Using Color in R

Stowers Institute for Medical Research
R/Bioconductor Discussion Group

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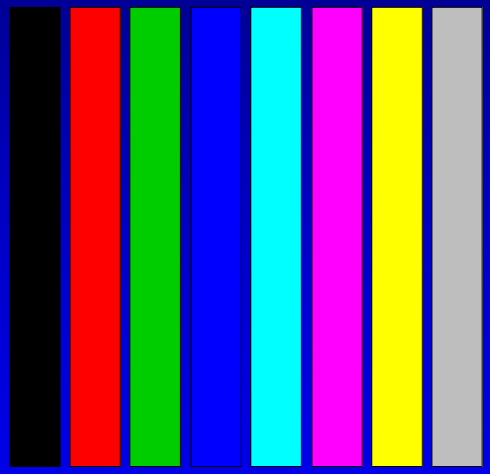
Using Color in R

- Color Basics in R
- Color Spaces
- Color Gradients / Color Ramps
- Color Blindness
- Why Don't Screen Colors Match Printout?
- Colors Tips

Color Basics: Palette

```
> barplot(rep(1,8), yaxt="n", col=1:8)
```

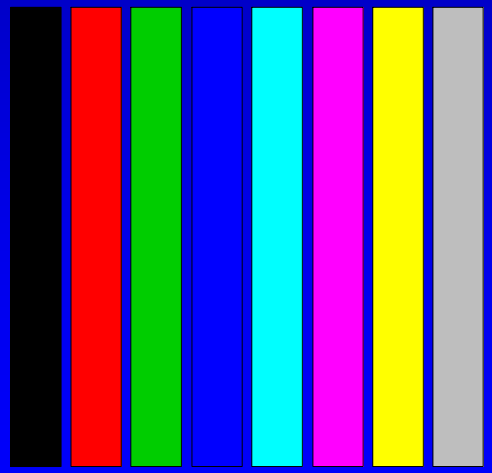


```
> palette()
[1] "black"   "red"     "green3"  "blue"    "cyan"
[6] "magenta" "yellow"  "gray"
```

Using Color in R

Color Basics: Palette

```
> barplot(rep(1,8), yaxt="n", col=1:8)
> barplot(rep(1,8), yaxt="n", col=palette())
> barplot(rep(1,8), yaxt="n",
  col=c("black", "red", "green3", "blue",
        "cyan", "magenta", "yellow", "gray"))
```



Integer color numbers represent offsets into the palette table

Using Color in R

Color Basics: Palette

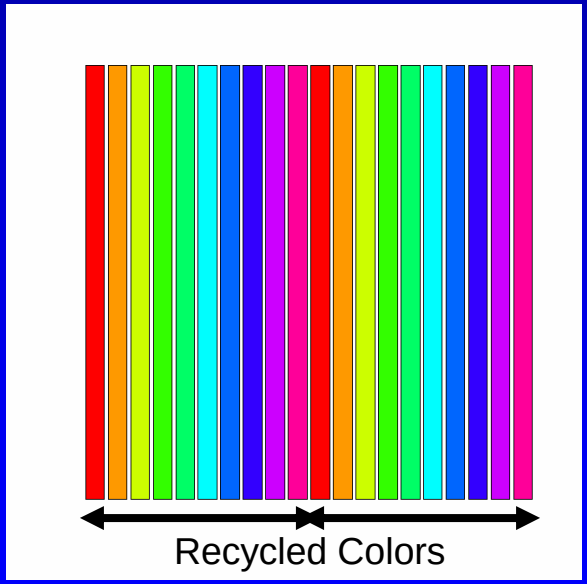
```
> palette(rainbow(10))  # Redefine palette
> palette()
 [1] "red"     "#FF9900" "#CCFF00" "#33FF00" "#00FF66"
 [6] "cyan"    "#0066FF" "#3300FF" "#CC00FF" "#FF0099"
> # colors are "recycled" if necessary
> barplot(rep(1,20),col=1:20, yaxt="n")
```

RGB Hex Constants

Color Names

Cut/Paste Bitmap

```
> palette("default")
> palette()
[1] "black"   "red"     "green3"
    "blue"    "cyan"
[6] "magenta" "yellow"  "gray"
```



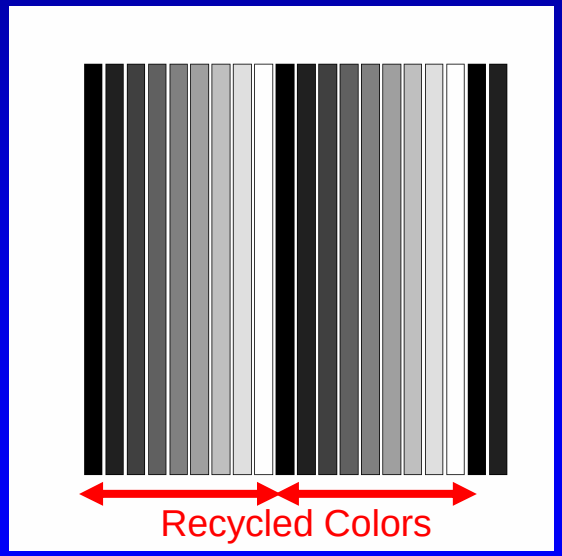
Specify number of colors with **`rainbow`**

Using Color in R

Color Basics: Palette

```
> 0:8 / 8
[1] 0.000 0.125 0.250 0.375 0.500 0.625 0.750 0.875 1.000
> palette(gray(0:8 / 8))
> palette()
[1] "black"   "#202020" "gray25"  "#606060" "#808080"
[6] "#9F9F9F" "gray75"  "#DFDFDF" "white"
> # colors are "recycled" if necessary
> barplot(rep(1,20),col=1:20, yaxt="n")
>
> palette("default")
> palette()
[1] "black"   "red"     "green3"
    "blue"    "cyan"
[6] "magenta" "yellow"  "gray"
```

RGB Hex Constants



Specify vector of floats 0.0 to 1.0 with **`grey/gray`**

Using Color in R

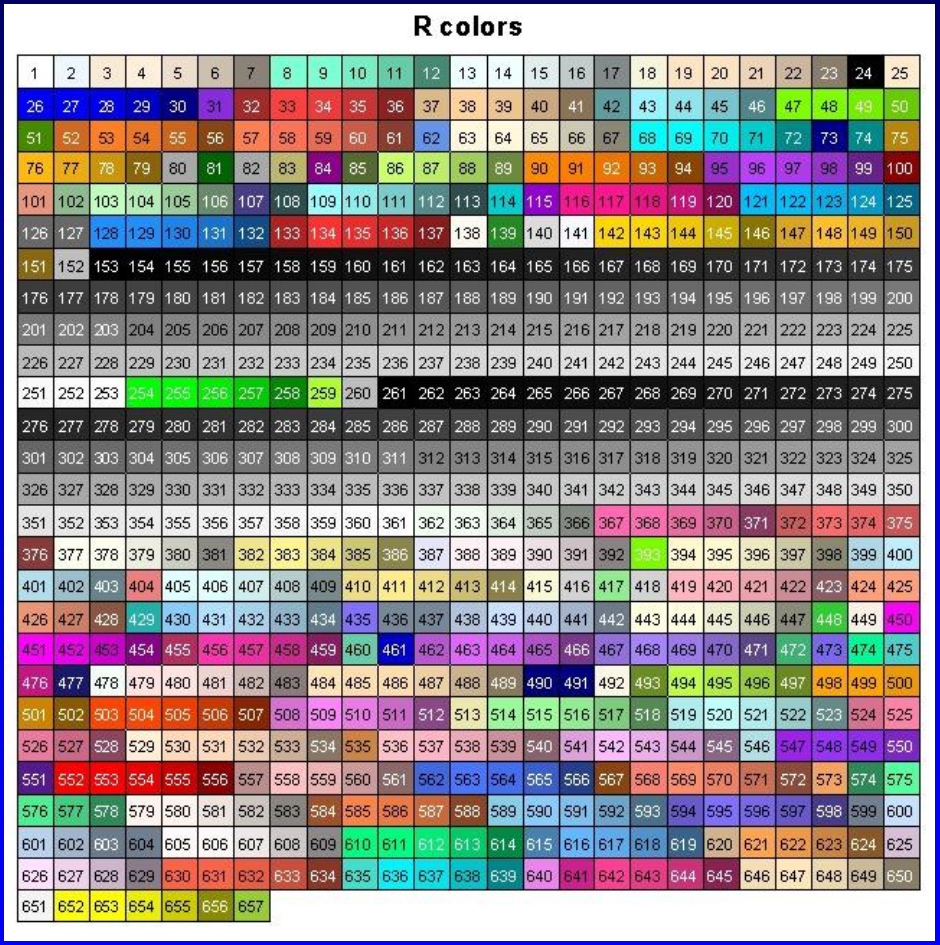
Color Basics: Color Names

```
> colors()  # or colours()
  [1] "white"                "aliceblue"            "antiquewhite"
  [4] "antiquewhite1"        "antiquewhite2"        "antiquewhite3"

[655] "yellow3"              "yellow4"              "yellowgreen"

> colors()[grep("red", colors())]
 [1] "darkred"          "indianred"        "indianred1"
 [4] "indianred2"       "indianred3"       "indianred4"
 [7] "mediumvioletred"  "orangered"        "orangered1"
[10] "orangered2"       "orangered3"       "orangered4"
[13] "palevioletred"    "palevioletred1"   "palevioletred2"
[16] "palevioletred3"   "palevioletred4"   "red"
[19] "red1"             "red2"             "red3"
[22] "red4"             "violetred"        "violetred1"
[25] "violetred2"       "violetred3"       "violetred4"
```

