BIOS 545 Lecture 4

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Lists

Lists

- Lists provide a way to store information of different types within a single data structure
- Remember that vectors and matrices restrict us to only one data type at a time.
- That is we cannot mix, for example, characters and numbers within a vector or matrix.
- Many functions in R return information stored in lists
- Consider the following example wherein we store information about a family. Not all this information is of the same type

Lists

```
family1 <- list(husband="Fred", wife="Wilma", numofchildren=3,
                agesofkids=c(8,11,14))

length(family1)  # Has 4 elements
[1] 4

family1
$husband
[1] "Fred"

$wife
[1] "Wilma"

$numofchildren
[1] 3

$agesofkids
[1]  8 11 14

str(family1)
List of 4
 $ husband      : chr "Fred"
 $ wife         : chr "Wilma"
 $ numofchildren: num 3
 $ agesofkids   : num [1:3] 8 11 14
```

Lists - Creating

If possible, always create named elements. It is easier for humans to index into a named list

```
family1 <- list(husband="Fred", wife="Wilma", numofchildren=3,
                agesofkids=c(8,11,14))

# If the list elements have names then use "$" to access the element

family1$agesofkids
[1]  8 11 14

family1$agesofkids[1:2]
[1]  8 11
```

Lists - Creating

If the list elements have no names then you have to use numeric indexing

```
family2 <- list("Barney","Betty",2,c(4,6))
[[1]]
[1] "Barney"

[[2]]
[1] "Betty"

[[3]]
[1] 2

[[4]]
[1] 4 6

str(family2)
List of 4
 $ : chr "Barney"
 $ : chr "Betty"
 $ : num 2
 $ : num [1:2] 4 6
```

Lists - Creating

If the list elements have no names then you have to use numeric indexing

```
family2 <- list("Barney","Betty",2,c(4,6))

family2[4]    # Accesses the 4th index and associated element
[[1]]
[1] 4 6

family2[[4]]   # Accesses the 4th element value only - more direct
[1] 4 6

family2[3:4]   # Get 3rd and 4th indices and associate values
[[1]]
[1] 2

[[2]]
[1] 4 6
```

Lists - Uses

As newcomers to R we usually create lists in two cases:

- As a precursor to creating a data frame, which represents a hybrid data structure with characteristics of a list, matrix, and vectors.
- We are writing a function that does some interesting stuff and we want to return to the user a structure that has information of varying types.

  R does this all of the time by returning list structures from statistical modeling functions.

Lists - Functions

R has lots of statistical functions that return lists of information.

```
data(mtcars)   # Load mtcars into the environment

mylm <- lm(mpg ~ wt, data = mtcars)

print(mylm)

Call:
lm(formula = mpg ~ wt, data = mtcars)

Coefficients:
(Intercept)           wt
     37.285       -5.344

# But there is a lot more information

typeof(mylm)
[1] "list"
```

Lists - Functions

```
str(mylm,give.attr=F)  # Lots of stuff here

List of 12
 $ coefficients : Named num [1:2] 37.29 -5.34
 $ residuals    : Named num [1:32] -2.28 -0.92 -2.09 1.3 -0.2 ...
 $ effects      : Named num [1:32] -113.65 -29.116 -1.661 1.631 0.111 ...
 $ rank         : int 2
 $ fitted.values: Named num [1:32] 23.3 21.9 24.9 20.1 18.9 ...
 $ assign       : int [1:2] 0 1
 $ qr           :List of 5
  ..$ qr   : num [1:32, 1:2] -5.657 0.177 0.177 0.177 0.177 ...
  ..$ qraux: num [1:2] 1.18 1.05
  ..$ pivot: int [1:2] 1 2
  ..$ tol  : num 1e-07
  ..$ rank : int 2
 $ df.residual  : int 30
 $ xlevels      : Named list()
 $ call         : language lm(formula = mpg ~ wt, data = mtcars)
 $ terms        :Classes 'terms', 'formula' length 3 mpg ~ wt
 $ model        :'data.frame':  32 obs. of  2 variables:
  ..$ mpg: num [1:32] 21 21 22.8 21.4 18.7 18.1 14.3 24.4 22.8 19.2 ...
  ..$ wt : num [1:32] 2.62 2.88 2.32 3.21 3.44 ...
```

