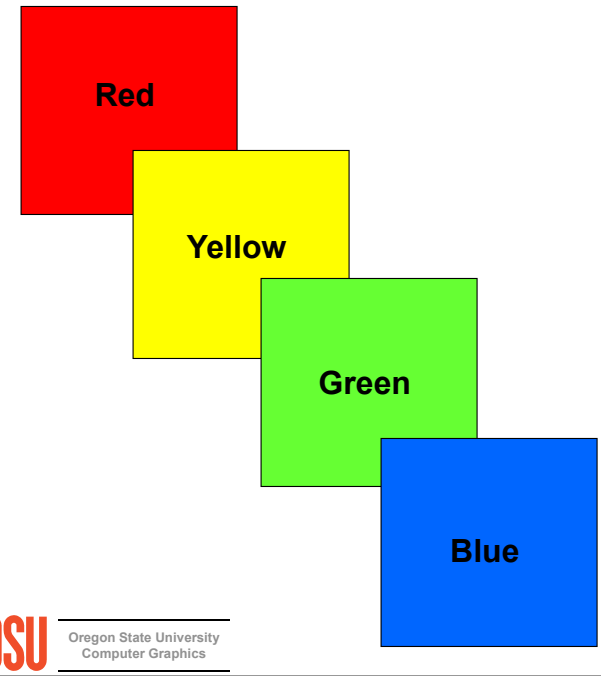
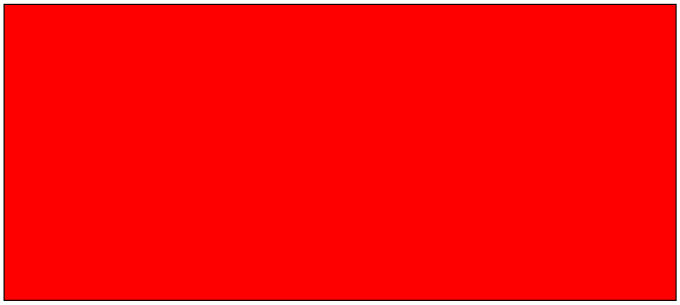
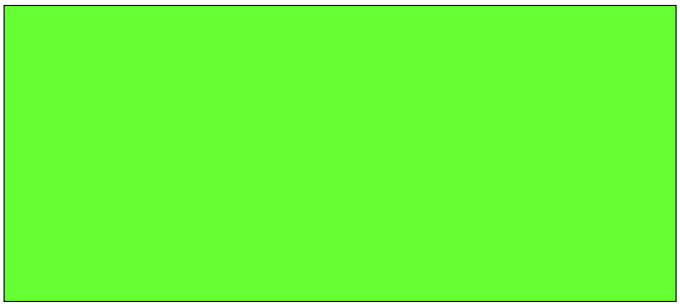
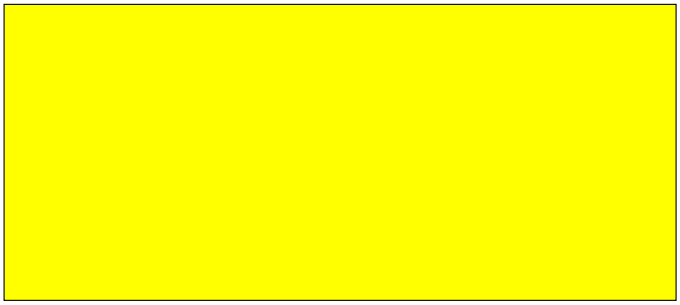
Color and the Display of Information:

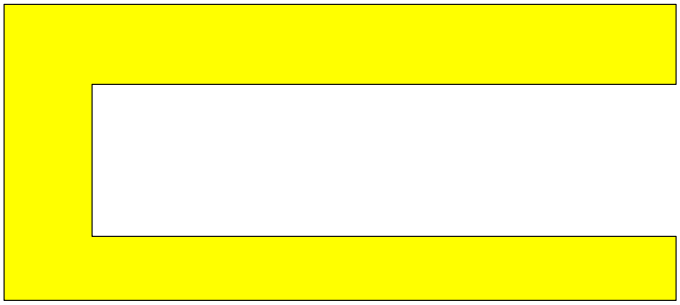
Yes, this is still Computer Science

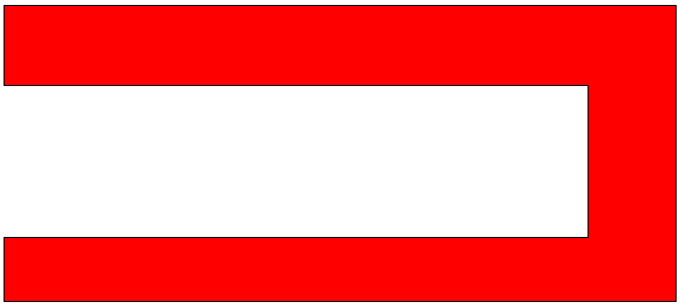


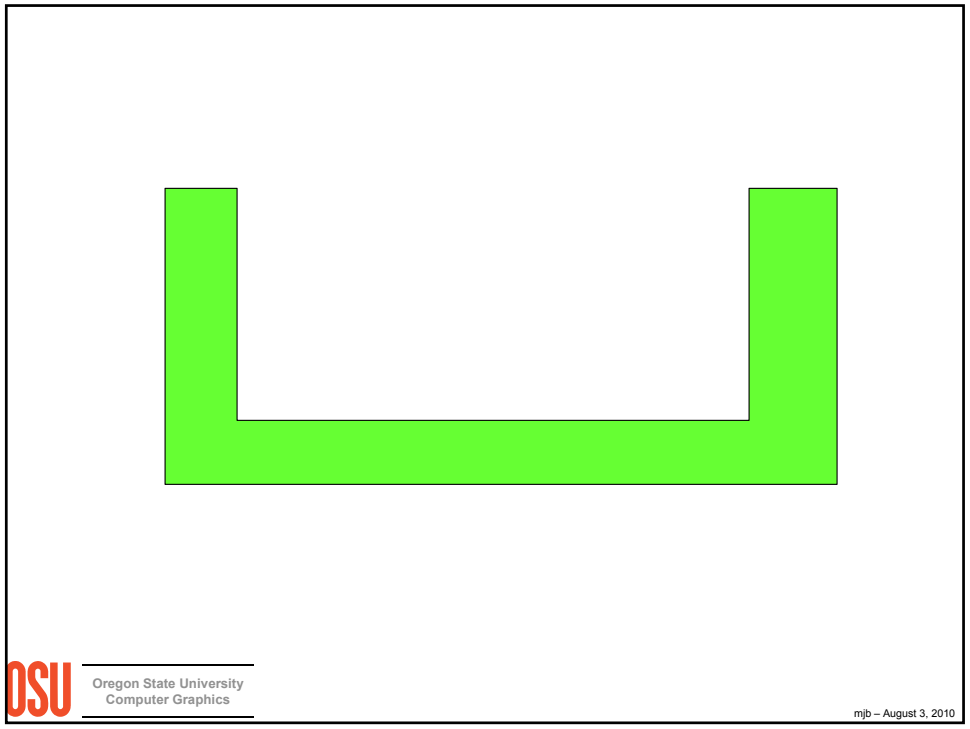


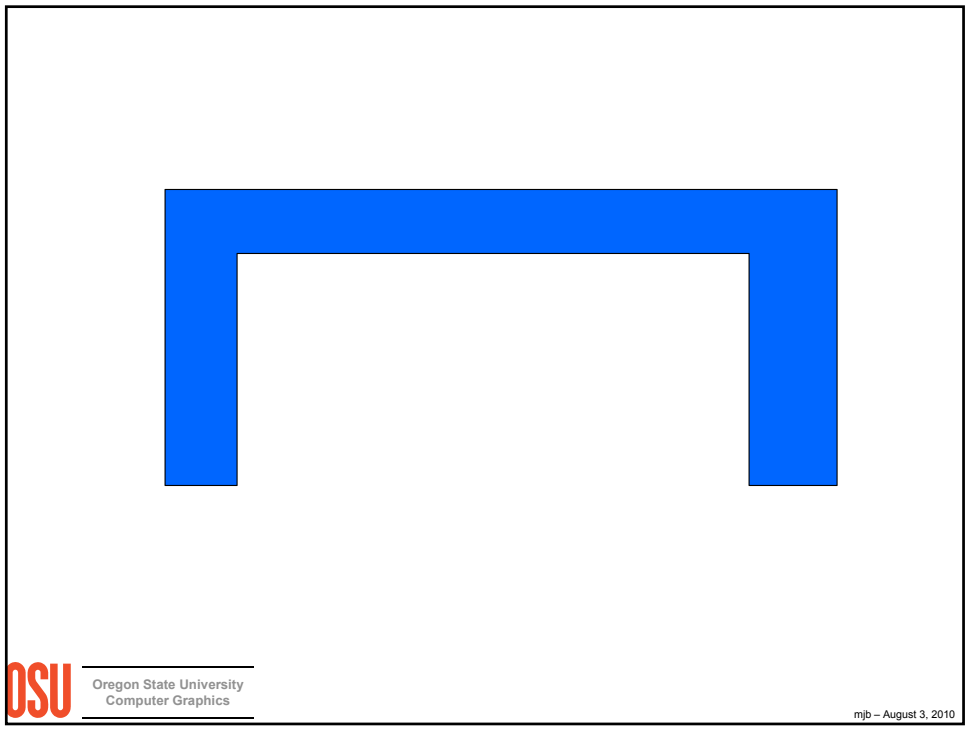






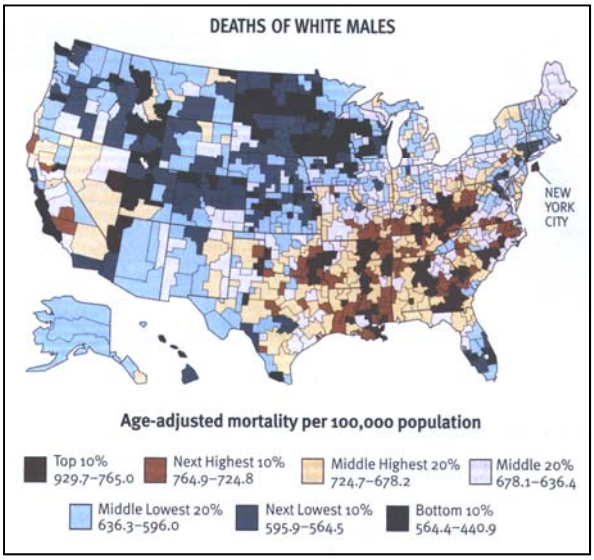






Red

What's Wrong with this Picture?



Source:
Scientific American, June 2000

Physiology of the Human Eye

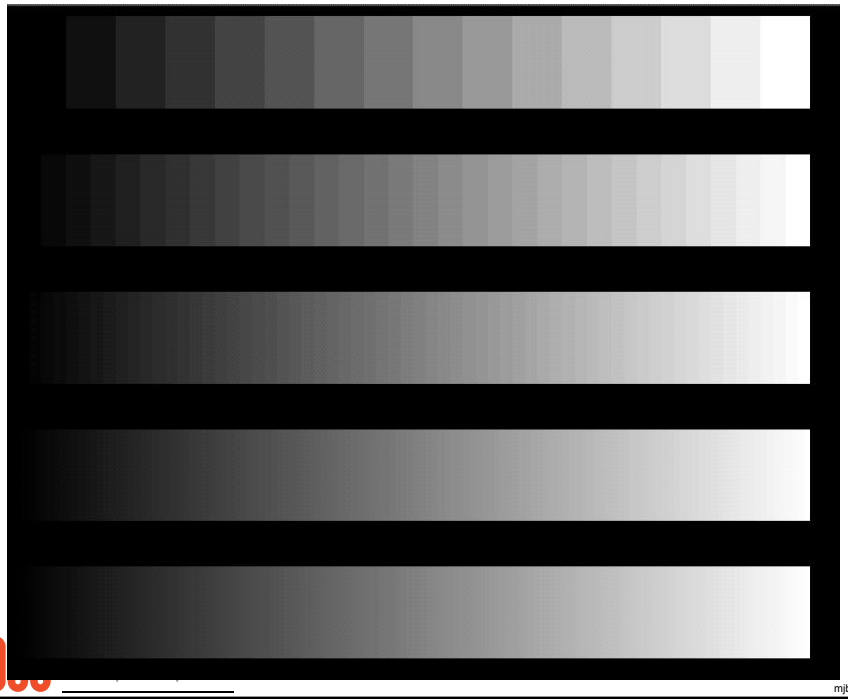
Rods

- ~115,000,000
- Concentrated on the periphery of the retina
- Sensitive to *intensity*
- Most sensitive at 500 nm (~green)