Color names from C:\Program Files\R\R-2.5.1\etc\rgb.txt

Using Color in R

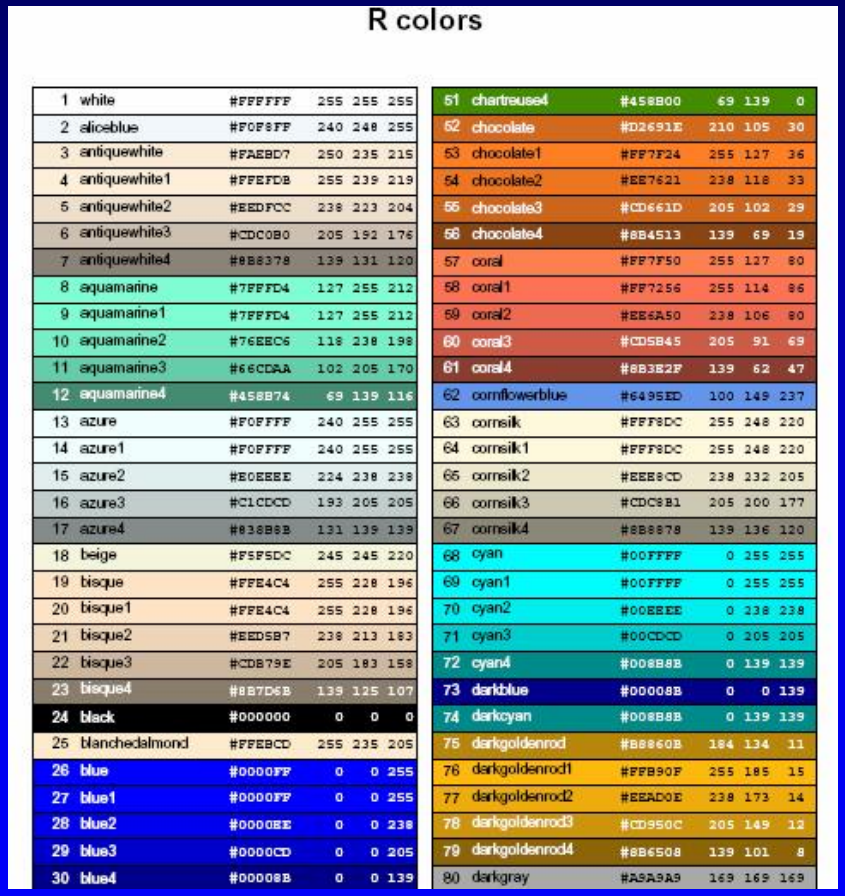
Color Basics: Color Names



http://research.stowers-institute.org/efg/R/Color/Chart/index.htm

Using Color in R

Color Basics: Color Names



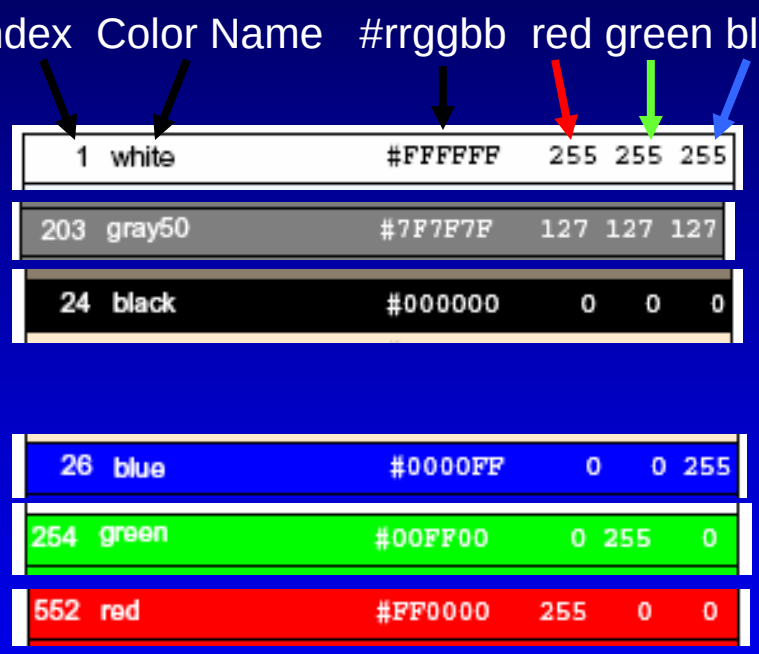
Alphabetical except first color, which is white

Print seven page table to compare screen colors with printed colors.
http://research.stowers-institute.org/efg/R/Color/Chart/ColorChart.pdf

Using Color in R

Color Basics: Hex Constants

Hex	Decimal
0	0
1	1
2	2
3	3
4	4
5	5
6	6
7	7
8	8
9	9
A	10
B	11
C	12
D	13
E	14
F	15



"Unsaturated" shades of gray

"Saturated" Primary Colors

Hex "FF" = $15*16^1 + 15*16^0 = 255$

Hex "00" to "FF" can be interpreted as 0.0 to 1.0.

Numbers represented in "base 16" are called "hexadecimal".
Hex "FF" is largest value represented by one byte (8 bits).

Using Color in R

Color Basics

In R Color can be represented by

- index into palette
- color name
- hex constant (24-bit "True Color": 256^3 colors = 16,777,216 colors)

Using Color in R

Color Basics

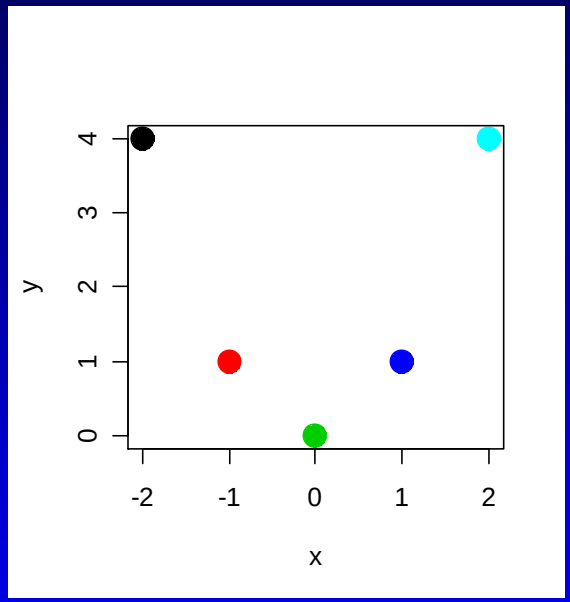
In R many objects can take on different colors:

- points
- lines
- axes
- text
- legends
- background

Using Color in R

Color Basics: Points

```
> palette()
[1] "black"   "red"     "green3"  "blue"    "cyan"
[6] "magenta" "yellow"  "gray"

> x <- -2:2    Five (x,y) points to plot
> y <- x^2

# Equivalent point colors
> plot(x,y, col=1:5,
       pch=CIRCLE<-16, cex=2)

> plot(x,y,
       col=c("black", "red", "green3", "blue", "cyan"),
       pch=CIRCLE, cex=2)

> plot(x,y,
       col=c("#000000", "#FF0000", "green3", 4, 5),
       pch=CIRCLE, cex=2)
```

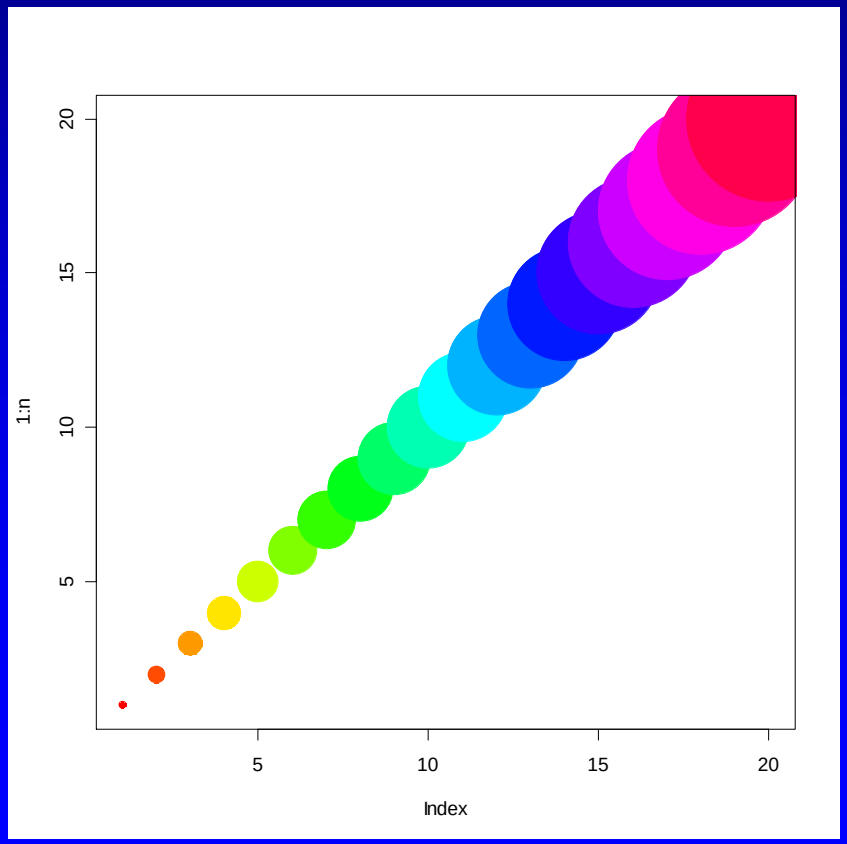


Hex #rrggbb *Color name* *Palette Index*

Using Color in R

Color Basics: Points

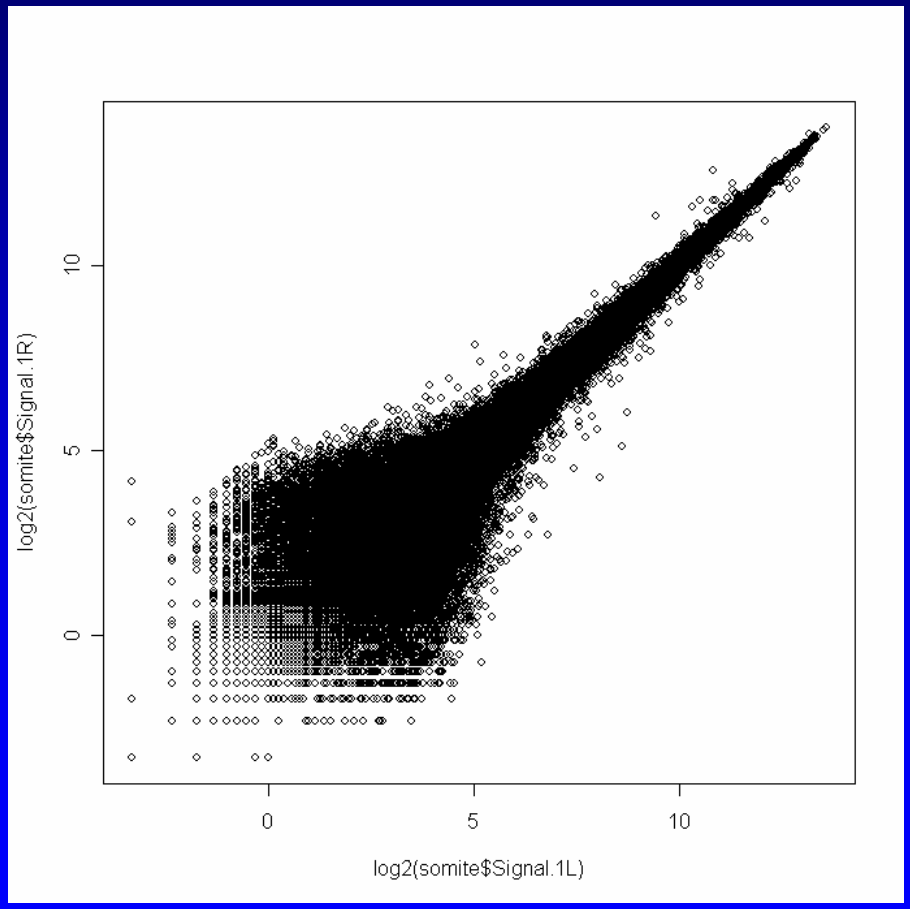
```
n <- 20
plot(1:n, pch=CIRCLE<-16, cex=1:n, col=rainbow(n))
```

