Working with Colors

```
> library(swirl)

| Hi! I see that you have some variables saved in your workspace. To keep thi
ngs running smoothly, I
| recommend you clean up before starting swirl.

| Type ls() to see a list of the variables in your workspace. Then, type rm(l
ist=ls()) to clear your
| workspace.

| Type swirl() when you are ready to begin.

> swirl()

| Welcome to swirl! Please sign in. If you've been here before, use the same
name as you did then. If
| you are new, call yourself something unique.

What shall I call you? Stephen

| Would you like to continue with one of these lessons?

1: R Programming Workspace and Files
2: No. Let me start something new.

Selection: 2

| Please choose a course, or type 0 to exit swirl.

1: Data Analysis
2: Exploratory Data Analysis
3: Getting and Cleaning Data
4: Mathematical Biostatistics Boot Camp
5: Open Intro
6: R Programming
7: Regression Models
8: Statistical Inference
9: Take me to the swirl course repository!

Selection: 2

| Please choose a lesson, or type 0 to return to course menu.

 1: Principles of Analytic Graphs   2: Exploratory Graphs
 3: Graphics Devices in R           4: Plotting Systems
 5: Base Plotting System            6: Lattice Plotting System
 7: Working with Colors             8: GGPlot2 Part1
 9: GGPlot2 Part2                  10: GGPlot2 Extras
11: Hierarchical Clustering        12: K Means Clustering
13: Dimension Reduction            14: Clustering Example
15: CaseStudy

Selection: 7
```

```
| Attempting to load lesson dependencies...

| Package ‘jpeg’ loaded correctly!

| Package ‘RColorBrewer’ loaded correctly!

| Package ‘datasets’ loaded correctly!

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| Working_with_Colors. (Slides for this and other Data Science courses may be
found at github
| https://github.com/DataScienceSpecialization/courses/. If you care to use t
hem, they must be
| downloaded as a zip file and viewed locally. This lesson corresponds to
| 04_ExploratoryAnalysis/Colors.)

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| This lesson is about using colors in R. It really supplements the lessons o
n plotting with the base
| and lattice packages which contain functions that are able to take the argu
ment col. We'll discuss
| ways to set this argument more colorfully.

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| Of course, color choice is secondary to your data and how you analyze it, b
ut effectively using
| colors can enhance your plots and presentations, emphasizing the important
points you're trying to
| convey.

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| The motivation for this lesson is that the default color schemes for most p
lots in R are not
| optimal. Fortunately there have been recent developments to improve the han
dling and specification
| of colors in plots and graphs. We'll cover some functions in R as well as i
n external packages that
| are very handy. If you know how to use some of these then you'll have more
options when you create
| your displays.

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| We'll begin with a motivating example - a typical R plot using 3 default co
lors.

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| According to the plot, what is color 2?

1: Red
2: Blue
3: Empty black circles
4: Green

Selection: 1

| Excellent job!

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| So these are the first 3 default values. If you were plotting and just spec
ified col=c(1:3) as one
| of your arguments, these are colors you'd get. Maybe you like them, but the
y might not be the best
| choice for your application.

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| To show you some options, here's a display of two color palettes that come
with the grDevices
| package available to you. The left shows you some colors from the function
heat.colors. Here low
| values are represented in red and as the values increase the colors move th
rough yellow towards
| white. This is consistent with the physical properties of fire. The right d
isplay is from the
| function topo.colors which uses topographical colors ranging from blue (low
values) towards brown
| (higher values).

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| So we'll first discuss some functions that the grDevices package offers. Th
e function colors()
| lists the names of 657 predefined colors you can use in any plotting functi
on.  These names are
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| returned as strings. Run the R command sample with colors() as its first ar
gument and 10 as its
| second to give you an idea of the choices you have.

> sample(colors(),10)
 [1] "lightyellow2"   "ivory2"         "palevioletred1" "grey100"        "gra
y76"
 [6] "coral"          "mediumpurple2"  "rosybrown4"     "grey94"         "cha
rtreuse"

| That's the answer I was looking for.

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| We see a lot of variety in the colors, some of which are names followed by
numbers indicating that
| there are multiple forms of that particular color.

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| So you're free to use any of these 600+ colors listed by the colors functio
n. However, two
| additional functions from grDevices, colorRamp and colorRampPalette, give y
ou more options. Both of
| these take color names as arguments and use them as "palettes", that is, th
ese argument colors are
| blended in different proportions to form new colors.

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| The first, colorRamp, takes a palette of colors (the arguments) and returns
a function that takes
| values between 0 and 1 as arguments. The 0 and 1 correspond to the extremes
of the color palette.
| Arguments between 0 and 1 return blends of these extremes.

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| Let's see what this means. Assign to the variable pal the output of a call
to colorRamp with the
| single argument, c("red","blue").

> pal <- colorRamp(c("red","blue"))

| Excellent job!
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| We don't see any output, but R has created the function pal which we ca
ll with a single
| argument between 0 and 1. Call pal now with the argument 0.

> View(pal)

| Almost! Try again. Or, type info() for more options.

| Type pal(0) at the command prompt.

> pal(0)
     [,1] [,2] [,3]
[1,]  255    0    0

| Excellent work!

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| We see a 1 by 3 array with 255 as the first entry and 0 in the other 2. Thi
s 3 long vector
| corresponds to red, green, blue (RGB) color encoding commonly used in telev
isions and monitors. In
| R, 24 bits are used to represent colors. Think of these 24 bits as 3 sets o
f 8 bits, each of which
| represents an intensity for one of the colors red, green, and blue.

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| The 255 returned from the pal(0) call corresponds to the largest possible n
umber represented with 8
| bits, so the vector (255,0,0) contains only red (no green or blue), and mor
eover, it's the highest
| possible value of red.

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| Given that you created pal with the palette containing "red" and "blue", wh
at color do you think
| will be represented by the vector that pal(1) returns? Recall that pal will
only take arguments
| between 0 and 1, so 1 is the largest argument you can pass it.

1: green
2: blue
3: red
4: yellow
```

