

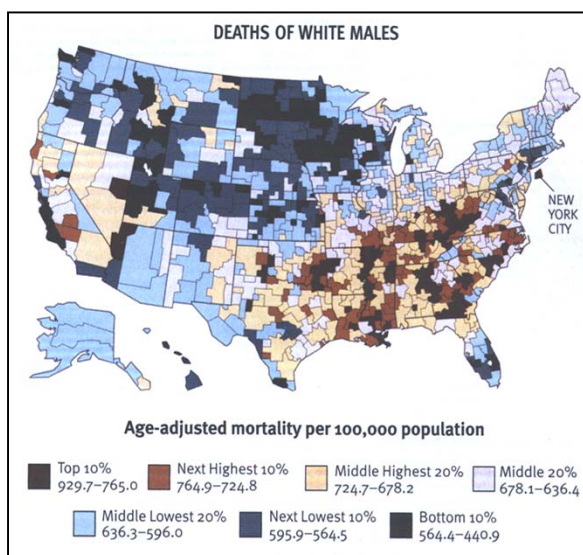
Color and the Display of Information: Yes, this is still Computer Science



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What's Wrong with this Picture?



Source:
Scientific American,
June 2000



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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)

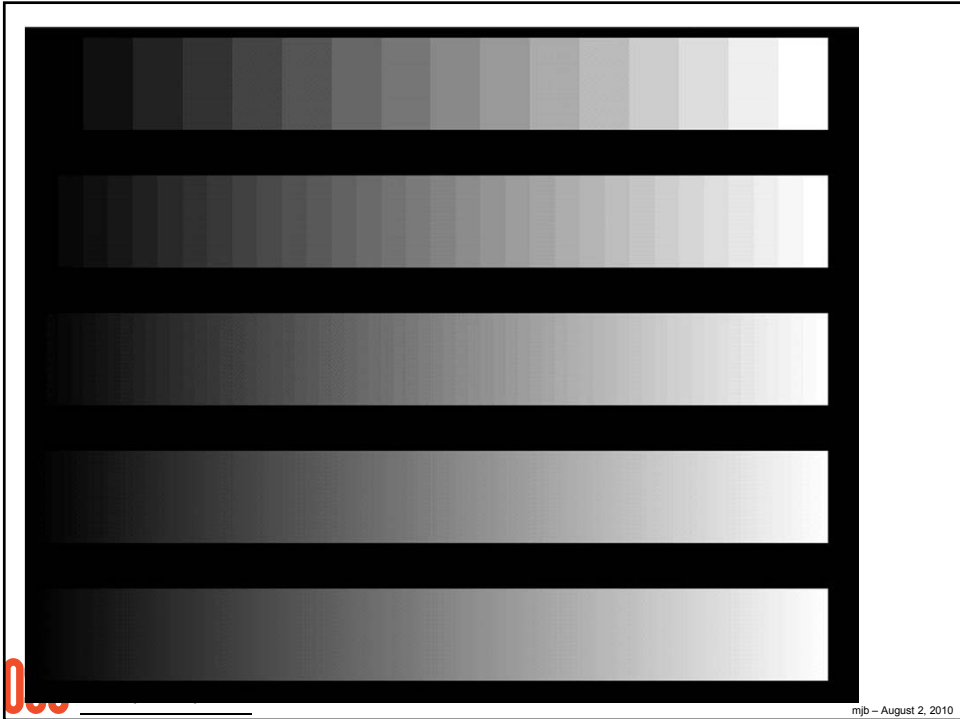
Cones

- ~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

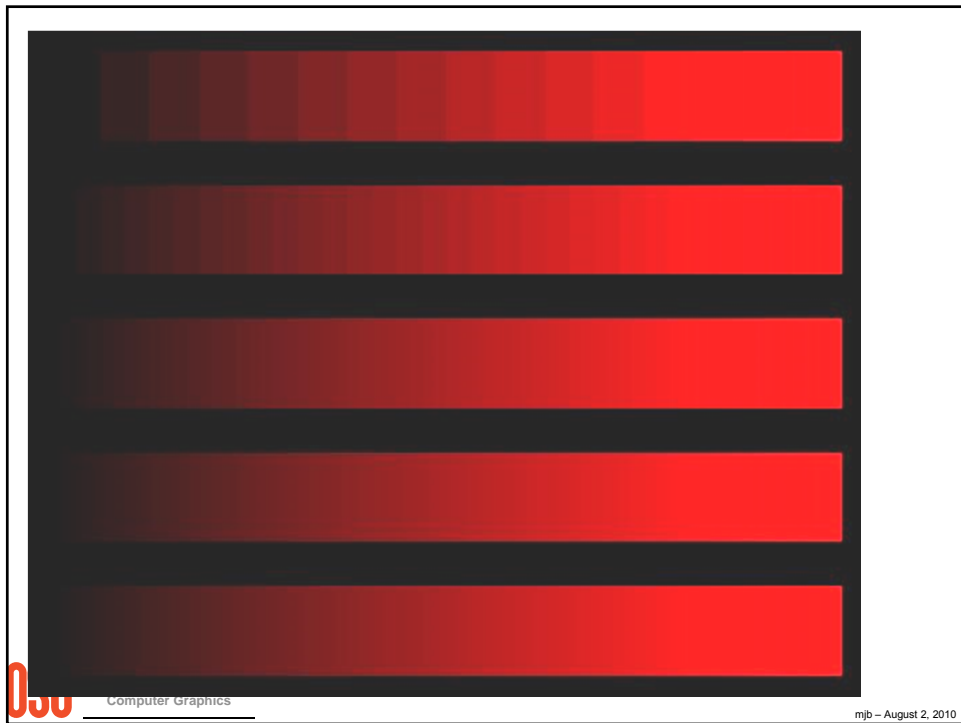
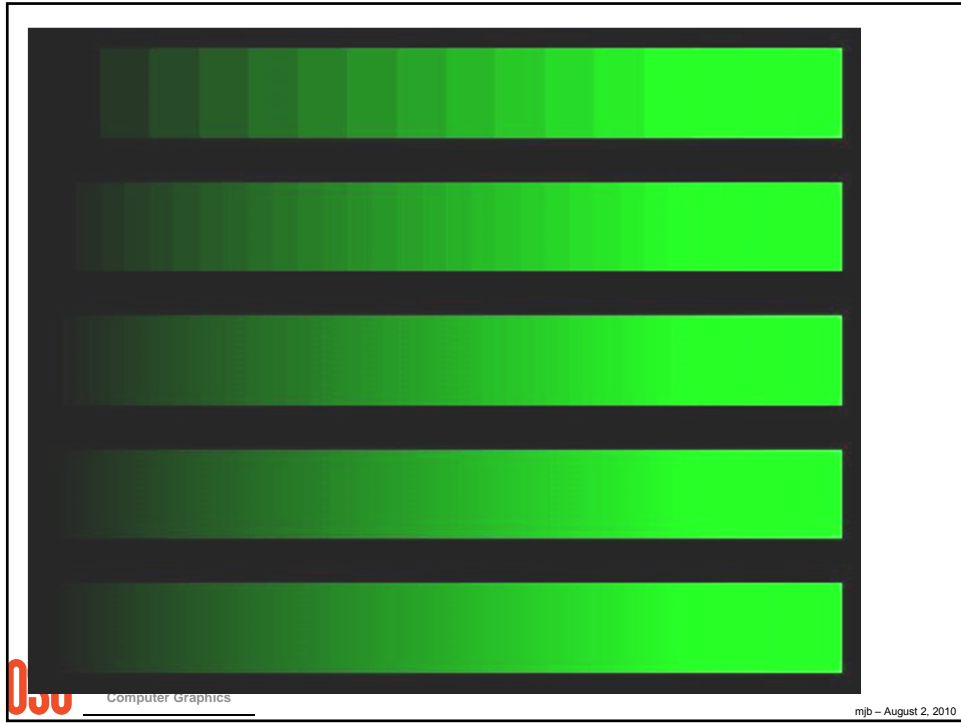