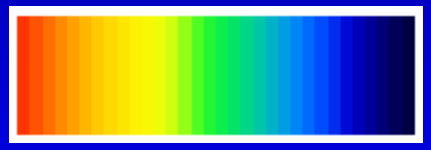


Using Color in R

Color Basics: Points

```
> plot(log2(somite$Signal.1L), log2(somite$Signal.1R))
```





p=0 p=1

```
> library(gplots)
> palette(rev(rich.colors(32)))
```

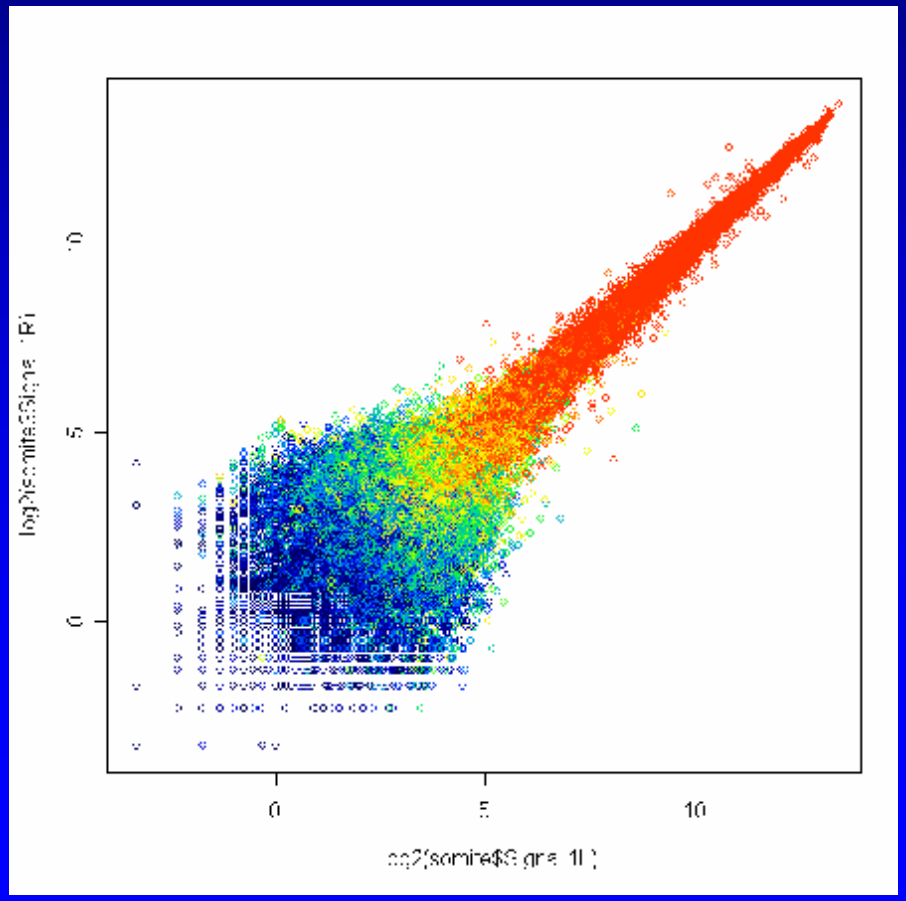
Colors 1 to 32

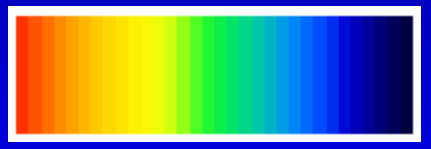
How to associate color with p-values at each point?

Using Color in R

Color Basics: Points

```
> palette( rev(rich.colors(32)) )  # colors:  1 to 32
> plot(log2(somite$Signal.1L), log2(somite$Signal.1R),
    col=1 + 31*somite$worst.p)      # col values from 1 to 32
```

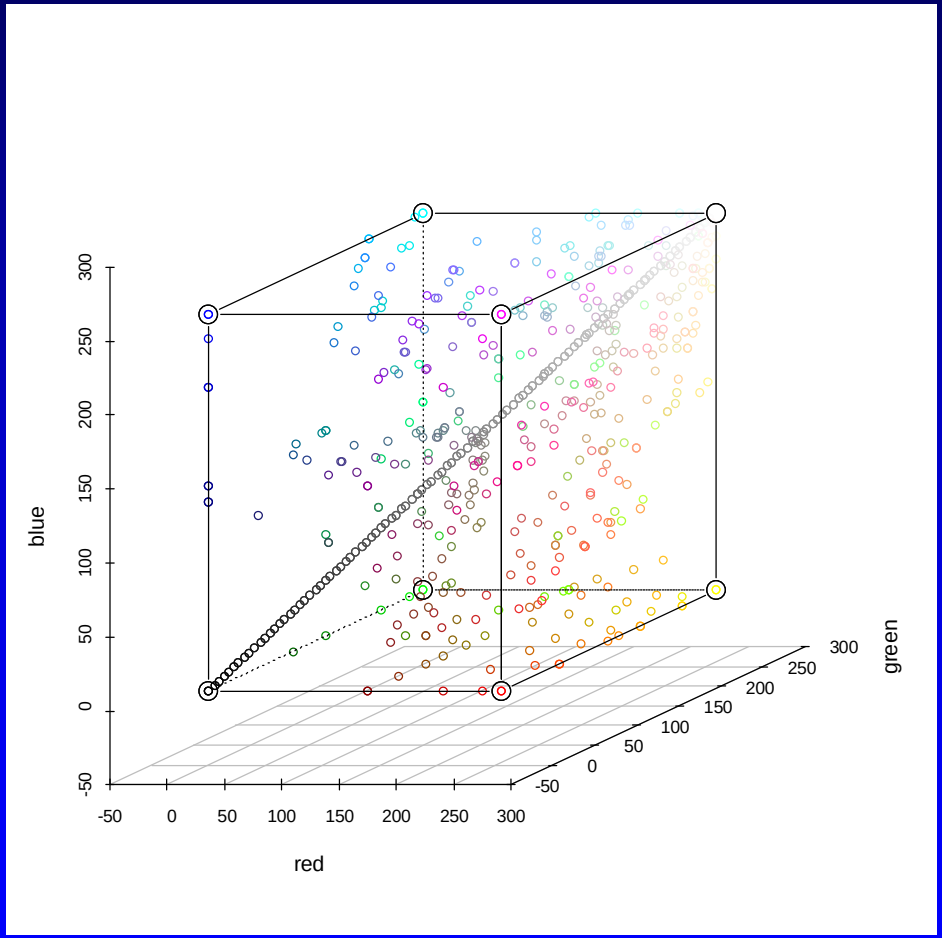




p=0 p=1

Using Color in R

Color Basics: Points and Lines



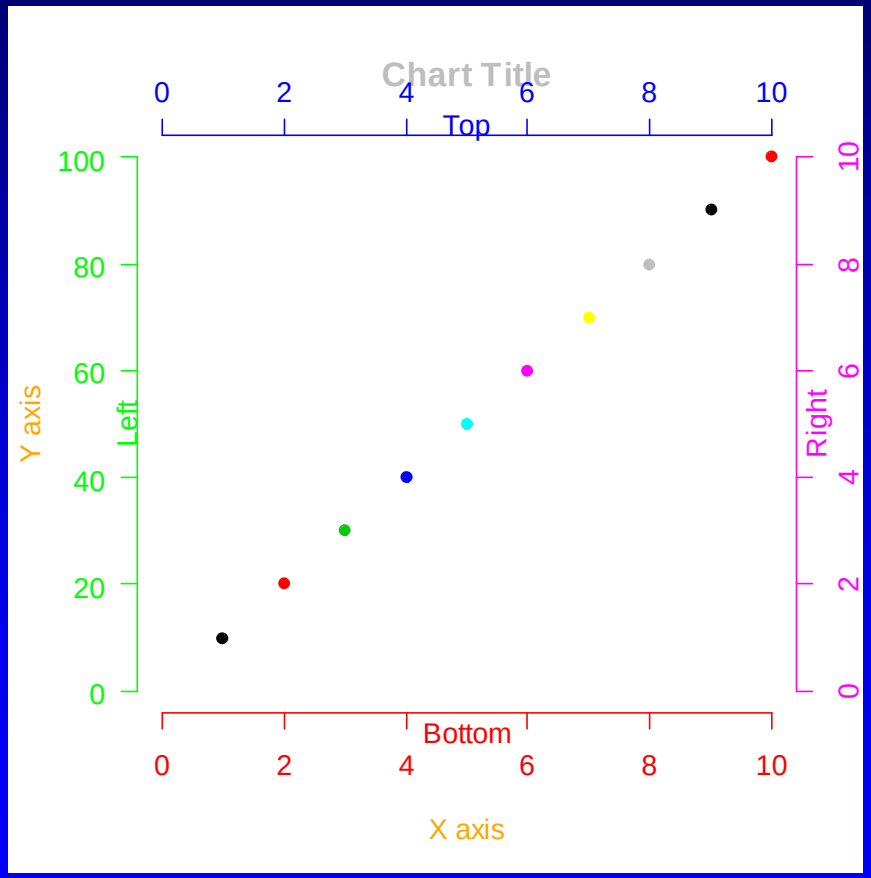

```
library(scatterplot3d)
?scatterplot3d
# Example 6
```