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Selection: 1

| One more time. You can do it!

| If the one extreme (0) returned red, it makes sense that pal(1) will return
a vector representing
| blue.

1: blue
2: yellow
3: green
4: red

Selection: 1

| You are amazing!

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| Check your answer now by calling pal with the argument 1.

> pal(1)
     [,1] [,2] [,3]
[1,]    0    0  255

| Keep working like that and you'll get there!

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| You see the vector (0,0,255) which represents the highest intensity of blue
. What vector do you
| think the call pal(.5) will return?

1: (255,255,255)
2: (127.5,0,127.5)
3: (0,255,0)
4: (255,0,255)

Selection: 3

| That's not exactly what I'm looking for. Try again.

| The correct answer should be halfway between (255,0,0) and (0,0,255). Which
is the only choice that
| is the average (mean) of these two?

1: (127.5,0,127.5)
2: (0,255,0)
3: (255,0,255)
4: (255,255,255)

Selection: 1

| Your dedication is inspiring!
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| The function pal can take more than one argument. It returns one 3-long (or
4-long, but more about
| this later) vector for each argument. To see this in action, call pal with
the argument
| seq(0,1,len=6).

> pal(seq(0,1,len-6))
Error in seq.default(0, 1, len - 6) : object 'len' not found
> pal(seq(0,1,len=6))
     [,1] [,2] [,3]
[1,]  255    0    0
[2,]  204    0   51
[3,]  153    0  102
[4,]  102    0  153
[5,]   51    0  204
[6,]    0    0  255

| That's a job well done!

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| Six vectors (each of length 3) are returned. The i-th vector is identical t
o output that would be
| returned by the call pal(i/5) for i=0,...5. We see that the i-th row (for i
=1,...6) differs from
| the (i-1)-st row in the following way. Its red entry is 51 = 255/5 points l
ower and its blue entry
| is 51 points higher.

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| So pal creates colors using the palette we specified when we called colorRa
mp. In this example none
| of pal's outputs will ever contain green since it wasn't in our initial pal
ette.

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| We'll turn now to colorRampPalette, a function similar to colorRamp. It als
o takes a palette of
| colors and returns a function. This function, however, takes integer argume
nts (instead of numbers
| between 0 and 1) and returns a vector of colors each of which is a blend of
colors of the original
| palette.

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| The argument you pass to the returned function specifies the number of colo
rs you want returned.
| Each element of the returned vector is a 24 bit number, represented as 6 he
xadecimal characters,
| which range from 0 to F. This set of 6 hex characters represents the intens
ities of red, green, and
| blue, 2 characters for each color.

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| To see this better, assign to the variable p1 the output of a call to color
RampPalette with the
| single argument, c("red","blue"). We'll compare it to our experiments using
colorRamp.

> p1 <- colorRampPalette(c("red","blue"))

| Keep up the great work!

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| Now call p1 with the argument 2.

> p1(2)
[1] "#FF0000" "#0000FF"

| Nice work!

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| We see a 2-long vector is returned. The first entry FF0000 represents red.
The FF is hexadecimal
| for 255, the same value returned by our call pal(0). The second entry 0000F
F represents blue, also
| with intensity 255.

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| Now call p1 with the argument 6. Let's see if we get the same result as we
did when we called pal
| with the argument seq(0,1,len=6).