Lists - Functions

```
names(mylm)
 [1] "coefficients"  "residuals"     "effects"       "rank"
 [5] "fitted.values" "assign"        "qr"            "df.residual"
 [9] "xlevels"       "call"          "terms"         "model"

mylm$effects
 (Intercept)          wt
-113.6497374 -29.1157217  -1.6613339   1.6313943   0.1111305  -0.3840041
  -3.6072442   4.5003125   2.6905817   0.6111305  -0.7888695   1.1143917
   0.2316793  -1.6061571   1.3014525   2.2137818   6.0995633   7.3094734
   2.2421594   6.8956792  -2.2010595  -2.6694078  -3.4150859  -3.1915608
   2.7346556   0.8200064   0.5948771   1.7073457  -4.2045529  -2.4018616
  -2.9072442  -0.6494289

# Some use the $ notation to extract desired information they want straight
# from the function call

lm(mpg ~ wt, data = mtcars)$coefficients
(Intercept)          wt
  37.285126   -5.344472
```

Lists - Functions

Some other basic R functions will return a list - such as some of the character functions:

```
mystring <- "This is a test"

mys <- strsplit(mystring, " ")

str(mys)
List of 1
 $ : chr [1:4] "This" "is" "a" "test"

mys
[[1]]
[1] "This" "is"   "a"    "test"

mys[[1]][1]
[1] "This"

mys[[1]][1:2]
[1] "This" "is"

unlist(mys)
[1] "This" "is"   "a"    "test"
```

Lists - Functions

When we create our own functions we can return a list

```
my.summary <- function(x) {
  return.list <- list()
  return.list$mean <- mean(x)
  return.list$sd <- sd(x)
  return.list$var <- var(x)
  return(return.list)
}

my.summary(1:10)
$mean
[1] 5.5

$sd
[1] 3.02765

$var
[1] 9.166667

names(my.summary(1:10))
[1] "mean" "sd"   "var"

my.summary(1:10)$var
[1] 9.166667
```

Lists - sapply/lapply

As with the apply command for matrices, there is a command(s) that will allow us to process each element of a list. This helps us avoid having to write a "for-loop" every time we want to process a list.

```
# sapply( vector_or_list, function_to_apply_to_each element)

family1 <- list(husband="Fred", wife="Wilma", numofchildren=3,
                agesofkids=c(8,11,14))

sapply(family1,class)
      husband          wife numofchildren    agesofkids
  "character"   "character"     "numeric"     "numeric"

sapply(family1,length)
      husband          wife numofchildren    agesofkids
            1             1             1             3
```

Lists - sapply/lapply

sapply tries to return a ”simplified” version of the output (either a vector, list, or a matrix), hence the ”s” in the ”sapply”. If you don't use something like sapply then the example on the previous slide would look this:

```
# sapply( vector_or_list, function_to_apply_to_each element)

family1 <- list(husband="Fred", wife="Wilma", numofchildren=3,
                agesofkids=c(8,11,14))

for (ii in 1:length(family1)) {
   cat(names(family1)[ii]," : ",class(family1[[ii]]),"\n")
}

# More involved than just doing

sapply(family1,class)
      husband          wife numofchildren    agesofkids
  "character"   "character"     "numeric"     "numeric"
```

Lists - sapply/lapply

- Similar to **sapply**, the **lapply** function let's you "apply" some function over each element of a list or vector. (In reality the sapply is a "wrapper" for the lapply command).
- It will return a list version of the output hence the "l" in the "lapply".
- So deciding between sapply and lapply simply is a question of format. What do you want back ? A vector or list ? Most of the time I use sapply.

