Color in Computer Graphics

1

This work is licensed under a Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License

Oregon State University Computer Graphics

Your Intensity/Color Sensors

2

Rods

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

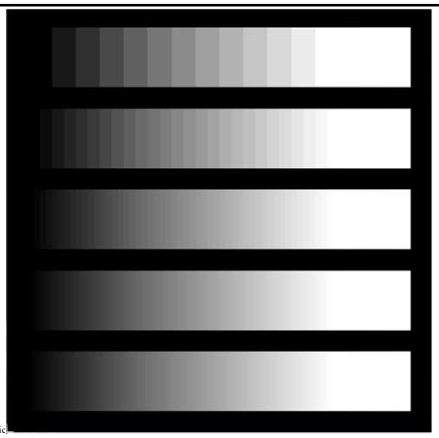
Cones

- ~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

Oregon State University Computer Graphics

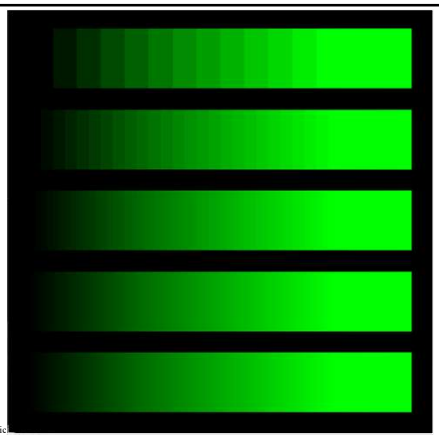
But are you equally-sensitive to all wavelengths?

3



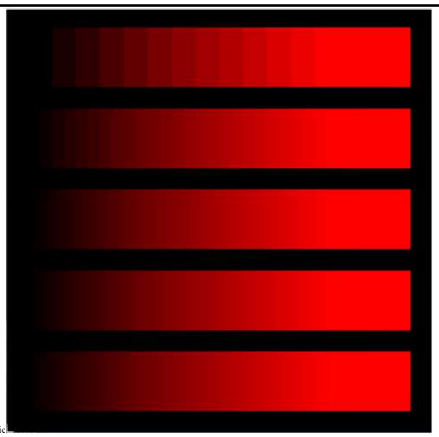
Oregon State University Computer Graphics

4



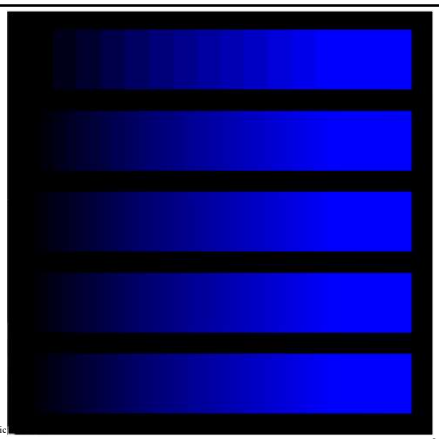
Oregon State University Computer Graphics

5



Oregon State University Computer Graphics

6



Oregon State University Computer Graphics

Sidebar: How Many Pixels Do You Need?

7

A person with 20/20 vision has a visual acuity of:
1 arc-minute = 1/60°

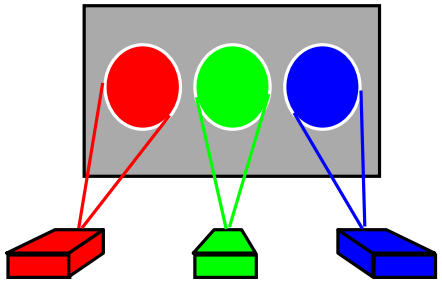
$\Theta = {}^{1}/_{60}{}^{\circ} = .00029^{R}$

$\text{Density} = \frac{1}{D\Theta}$

Viewing Distance (inches)	Required Pixel Density (ppi)	If the monitor's resolution is 1600 x 1200, then its diagonal size would need to be:
36	95	21"
31	111	18"
24	143	14"
12	286	7"
9	400	5"
6	600	3"