> p1(6)
[1] "#FF0000" "#CC0033" "#990066" "#650099" "#3200CC" "#0000FF"
```

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| You nailed it! Good job!

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| Now we get the 6-long vector (FF0000, CC0033, 990066, 650099, 3200CC, 0000F
F). We see the two ends
| (FF0000 and 0000FF) are consistent with the colors red and blue. How about
CC0033? Type 0xcc or
| 0xCC at the command line to see the decimal equivalent of this hex number.
You must include the 0
| before the x to specify that you're entering a hexadecimal number.

> 0xcc
[1] 204

| You're the best!

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| So 0xCC equals 204 and we can easily convert hex 33 to decimal, as in 0x33=
3*16+3=51. These were
| exactly the numbers we got in the second row returned from our call to pal(
seq(0,1,len=6)). We see
| that 4 of the 6 numbers agree with our earlier call to pal. Two of the 6 di
ffer slightly.

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| We can also form palettes using colors other than red, green and blue. Form
a palette, p2, by
| calling colorRampPalette with the colors "red" and "yellow". Remember to co
ncatenate them into a
| single argument.

> p2 <- colorRampPalette(c("red","yellow"))

| You got it right!

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| Now call p2 with the argument 2. This will show us the two extremes of the
blends of colors we'll
| get.

> p2(2)
[1] "#FF0000" "#FFFF00"

| All that hard work is paying off!

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| Not surprisingly the first color we see is FF0000, which we know represents
red. The second color
| returned, FFFF00, must represent yellow, a combination of full intensity re
d and full intensity
| green. This makes sense, since yellow falls between red and green on the co
lor wheel as we see
| here. (We borrowed this image from lucaskrech.com.)

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| Let's now call p2 with the argument 10. This will show us how the two extre
mes, red and yellow, are
| blended together.

>
> p2(10)
 [1] "#FF0000" "#FF1C00" "#FF3800" "#FF5500" "#FF7100" "#FF8D00" "#FFAA00" "#
FFC600" "#FFE200"
[10] "#FFFF00"

| Excellent job!

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| So we see the 10-long vector. For each element, the red component is fixed
at FF, and the green
| component grows from 00 (at the first element) to FF (at the last).

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| This is all fine and dandy but you're probably wondering when you can see h
ow all these colors show
| up in a display. We copied some code from the R documentation pages (color.
scale if you're
| interested) and created a function for you, showMe. This takes as an argume
nt, a color vector,
| which as you know, is precisely what calls to p1 and p2 return to you. Call
showMe now with p1(20).

> View(showMe)

| Nice try, but that's not exactly what I was hoping for. Try again. Or, type
info() for more
| options.

| Type showMe(p1(20)) at the command prompt.

> View(showMe)
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| Not quite! Try again. Or, type info() for more options.

| Type showMe(p1(20)) at the command prompt.

> showMe(p1(20))

| That's a job well done!

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| We see the interpolated palette here. Low values in the lower left corner a
re red and as you move
| to the upper right, the colors move toward blue. Now call showMe with p2(20
) as its argument.

> showMe(p2(20))

| You are doing so well!

