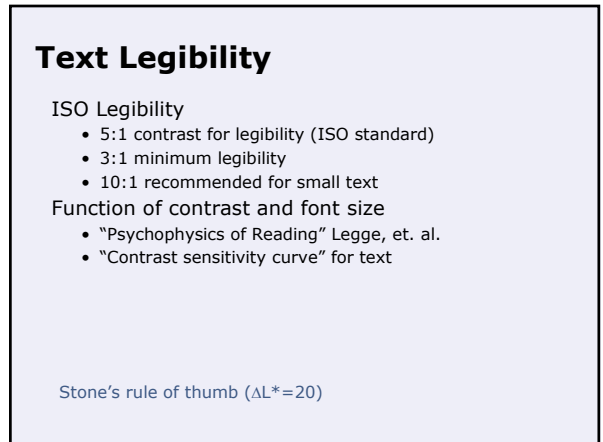
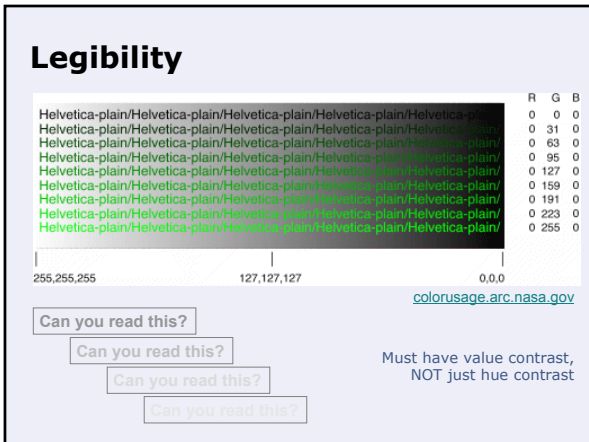
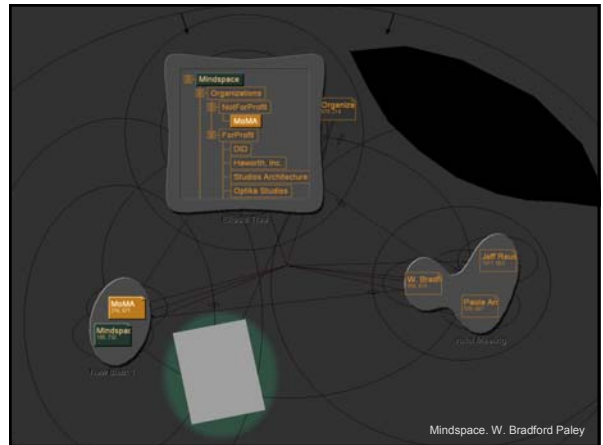
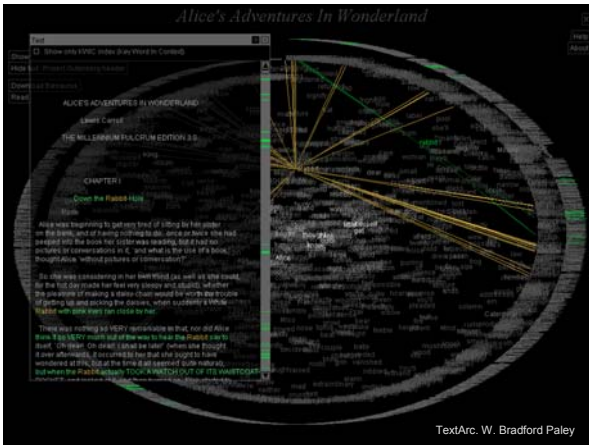
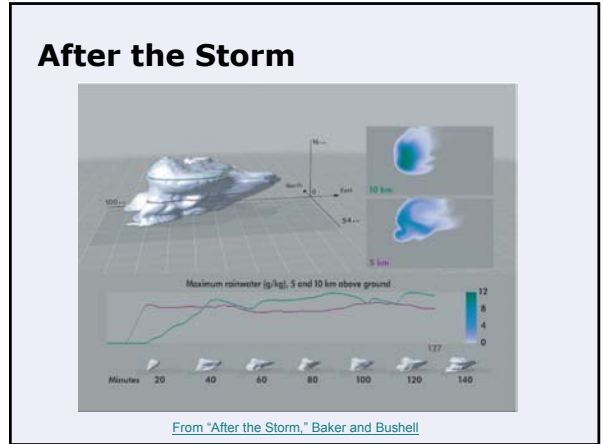
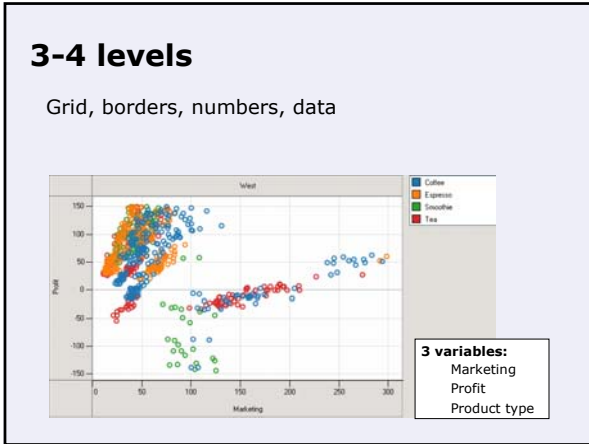
Right



[colorusage.arc.nasa.gov](http://colorusage.arc.nasa.gov)



Tufte *Envisioning Information*, ch 3



**Why is this bad?**

If you can't use color wisely,  
it is best to avoid it entirely  
Above all, do no harm

If you can't use color wisely,  
it is best to avoid it entirely  
Above all, do no harm.

**Why isn't this bad?**



**Value Control**