Lists - sapply/lapply

```
sapply(family1,mean)
$husband
NULL

$wife
NULL

$numofchildren
[1] 3

$agesofkids
[1] 11

Warning messages:
1: In mean.default(X[[1L]], ...) :
  argument is not numeric or logical: returning NA
2: In mean.default(X[[2L]], ...) :
  argument is not numeric or logical: returning NA
```

Lists - sapply/lapply

```
my.func <- function(x) {
  if(class(x)=="numeric") {
    return(mean(x))
  }
}

sapply(family1, my.fun)
$husband
NULL

$wife
NULL

$num.of.children
[1] 3

$child.ages
[1] 6.67
```

See these videos on the lapply function at:

`https://www.youtube.com/playlist?list=PL905DXZOAgwwj16m6C3ioh6aVKDDrEiiO`

See this Blog post on lapply

`https://rollingyours.wordpress.com/2014/10/20/the-lapply-command-101/`

Data Frames

Activity	Solution
Creating	read.table, data.frame, as.data.frame (to convert matrices)
Editing	Workspace viewer in RStudio
Meta Info:	rownames, names, nrow, ncol, sapply
Indexing:	Use bracket notation, subset command, or split command
Transform:	Use transform command, rbind, cbind, or $ notation to create new columns
Missing Values:	Use complete.cases to find only complete cases
Combining:	Use cbind, rbind, or merge
Summarizing:	Use summary, colmeans, rowmeans, (make sure you are dealing with numeric)
Factors:	Use factor command or leave as character until you need the factor
Sort:	Use the order function or rank function

Why Use Data Frames ?

- A data frame is a special type of list that contains data in a format that allows for easier manipulation, reshaping, and open-ended analysis
- Data frames are tightly coupled collections of variables. It is one of the more important constructs you will encounter when using R so learn all you can about it
- A data frame is an analogue to the Excel spreadsheet but is much more flexible for storing, manipulating, and analyzing data
- Data frames can be constructed from existing vectors, lists, or matrices. Many times they are created by reading in comma delimited files, (CSV files), using the read.table command
- Once you become accustomed to working with data frames, R becomes so much easier to use

Why Use Data Frames ?

Here we have 2 character vectors and 2 numeric vectors. Let's say we want to do some summary on them:

```
names  <- c("P1","P2","P3","P4","P5")
temp   <- c(98.2,101.3,97.2,100.2,98.5)
pulse  <- c(66,72,83,85,90)
gender <- c("M","F","M","M","F")

# We could write a for loop to get information for each patient

for (ii in 1:length(gender)) {
   print.string = c(names[ii],temp[ii],pulse[ii],gender[ii])
   print(print.string)
}

[1] "P1"   "98.2" "66"   "M"
[1] "P2"    "101.3" "72"    "F"
[1] "P3"   "97.2" "83"   "M"
[1] "P4"    "100.2" "85"    "M"
[1] "P5"   "98.5" "90"   "F"
```

Why Use Data Frames ?

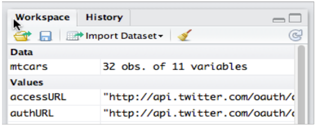
That doesn't generalize at all. Use the **dataframe()** function to create a data frame. It looks like a matrix but allows for mixed data types

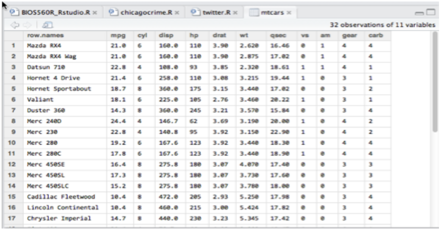
```
names  <- c("P1","P2","P3","P4","P5")
temp   <- c(98.2,101.3,97.2,100.2,98.5)
pulse  <- c(66,72,83,85,90)
gender <- c("M","F","M","M","F")

my_df <- data.frame(names,temp,pulse,gender) # Much more flexible

  names  temp pulse gender
1    P1  98.2    66      M
2    P2 101.3    72      F
3    P3  97.2    83      M
4    P4 100.2    85      M
5    P5  98.5    90      F

plot(my_df$pulse ~ my_df$temp,main="Pulse Rate",xlab="Patient",ylab="BPM")
mean(my_df[,2:3])
 temp pulse
99.08 79.20
```

Why Use Data Frames ?