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| Here we see a similar display, the colors moving from red to yellow, the ba
se colors of our p2
| palette. For fun, see what p2(2) looks like using showMe.

> p2(2)
[1] "#FF0000" "#FFFF00"

| Not quite, but you're learning! Try again. Or, type info() for more options
.

| Type showMe(p2(2))) at the command prompt.

> showMe((p2(2)))

| Keep trying! Or, type info() for more options.

| Type showMe(p2(2))) at the command prompt.

> showMe(p2(2))

| You're the best!

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| A much more basic pattern, simple but elegant.

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| We mentioned before that colorRamp (and colorRampPalette) could return a 3
or 4 long vector of
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| colors. We saw 3-long vectors returned indicating red, green, and blue inte
nsities. What would the
| 4th entry be?

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| We'll answer this indirectly. First, look at the function p1 that colorRamp
Palette returned to you.
| Just type p1 at the command prompt.

> p1
function (n)
{
    x <- ramp(seq.int(0, 1, length.out = n))
    if (ncol(x) == 4L)
        rgb(x[, 1L], x[, 2L], x[, 3L], x[, 4L], maxColorValue = 255)
    else rgb(x[, 1L], x[, 2L], x[, 3L], maxColorValue = 255)
}
<bytecode: 0x000000000579dbb8>
<environment: 0x0000000005889240>

| You're the best!

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| We see that p1 is a short function with one argument, n. The argument n is
used as the length in a
| call to the function seq.int, itself an argument to the function ramp. We c
an infer that ramp is
| just going to divide the interval from 0 to 1 into n pieces.

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| The heart of p1 is really the call to the function rgb with either 4 or 5 a
rguments. Use the ?fun
| construct to look at the R documentation for rgb now.

> ?fun
No documentation for ‘fun’ in specified packages and libraries:
you could try ‘??fun’

| Give it another try. Or, type info() for more options.

| Type ?rgb at the command prompt.

> ?rgb

| Keep up the great work!
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| We see that rgb is a color specification function that can be used to produ
ce any color with red,
| green, blue proportions. We see the maxColorValue is 1 by default, so if we
called rgb with values
| for red, green and blue, we would specify numbers at most 1 (assuming we di
dn't change the default
| for maxColorValue). According to the documentation, what is the maximum num
ber of arguments rgb can
| have?

1: 6
2: 3
3: 5
4: 4

Selection: 1

| Keep working like that and you'll get there!

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|  64%

| So the fourth argument is alpha which can be a logical, i.e., either TRUE o
r FALSE, or a numerical
| value. Create the function p3 now by calling colorRampPalette with the colo
rs blue and green
| (remember to concatenate them into a single argument) and setting the alpha
argument to .5.

> p3 <- colorRampPalette(c("blue","green"),alpha=.5)

| All that hard work is paying off!

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| Now call p3 with the argument 5.

> p3(5)
[1] "#0000FFFF" "#003FBFFF" "#007F7FFF" "#00BF3FFF" "#00FF00FF"

| You are doing so well!

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| We see that in the 5-long vector that the call returned, each element has 3
2 bits, 4 groups of 8
| bits each. The last 8 bits represent the value of alpha. Since it was NOT Z
ERO in the call to
| colorRampPalette, it gets the maximum FF value. (The same result would happ