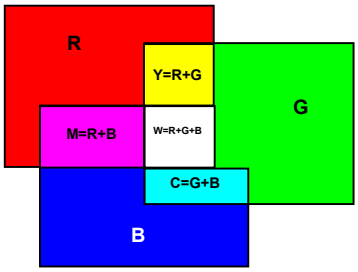
Monitors: Additive Colors

8



Additive Color (RGB)

9

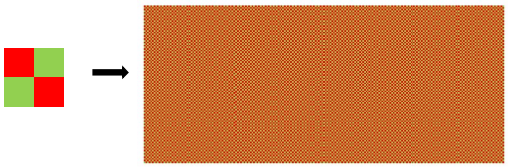


OpenGL: → **glColor3f(r, g, b);**

0. ≤ r, g, b ≤ 1.

Yes, Our Vision System Really Does Mush Red and Green Together to Make Yellow!

10

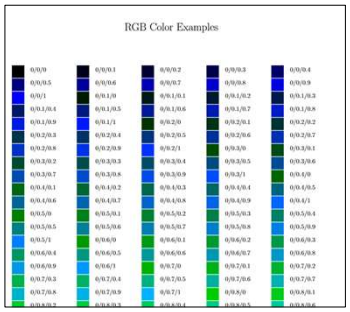


Color Combinations

11

Here's a cool website that shows a lot of different color combinations:

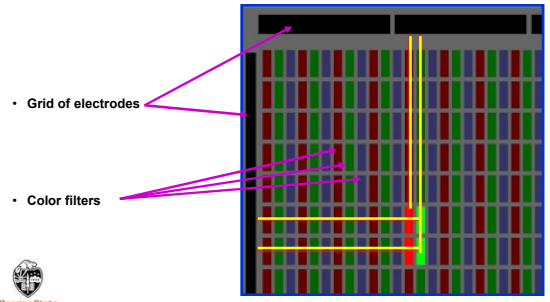
https://www.tug.org/pracjourn/2007-4/walden/color.pdf



LCD Displays "Gate" Color

12

Most desktop monitors are LCD displays that use white LEDs for backlighting

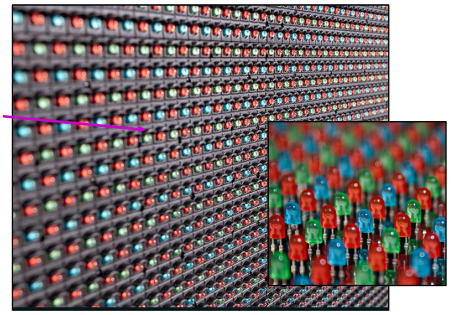


http://electronics.howstuffworks.com

LED Displays *Emit* Color

13

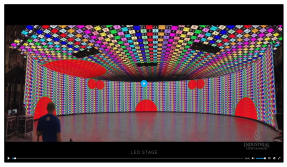
- Grid of LEDs

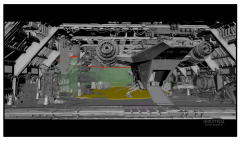


https://www.expromo.eu/en/led-display-facts/

The New Sound Stages use LED Displays

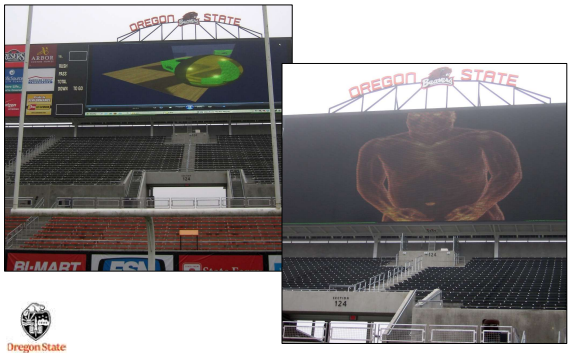
14





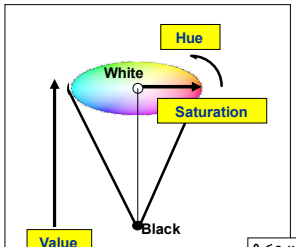
Stadium Jumbotrons use LED Displays

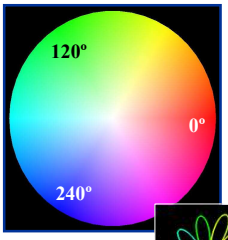
15



Hue-Saturation-Value (HSV):
For many applications, a more intuitive way to specify additive color