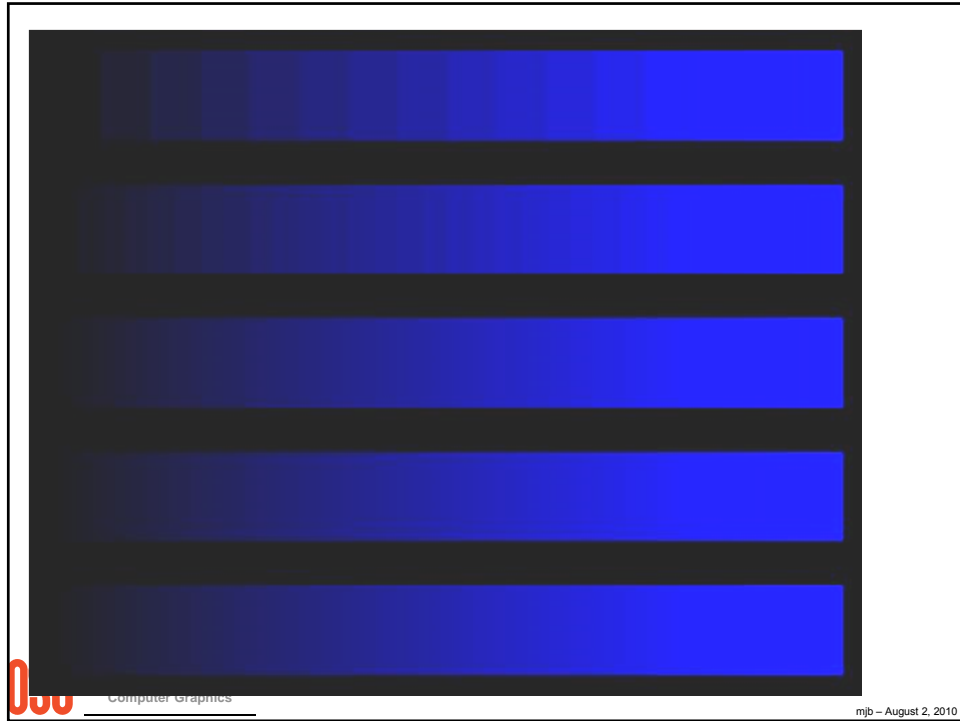
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What Makes a Good Contrast?

- 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!**



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Luminance Contrast is Crucial !

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

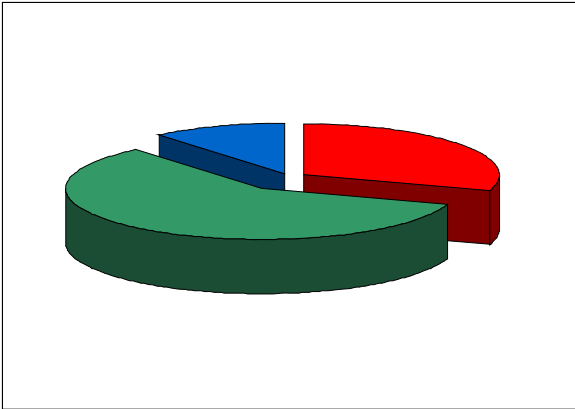


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The Luminance Equation

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



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 |

| | | | | | | | | |
|--------|--------|--------|--------|--------|--------|--------|--------|--------|
| Black | Black | Black | Black | Black | Black | Black | Black | Black |
| White | White | White | White | White | White | White | White | White |
| Red | Red | Red | Red | Red | Red | Red | Red | Red |
| Yellow | Yellow | Yellow | Yellow | Yellow | Yellow | Yellow | Yellow | Yellow |
| Green | Green | Green | Green | Green | Green | Green | Green | Green |
| Blue | Blue | Blue | Blue | Blue | Blue | Blue | Blue | Blue |

Do Not Attempt to Fight Pre-Established Color Meanings

Red:

Stop
On
Off
Dangerous
Hot
High stress
Oxygen
Shallow
Money loss

Green:

On
Plants
Carbon
Moving
Money

Blue:

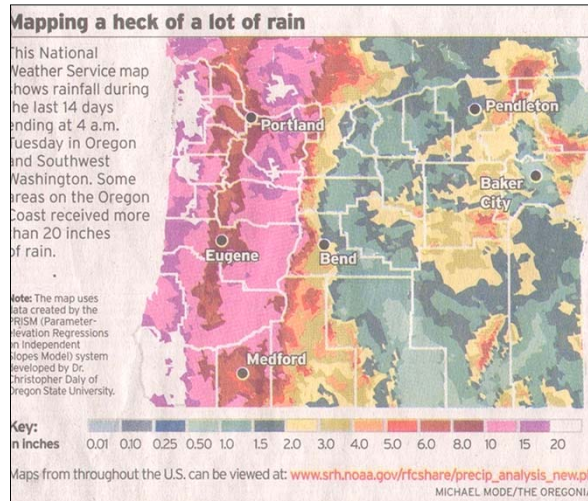
Cool
Safe
Deep
Nitrogen



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



Source:
The Oregonian,
January 11, 2006

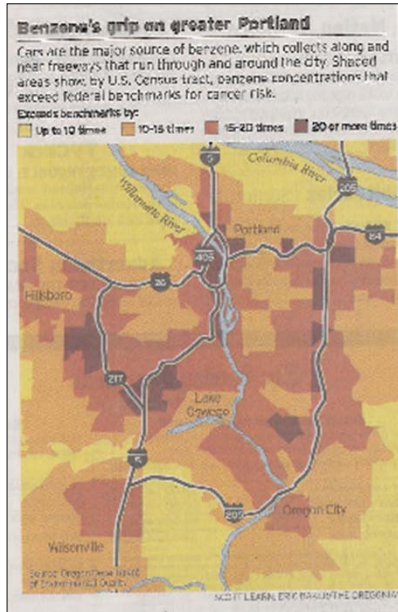
Shouldn't lush-green colors represent wet and sand-colors represent dry?



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This one is better

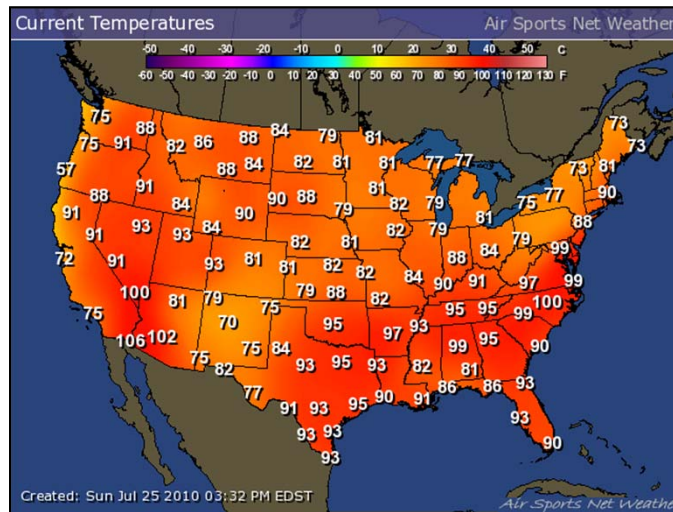


Source:
 The Oregonian,
 October 31, 2006

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



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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

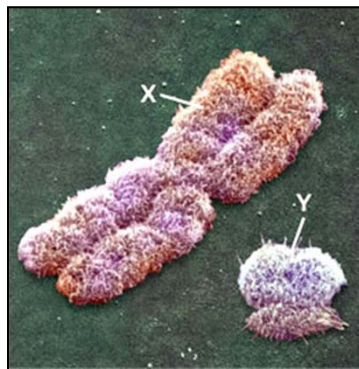


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Q: Why are more men affected by CVD than women?

A: A common CVD is carried on the X Chromosome



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



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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...

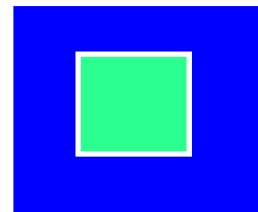
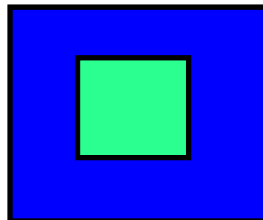
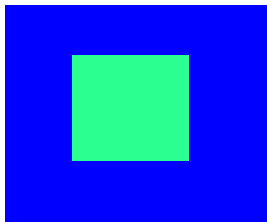
Four score and
seven years ago,
our forefathers
brought forth
upon this
continent a new
nation...