en if alpha had been set
| to TRUE.) When it was 0 or FALSE (as in previous calls to colorRampPalette)
it was given the value
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| 00 and wasn't shown. The leftmost 24 bits of each element are the same RGB
encoding we previously
| saw.

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| So what is alpha? Alpha represents an opacity level, that is, how transpare
nt should the colors be.
| We can add color transparency with the alpha parameter to calls to rgb. We
haven't seen any
| examples of this yet, but we will now.

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| We generated 1000 random normal pairs for you in the variables x and y. We'
ll plot them in a
| scatterplot by calling plot with 4 arguments. The variables x and y are the
first 2. The third is
| the print character argument pch. Set this equal to 19 (filled circles). Th
e final argument is col
| which should be set equal to a call to rgb. Give rgb 3 arguments, 0, .5, an
d .5.

> plot(x,y,pch=19,col=rgb(0,.5,.5))

| Keep up the great work!

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| Well this picture is okay for a scatterplot, a nice mix of blue and green,
but it really doesn't
| tell us too much information in the center portion, since the points are so
thick there. We see
| there are a lot of points, but is one area more filled than another? We can
't really discriminate
| between different point densities. This is where the alpha argument can hel
p us. Recall your plot
| command (use the up arrow) and add a 4th argument, .3, to the call to rgb.
This will be our value
| for alpha.

> plot(x,y,pch=19,col=rgb(0,.5,.5,alpha = 0.3))

| You are really on a roll!

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| Clearly this is better. It shows us where, specifically, the densest areas
of the scatterplot
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| really are.

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| Our last topic for this lesson is the RColorBrewer Package, available on CR
AN, that contains
| interesting and useful color palettes, of which there are 3 types, sequenti
al, divergent, and
| qualitative. Which one you would choose to use depends on your data.

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| Here's a picture of the palettes available from this package. The top secti
on shows the sequential
| palettes in which the colors are ordered from light to dark. The divergent
palettes are at the
| bottom. Here the neutral color (white) is in the center, and as you move fr
om the middle to the two
| ends of each palette, the colors increase in intensity. The middle display
shows the qualitative
| palettes which look like collections of random colors. These might be used
to distinguish factors
| in your data.

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| These colorBrewer palettes can be used in conjunction with the colorRamp()
and colorRampPalette()
| functions. You would use colors from a colorBrewer palette as your base pal
ette,i.e., as arguments
| to colorRamp or colorRampPalette which would interpolate them to create new
colors.

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| As an example of this, create a new object, cols by calling the function br
ewer.pal with 2
| arguments, 3 and "BuGn". The string "BuGn" is the second last palette in th
e sequential display.
| The 3 tells the function how many different colors we want.

> cols <- brewer.pal(3, "BuGn")

| That's the answer I was looking for.
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| Use showMe to look at cols now.