Once you have a data frame you could edit it with the Workspace viewer in RStudio although this doesn't generalize. Imagine if your data set had 10,000 lines ?

```
data(mtcars)   # Load the builtin mtcars dataframe
```





	row.names	mpg	cyl	disp	hp	drat	wt	qsec	vs	am	gear	carb
1	Mazda RX4	21.0	6	160.0	110	3.90	2.620	16.46	0	1	4	4
2	Mazda RX4 Wag	21.0	6	160.0	110	3.90	2.875	17.02	0	1	4	4
3	Datsun 710	22.8	4	108.0	93	3.85	2.320	18.61	1	1	4	1
4	Hornet 4 Drive	21.4	6	258.0	110	3.08	3.215	19.44	1	0	3	1
5	Hornet Sportabout	18.7	8	360.0	175	3.15	3.440	17.02	0	0	3	2
6	Valiant	18.1	6	225.0	105	2.76	3.460	20.22	1	0	3	1
7	Duster 360	14.3	8	360.0	245	3.21	3.570	15.84	0	0	3	4
8	Merc 240D	24.4	4	146.7	62	3.69	3.190	20.00	1	0	4	2
9	Merc 230	22.8	4	140.8	95	3.92	3.150	22.90	1	0	4	2
10	Merc 280	19.2	6	167.6	123	3.92	3.440	18.30	1	0	4	4
11	Merc 280C	17.8	6	167.6	123	3.92	3.440	18.90	1	0	4	4
12	Merc 450SE	16.4	8	275.8	180	3.07	4.070	17.40	0	0	3	3
13	Merc 450SL	17.3	8	275.8	180	3.07	3.730	17.60	0	0	3	3
14	Merc 450SLC	15.2	8	275.8	180	3.07	3.780	18.00	0	0	3	3
15	Cadillac Fleetwood	10.4	8	472.0	205	2.93	5.250	17.98	0	0	3	4
16	Lincoln Continental	10.4	8	460.0	215	3.00	5.424	17.82	0	0	3	4
17	Chrysler Imperial	14.7	8	440.0	230	3.23	5.345	17.42	0	0	3	4

Data Frames - Builtin

R comes with a variety of built-in data sets that are very useful for getting used to data sets and how to manipulate them.

```
library(help="datasets")

# Gives detailed descriptions on available data sets

AirPassengers           Monthly Airline Passenger Numbers 1949-1960
BJsales                 Sales Data with Leading Indicator
BOD                     Biochemical Oxygen Demand
CO2                     Carbon Dioxide Uptake in Grass Plants
ChickWeight             Weight versus age of chicks on different diets
DNase                   Elisa assay of DNase
EuStockMarkets          Daily Closing Prices of Major European Stock
                        Indices, 1991-1998
Formaldehyde            Determination of Formaldehyde
HairEyeColor            Hair and Eye Color of Statistics Students

help(mtcars)  # Get details on a given data set
```

Data Frames - Builtin

R comes with a variety of built-in data sets that are very useful for getting used to data sets and how to manipulate them.

```
data(mtcars)

str(mtcars)
'data.frame':  32 obs. of  11 variables:
 $ mpg : num  21 21 22.8 21.4 18.7 18.1 14.3 24.4 22.8 19.2 ...
 $ cyl : num  6 6 4 6 8 6 8 4 4 6 ...
 $ disp: num  160 160 108 258 360 ...
 $ hp  : num  110 110 93 110 175 105 245 62 95 123 ...
 $ drat: num  3.9 3.9 3.85 3.08 3.15 2.76 3.21 3.69 3.92 3.92 ...
 $ wt  : num  2.62 2.88 2.32 3.21 3.44 ...
 $ qsec: num  16.5 17 18.6 19.4 17 ...
 $ vs  : num  0 0 1 1 0 1 0 1 1 1 ...
 $ am  : num  1 1 1 0 0 0 0 0 0 0 ...
 $ gear: num  4 4 4 3 3 3 3 4 4 4 ...
 $ carb: num  4 4 1 1 2 1 4 2 2 4 ...

nrow(mtcars) # How many rows does it have ?
[1] 32

ncol(mtcars) # How many columns are there ?
[1] 11
```