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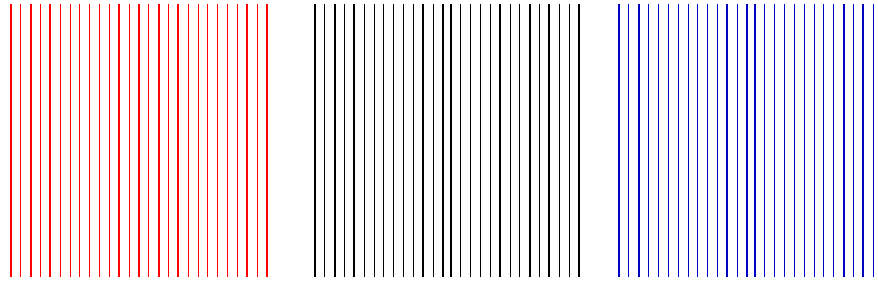
Use a Black or White Line as the Boundary Between Colored Regions



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



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**Watch the Use of Saturated Reds and
Blues Together**

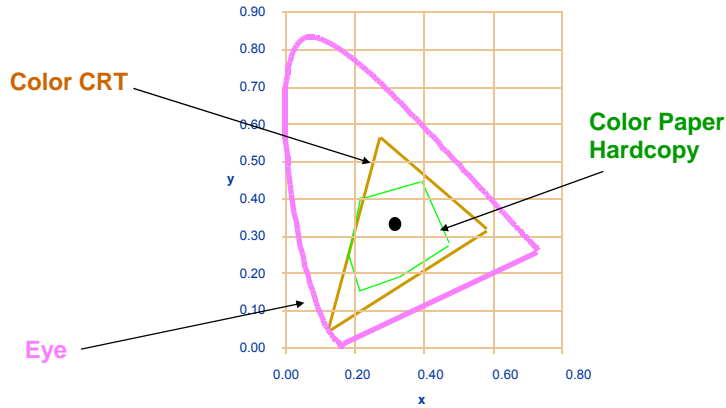
**Reds and Blues are
on opposite ends of
the color spectrum.
It is hard for your
eyes to focus on
both.**



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**Be Aware of the Difference in Color Gamuts
between a Monitor and a Color Printer
(and a Projector)**