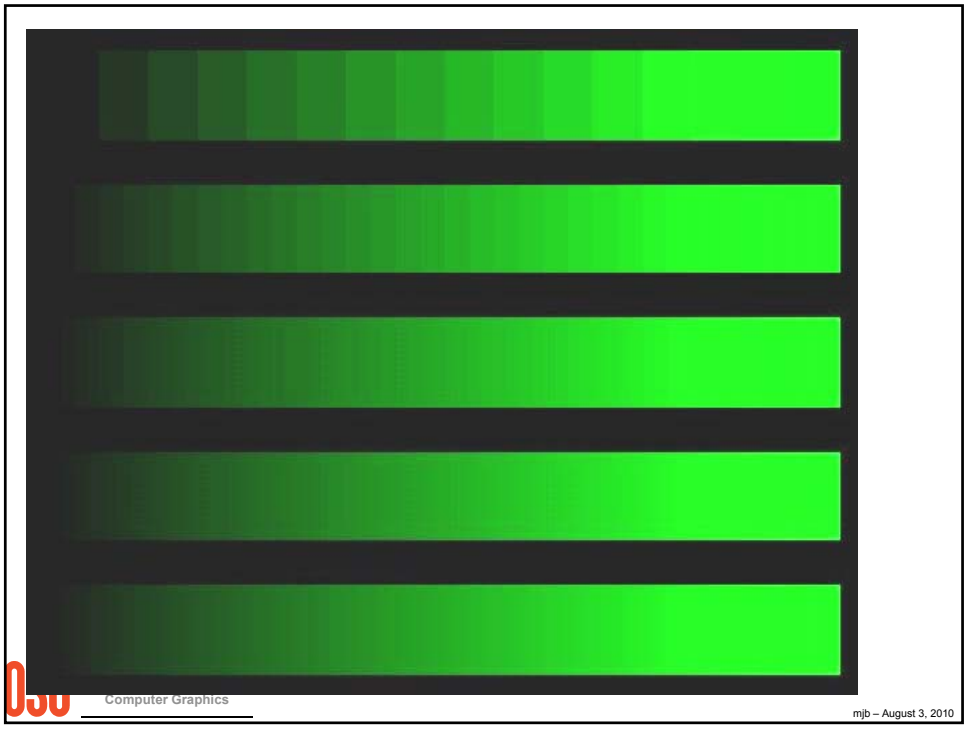
Cones

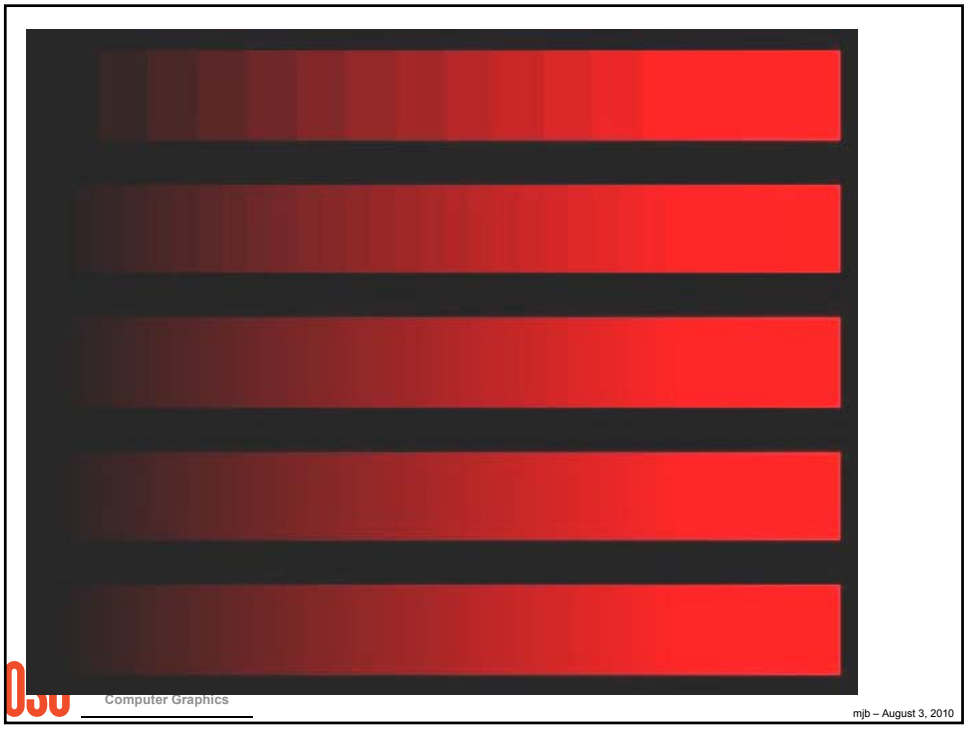
- ~7,000,000
- Concentrated near the center of the retina
- Sensitive to *color*
- Three types of cones: long(~red), medium (~green), and short (~blue) wavelengths

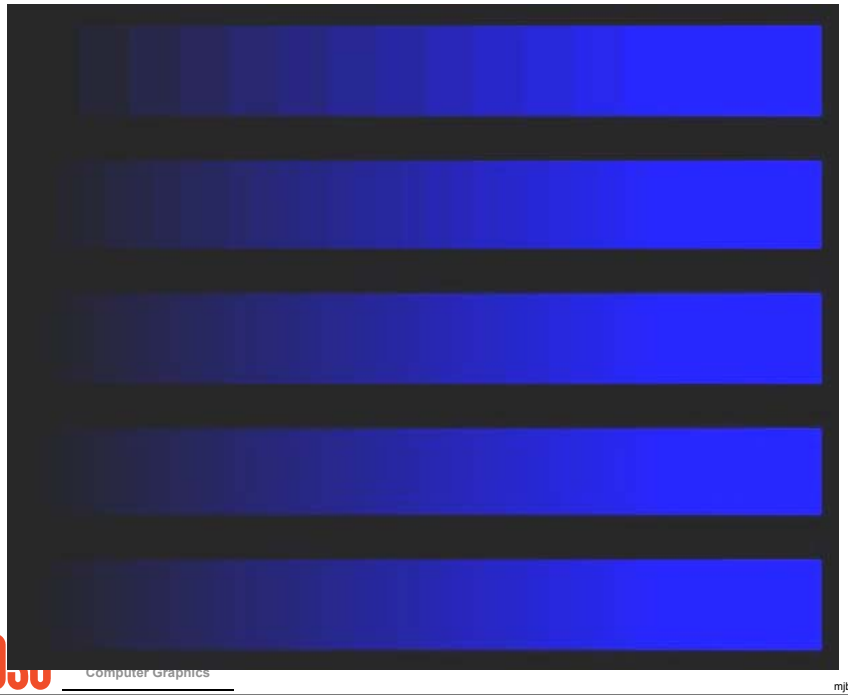
OSU Oregon State Computer



OSU


Computer Graphics
mjb – August 3, 2010


Computer Graphics
mjb – August 3, 2010



What Makes a Good Contrast?

- Many people think that simply adding color onto another color makes a good contrast
- In fact, a better measure is the Δ Luminance

Color Alone Doesn't Cut It !