16





0. ≤ s, v, r, g, b ≤ 1.
0. ≤ h ≤ 360.

```
float hsv[3], rgb[3];
hsv[0] = something between 0. and 360.
hsv[1] = hsv[2] = 1.;
HsvRgb( hsv, rgb );
glColor3fv( rgb );
```

The HsvRgb( ) function is in your sample code

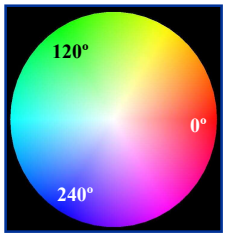
Marching around the Hue color wheel is a nice way to get a range of colors

Home Depot uses a form of HSV :-)

17

Hue-Saturation-Value (HSV):
For many vis applications, a simpler way to specify additive color

18

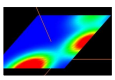


Notice that blue-green-red in HSV space corresponds to the visible portion of the electromagnetic spectrum

Blue: 380 nm Green: 520 nm Red: 780 nm

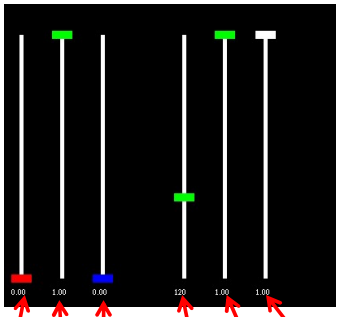
$$Hue = 240. - 240.\frac{S - S_{min}}{S_{max} - S_{min}}$$

Turning a scalar value into a hue when using the Rainbow Color Scale



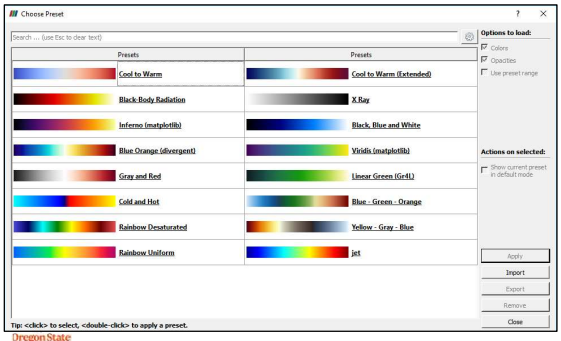
Hue-Saturation-Value: The *OSU ColorPicker* Program

19



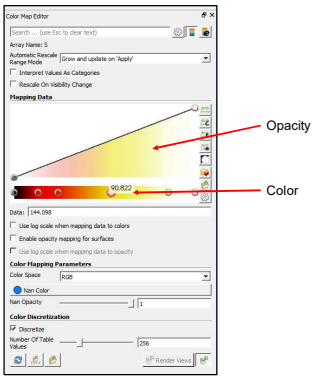
ParaView Allows You to Pick Among Several Preset Color Ranges

20



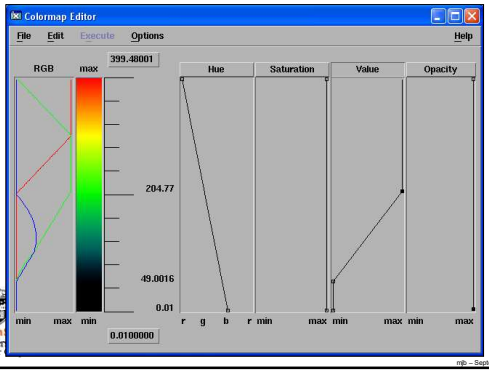
ParaView Allows You to Sculpt Your Own Color Range