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

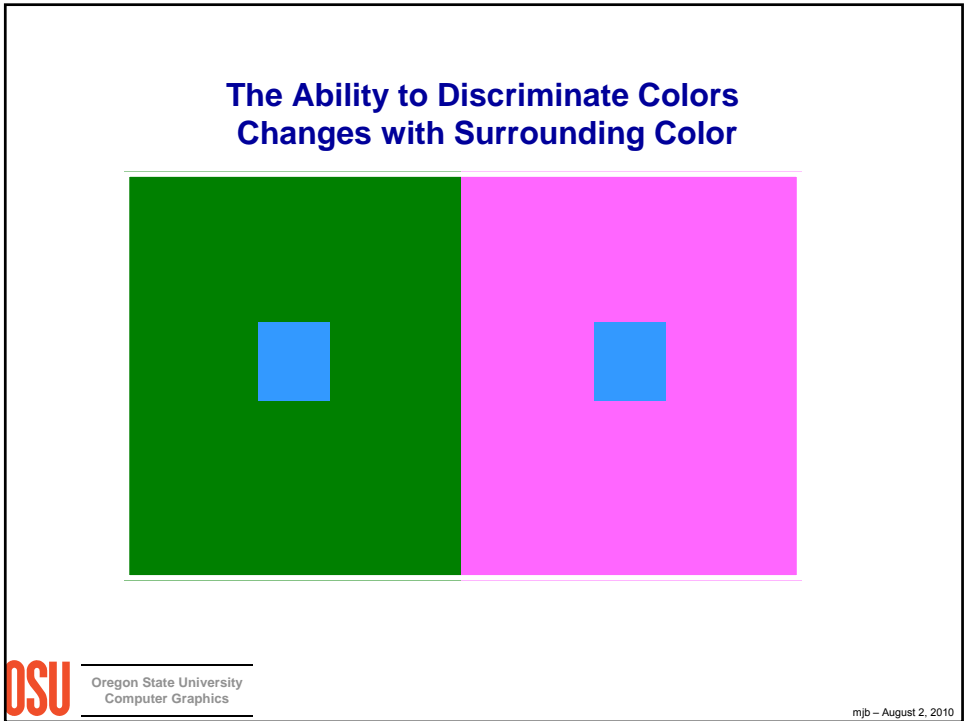
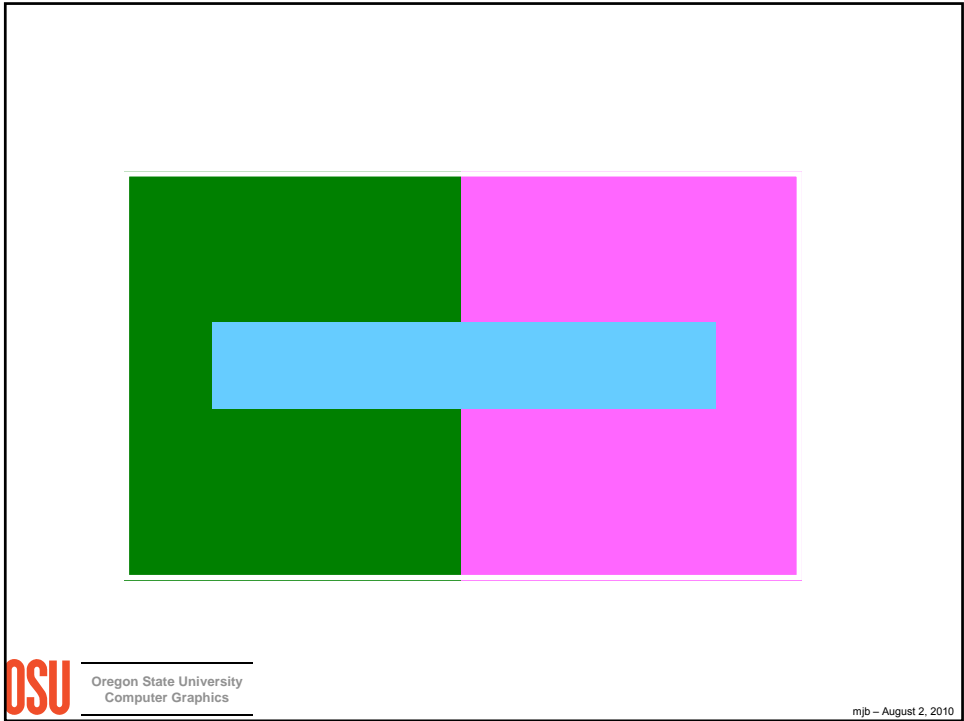
NTSC Cycles-of-Encoding per Scanline