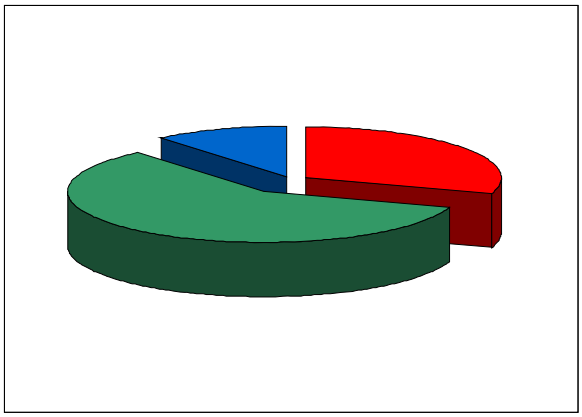
I sure hope that my life does not depend on being able to read this quickly and accurately!

Luminance Contrast is Crucial !

I would prefer that my life depend on being able to read *this* quickly and accurately!

The Luminance Equation

$$L = .30*Red + .59*Green + .11*Blue$$



Luminance Table

	R	G	B	Y
Black	0.0	0.0	0.0	0.00
White	1.0	1.0	1.0	1.00
Red	1.0	0.0	0.0	0.30
Green	0.0	1.0	0.0	0.59
Blue	0.0	0.0	1.0	0.11
Cyan	0.0	1.0	1.0	0.70
Magenta	1.0	0.0	1.0	0.41
Orange	1.0	0.5	0.0	0.60
Yellow	1.0	1.0	0.0	0.89

≈ Contrast Table

	Black	White	Red	Green	Blue	Cyan	Magenta	Orange	Yellow
Black	0.00	1.00	0.30	0.59	0.11	0.70	0.41	0.60	0.89
White	1.00	0.00	0.70	0.41	0.89	0.30	0.59	0.41	0.11
Red	0.30	0.70	0.00	0.29	0.19	0.40	0.11	0.30	0.59
Green	0.59	0.41	0.29	0.00	0.48	0.11	0.18	0.01	0.30
Blue	0.11	0.89	0.19	0.48	0.00	0.59	0.30	0.49	0.78
Cyan	0.70	0.30	0.40	0.11	0.59	0.00	0.29	0.11	0.19
Magenta	0.41	0.59	0.11	0.18	0.30	0.29	0.00	0.19	0.48
Orange	0.60	0.41	0.30	0.01	0.49	0.11	0.19	0.00	0.30
Yellow	0.89	0.11	0.59	0.30	0.78	0.19	0.48	0.30	0.00

$\Delta L^* \approx 0.40$

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	Black	Black	Black	Black	Black	Black	Black	Black
White		White	White	White	White	White	White	White
Red	Red		Red	Red	Red	Red	Red	Red
Yellow	Yellow	Yellow		Yellow	Yellow	Yellow	Yellow	Yellow
Green	Green	Green	Green	Green		Green	Green	Green
Blue	Blue	Blue	Blue	Blue	Blue	Blue		Blue

OSU Oregon State University Computer Graphics

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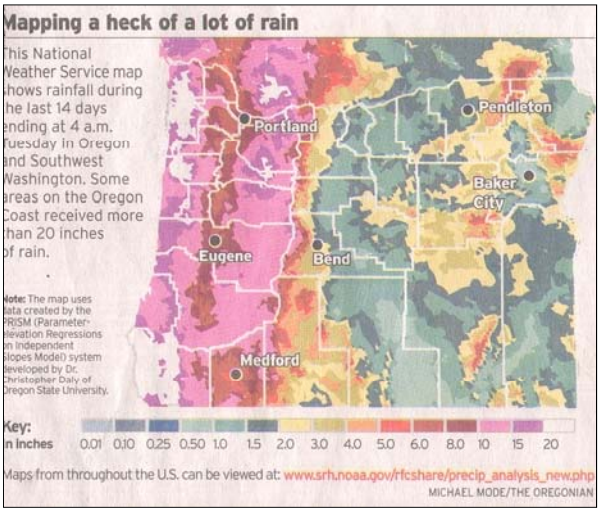
Do Not Attempt to Fight Pre-Established Color Meanings

Red:	Green:	Blue:
Stop	On	Cool
On	Plants	Safe
Off	Carbon	Deep
Dangerous	Moving	Nitrogen
Hot	Money	
High stress		
Oxygen		
Shallow		
Money loss		

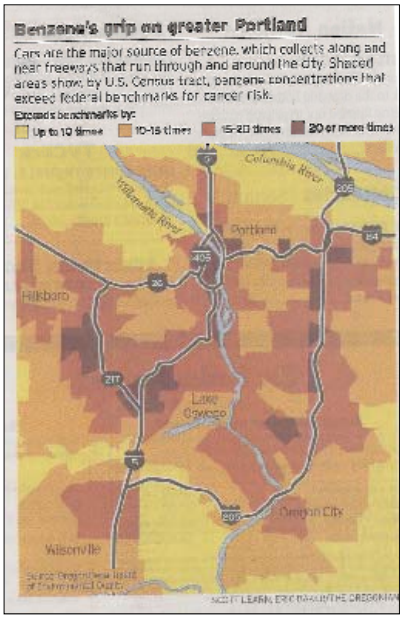
What in the World was *The Oregonian* Thinking When They Chose This Color Scale?



Source:
The Oregonian,
January 11, 2006

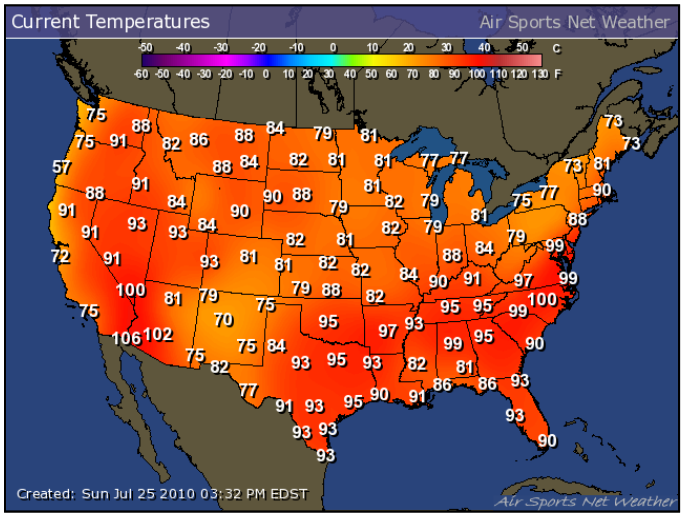
Shouldn't lush-green colors represent wet and sand-colors represent dry?