> showMe(cols)

| Your dedication is inspiring!

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| We see 3 colors, mixes of blue and green. Now create the variable pal by ca
lling colorRampPalette
| with cols as its argument.

> pal <- colorRampPalette(cols)

| That's the answer I was looking for.

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| The call showMe(pal(3)) would be identical to the showMe(cols) call. So use
showMe to look at
| pal(20).

> showMe(pal(20))

| You are quite good my friend!

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| Now we can use the colors in pal(20) to display topographic information on
Auckland's Maunga Whau
| Volcano. R provides this information in a matrix called volcano which is in
cluded in the package
| datasets.  Call the R function image with volcano as its first argument and
col set equal to
| pal(20) as its second.

> image(volcano,col = pal(20))

| You got it right!

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| We see that the colors here of the sequential palette clue us in on the top
ography. The darker
| colors are more concentrated than the lighter ones. Just for fun, recall yo
ur last command calling
| image and instead of pal(20), use p1(20) as the second argument.

> image(volcano,col = p1(20))
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| All that hard work is paying off!

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| Not as nice a picture since the palette isn't as well suited to this data,
but that's okay. It's
| review time!!!!

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| True or False? Careful use of colors in plots/maps/etc. can make it easier
for the reader to
| understand what points you're trying to convey.

1: True
2: False

Selection: 1

| Keep up the great work!

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| Which of the following is an R package that provides color palettes for seq
uential, categorical,
| and diverging data?

1: RColorVintner
2: RColorBrewer
3: RColorStewer
4: RColorBluer

Selection: 2

| That's correct!

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| True or False? The colorRamp and colorRampPalette functions can be used in
conjunction with color
| palettes to connect data to colors.

1: False
2: True

Selection: 2

| You nailed it! Good job!

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| True or False?  Transparency can NEVER be used to clarify plots with many p
oints

1: False
2: True

Selection: 1

| Perseverance, that's the answer.

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| True or False?  The call p7 <- colorRamp("red","blue") would work (i.e., no
t generate an error).

1: True
2: False

Selection: 2

| All that hard work is paying off!

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| True or False?  The function colors returns only 10 colors.

1: True
2: False

Selection: 2

| You're the best!

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| Transparency is determined by which parameter of the rgb function?

1: alpha
2: beta
3: gamma
4: delta
5: it's all Greek to me

Selection: 1

| You got it!

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| Congratulations! We hope this lesson didn't make you see red. We're green w
ith envy that you blue
| through it.
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| Would you like to receive credit for completing this course on Coursera.org
?

1: Yes
2: No
```
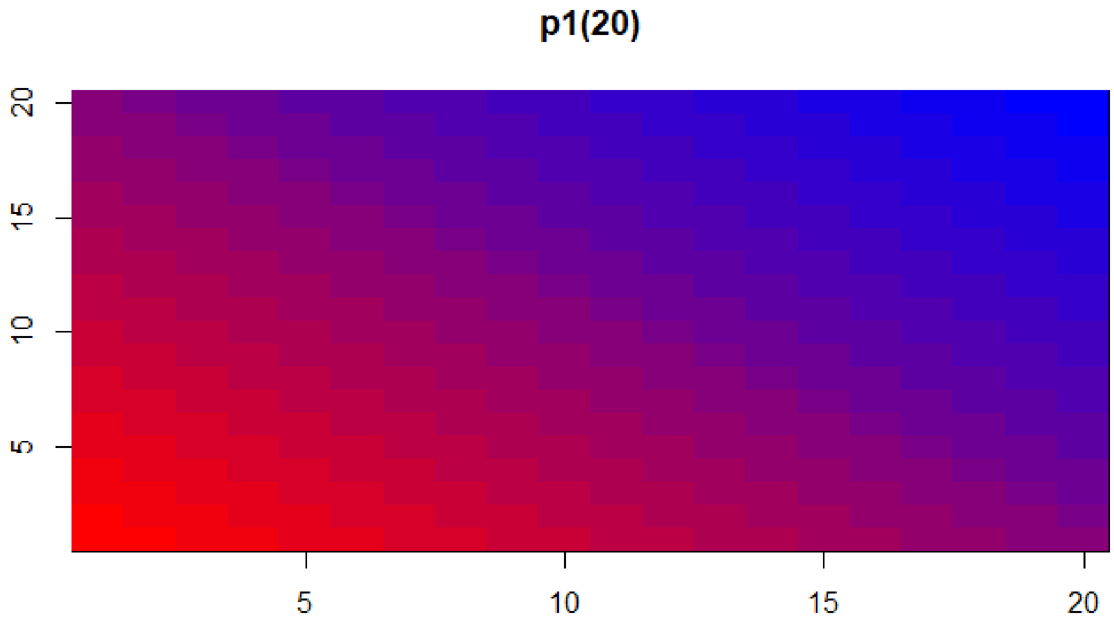
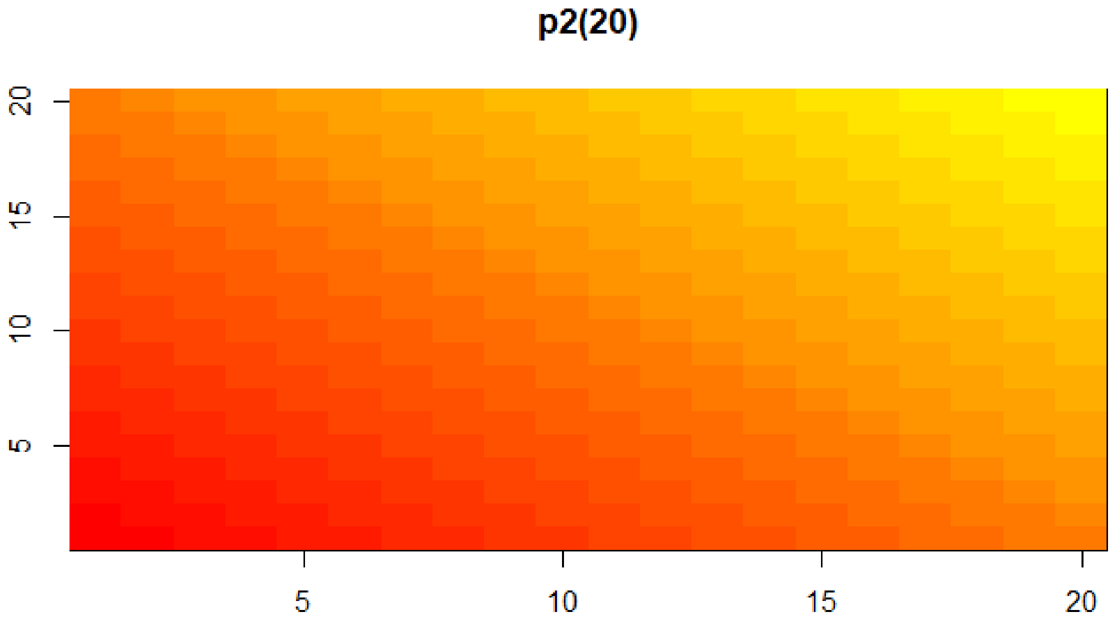
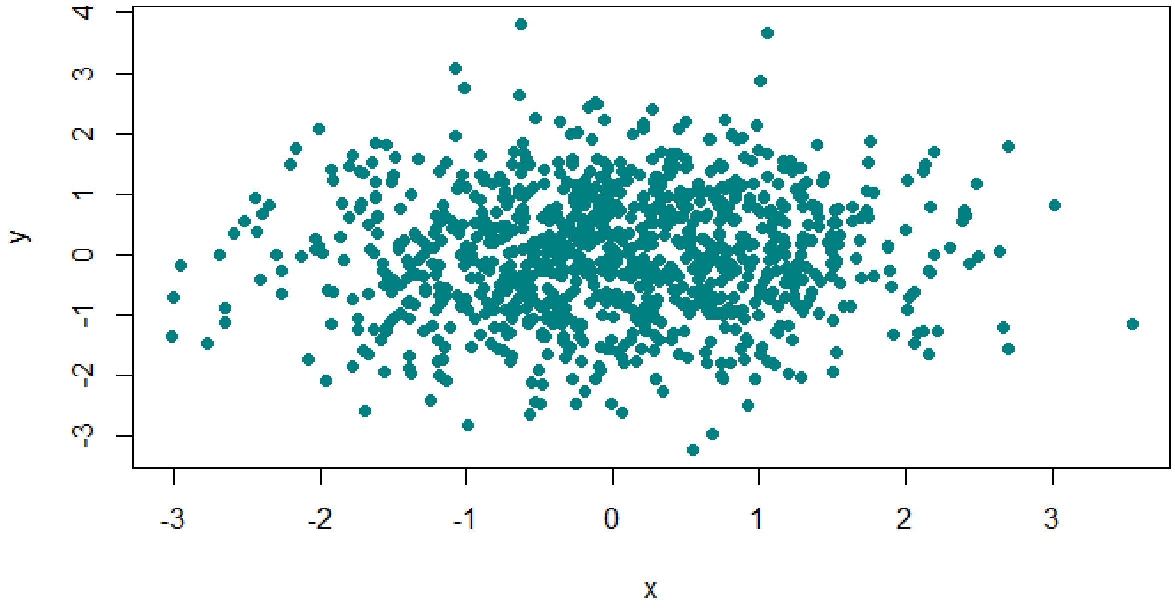
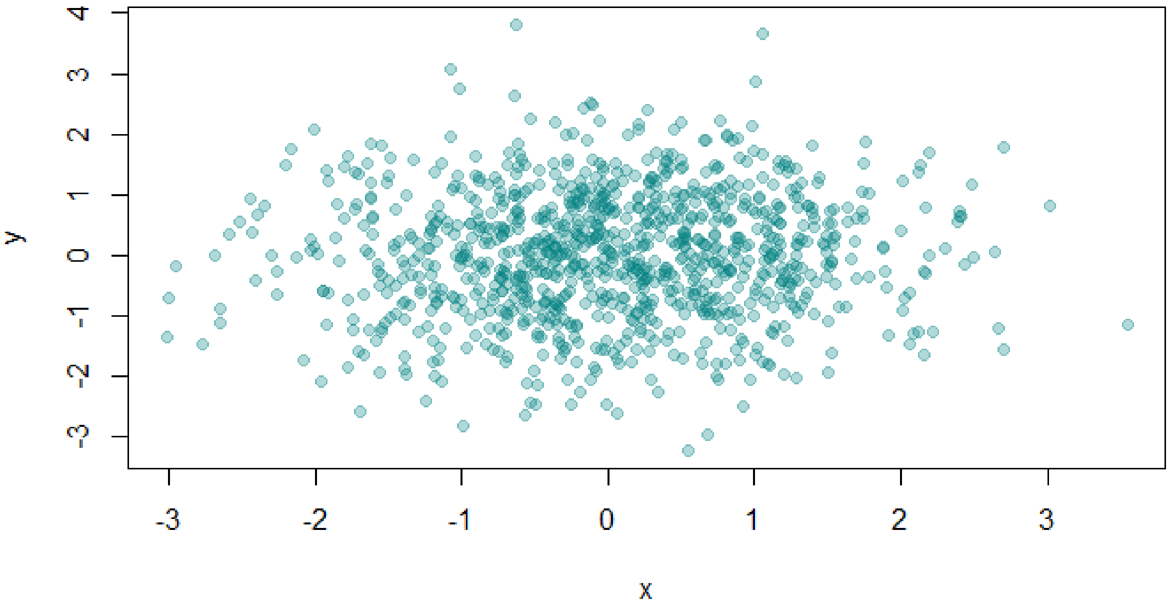