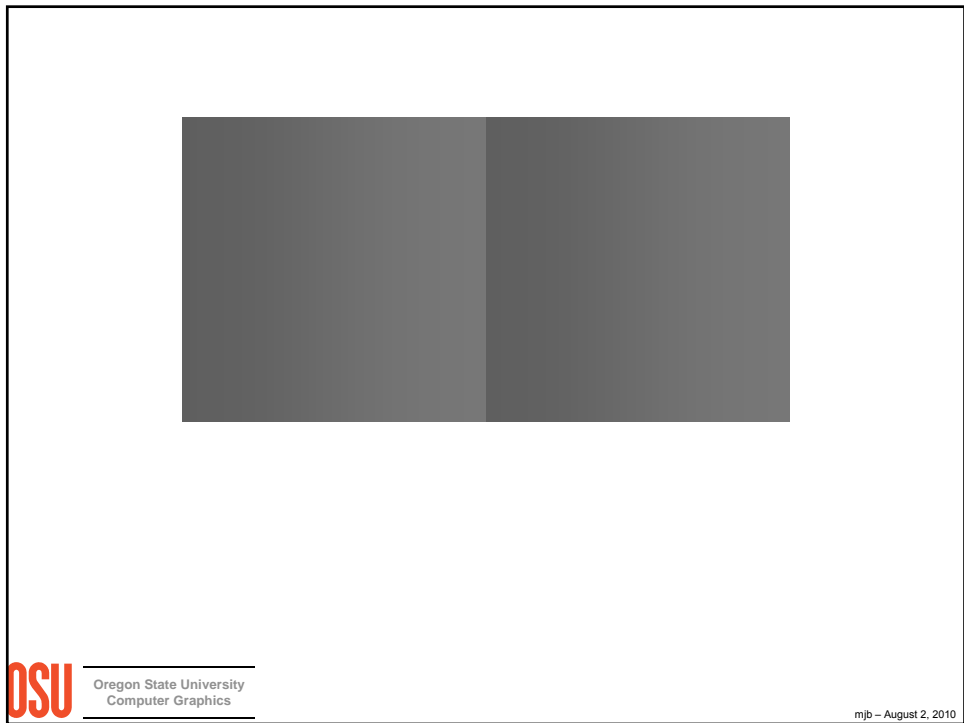
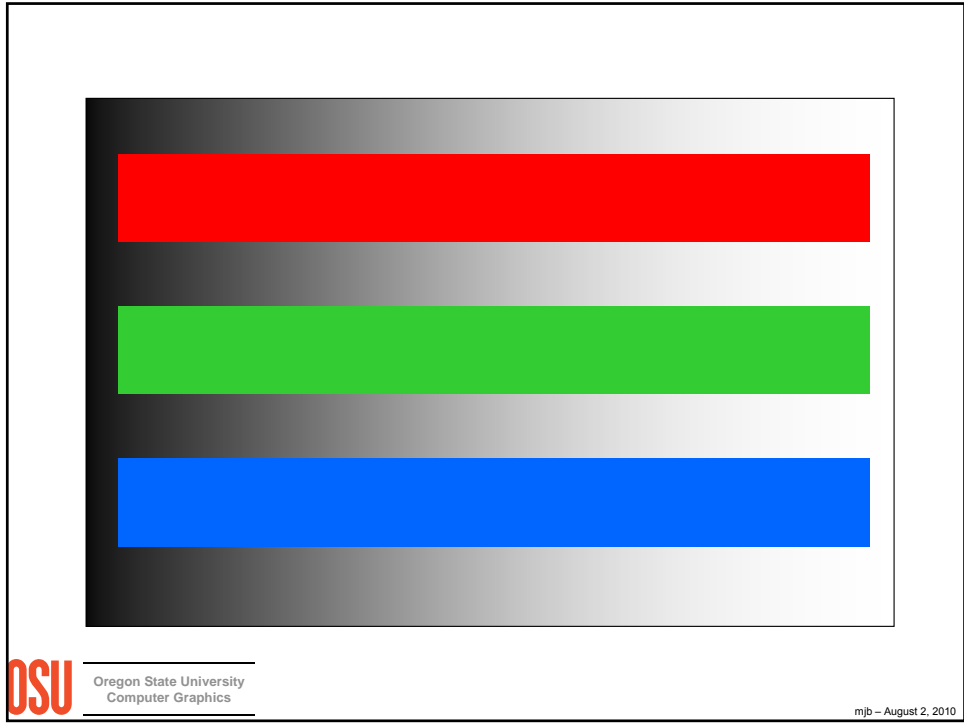
| What: | Cycles/Scanline: |
|--------------|------------------|
| Intensity | 267 |
| Orange-Blue | 96 |
| Purple-Green | 35 |

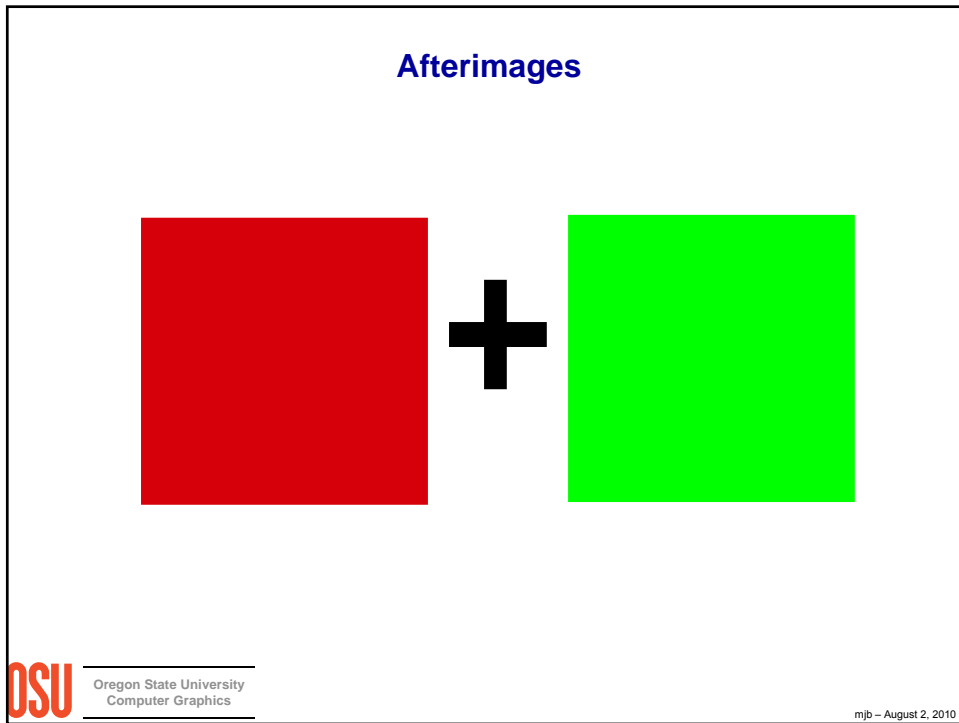
Sometimes You Have to Try Goofy Color Experiments Just Because You Can