21



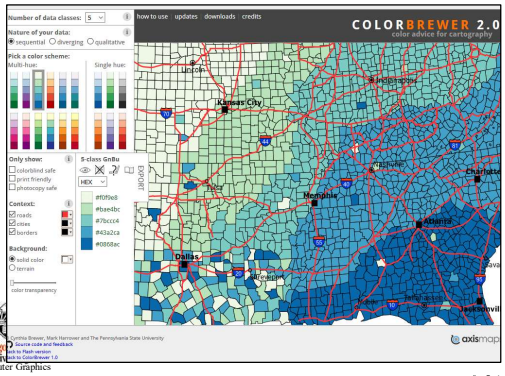
OpenDX Allows you to Sculpt the Transfer Function in HSV

22



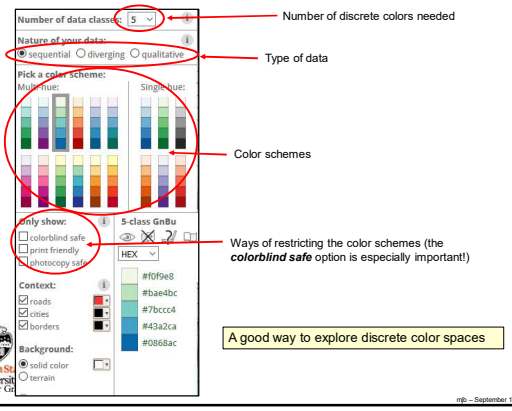
http://colorbrewer2.org

23



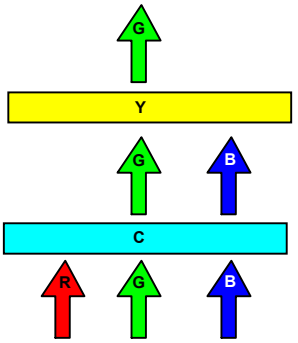
http://colorbrewer2.org

24



Subtractive Colors (CMYK)

25

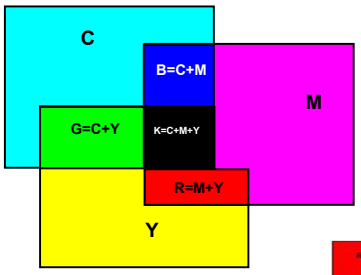


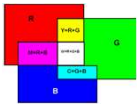
R = Red
G = Green
B = Blue
W = White

C = Cyan
M = Magenta
Y = Yellow
K = Black

Subtractive Colors (CMYK)

26

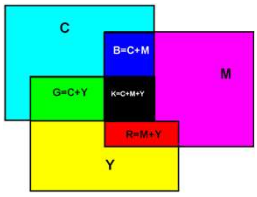




Color Printing

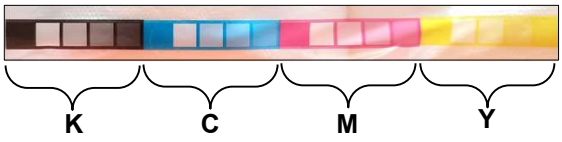
27

- Uses subtractive colors
- Uses 3 (CMY) or 4 (CMYK) passes
- CMYK printers have a better-looking black
- There is a considerable variation in color *gamut* between products



You Often See Color Printing QA Tests Like This

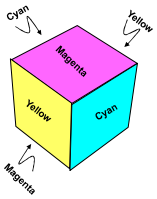
28



The CMY Cube

29

How the Cube is setup:

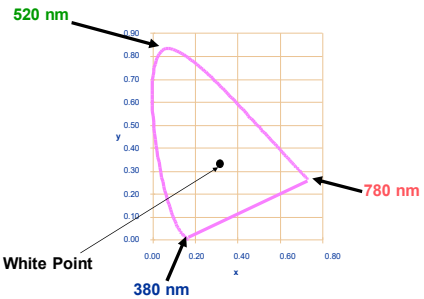


How it looks when you sight through two faces:

I have one of these in my office! ☺

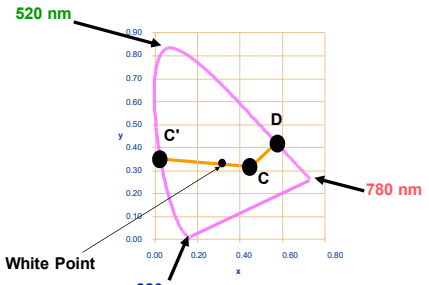
CIE Chromaticity Diagram

30



31

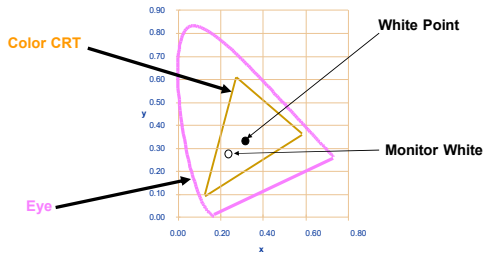
CIE Chromaticity Diagram



C = the color
D = the dominant wavelength
C ' = the complementary color

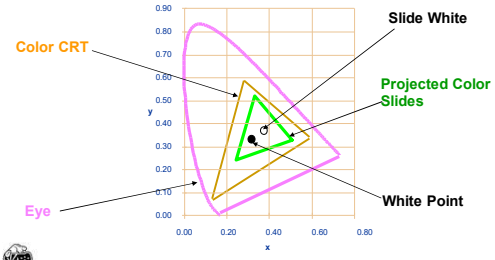
32

Color Gamut for a Workstation Monitor



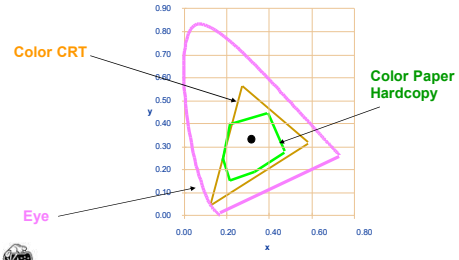
33

Color Gamut for a Monitor and Color Slides



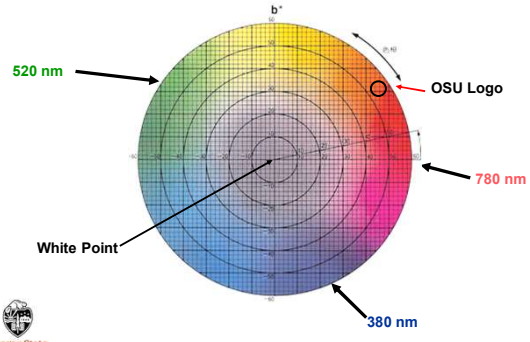
34

Color Gamut for a Monitor and Color Printer



35

The *Perceptually Uniform* L-a-b Color Space



36

Color Meters Are Able to Measure L-a-b Coordinates

What Makes a Good Contrast?

37

- Many people think simply adding color onto another color makes a good contrast
- In fact, a better measure is the **Δ Luminance**
- Using this also helps if someone makes a grayscale photocopy of your color hardcopy

38

Color Alone Doesn't Cut It !

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

39

Luminance Contrast is Crucial !

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

40

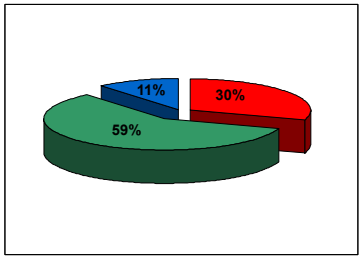
TUESDAY
MARCH 29
3–4 PM

RSVP to:
http://oregonstate.qualtrics.com/jfe/form/SV_cGCdeS2t9JlFKiR
Or call: 541.737.0664

41

The Luminance Equation

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



42

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

(I use a ΔL* of about 0.40)

	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

Oregon State University Computer Graphics

Oregon State University Computer Graphics

Limit the Total Number of Colors if Viewers are to Discern Information Quickly

Instructions:

1. Press red to logoff normally

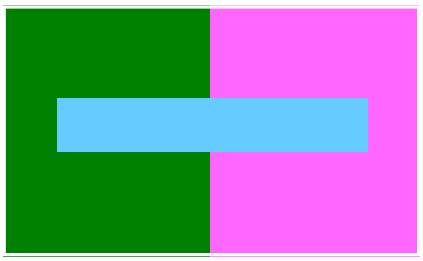
2. Press light red to delete all your files, change your password to something random, and logoff

You have 2 seconds • • •

Oregon State University Computer Graphics

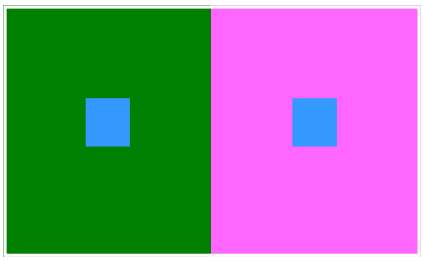
Oregon State University Computer Graphics

The Ability to Discriminate Colors Changes with Surrounding Color: "Simultaneous Contrast"



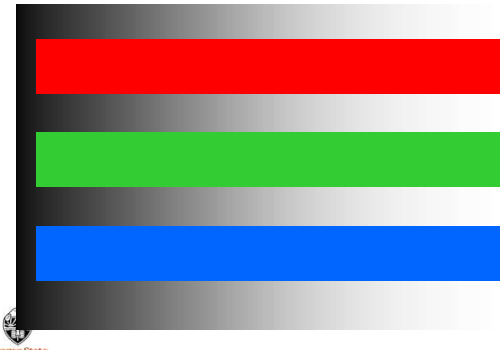
Oregon State University Computer Graphics

The Ability to Discriminate Colors Changes with Surrounding Color: "Simultaneous Contrast"



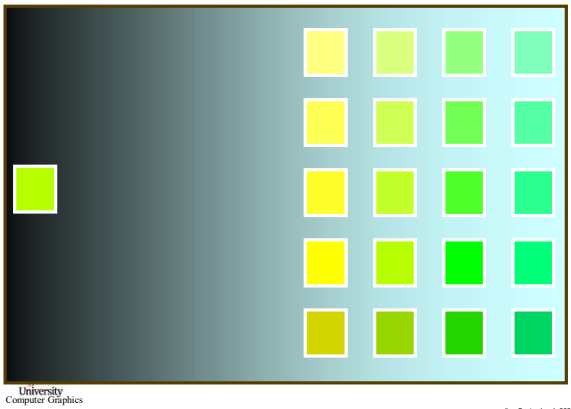
Oregon State University Computer Graphics

49



50

51



52

So, What's Up with the "Blue Dress" Debate?

It's all part of the ***Color Constancy*** effect

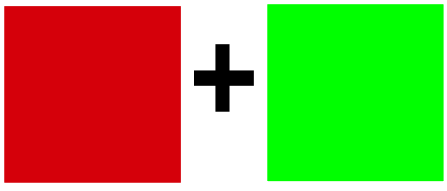
New York Times

If you see this color, but you think that the dress is currently in a shadow, you "know" that it must *really* be this color.

If you see this color, but you think that the dress is currently in bright light, you "know" that it must *really* be this color.