Data Frames - Getting/Setting Info

```
rownames(mtcars)
 [1] "Mazda RX4"           "Mazda RX4 Wag"       "Datsun 710"
 [4] "Hornet 4 Drive"      "Hornet Sportabout"   "Valiant"
 ..
[19] "Honda Civic"         "Toyota Corolla"      "Toyota Corona"
[22] "Dodge Challenger"    "AMC Javelin"         "Camaro Z28"
[25] "Pontiac Firebird"    "Fiat X1-9"           "Porsche 914-2"
[28] "Lotus Europa"        "Ford Pantera L"      "Ferrari Dino"
[31] "Maserati Bora"       "Volvo 142E"

rownames(mtcars) <- 1:32

head(mtcars)
   mpg cyl disp  hp drat   wt qsec vs transmission gear carb
1 21.0   6  160 110 3.90 2.62 16.5  0            1    4    4
2 21.0   6  160 110 3.90 2.88 17.0  0            1    4    4

rownames(mtcars) = paste("car",1:32,sep="_")
head(mtcars)
       mpg cyl disp  hp drat   wt qsec vs transmission gear carb
car_1 21.0   6  160 110 3.90 2.62 16.5  0            1    4    4
car_2 21.0   6  160 110 3.90 2.88 17.0  0            1    4    4
car_3 22.8   4  108  93 3.85 2.32 18.6  1            1    4    1
```

Data Frames - Accessing

There are various ways to select, remove, or exclude rows and columns

```
mtcars[,-11]
                       mpg cyl disp  hp drat    wt  qsec vs am gear
Mazda RX4             21.0   6  160 110 3.90 2.620 16.46  0  1    4
Mazda RX4 Wag         21.0   6  160 110 3.90 2.875 17.02  0  1    4
Datsun 710            22.8   4  108  93 3.85 2.320 18.61  1  1    4

mtcars   # Notice that carb is included
                      mpg cyl  disp  hp drat    wt  qsec vs am gear carb
Mazda RX4            21.0   6 160.0 110 3.90 2.620 16.46  0  1    4    4
Mazda RX4 Wag        21.0   6 160.0 110 3.90 2.875 17.02  0  1    4    4
Datsun 710           22.8   4 108.0  93 3.85 2.320 18.61  1  1    4    1
```

Data Frames - Accessing

There are various ways to select, remove, or exclude rows and columns

```
mtcars[,-3:-5]  # Print all columns except for columns 3 through 5
                 mpg cyl    wt  qsec vs am gear      carb
Mazda RX4       21.0   6 2.620 16.46  0  1    4 0.6020600
Mazda RX4 Wag   21.0   6 2.875 17.02  0  1    4 0.6020600
Datsun 710      22.8   4 2.320 18.61  1  1    4 0.0000000

mtcars[,c(-3,-5)] # Print all columns except for colums 3 AND 5
                 mpg cyl  hp    wt  qsec vs am gear      carb
Mazda RX4       21.0   6 110 2.620 16.46  0  1    4 0.6020600
Mazda RX4 Wag   21.0   6 110 2.875 17.02  0  1    4 0.6020600
Datsun 710      22.8   4  93 2.320 18.61  1  1    4 0.0000000
```

Data Frames - Accessing

There are various ways to select, remove, or exclude rows and columns

```
mtcars[mtcars$mpg >= 30.0,]
                mpg cyl disp  hp drat    wt  qsec vs am gear carb
Fiat 128       32.4   4 78.7  66 4.08 2.200 19.47  1  1    4    1
Honda Civic    30.4   4 75.7  52 4.93 1.615 18.52  1  1    4    2
Toyota Corolla 33.9   4 71.1  65 4.22 1.835 19.90  1  1    4    1
Lotus Europa   30.4   4 95.1 113 3.77 1.513 16.90  1  1    5    2

mtcars[mtcars$mpg >= 30.0,2:6]

                mpg cyl disp  hp drat
Fiat 128       32.4   4 78.7  66 4.08
Honda Civic    30.4   4 75.7  52 4.93
Toyota Corolla 33.9   4 71.1  65 4.22
Lotus Europa   30.4   4 95.1 113 3.77

mtcars[mtcars$mpg >= 30.0 & mtcars$cyl < 6,]
                mpg cyl disp  hp drat    wt  qsec vs am gear carb
Fiat 128       32.4   4 78.7  66 4.08 2.200 19.47  1  1    4    1
Honda Civic    30.4   4 75.7  52 4.93 1.615 18.52  1  1    4    2
Toyota Corolla 33.9   4 71.1  65 4.22 1.835 19.90  1  1    4    1
Lotus Europa   30.4   4 95.1 113 3.77 1.513 16.90  1  1    5    2
```

