

## Color in Scientific Visualization

1



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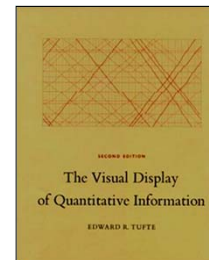


colorvis.pptx

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"The often scant benefits derived from coloring data indicate that even putting a good color in a good place is a complex matter. Indeed, so difficult and subtle that avoiding catastrophe becomes the first principle in bringing color to information. Above all, do no harm."

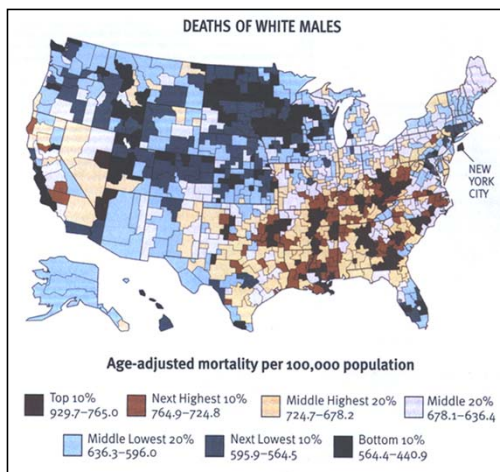
-- Edward Tufte



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## What's Wrong with this Color Scale?

3

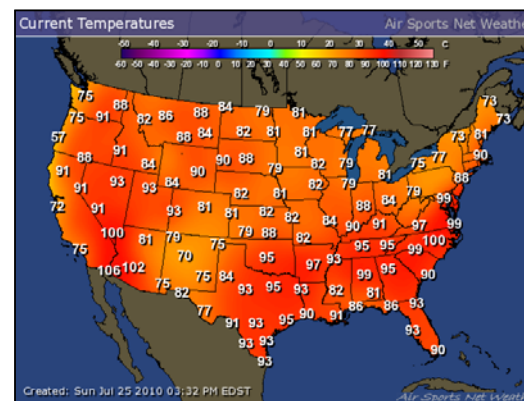


Source:  
Scientific American,  
June 2000

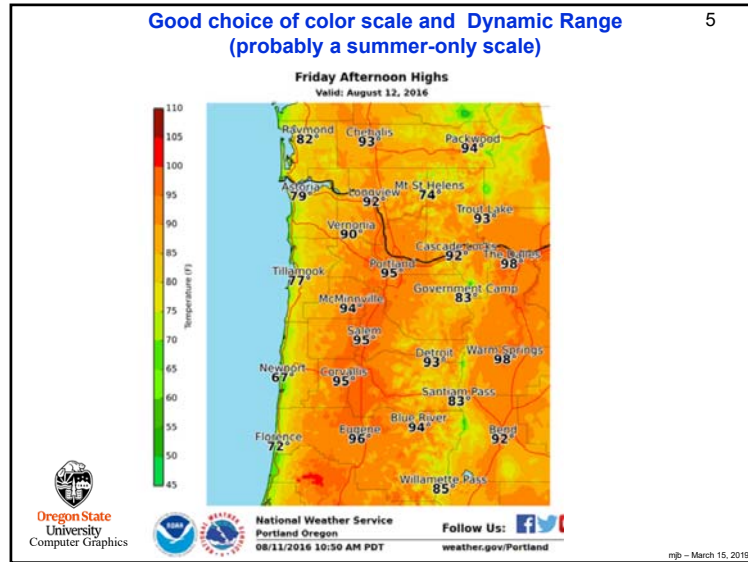
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## Not a bad choice of color scale, but the Dynamic Range needs some work

4



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7

Let's start with the most important component in a visualization system – You!

How Many Shades of Different Colors Are We Able to Detect?

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8

Sensors in Your Retina

**Rods**

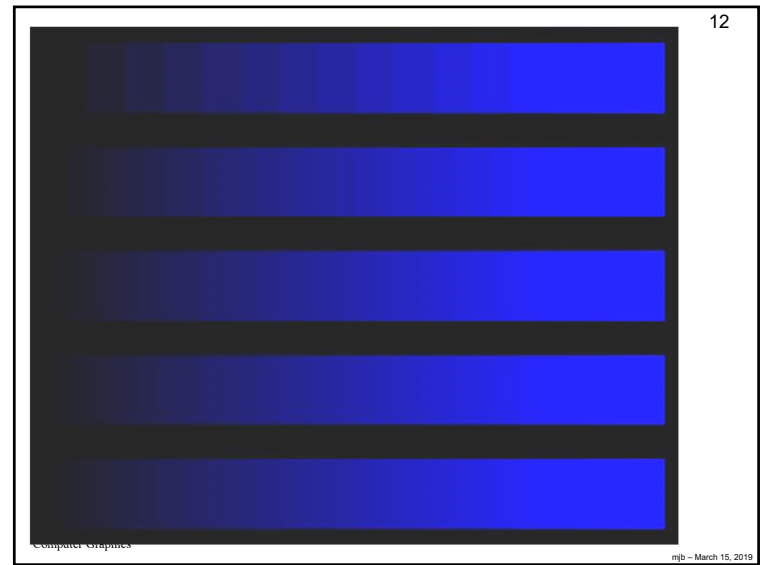
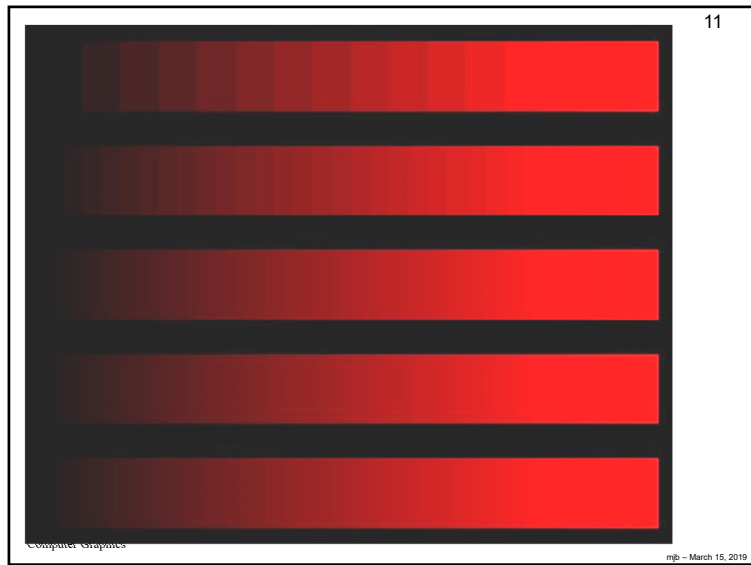
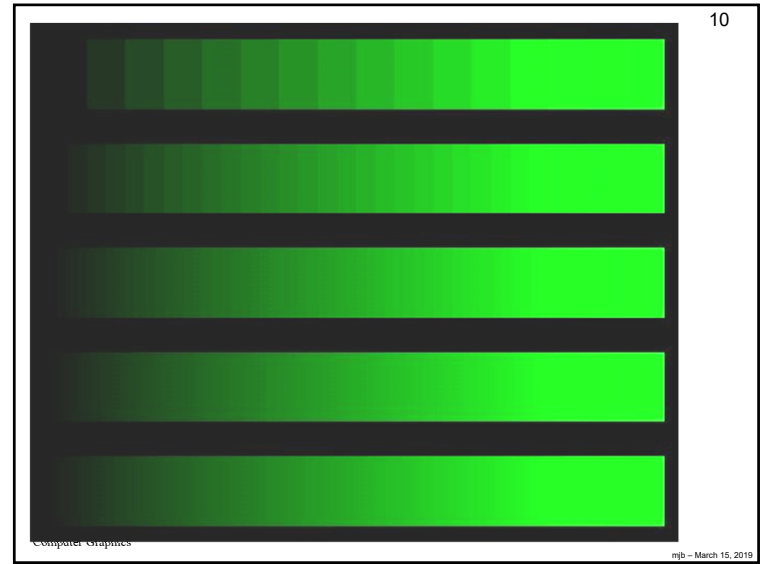
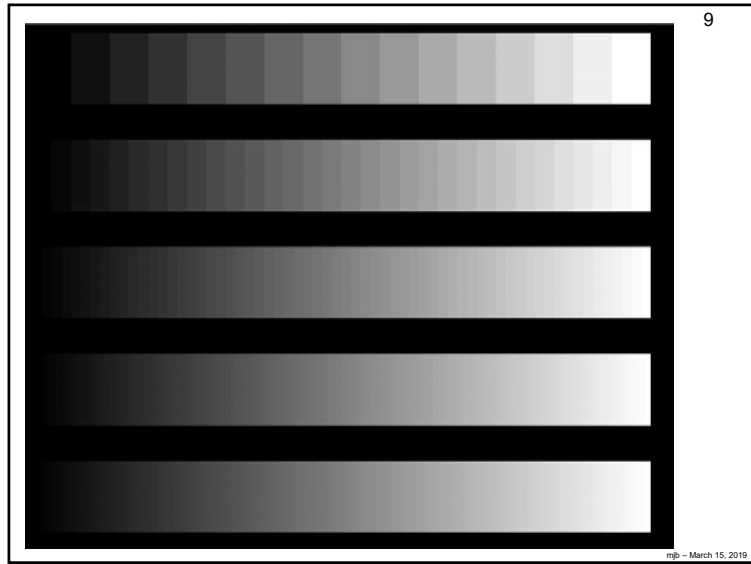
- ~115,000,000
- Concentrated on the periphery of the retina
- Sensitive to *intensity*
- Most sensitive at 500 nm (~green)