53

Afterimages

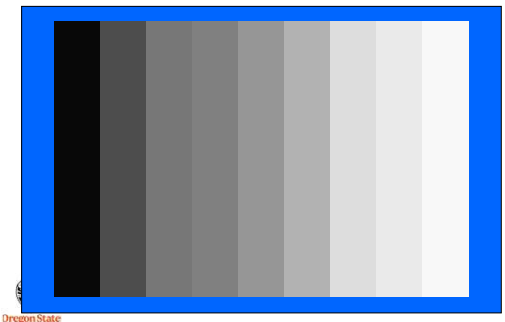


54

Afterimages

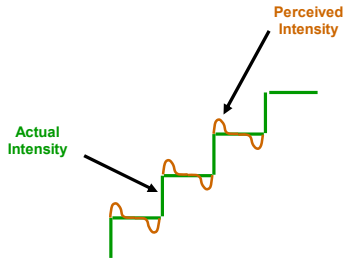
Beware of Mach Banding

55



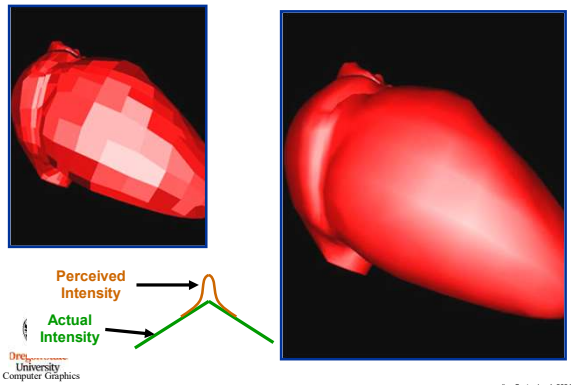
Beware of Mach Banding

56



Beware of Mach Banding

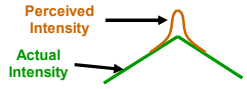
57



Beware of Mach Banding

58

Think of the Mach Banding problem as being similar to trying to round second base at a 90° angle.



Be Aware of Color Vision Deficiencies (CVD)

59

- In general, there is no such thing as total "color blindness"
- CVD affects ~10% of Caucasian men
- CVD affects ~4% of non-Caucasian men
- CVD affects ~0.5% of women
- The most common type of CVD is red-green
- Blue-yellow also exists

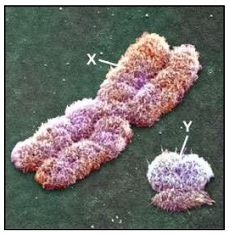
Resources for designing color schemes for people with color recognition deficiencies:

http://colorbrewer2.org
http://colororacle.org/usage.html
http://mkweb.bcgsc.ca/colorblind/

Why are more men affected by CVD than women?

60

It's because the red-green CVD defect is carried on the X Chromosome



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

An XX with the defective gene on one X chromosome probably has a dominant non-defective gene on the other. An XY with a defective gene on one X chromosome has no other gene to "fix" it.

Be Aware of CVD: Code Information Redundantly

61

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

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

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

Be Aware of CVD: Code Information Redundantly: Color + …

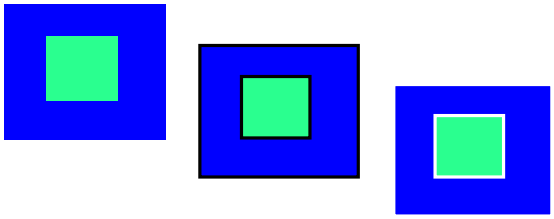
62

- Different fonts
- Symbols
- Fill pattern
- Outline pattern
- Outline thickness

This also helps if someone makes a grayscale photocopy of your color hardcopy

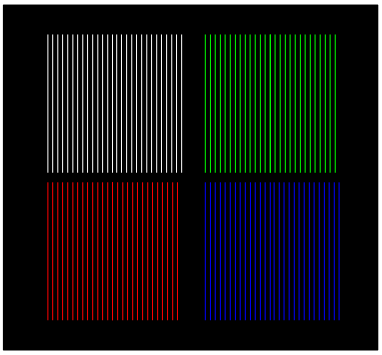
Use a Black or White Line as the Boundary Between Colored Regions