Data Frames - Interrogating

Find all rows that correspond to Automatic and Count them

```
mtcars[mtcars$am==0,]
                     mpg cyl  disp  hp drat    wt  qsec vs am gear carb
Hornet 4 Drive      21.4   6 258.0 110 3.08 3.215 19.44  1  0    3    1
Hornet Sportabout   18.7   8 360.0 175 3.15 3.440 17.02  0  0    3    2
Valiant             18.1   6 225.0 105 2.76 3.460 20.22  1  0    3    1
Duster 360          14.3   8 360.0 245 3.21 3.570 15.84  0  0    3    4
Merc 240D           24.4   4 146.7  62 3.69 3.190 20.00  1  0    4    2
Merc 230            22.8   4 140.8  95 3.92 3.150 22.90  1  0    4    2
..
..

nrow(mtcars[mtcars$am == 0,])
[1] 19

nrow(mtcars[mtcars$am == 1,])
[1] 13
```

Data Frames - Interrogating

Extract all rows whose MPG value exceeds the mean MPG for the entire data frame

```
mtcars[mtcars$mpg > mean(mtcars$mpg),]
```

```
mpg cyl  disp  hp drat    wt  qsec vs am gear carb
Mazda RX4      21.0   6 160.0 110 3.90 2.620 16.46  0  1    4    4
Mazda RX4 Wag  21.0   6 160.0 110 3.90 2.875 17.02  0  1    4    4
Datsun 710     22.8   4 108.0  93 3.85 2.320 18.61  1  1    4    1
Hornet 4 Drive 21.4   6 258.0 110 3.08 3.215 19.44  1  0    3    1
Merc 240D      24.4   4 146.7  62 3.69 3.190 20.00  1  0    4    2
Merc 230       22.8   4 140.8  95 3.92 3.150 22.90  1  0    4    2
Fiat 128       32.4   4  78.7  66 4.08 2.200 19.47  1  1    4    1
Honda Civic    30.4   4  75.7  52 4.93 1.615 18.52  1  1    4    2
Toyota Corolla 33.9   4  71.1  65 4.22 1.835 19.90  1  1    4    1
Toyota Corona  21.5   4 120.1  97 3.70 2.465 20.01  1  0    3    1
Fiat X1-9      27.3   4  79.0  66 4.08 1.935 18.90  1  1    4    1
Porsche 914-2  26.0   4 120.3  91 4.43 2.140 16.70  0  1    5    2
Lotus Europa   30.4   4  95.1 113 3.77 1.513 16.90  1  1    5    2
Volvo 142E     21.4   4 121.0 109 4.11 2.780 18.60  1  1    4    2
```

Data Frames - Interrogating

Extract all rows whose MPG value exceeds the mean MPG for the entire data frame

```
# Find the quartiles for the MPG vector

quantile(mtcars$mpg)
    0%    25%    50%    75%   100%
10.400 15.425 19.200 22.800 33.900

# Now find the cars for which the MPG exceeds the 75% value:

mtcars[mtcars$mpg > quantile(mtcars$mpg)[4],]
                mpg cyl  disp  hp drat    wt  qsec vs am gear carb
Merc 240D      24.4   4 146.7  62 3.69 3.190 20.00  1  0    4    2
Fiat 128       32.4   4  78.7  66 4.08 2.200 19.47  1  1    4    1
Honda Civic    30.4   4  75.7  52 4.93 1.615 18.52  1  1    4    2
Toyota Corolla 33.9   4  71.1  65 4.22 1.835 19.90  1  1    4    1
Fiat X1-9      27.3   4  79.0  66 4.08 1.935 18.90  1  1    4    1
Porsche 914-2  26.0   4 120.3  91 4.43 2.140 16.70  0  1    5    2
Lotus Europa   30.4   4  95.1 113 3.77 1.513 16.90  1  1    5    2
```