Red-Green-Blue 3D Plot of `colors()`

Using Color in R

Color Basics: Axes and Text

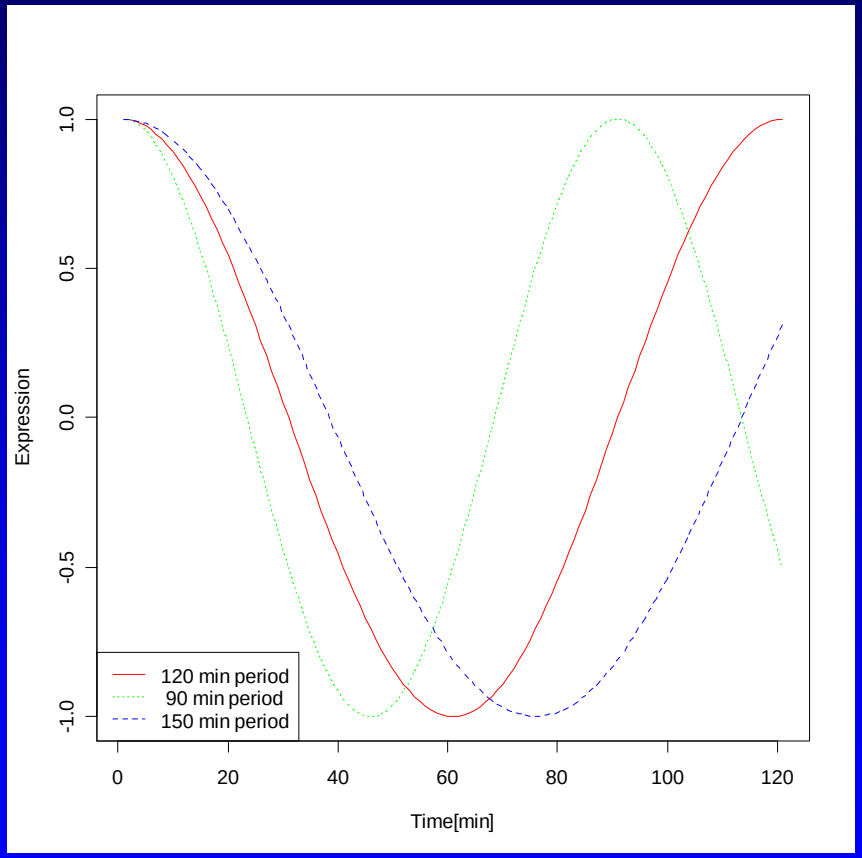
```
BOTTOM <- 1
LEFT   <- 2
TOP    <- 3
RIGHT  <- 4

par(col.lab="orange", col.main="gray")


plot(0:10,0:10, col=0:10, pch=CIRCLE<-16,
     main="Chart Title", axes=FALSE,
     xlab="X axis",ylab="Y axis")

# Margin Text
mtext("Bottom", BOTTOM, col="red")
mtext("Left",   LEFT,   col="green")
mtext("Top",    TOP,    col="blue")
mtext("Right",  RIGHT,  col="magenta")

axis(BOTTOM, col="red",
   col.axis="red")   # 2, ...  10 in red

AXIS_LABEL_HORIZONTAL <- 1
axis(LEFT,  col="green", col.axis="green",
  at=2*0:5, labels=paste(20*0:5),
  las=AXIS_LABEL_HORIZONTAL)


axis(TOP,   col="blue",    col.axis="blue")
axis(RIGHT, col="magenta", col.axis="magenta")
```



Using Color in R

Color Basics: Legends

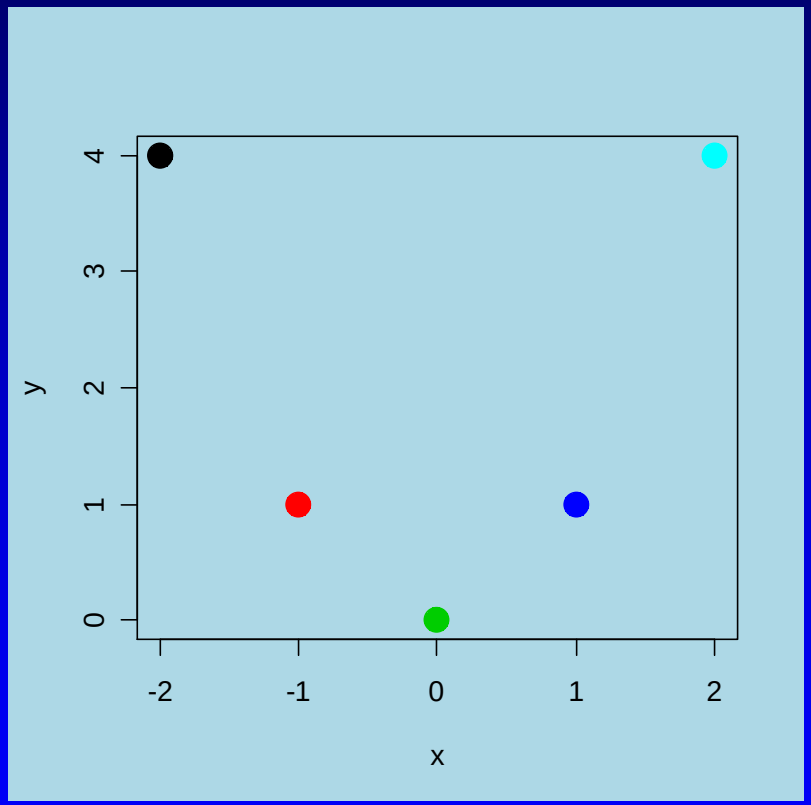
```
Time <- 0:120


Period1 <- cos(2*pi*Time/120)
Period2 <- cos(2*pi*Time/90)
Period3 <- cos(2*pi*Time/150)


COLORS     <- c("red", "green", "blue")
LINE.TYPES <- c("solid", "dotted", "dashed")


Periods <- data.frame(  Period1=Period1,
                        Period2=Period2,
                        Period3=Period3)

matplot(Periods, type = "l",
        xlab="Time[min]",ylab="Expression",
        col = COLORS, lty = LINE.TYPES)

legend("bottomleft",
       c("120 min period", " 90 min period",
         "150 min period"),
       col = COLORS, lty = LINE.TYPES)
```



Using Color in R

Color Basics: Background

```
par(bg="light blue")

x <- -2:2
y <- x^2

plot(x,y, col=1:5,
     pch=CIRCLE<-16,cex=2)
```



R's default background color is "transparent."

Set graphic background to simplify cutting and pasting to PowerPoint!
Avoids in PowerPoint: Format Picture | Colors and Lines | Fill Color

Using Color in R

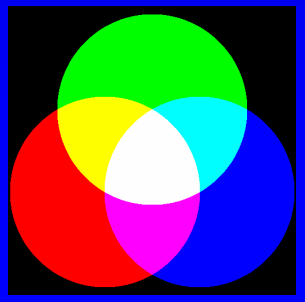
- Color Basics in R
- Color Spaces
- Color Gradients / Color Ramps
- Color Blindness
- Why Don't Screen Colors Match Printout?
- Colors Tips

Using Color in R

Color Space: RGB Color Model

```
> rgb(1,0,0)
[1] "#FF0000"
> rgb(0,1,0)
[1] "#00FF00"
> rgb(1,1,0)
[1] "#FFFF00"

> rgb(255,0,0, maxColorValue=255)
[1] "#FF0000"

> col2rgb(c("blue", "yellow"))
      [,1] [,2]
red      0  255
green    0  255
blue   255    0
```

		#rrggbb	R	G	B
26	blue	#0000FF	0	0	255
254	green	#00FF00	0	255	0
552	red	#FF0000	255	0	0
450	magenta	#FF00FF	255	0	255
652	yellow	#FFFF00	255	255	0
68	cyan	#00FFFF	0	255	255

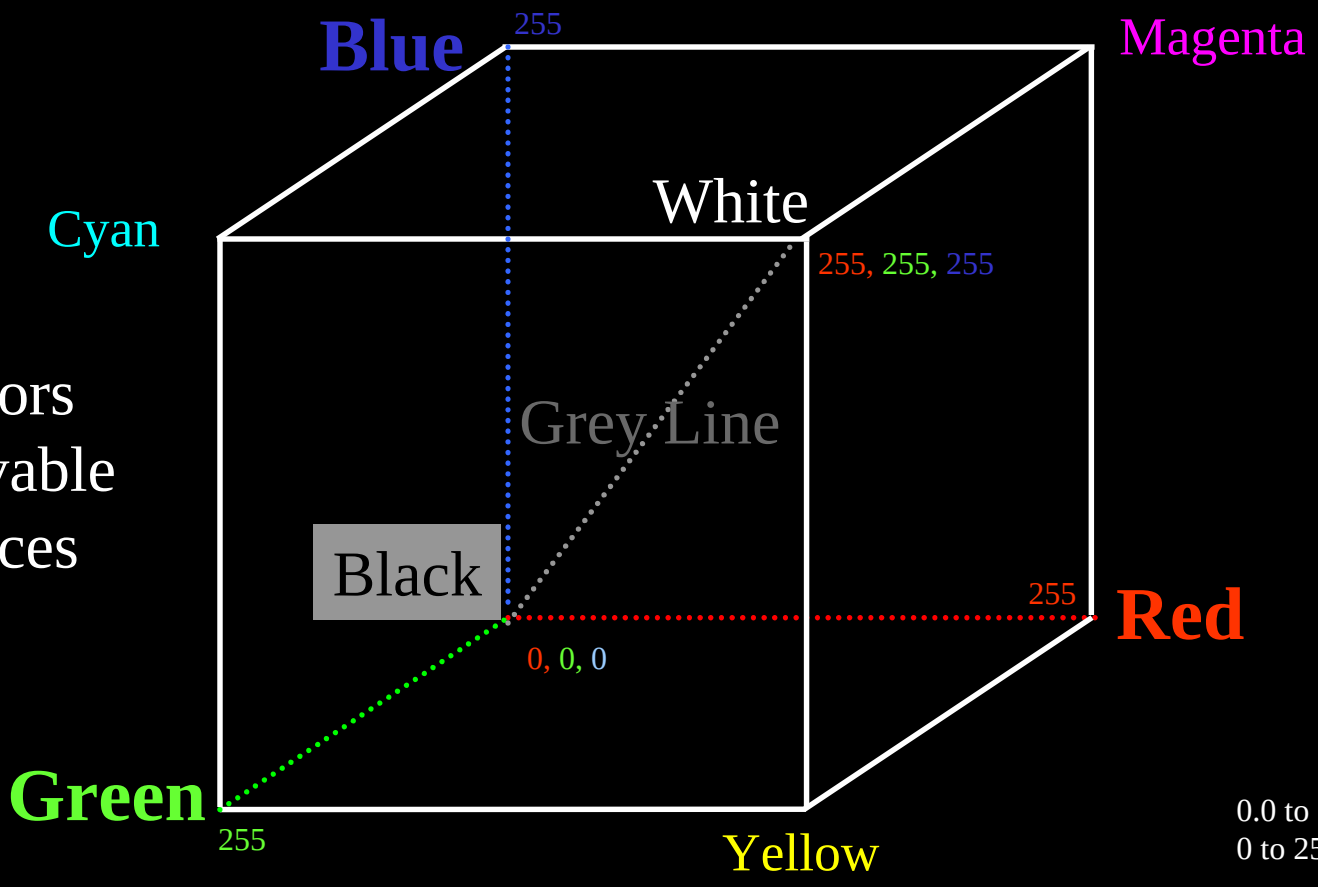


Color is additive in the RGB Color Model.
Coordinate values not always obvious.