**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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### Sidebar: How Many Pixels Do You Need?

13

A person with 20/20 vision has a visual acuity of:  
1 arc-minute =  $1/60^\circ$

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

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

Viewing Distance (inches)	Required Pixel Density (ppi)
36	95
31	111
24	143
12	286
9	400
6	600

If the monitor's resolution is 1600 x 1200, then its diagonal size would need to be:

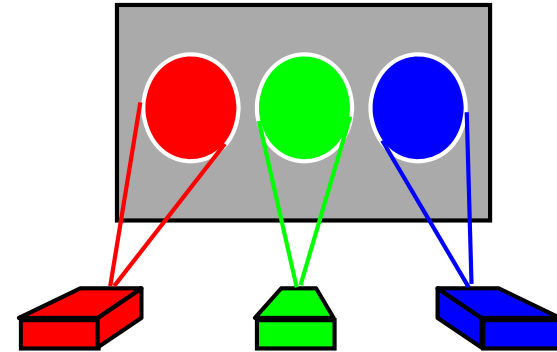
21"  
18"  
14"  
7"  
5"  
3"



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### Monitors: Additive Colors

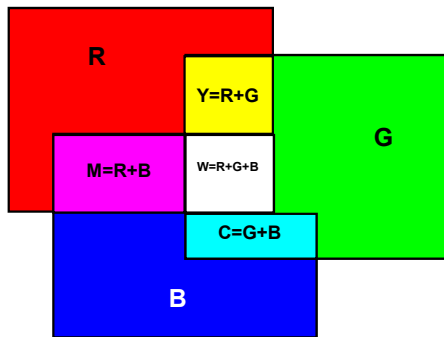
14



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### Additive Color (RGB)

15



OpenGL: `glColor3f( r, g, b );`

$0. \leq r, g, b \leq 1.$

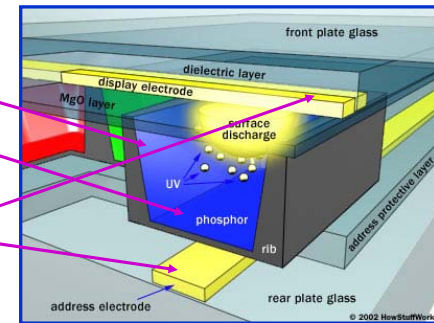


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### Plasma Displays use Additive Color

16

- Gas cell
- Phosphor
- Grid of electrodes



<http://electronics.howstuffworks.com>



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### LCD Displays use Additive Color

17

- Grid of electrodes
- Color filters

http://electronics.howstuffworks.com

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### Hue-Saturation-Value (HSV):

For many vis applications, a simpler way to specify additive color

18

float hsv[3], rgb[3];  
HsvRgb( hsv, rgb );  
glColor3fv( rgb );

The HsvRgb function is on the web site

0. ≤ s, v, r, g, b ≤ 1.  
0. ≤ h ≤ 360.