Data Frames - Interrogating

What columns appear to be factors ? Variables with only a “few” different unique values perhaps ?

```
str(mtcars)
'data.frame':  32 obs. of  11 variables:
 $ mpg : num  21 21 22.8 21.4 18.7 18.1 14.3 24.4 22.8 19.2 ...
 $ cyl : num  6 6 4 6 8 6 8 4 4 6 ...
 $ disp: num  160 160 108 258 360 ...
 $ hp  : num  110 110 93 110 175 105 245 62 95 123 ...
 $ drat: num  3.9 3.9 3.85 3.08 3.15 2.76 3.21 3.69 3.92 3.92 ...
 $ wt  : num  2.62 2.88 2.32 3.21 3.44 ...
 $ qsec: num  16.5 17 18.6 19.4 17 ...
 $ vs  : num  0 0 1 1 0 1 0 1 1 1 ...
 $ am  : num  1 1 1 0 0 0 0 0 0 0 ...
 $ gear: num  4 4 4 3 3 3 3 4 4 4 ...
 $ carb: num  4 4 1 1 2 1 4 2 2 4 ...

unique(mtcars$am)   # Tells us what the unique values are
[1] 1 0
```

Data Frames - Factors

See how many unqiue values each column takes on

```
sapply(mtcars, function(x) length(unique(x)))
 mpg  cyl disp   hp drat   wt qsec   vs   am gear carb
  25    3   27   22   22   29   30    2    2    3    6
```

If we summarize one of these potential factors right now, R will treat it as being purely numeric which we might not want

```
summary(mtcars$am)
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
 0.0000  0.0000  0.0000  0.4062  1.0000  1.0000
```

So this really isn't helpful since we know that the "am" values are transmission types

```
mtcars$am <- factor(mtcars$am, levels = c(0,1), labels = c("Auto","Man") )

summary(mtcars$am)
Auto Manu
  19   13
```

Data Frames - Factors

We can add columns to a data frame. Let's say we want to create a new column called "mpgrate" that, based on the output of the quantile command, will have a rating of the that car's MPG in terms of "horrible","bad","good","great".

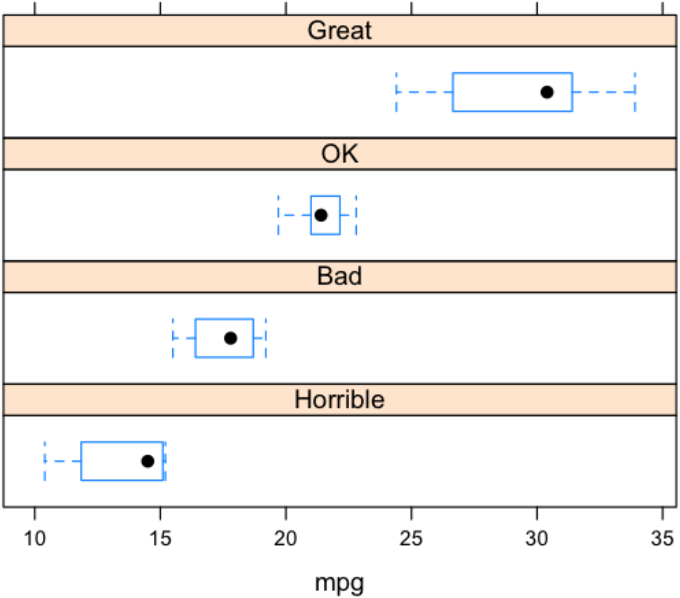
The labels could be more scientific but this is still a good use case. There are a couple of ways to do this:

```
data(mtcars)   # Reload a "pure" copy of mtcars

mpgrate <- cut(mtcars$mpg,
              breaks = quantile(mtcars$mpg),
              labels=c("horrible","Bad","Good","Great"),include.lowest=T)

mtcars <- cbind(mtcars,mpgrate)

-OR-

mtcars$mpgrate <- mpgrate   # The column just magically appears !
```

Data Frames - Factors

```
head(mtcars)
                   mpg cyl disp  hp drat    wt  qsec vs am gear carb mpgrate
Mazda RX4         21.0   6  160 110 3.90 2.620 16.46  0  1    4    4    Good
Mazda RX4 Wag     21.0   6  160 110 3.90 2.875 17.02  0  1    4    4    Good
Datsun 710        22.8   4  108  93 3.85 2.320 18.61  1  1    4    1    Good
Hornet 4 Drive    21.4   6  258 110 3.08 3.215 19.44  1  0    3    1    Good
Hornet Sportabout 18.7   8  360 175 3.15 3.440 17.02  0  0    3    2     Bad
Valiant           18.1   6  225 105 2.76 3.460 20.22  1  0    3    1     Bad

library(lattice)
bwplot(~mpg|mpgrate,data=mtcars,layout=c(1,4))
```