p2(20)

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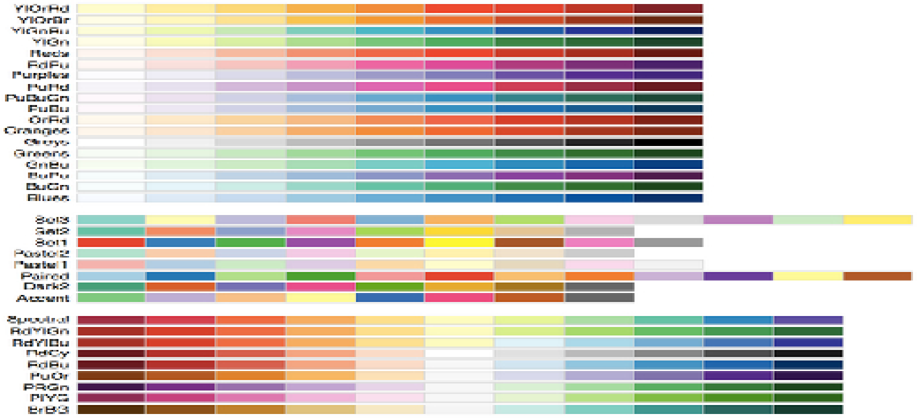
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YlGnBu
YlGn
Reds
RdPu
Purples
PuRd
PuBuGn
PuBu
OrRd
Oranges
Greys
Greens
GnBu
BuPu
BuGn
Blues
Set3
Set2
Set1
Pastel2
Pastel1
Paired
Dark2
Accent
Spectral
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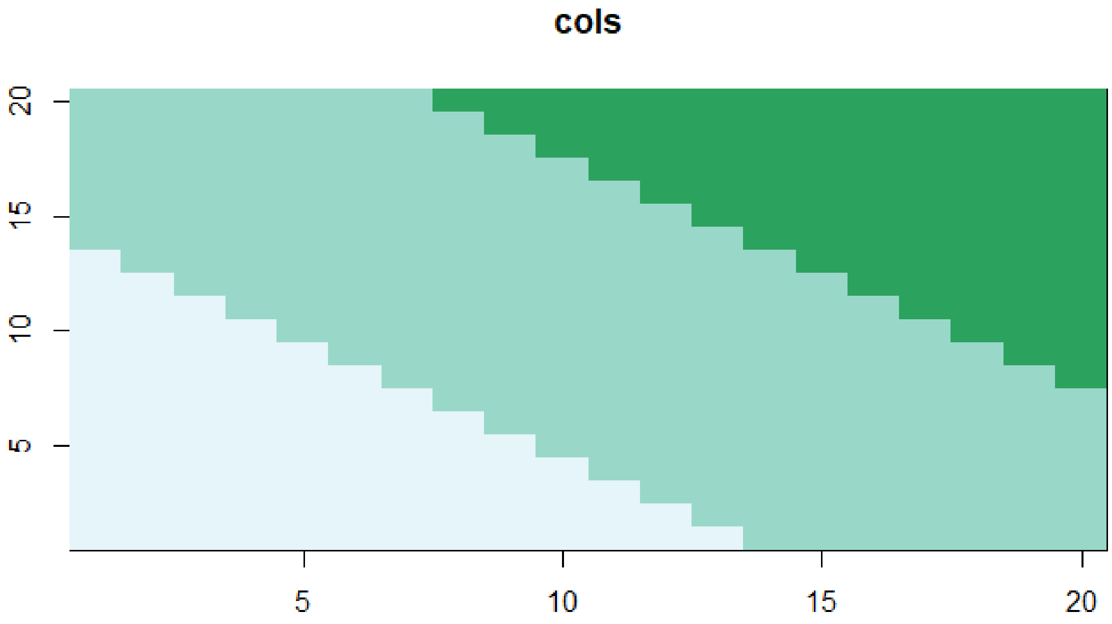