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### Home Depot uses a form of HSV :-)

19

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### Hue-Saturation-Value (HSV):

For many vis applications, a simpler way to specify additive color

20

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

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

21

Red, Green, Blue      Hue, Saturation, Value

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### ParaView Allows You to Pick Among Several Preset Color Ranges

22

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### ParaView Allows You to Sculpt Your Own Color Range

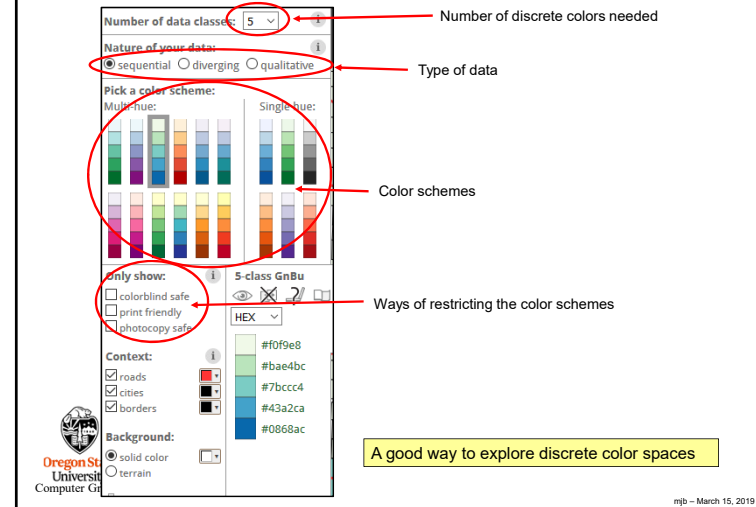
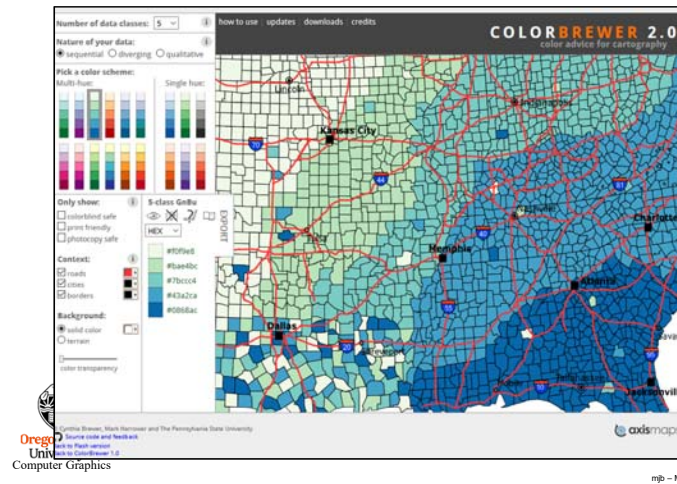
23

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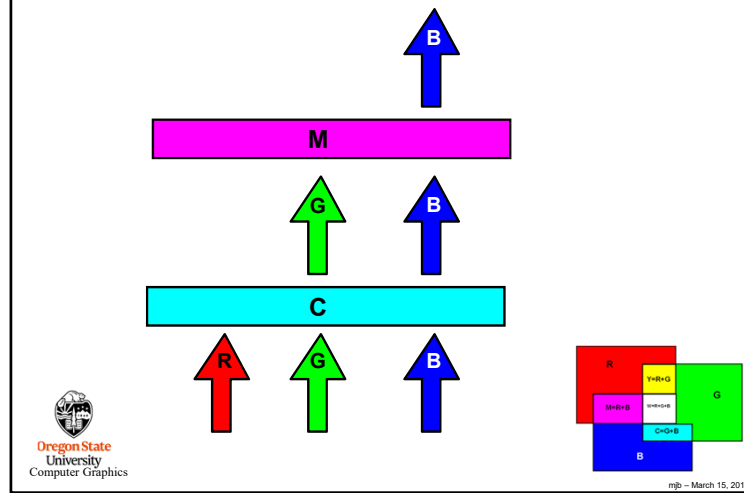
### OpenDX Allows you to Sculpt the Transfer Function in HSV

24

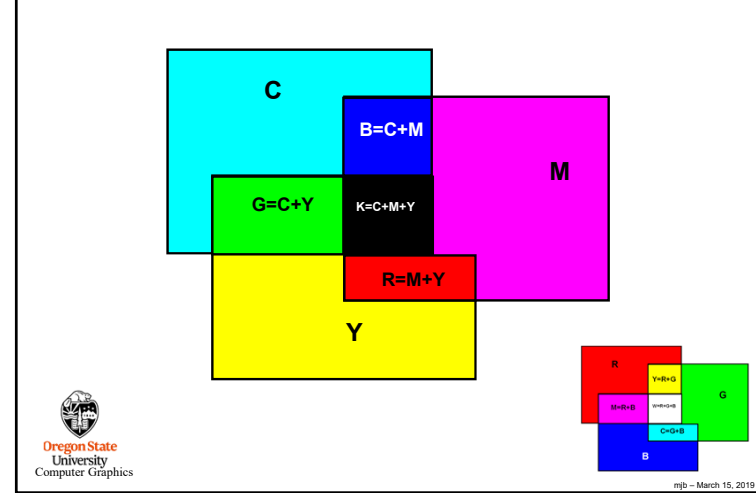
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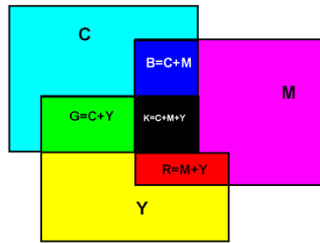
Subtractive Colors (CMYK)



Subtractive Color (CMYK)



- 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



How Do Color Separations Work in Color Printing?



Source: R. Daniel Overheim and David Wagner, *Light and Color*, John Wiley & Sons, 1982.