This one is better

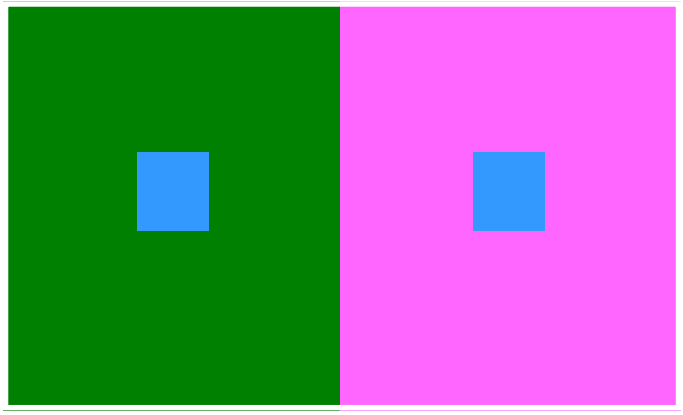


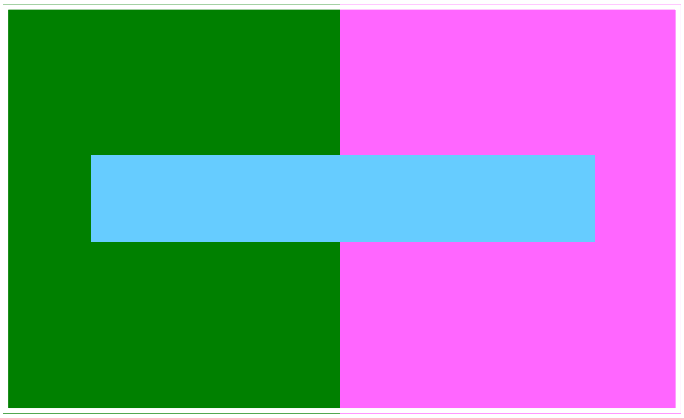
Source:
The Oregonian,
October 31, 2006

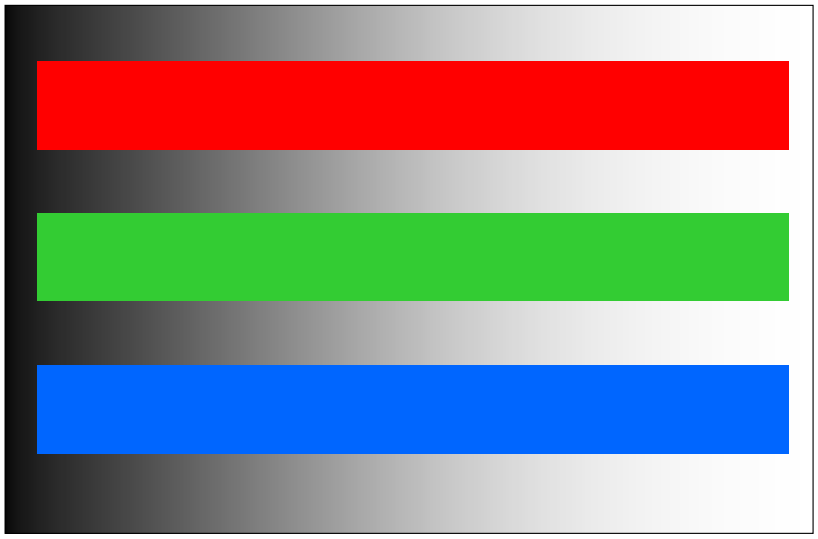
Not a bad choice of colors, but the Dynamic Range needs some work

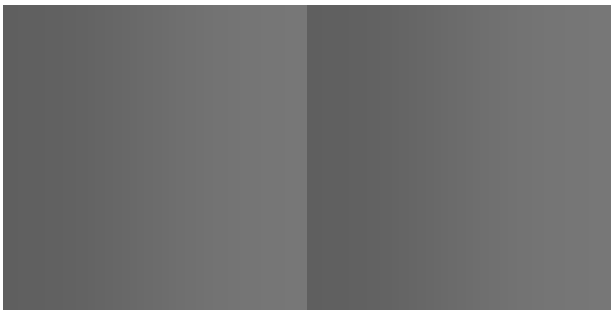


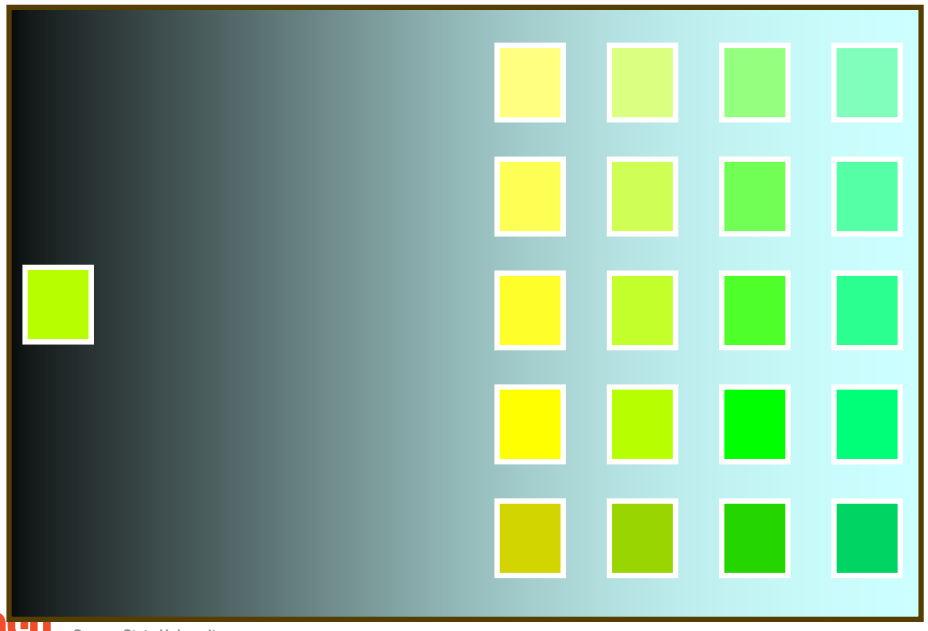
The Ability to Discriminate Colors Changes with Surrounding Color