Beware of Lots of Other Stuff



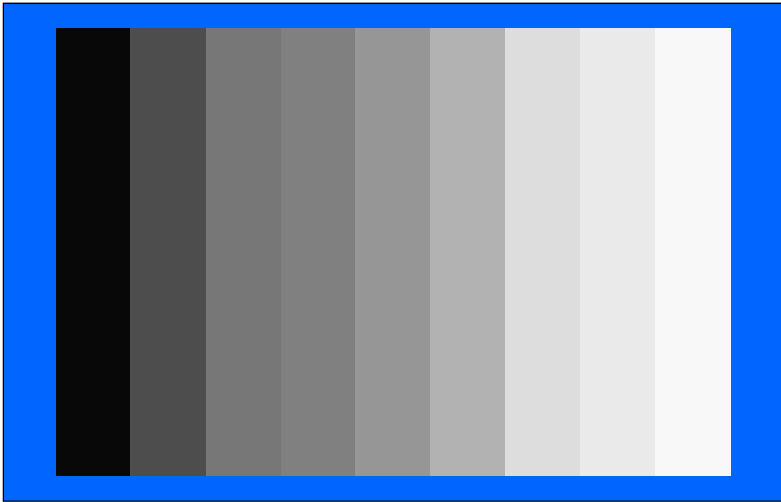




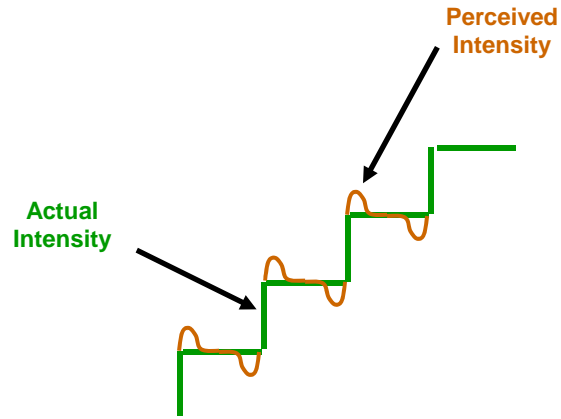
Afterimages



Beware of Mach Banding



Beware of Mach Banding

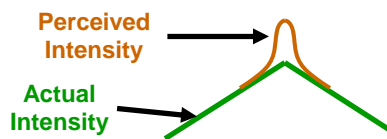
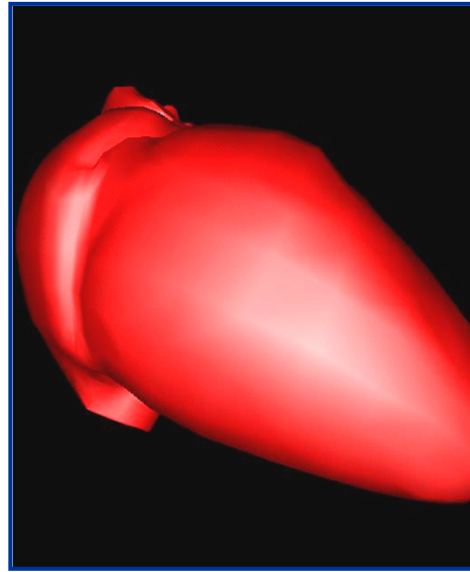


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Beware of Mach Banding



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