### Getting the CMYK Colors

33



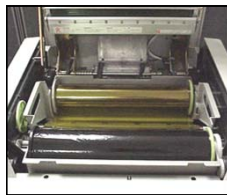
Wax



Toner



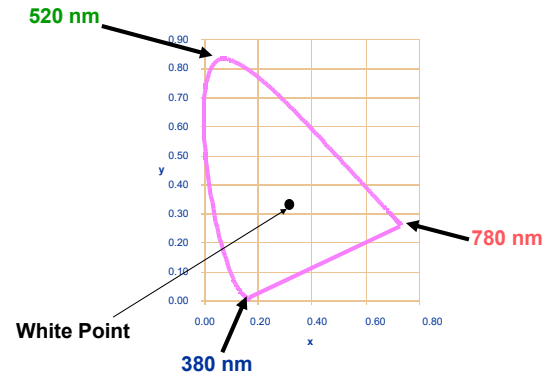
Toner



Sheets

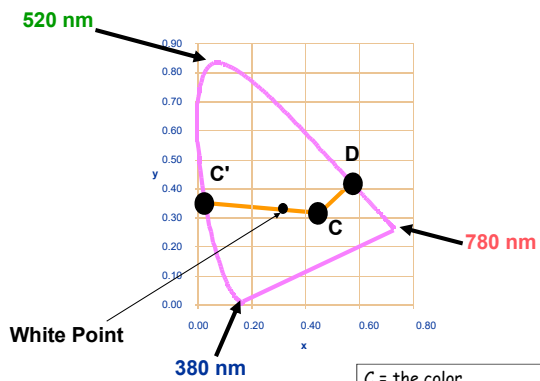
### CIE Chromaticity Diagram

34



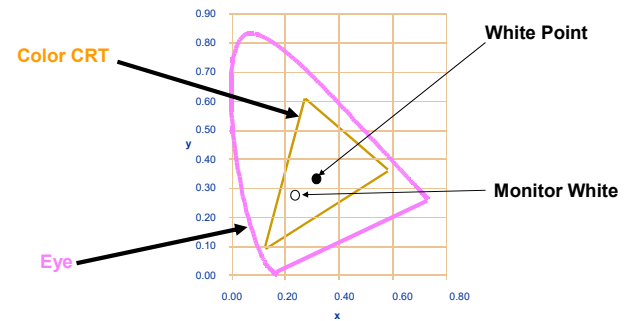
### CIE Chromaticity Diagram

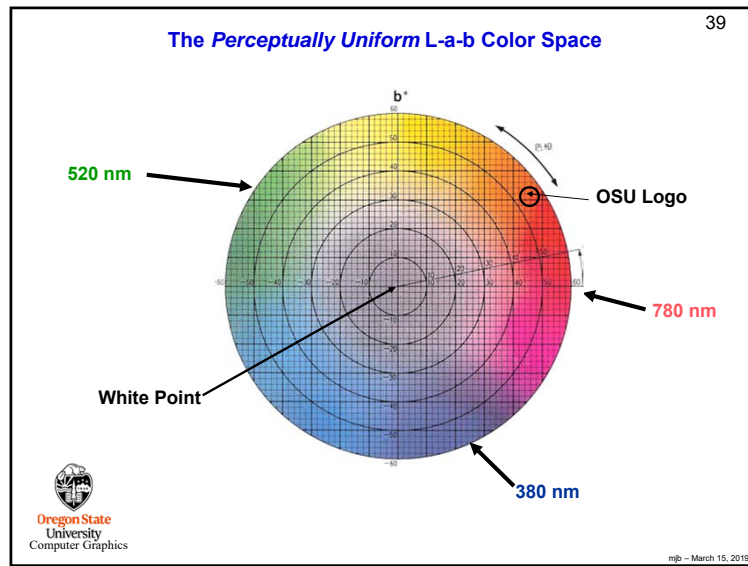
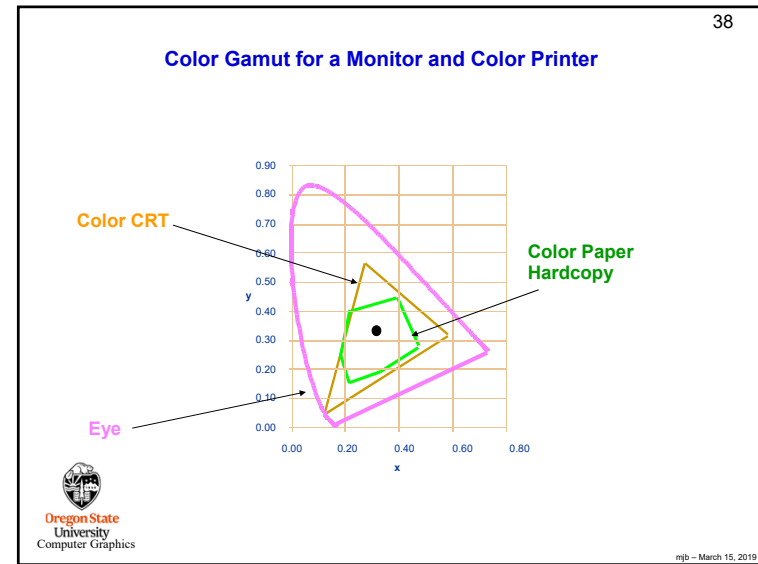
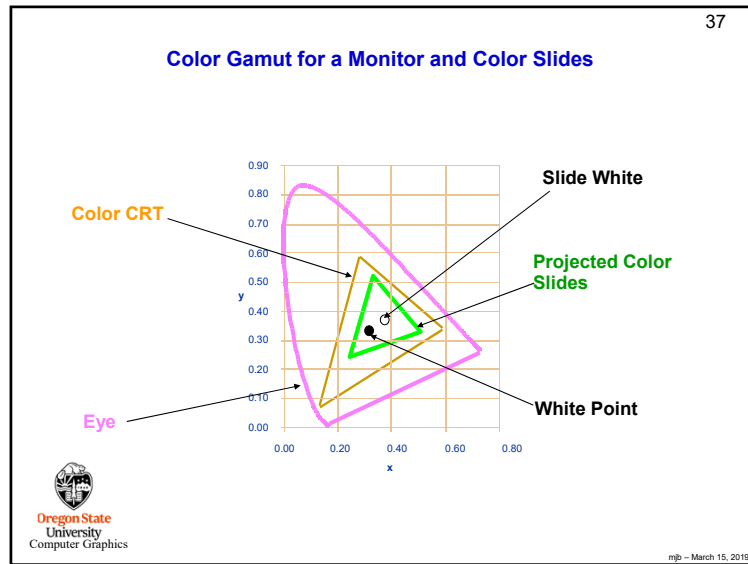
35



### Color Gamut for a Workstation Monitor

36





## Some Good Rules of Thumb When Using Color for Scientific Visualization



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



## 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!



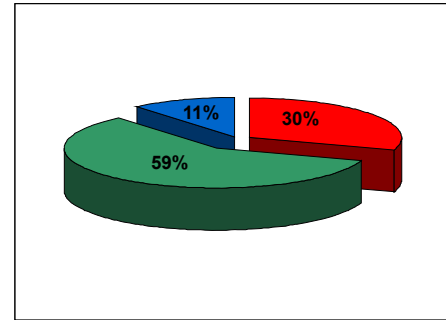
**TUESDAY  
MARCH 29  
3-4 PM**

RSVP to:  
[http://oregonstate.qualtrics.com/jfe/form/SV\\_cGCds\\$2.19jFXjR](http://oregonstate.qualtrics.com/jfe/form/SV_cGCds$2.19jFXjR)  
 Or call: 541.737.0664



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

(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



	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

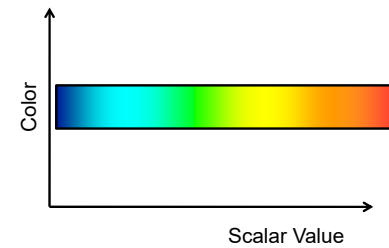


### Pre-Established Color Meanings

<b>Red:</b>	<b>Green:</b>	<b>Blue:</b>	<b>White:</b>
Stop	On	Cool	Neutral
On	Plants	Safe	Hydrogen
Off	Carbon	Deep	
Dangerous	Moving	Nitrogen	
Hot	Money		
High stress			
Oxygen			
Shallow			
Money loss			



### In Visualization, we Use the Concept of a *Transfer Function* to set Color and Opacity as a Function of Scalar Value



### Use the Right Transfer Function Color Scale to Represent a Range of Scalar Values

53

- Gray scale
- Intensity Interpolation
- Saturation interpolation
- Two-color interpolation
- Rainbow scale
- Heated object interpolation
- Blue-White-Red