Using Color in R

Red-Green-Blue Color Cube

R = 0 to 255 G = 0 to 255 B = 0 to 255



Not all colors are perceivable on all devices

0.0 to 1.0
0 to 255 (8-bits)

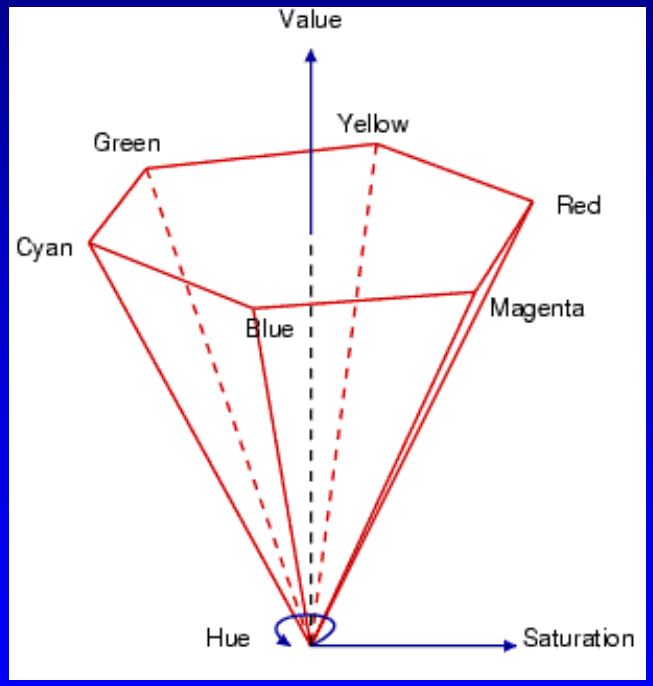
24-bit graphics:
256 x 256 x 256 = 16,777,216 colors
256 shades of grey

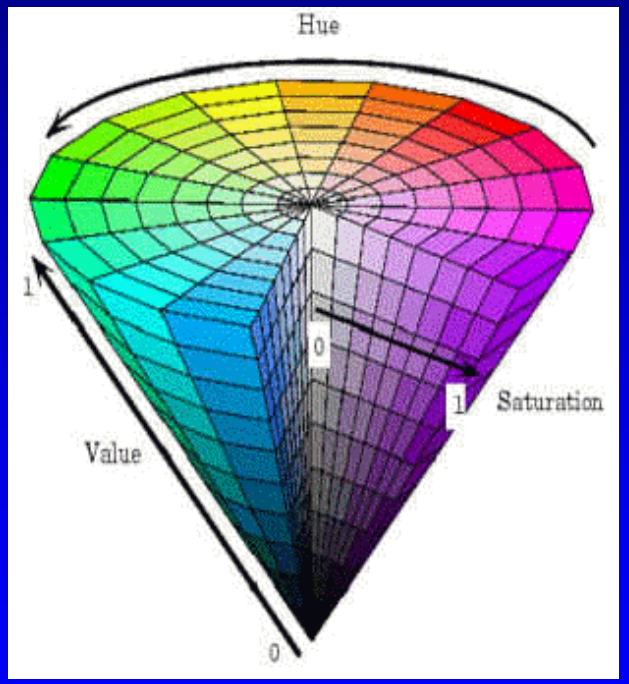
Contrasting Colors?

Color Space: HSV

Hue-Saturation-Value

Match perception of color better than RGB





Source: http://scien.stanford.edu/class/psych221/projects/02/sojeong/

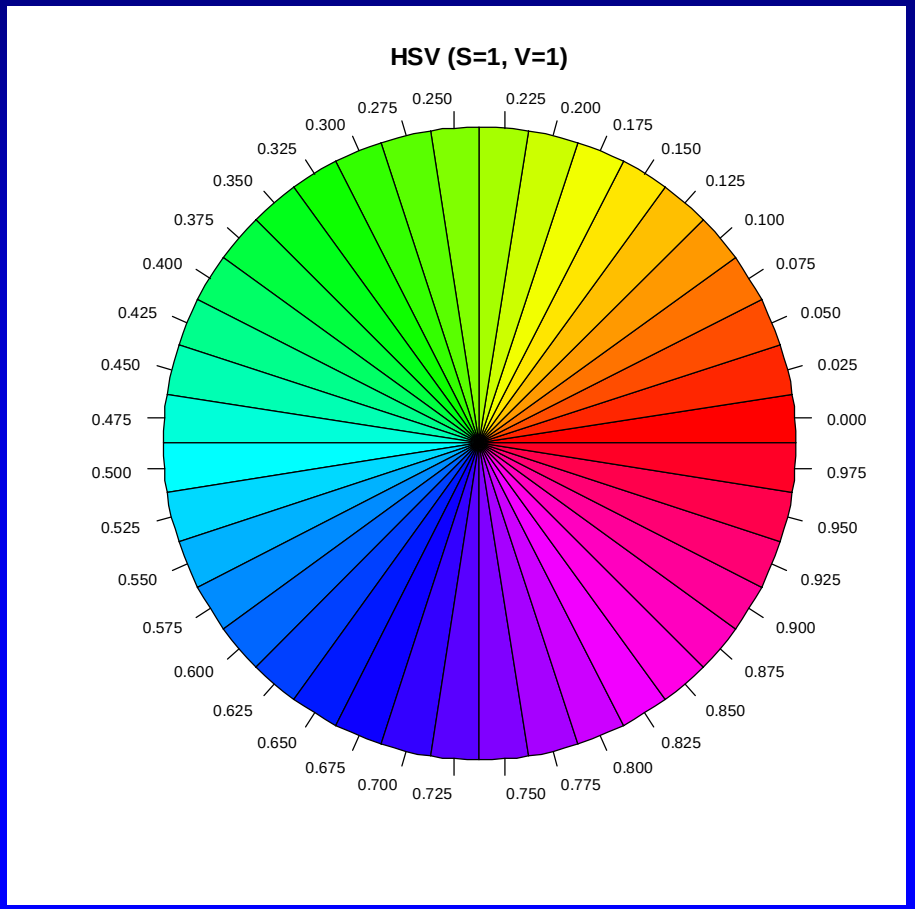
Using Color in R

Color Space: HSV

Hue-Saturation-Value

```
> hsv(1,1,1)
[1] "#FF0000"

> hsv(1/3,1,1)
[1] "#00FF00"

> hsv(2/3,1,1)
[1] "#0000FF"

hue <- seq(0.0, 1.0, by=1/40)

pie(rep(1,40),
    labels=formatC(hue, digits=3,
                   format="f"),
    cex=0.75,
    col=hsv(hue, 1.0, 1.0),
    radius=1.0,
    main="HSV (S=1, V=1)" )

> rgb2hsv(col2rgb("blue"))
      [,1]
h 0.6666667
s 1.0000000
v 1.0000000
```

Contrasting Colors?



Using Color in R

Color Spaces

help(package=colorspace)

HSV	Create HSV Colors
LAB	Create LAB Colors
LUV	Create LUV Colors
RGB	Create RGB Colors
XYZ	Create XYZ Colors
color-class	Class "color"
coords	Extract the numerical coordinates of a color
hex	Convert Colors To Hexadecimal Strings
hex2RGB	Convert Hexadecimal Color Specifications To RGB Objects
mixcolor	Compute the convex combination of two colors
polarLAB	Create polarLAB Colors
polarLUV	Create polarLUV Colors
readRGB	Read RGB Color Descriptions
readhex	Read Hexadecimal Color Descriptions
writehex	Write Hexadecimal Color Descriptions