RdGy
RdBu
PuOr
PRGn
PiYG
BrBG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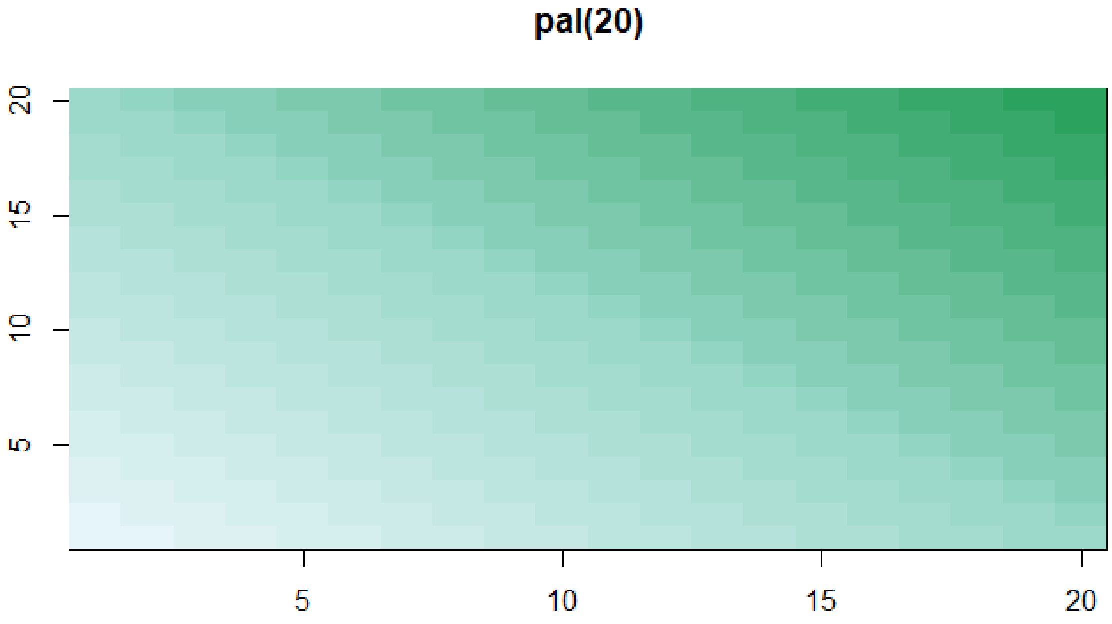
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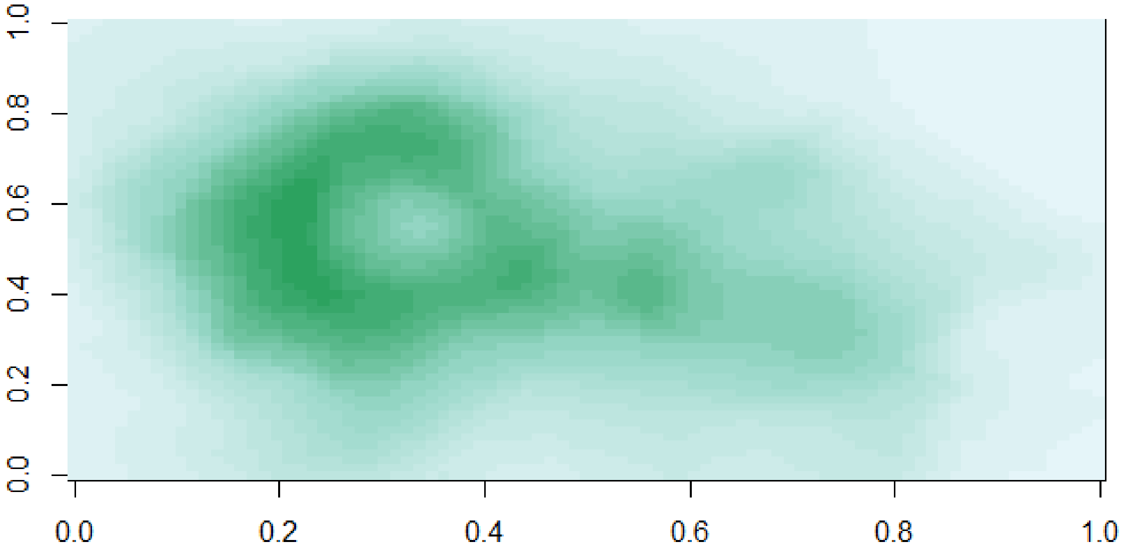
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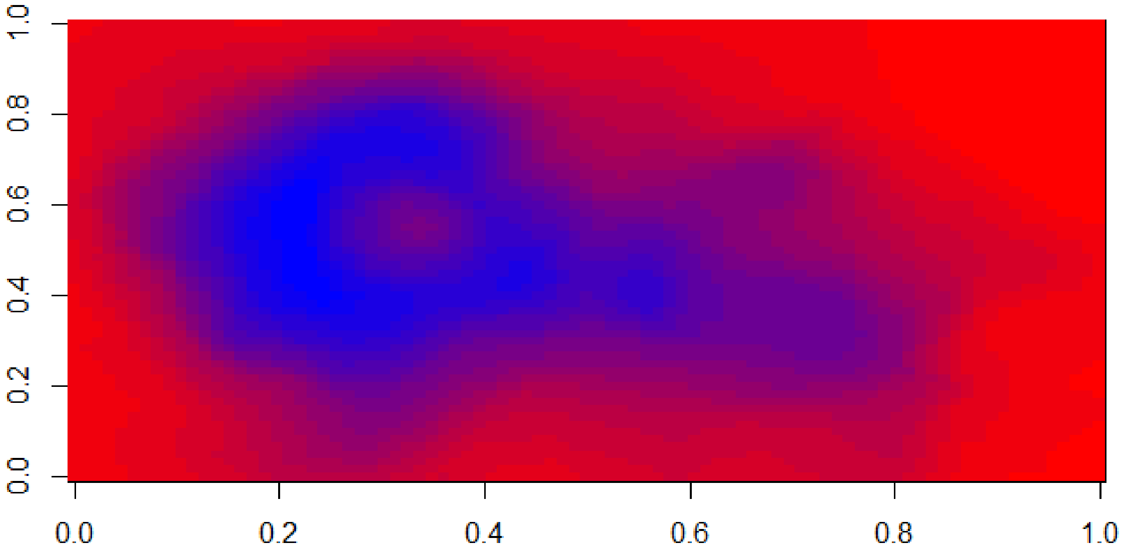
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