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### Gray Scale

54

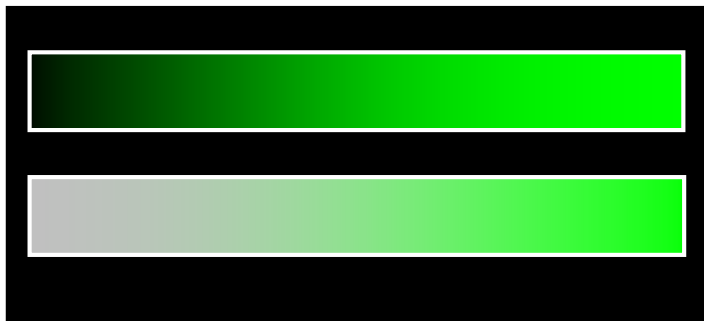


E.g., x-rays

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### Intensity and Saturation Color Scales

55

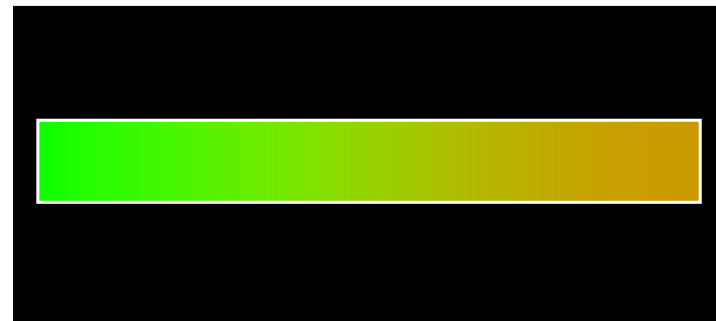


E.g., data uncertainty

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### Two-Color Interpolation

56


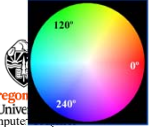


E.g., geography

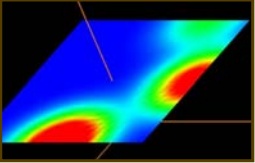
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### Rainbow Color Scale

57

Implementation:  
240° → 120° → 0°


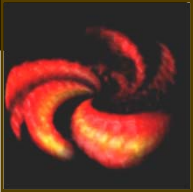


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### Heated Object Color Scale

58

Implementation: add one color component at a time

R+G+B


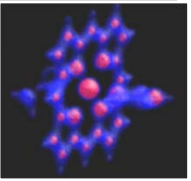


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### Blue-White-Red Color Scale

59


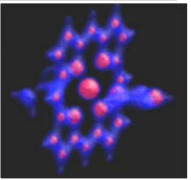
E.g., molecules

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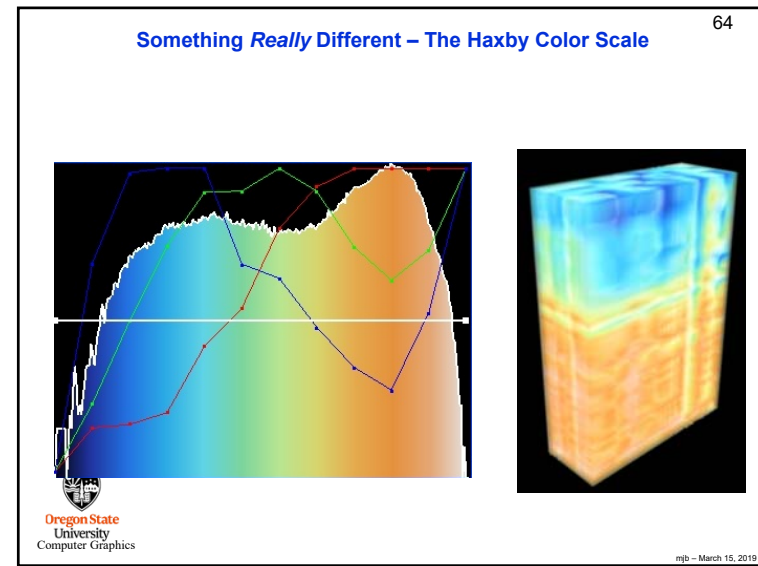
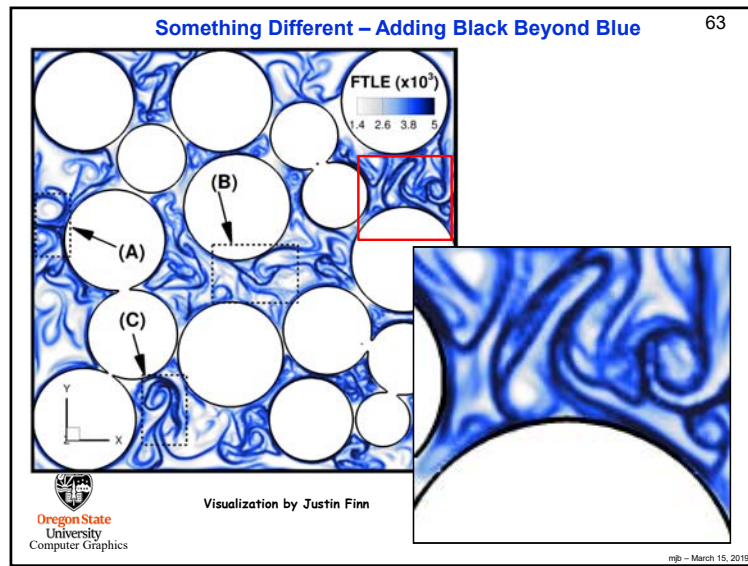
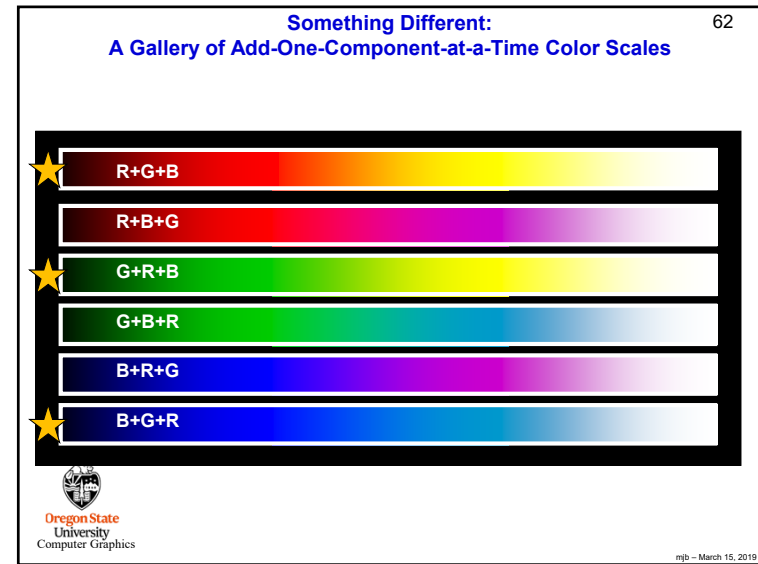
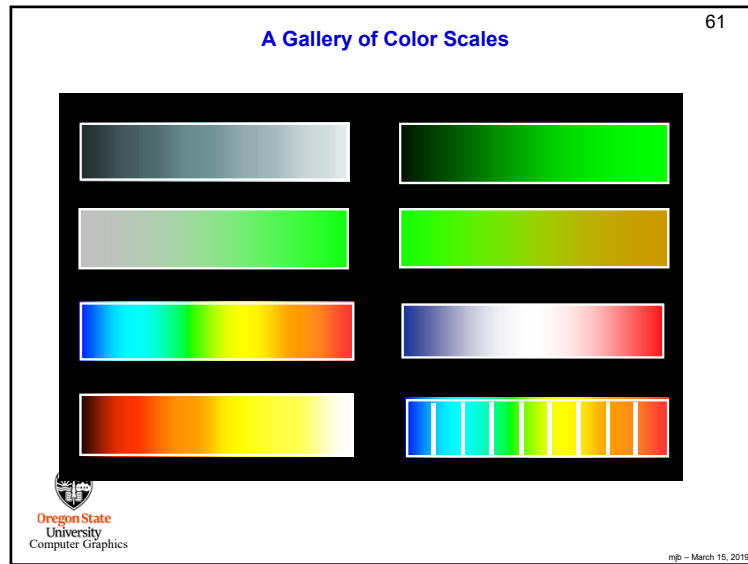
### Color Scale Contours