Using Color in R

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Using Color in R

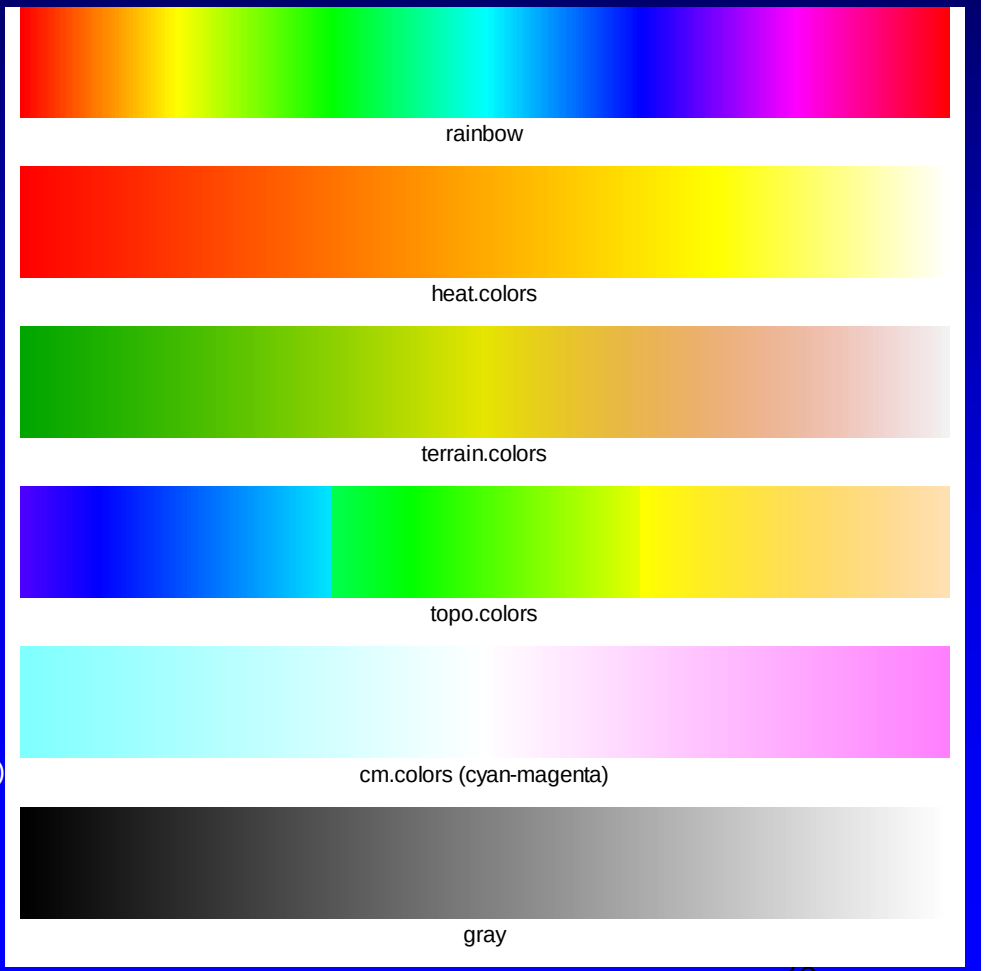
Color Gradients / Color Ramps

```
par(mfrow=c(6,1), mar=c(3,1,0,1))
BOTTOM <- 1

colorstrip <- function(colors, description,
                       ShowAxis=FALSE)
{
  count <- length(colors)
  m <- matrix(1:count, count, 1)
  image(m, col=colors, ylab="", axes=FALSE)


  if (ShowAxis)
  {
    axis(BOTTOM)
  }
  mtext(description, BOTTOM, adj=0.5, line=0.5)
}


COLOR.COUNT <- 256
colorstrip(rainbow(COLOR.COUNT),         "rainbow")
colorstrip(heat.colors(COLOR.COUNT),     "heat.colors")
colorstrip(terrain.colors(COLOR.COUNT), "terrain.colors")
colorstrip(topo.colors(COLOR.COUNT),     "topo.colors")
colorstrip(cm.colors(COLOR.COUNT),
           "cm.colors (cyan-magenta)")
colorstrip(gray(0:COLOR.COUNT / COLOR.COUNT),"gray")
```



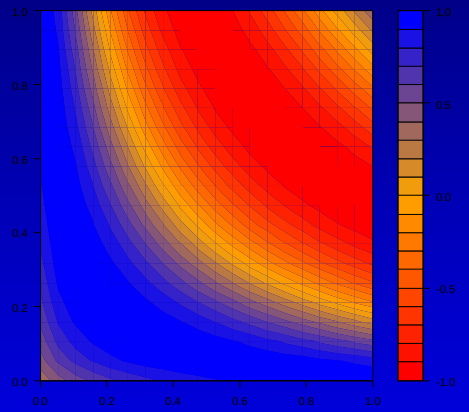
Using Color in R

Color Gradients / Color Ramps

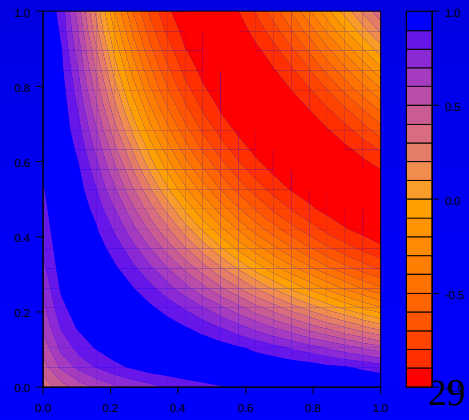
colorRamp and colorRampPalette added in R 2.1.0

```
m <- outer(1:20,1:20,function(x,y) sin(sqrt(x*y)/3))

rgb.palette <- colorRampPalette(c("red", "orange",
"blue"), space = "rgb")
filled.contour(m,col = rgb.palette(20))
```



```
# space="Lab" helps when colors don't form a
# natural sequence
Lab.palette <- colorRampPalette(c("red", "orange",
"blue"), space = "Lab")
filled.contour(m,col = Lab.palette(20))
```

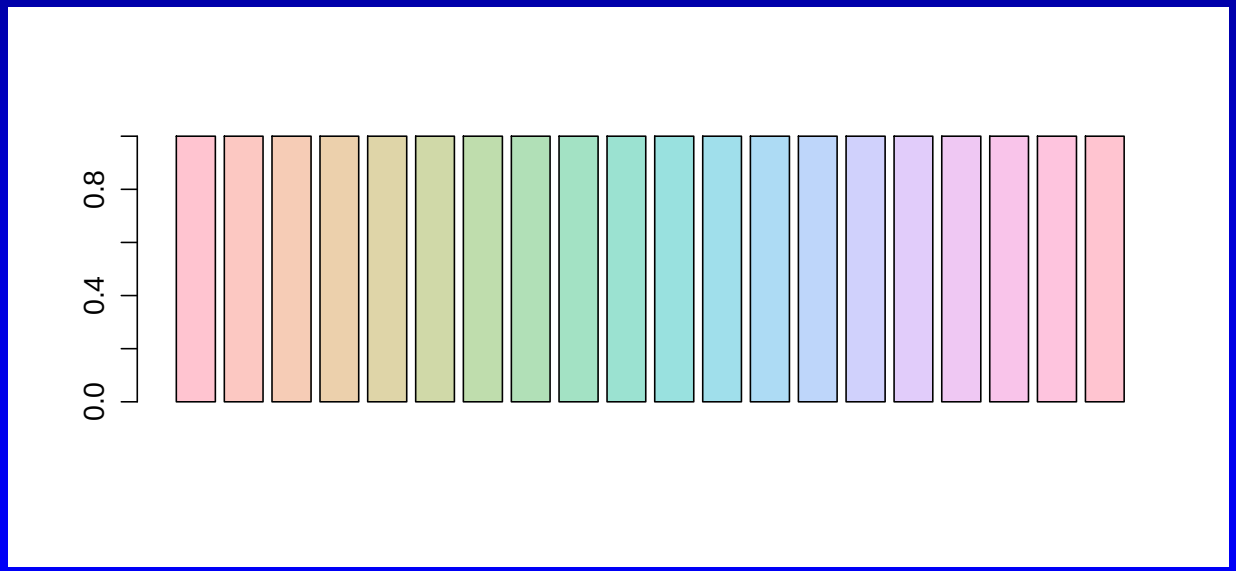


Using Color in R

Color Gradients / Color Ramps

HCL (Hue, Chroma, Luminance)

```
> ?hcl
>  barplot(rep(1, 20), col = hcl(seq(0, 360, length = 20)))
```



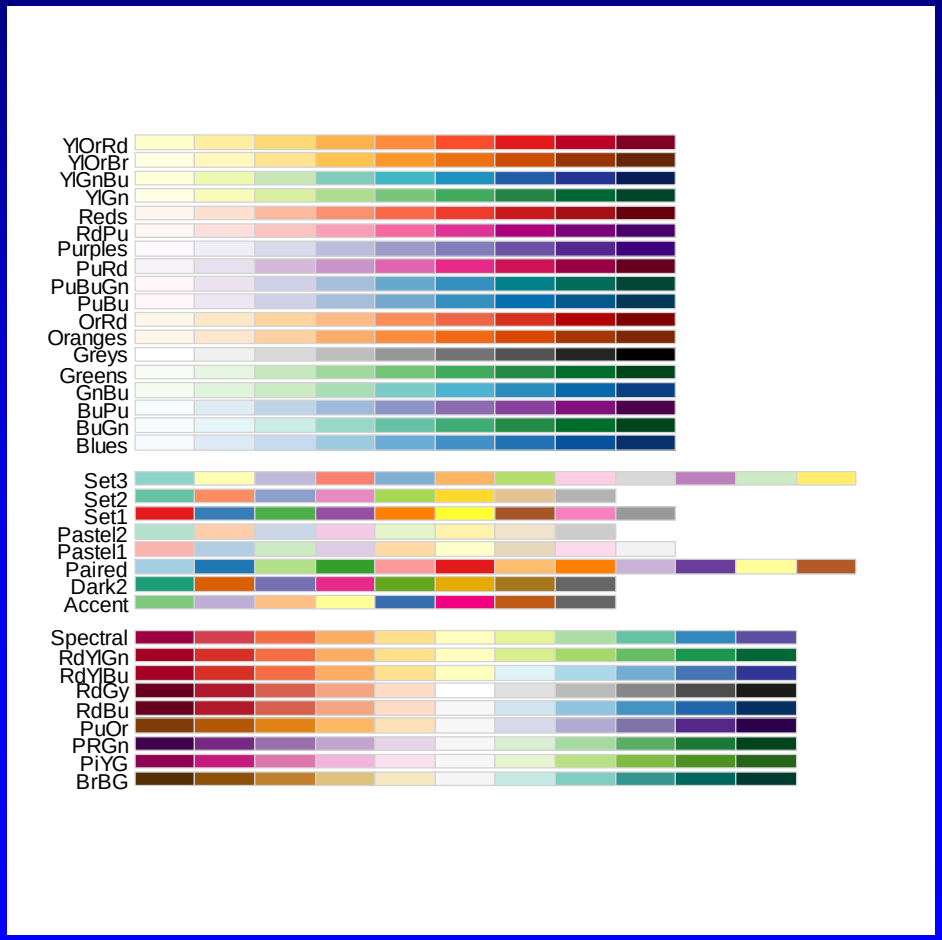
See: HCL(Hue-Chroma-Luminance)-based Color Palettes in R
http://cran.r-project.org/doc/vignettes/vcd/hcl-colors.pdf

Using Color in R

Color Gradients / Color Ramps

RColorBrewer Package

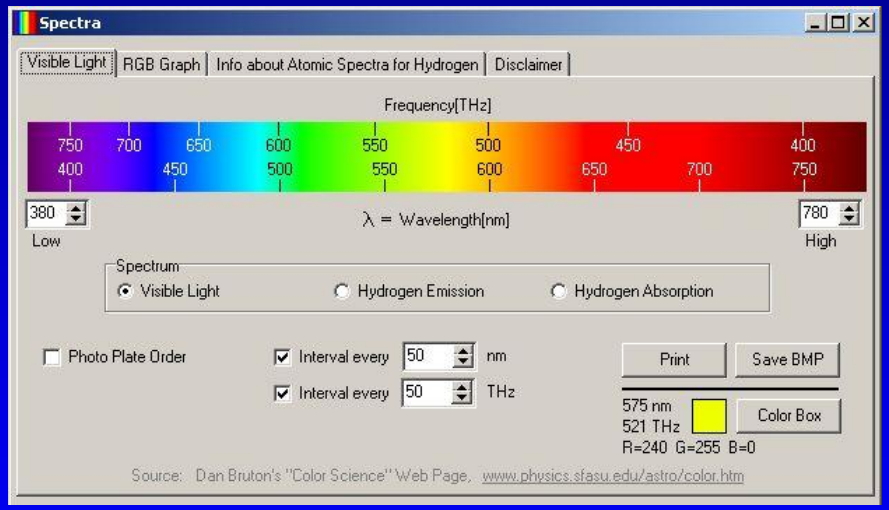
```
> library(RColorBrewer)
> display.brewer.all()
```