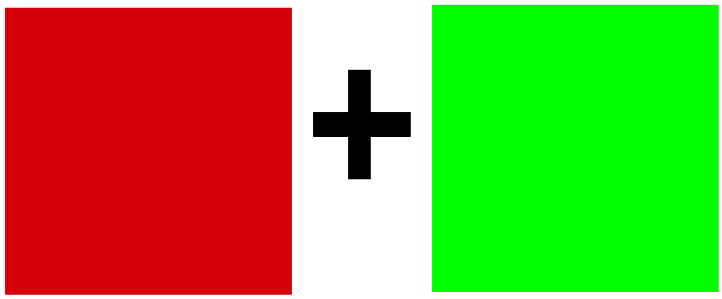




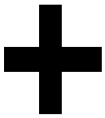




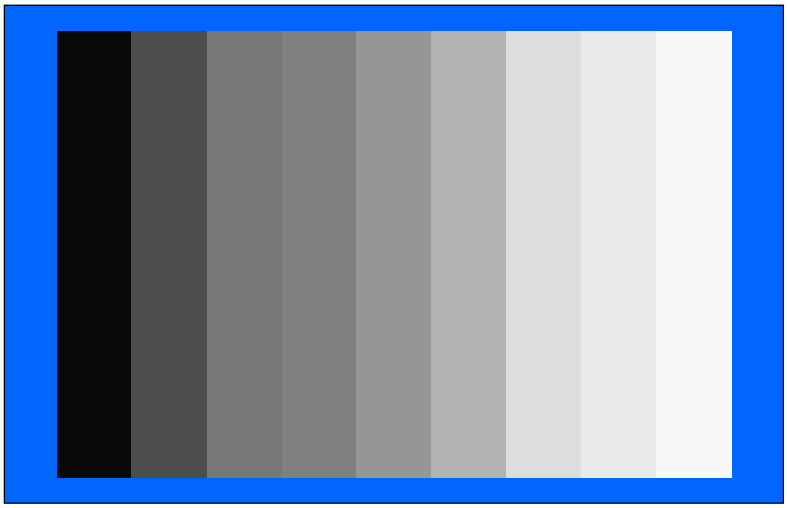
Afterimages



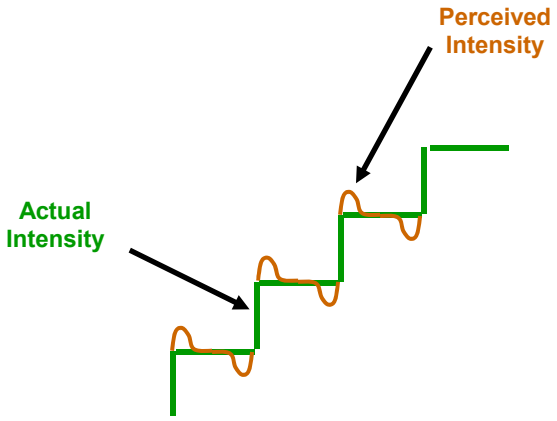
Afterimages



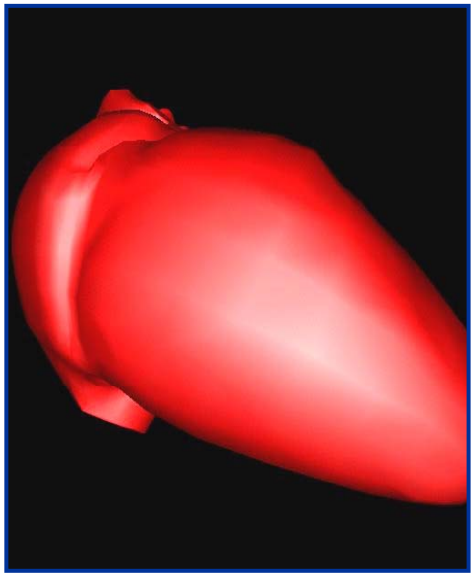
Beware of Mach Banding

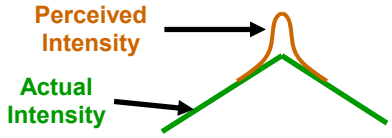


Beware of Mach Banding



Beware of Mach Banding



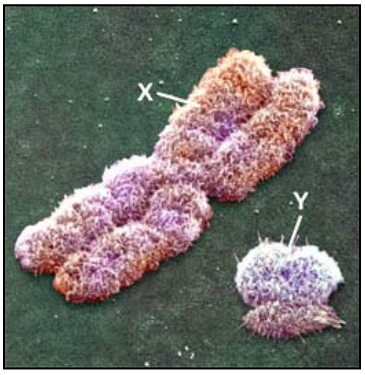


Be Aware of Color Vision Deficiencies (CVD)

- There is actually no such thing as "color blindness"
- CVD affects ~10% of Caucasian men
- CVD affects ~4% of non-Caucasian men
- CVD affects ~0.5% of women
- Most common type of CVD is red-green
- Blue-yellow also exists

Q: Why are more men affected by CVD than women?

A: A common CVD is carried on the X Chromosome

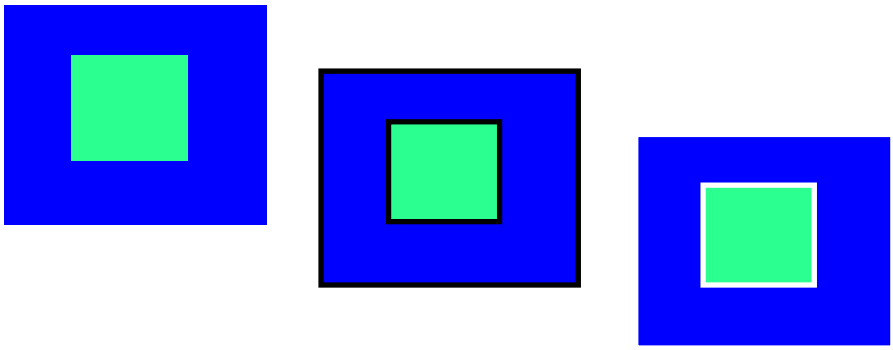


http://www.bio.miami.edu/~cmallery/150/mendel/c7.15.X.Y.jpg

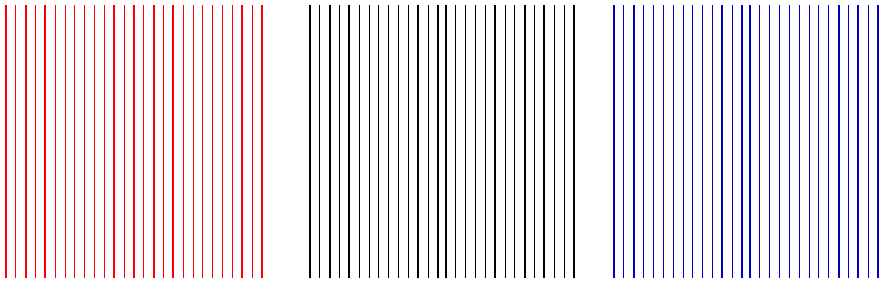
Be Aware of CVD:
Code Information Redundantly

Four score and seven years ago, our forefathers brought forth upon this continent a new nation...	Four score and seven years ago, our forefathers brought forth upon this continent a new nation...	Four score and seven years ago, our forefathers brought forth upon this continent a new nation...