60

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**But, Here's What's Really Important:** 65

Given any 2 colors, make it *intuitively obvious* which represents "higher" and which represents "lower"

**Obvious:**

**Not obvious:**

Top 10% 979.7-765.0	Next Highest 10% 764.9-724.8	Middle Highest 20% 724.7-678.2	Middle 20% 678.1-636.4
Middle Lowest 20% 636.3-596.0	Next Lowest 10% 595.9-564.5	Bottom 10% 564.4-440.9	

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**But, Here's What's Really Important:** 66

Given any 2 colors, make it *intuitively obvious* which represents "higher" and which represents "lower" ?

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**What in the World was *The Oregonian* Thinking When They Chose This Color Scale?** 67

**Mapping a heck of a lot of rain**

This National Weather Service map shows rainfall during the last 14 days ending at 4 a.m. Tuesday in Oregon and Southwest Washington. Some areas on the Oregon Coast received more than 20 inches of rain.

Note: The map uses data created by the Spatial Parameter Revision Regressions an Independent Regress Model system developed by Dr. Christopher Daly of Oregon State University.

Key:  
in inches 0.01 0.10 0.25 0.50 1.0 1.5 2.0 3.0 4.0 5.0 6.0 8.0 10 15 20

Maps from throughout the U.S. can be viewed at: [www.srh.noaa.gov/rfcs/precip\\_analysis\\_new.php](http://www.srh.noaa.gov/rfcs/precip_analysis_new.php)  
MICHAEL MODEL/THE OREGONIAN

Source:  
*The Oregonian*, January 11, 2006

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

**This is Better ...** 68

**Benzene's grip on greater Portland**

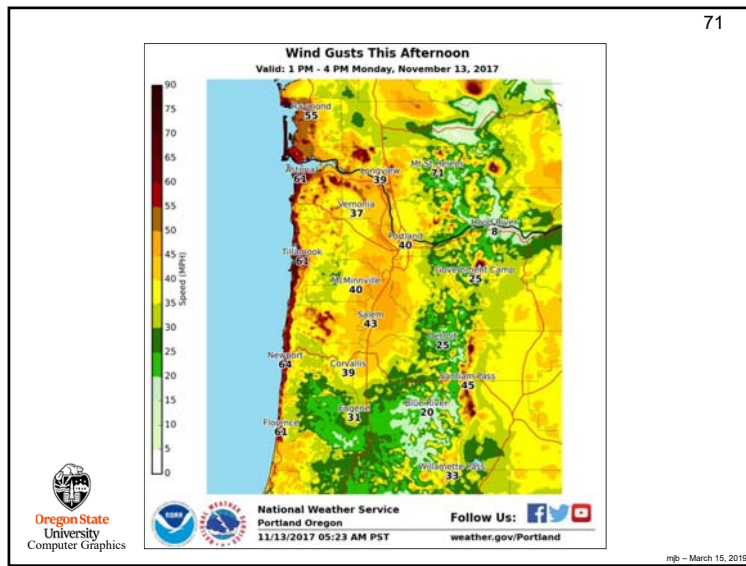
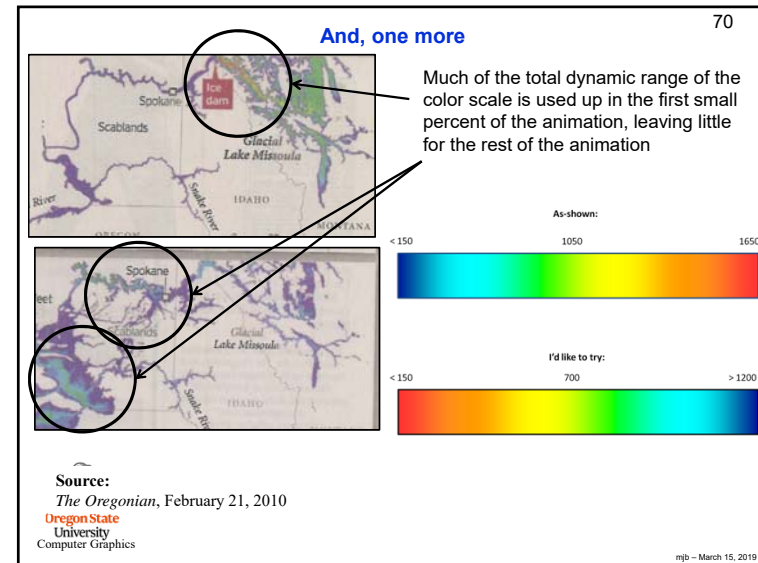
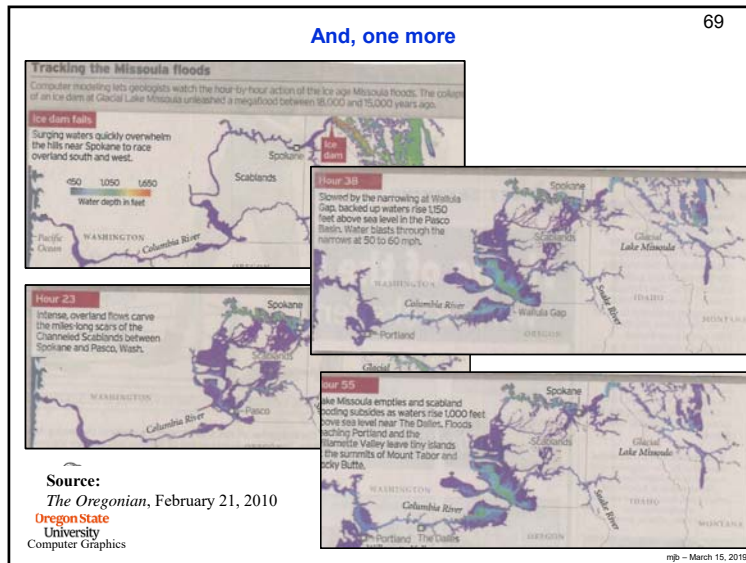
Cars are the major source of benzene, which collects along and near freeways that run through and around the city. Shaded areas show by U.S. Census tract, benzene concentrations that exceed Redfem's benchmarks for cancer risk.