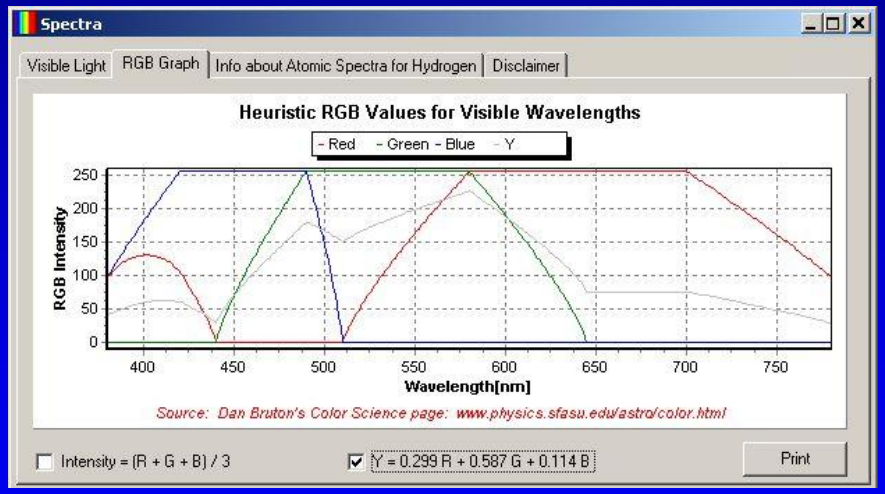


Using Color in R

Color Gradients / Color Ramps

Representative Color for Given Wavelength





Source: http://www.efg2.com/Lab/ScienceAndEngineering/Spectra.htm

Using Color in R

- Color Basics in R
- Color Spaces
- Color Gradients / Color Ramps
- Color Blindness
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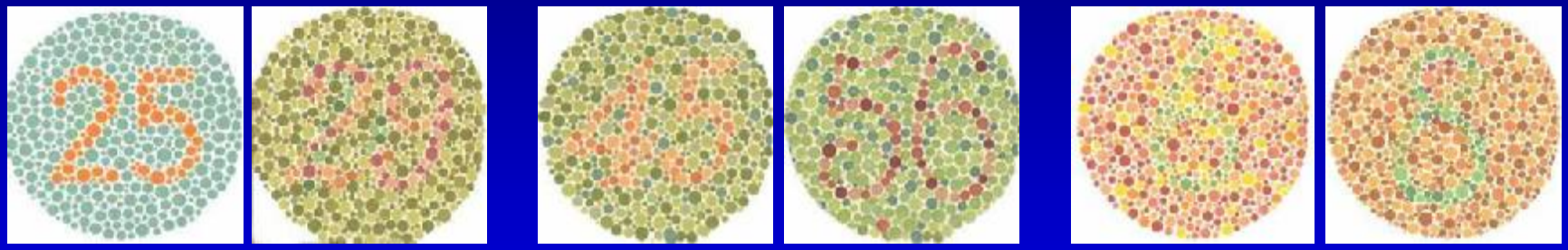
Using Color in R

Color Blindness

Ishihara Test for Color Blindness



Normal Color Vision: 25, 29, 45, 56, 6, 8

Red-Green Color Blind: 25, spots, spots, 56, spots, spots

Source: http://www.toledo-bend.com/colorblind/Ishihara.html

About 1 in 12 have some sort of color deficiency:
About ~8% of men and ~0.4% of women in the US.

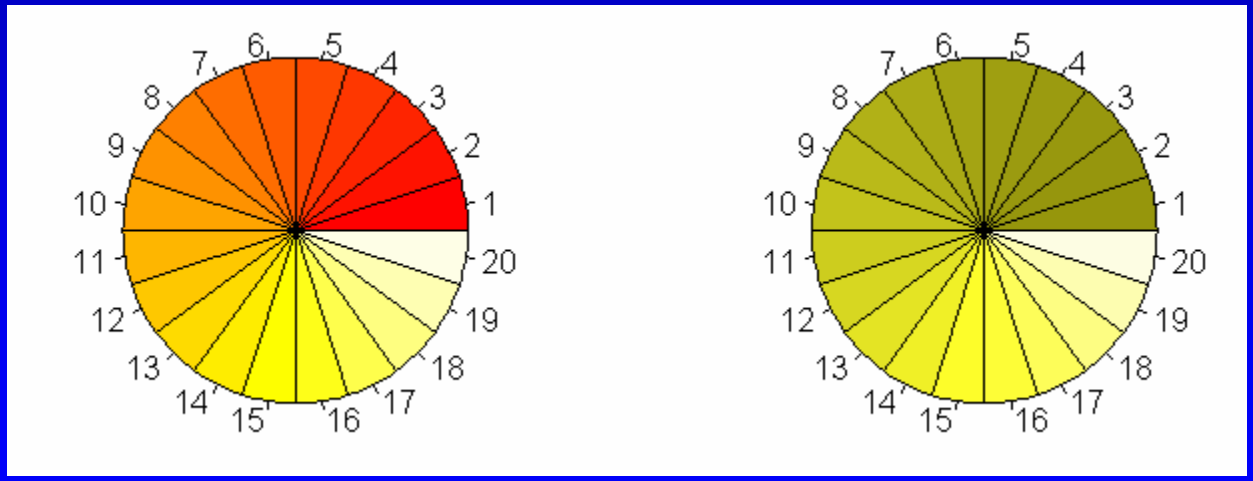
http://en.wikipedia.org/wiki/Color_blindness

Using Color in R

Color Blindness

R dichromat Package: Color Schemes for dichromats

```
library(dichromat)
par(mfcol=c(1,2))
N <- 20
pie(rep(1,N),col=heat.colors(N))
pie(rep(1,N),col=dichromat(heat.colors(N)))
```



dichromat function collapses red-green color distinctions to approximate the effect of the two common forms of red-green color blindness, protanopia and deuteranopia.

Using Color in R

Color Blindness

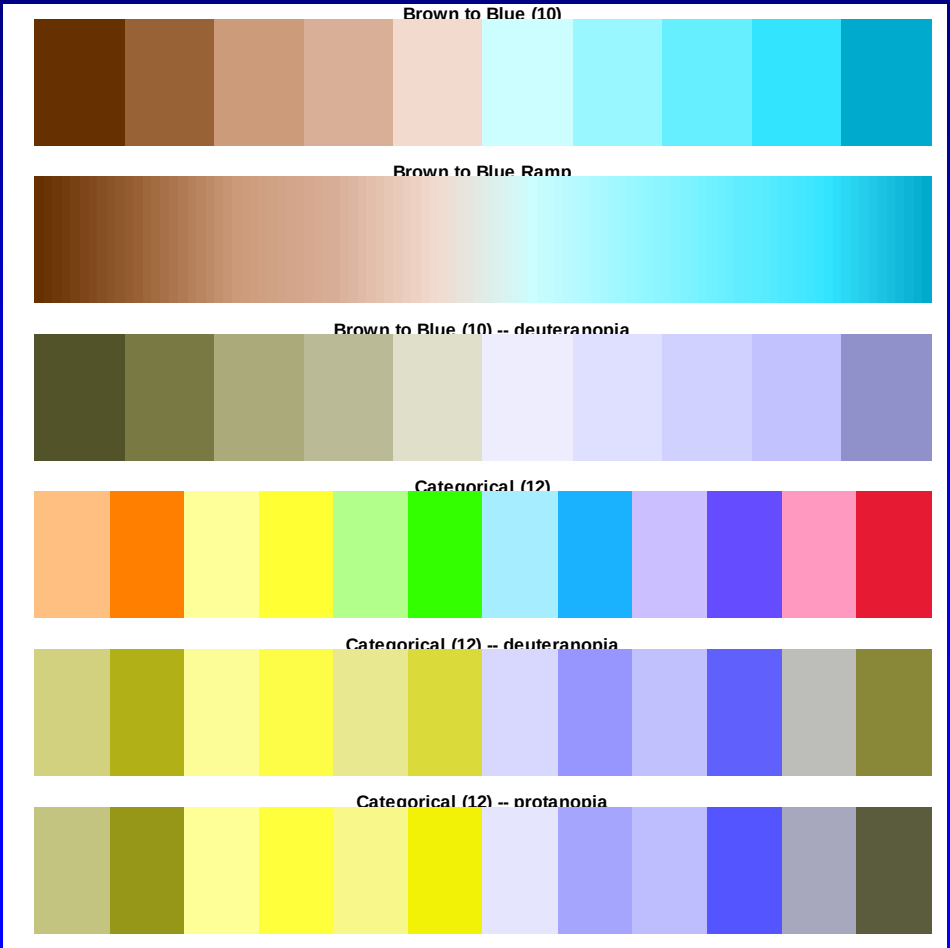
R dichromat Package: Color Schemes for dichromats

```
library(dichromat)
par(mar=c(1,2,1,1))
layout(matrix(1:6,ncol=1))
image(1:10,1,matrix(1:10, ncol=1),
     col=colorschemes$BrowntoBlue.10,
     main="Brown to Blue (10)", axes=FALSE)
image(1:100,1,matrix(1:100 ,ncol=1),
     col=colorRampPalette(colorschemes$BrowntoBlue.10,space="Lab")(100),
     main="Brown to Blue Ramp", axes=FALSE)
image(1:10,1,matrix(1:10, ncol=1),
     col=dichromat(colorschemes$BrowntoBlue.10),
     main="Brown to Blue (10) -- deuteranopia", axes=FALSE)
image(1:12,1,matrix(1:12, ncol=1),col=colorschemes$Categorical.12,
     main="Categorical (12)", axes=FALSE)
image(1:12,1,matrix(1:12, ncol=1),
     col=dichromat(colorschemes$Categorical.12),
     main="Categorical (12) -- deuteranopia", axes=FALSE)
image(1:12,1,matrix(1:12,ncol=1),
     col=dichromat(colorschemes$Categorical.12, "protan"),
     main="Categorical (12) -- protanopia", axes=FALSE)
```