Use a Black or White Line as the Boundary Between Colored Regions



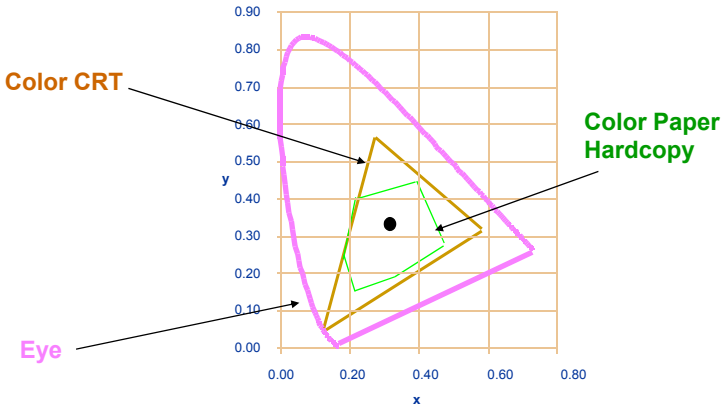
Do Not Display Fast-moving or High-detail Items in Color, Especially Blue



Watch the Use of Saturated Reds and Blues Together

Reds and Blues are on opposite ends of the color spectrum. It is hard for your eyes to focus on both.

Be Aware of the Difference in Color Gamuts between a Monitor and a Color Printer

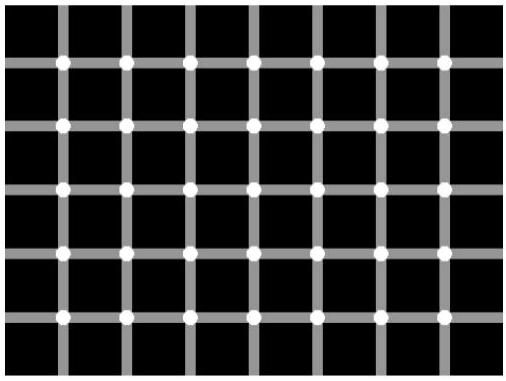


I'm really happy that analog video is on its way out!

NTSC Cycles-of-Encoding per Scanline

What:	Cycles/Scanline:
Intensity	267
Orange-Blue	96
Purple-Green	35

Beware of Lots of Other Stuff



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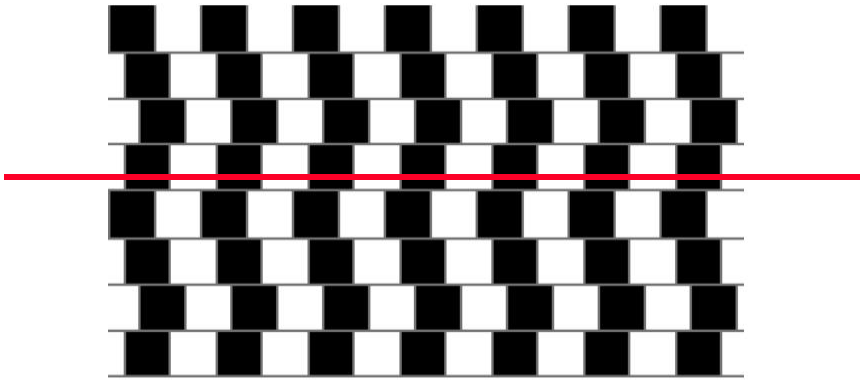
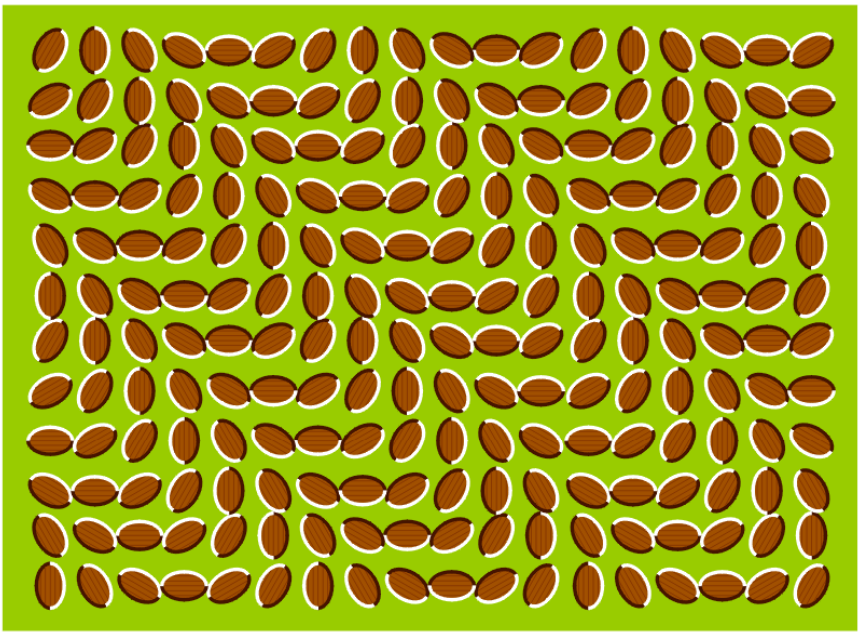
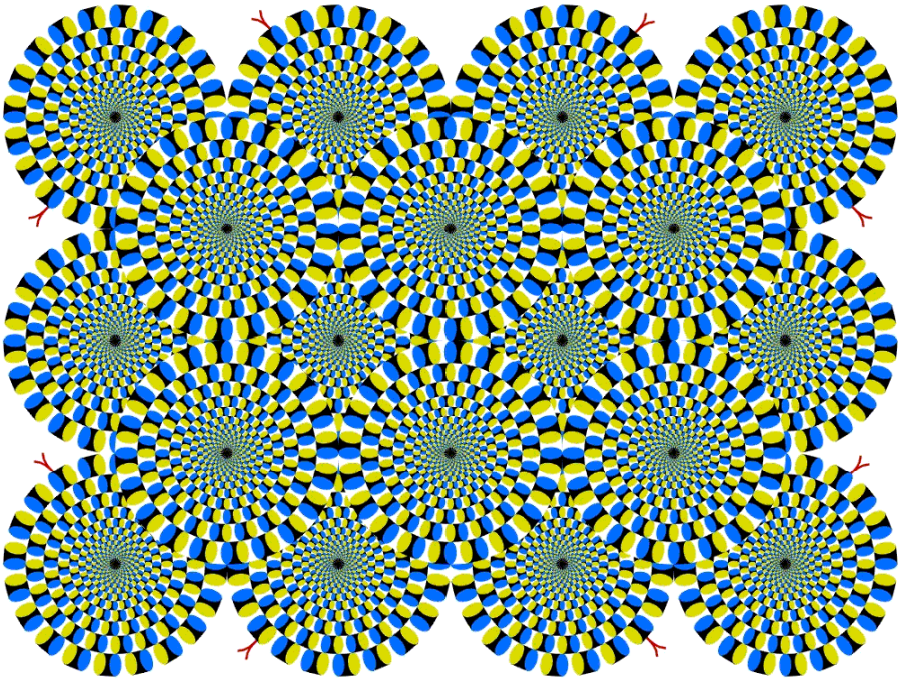
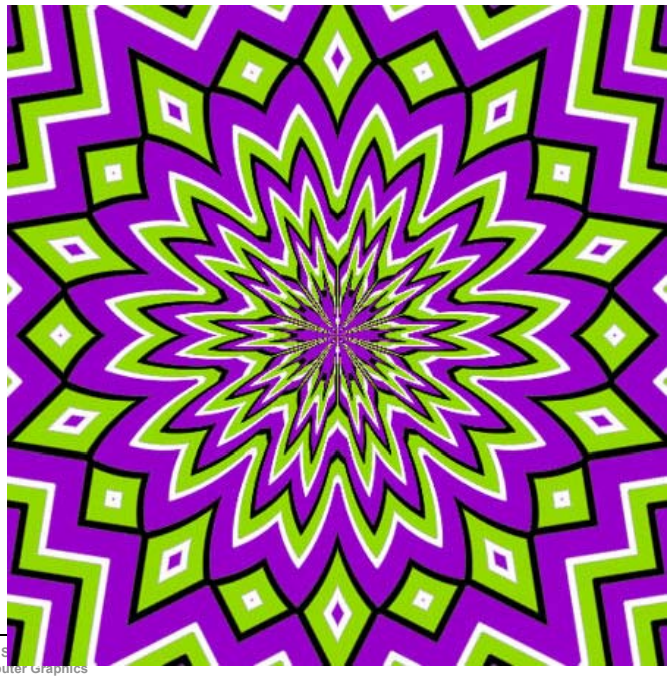
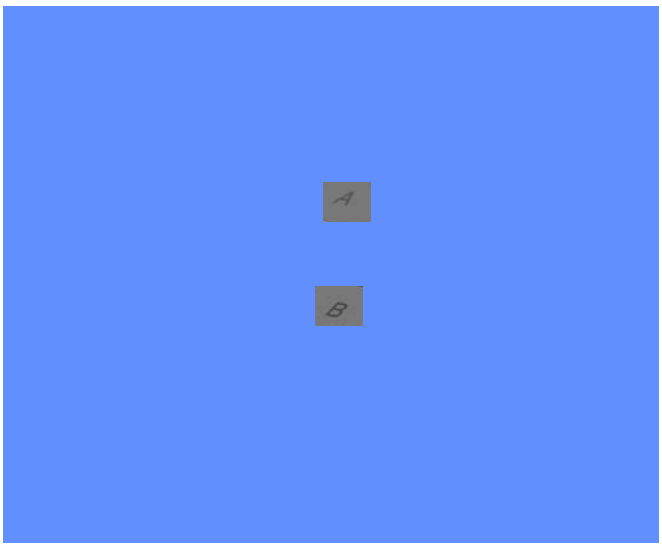
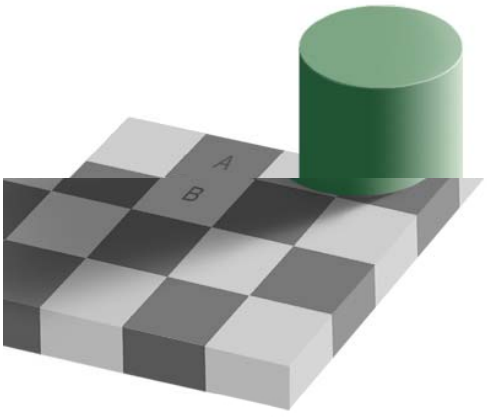