Exceeds benchmarks by:

- Up to 10 times
- 10-15 times
- 15-20 times
- 20 or more times

Source:  
*The Oregonian*, October 31, 2006

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72

### 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 ...

**Source:**  
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73



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Color Rules 74

In visualization applications, we must be aware that our perception of color changes with:

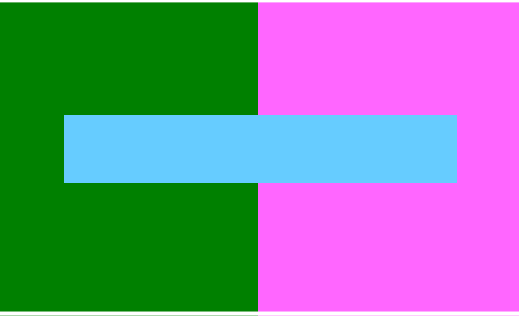
- The surrounding color
- How close two objects are
- How long you have been staring at the color
- Sudden changes in the color intensity

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75

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

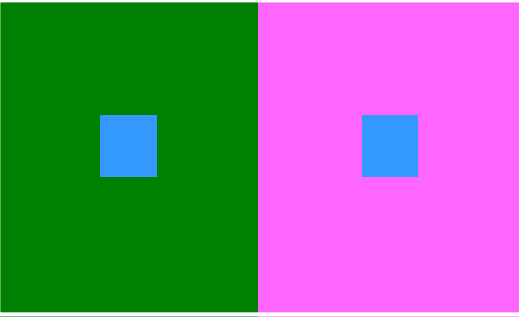


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76

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



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77

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

<http://xkcd.com>

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78

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

<http://xkcd.com>

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79

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80

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81

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82

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

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

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

New York Times

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

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83

### Afterimages

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84

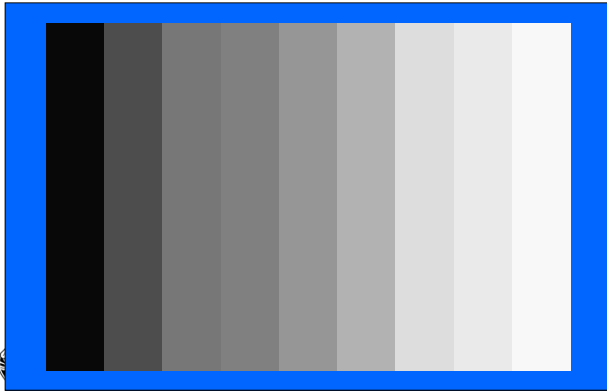
### Afterimages

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Beware of Mach Banding

85

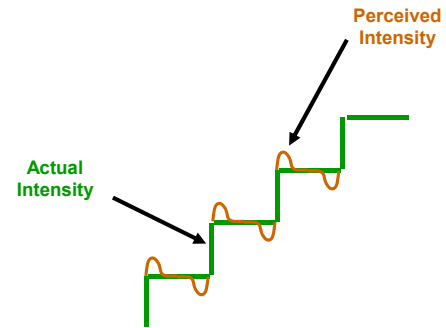


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Beware of Mach Banding

86

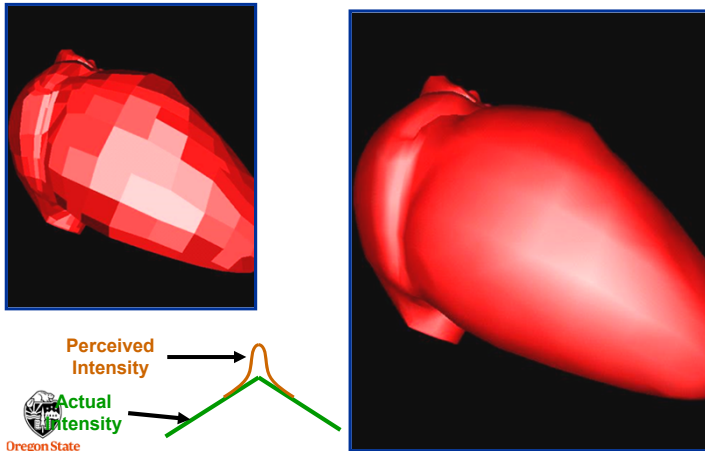


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Beware of Mach Banding

87



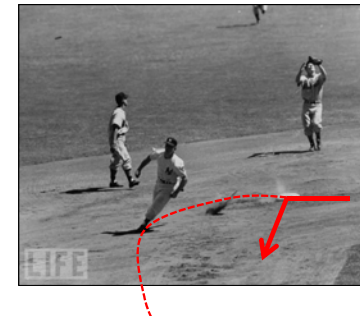
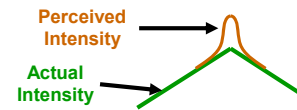
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Beware of Mach Banding

88

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



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## The Ability to Discriminate Colors Changes with the Size of the Colored Area

## The Ability to Discriminate Colors Changes with the Ambient Light

## The Ability to Discriminate Colors Changes with the Age of the Viewer

## Be Aware of Color Vision Deficiencies (CVD)

- 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

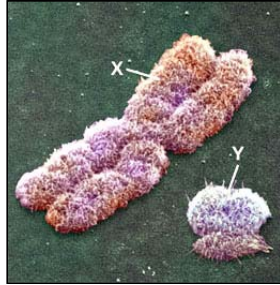
Resources for designing color schemes for people with color recognition deficiencies:

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

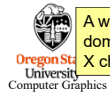
## Why are more men affected by CVD than women?

93

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>



A woman with the defective gene on one X chromosome probably has a dominant non-defective gene on the other. A man with a defect gene on his one X chromosome has no other gene to "fix" it.