63



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

64



Watch the Use of Saturated Reds and Blues Together

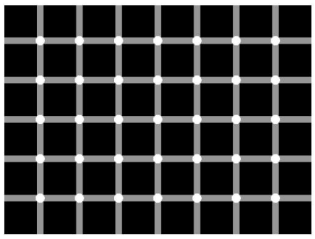
65

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

Beware of Lots of Other Stuff

66

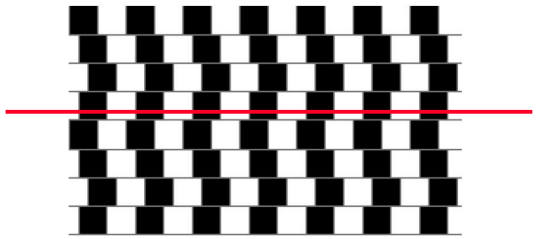
67



Oregon State University Computer Graphics

mjb – September 1, 2024

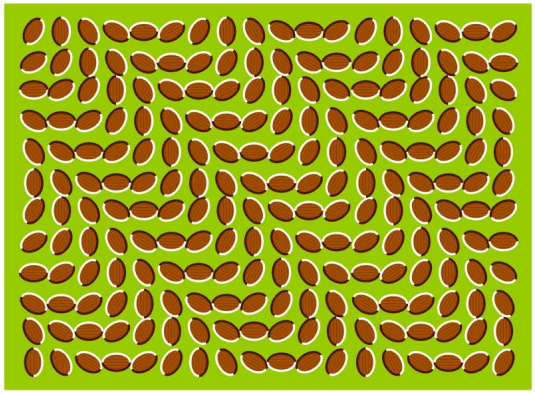
68



Oregon State University Computer Graphics

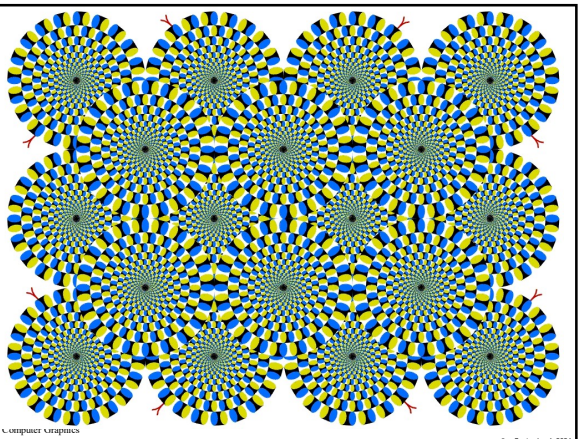
mjb – September 1, 2024

69



Computer Graphics

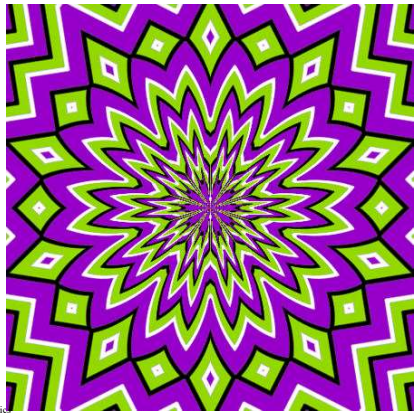
mjb – September 1, 2024



Computer Graphics

mjb – September 1, 2024

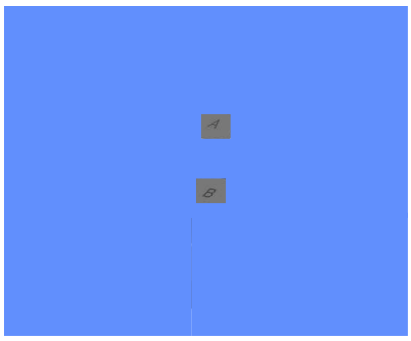
71



Oregon State University Computer Graphics

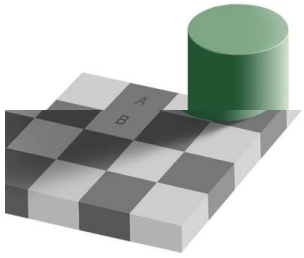
mjb – September 1, 2024

72



Oregon State University Computer Graphics

mjb – September 1, 2024



Good Color and Perception References

- Theresa-Marie Rhyne, *Applying Color Theory to Digital Media and Visualization*, Second Edition, CRC Press, 2025.
- 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.