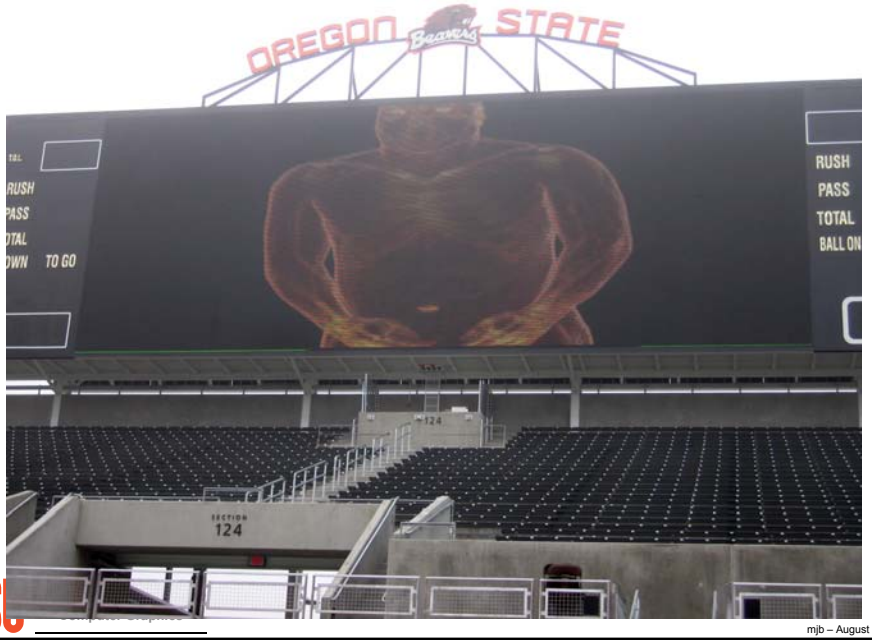

A
B


A
B

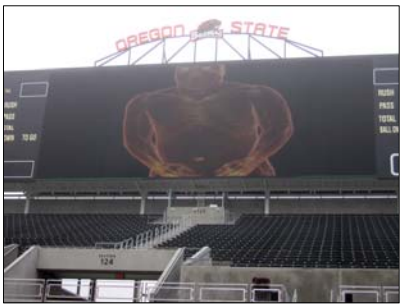
Some Good Color and Perception References

- Maureen Stone, *A Field Guide to Digital Color*, AK Peters, 2003.
- Roy Hall, *Illumination and Color in Computer Generated Imagery*, Springer-Verlag, 1989.
- R. Daniel Overheim and David Wagner, *Light and Color*, John Wiley & Sons, 1982.
- David Travis, *Effective Color Displays*, Academic Press, 1991.
- L.G. Thorell and W.J. Smith, *Using Computer Color Effectively*, Prentice Hall, 1990.
- Edward Tufte, *The Visual Display of Quantitative Information*, Graphics Press, 1983.
- Edward Tufte, *Envisioning Information*, Graphics Press, 1990.
- Edward Tufte, *Visual Explanations*, Graphics Press, 1997.
- Howard Resnikoff, *The Illusion of Reality*, Springer-Verlag, 1989.

Sometimes You Have to Try Things Just Because You Can



Color and the Display of Information



You can get these notes, and more, at:

http://cs.oregonstate.edu/~mjb/superquest2010