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## Be Aware of CVD: Code Information Redundantly

94

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  
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Four score and  
seven years ago,  
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## Be Aware of CVD: Code Information Redundantly: Color + ...

95

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

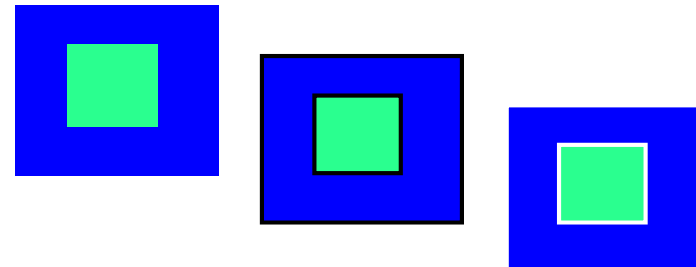
This also helps if someone makes a grayscale photocopy of your color hardcopy



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

96



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97

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

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98

**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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99

**Be Aware of the Differences Between Color Gamuts – Adapt by Deciding What is Most Important for Your Visualization**

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100

**Color Gamut for a Monitor and a Color Printer**

Color CRT

Color Paper Hardcopy

Eye

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101

### Color-Preserving vs. Contrast-Preserving Gamut Mappings

Monitor colors to be printed

1	→	3
2	→	3 ?
2	→	4 ?

White Point

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102

### Beware of Gratuitous Color Pollution

Just because you have millions of colors to choose from,

doesn't mean you must use them all ...

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103

### Beware of Lots of Other Stuff

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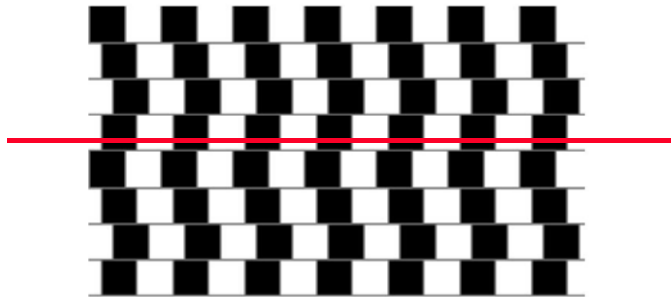
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104

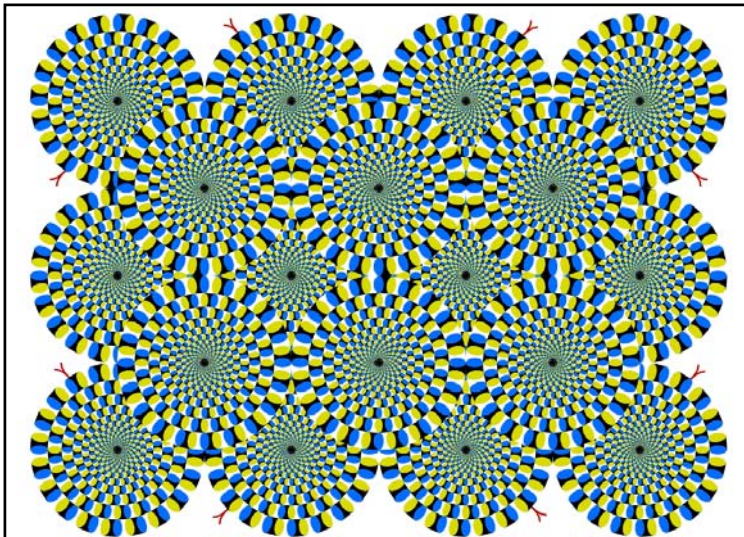
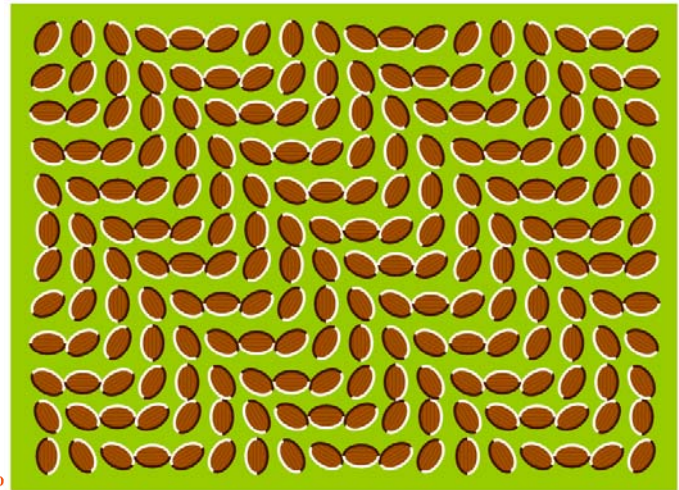
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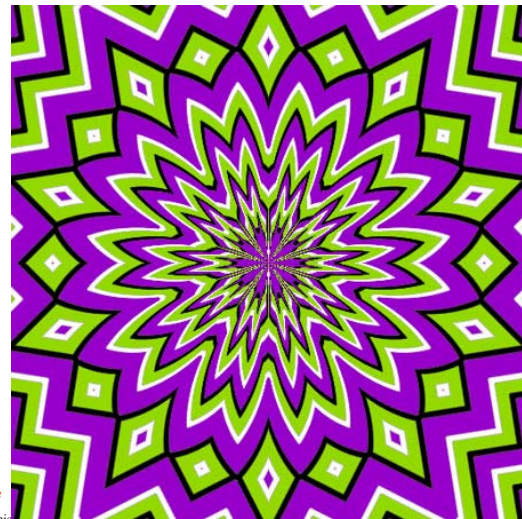
105

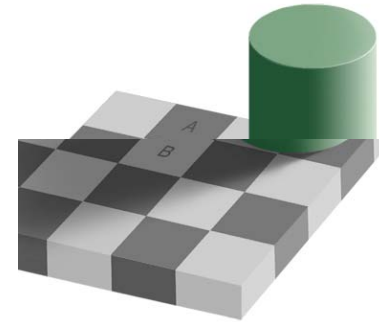
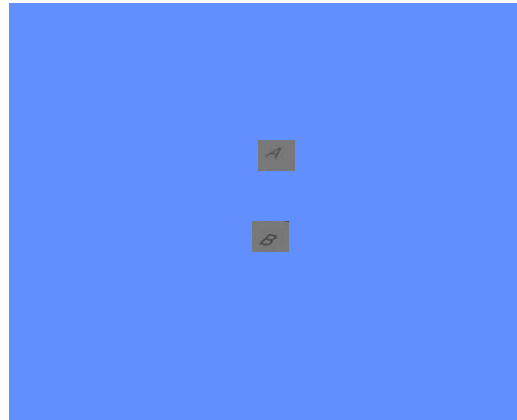


106



108





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