Using Color in R

Color Blindness

R dichromat Package: Color Schemes for dichromats



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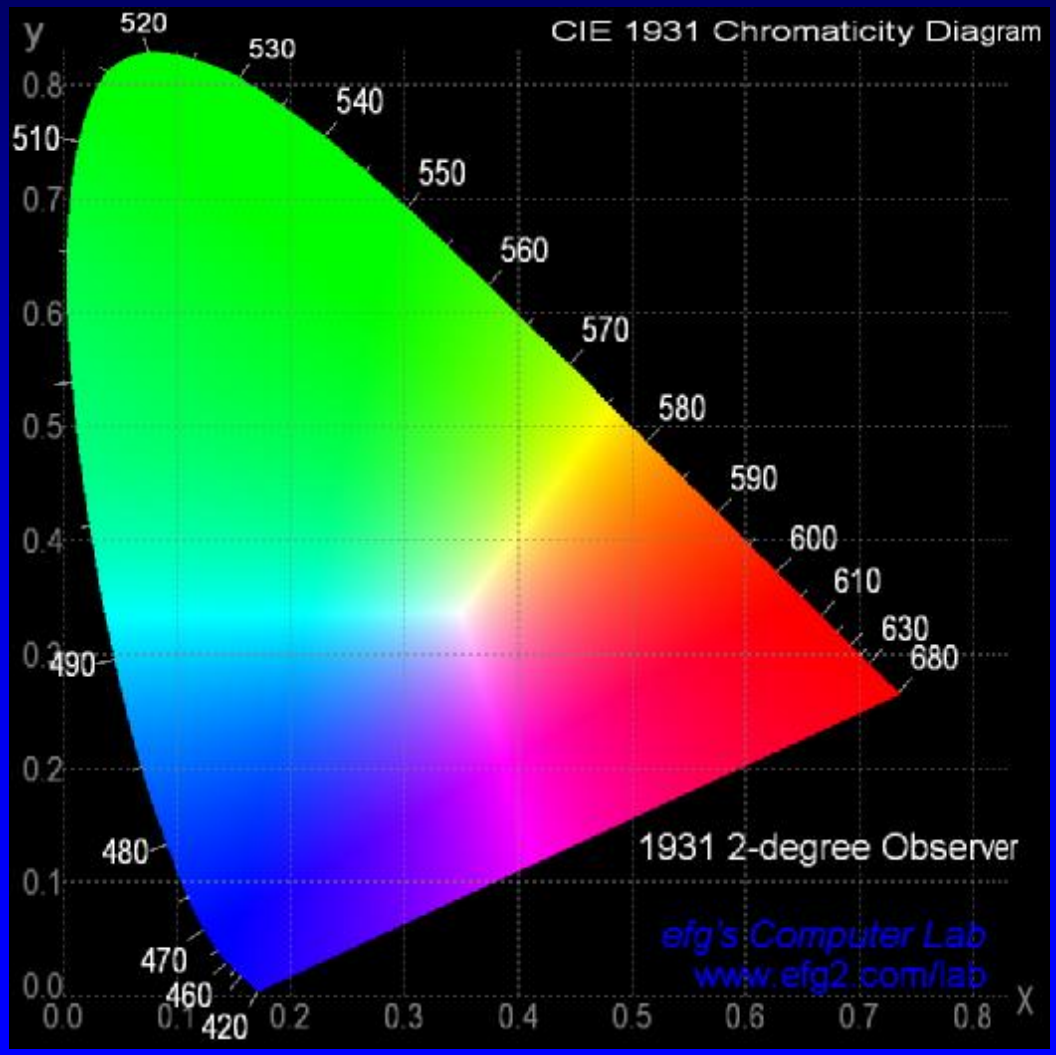
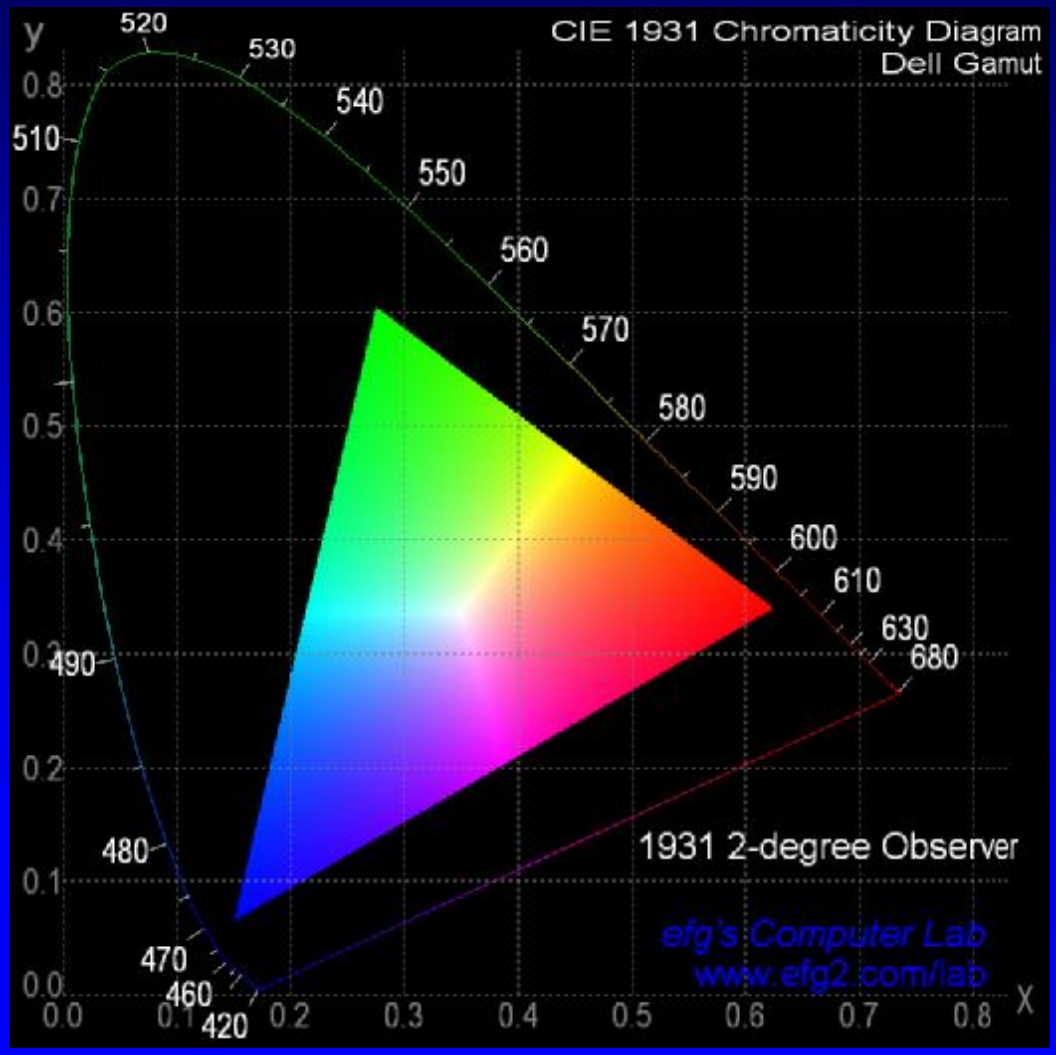
Why Don't Screen Colors Match Printout?



Conceptual Diagram of All Colors (2D Slice)

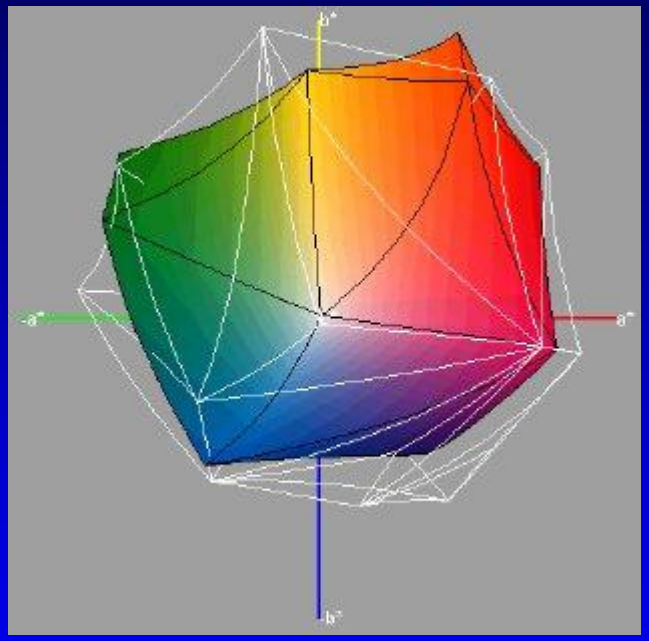
Why Don't Screen Colors Match Printout?



Each Device Has Own Gamut of Colors

Using Color in R

3D Color Gamut



From “Visualization of Expanded Printing Gamuts Using 3-Dimensional Convex Hulls”
by Karl Guyler, Hallmark Cards, Kansas City

Color calibration can be used to minimize needless differences

Why Don't Screen Colors Match Printout?

- Different color gamuts between devices:

  How should a color be represented if it doesn't exist on a device?

- Imperfect conversions:

  CRT screens with RGB (Red-Green-Blue) additive colors must be converted to CMYK (Cyan-Magenta-Yellow-Black) subtractive colors

- Color fidelity may not be accurate

- Paper/ink differences

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Color Tips

- Avoid unnecessary use of color.
- Use bright colors with small graphics to make them stand out.
- Be consistent in use of color.
- Don't use color as only attribute to show difference. E.g., consider color and line type.

Also see: Cool Color Commentary, http://www.public-speaking.org/public-speaking-color-article.htm

Color Tips: Palettes

- Qualitative Palette:
  - all same perceptual weight/importance
  - typical application: bar plot
- Sequential Palette
  - for coding numerical information in a range
  - typical application: heat map
- Diverging Palette
  - Like Sequential Palette but with neutral value

Source: Choosing Color Palettes for Statistical Graphics
http://epub.wu-wien.ac.at/dyn/virlib/wp/mediate/epub-wu-01_abd.pdf?ID=epub-wu-01_abd

References

Colour for Presentation Graphics
http://www.stat.auckland.ac.nz/~ihaka/colour/color-talk.pdf

Why should Engineers and Scientists be worried about color?
http://www.research.ibm.com/people/l/lloydt/color/color.HTM