Data Frames - Factors



Data Frames - transform()

You can also use the **transform()** command to change the types/classes of the columns

```
head(mtcars)
                   mpg cyl disp  hp drat    wt  qsec vs am gear carb
Mazda RX4         21.0   6  160 110 3.90 2.620 16.46  0  1    4    4
Mazda RX4 Wag     21.0   6  160 110 3.90 2.875 17.02  0  1    4    4
Datsun 710        22.8   4  108  93 3.85 2.320 18.61  1  1    4    1
Hornet 4 Drive    21.4   6  258 110 3.08 3.215 19.44  1  0    3    1
Hornet Sportabout 18.7   8  360 175 3.15 3.440 17.02  0  0    3    2
Valiant           18.1   6  225 105 2.76 3.460 20.22  1  0    3    1

transform(mtcars,wt = (wt*1000), qsec = round(qsec),
                       am = factor(am,labels=c("A","M")))

                     mpg cyl  disp  hp drat   wt qsec vs am gear carb
Mazda RX4           21.0   6 160.0 110 3.90 2620   16  0  M    4    4
Mazda RX4 Wag       21.0   6 160.0 110 3.90 2875   17  0  M    4    4
Datsun 710          22.8   4 108.0  93 3.85 2320   19  1  M    4    1
Hornet 4 Drive      21.4   6 258.0 110 3.08 3215   19  1  A    3    1
Hornet Sportabout   18.7   8 360.0 175 3.15 3440   17  0  A    3    2
```

Data Frames - Missing values

The NA (datum Not Available) is R's way of dealing with missing data. NAs can give you trouble unless you explicitly tell functions to ignore them.

You can also pass the data through na.omit(), na.exclude(), or complete.cases() to insure that R handles data accordingly.

```
data <- data.frame(x=c(1,2,3,4), y=c(5, NA, 8,3),z=c("F","M","F","M"))

data
  x  y z
1 1  5 F
2 2 NA M        # Note missing value
3 3  8 F
4 4  3 M

na.omit(data)
  x y z
1 1 5 F
3 3 8 F
4 4 3 M
```

Data Frames - Missing values

.

```
data <- data.frame(x=c(1,2,3,4), y=c(5, NA, 8,3),
                   z=c("F","M","F","M"))

complete.cases(data)
[1]  TRUE FALSE  TRUE  TRUE

sum(complete.cases(data))  # total number of complete cases
[1] 3

sum(!complete.cases(data)) # total number of incomplete cases
[1] 1

data[complete.cases(data),]  # Same as na.omit(data)
  x y z
1 1 5 F
3 3 8 F
4 4 3 M
```

Data Frames - Missing values

.

```
url <- "http://steviep42.bitbucket.org/bios545r/DATA.DIR/hs0.csv"
data1 <- read.table(url,header=F,sep=",")
names(data1) <- c("gender","id","race","ses","schtyp","prgtype",
                  "read", "write","math","science","socst")
head(data1, n=1)
  gender  id race ses schtyp  prgtype read write math science socst
1      0  70    4   1      1  general   57    52   41      47    57

nrow(data1)
[1] 200

sum(complete.cases(data1))
[1] 195

sum(!complete.cases(data1))
[1] 5
data1[!complete.cases(data1),]
   gender  id race ses schtyp  prgtype read write math science socst
9       0  84    4   2      1  general   63    57   54      NA    51
18      0 195    4   2      2  general   57    57   60      NA    56
37      0 200    4   2      2 academic   68    54   75      NA    66
55      0 132    4   2      1 academic   73    62   73      NA    66
76      0   5    1   1      1 academic   47    40   43      NA    31
```

Data Frames - Missing values

. Many R functions have an argument to exclude missing values

```
data1[!complete.cases(data1),]
   gender  id race ses schtyp  prgtype read write math science socst
9       0  84    4   2      1  general   63    57   54      NA    51
18      0 195    4   2      2  general   57    57   60      NA    56
37      0 200    4   2      2 academic   68    54   75      NA    66
55      0 132    4   2      1 academic   73    62   73      NA    66
76      0   5    1   1      1 academic   47    40   43      NA    31

mean(data1$science)
[1] NA

mean(data1$science,na.rm=T)
[1] 51.66154
```

Data Frames - Reading CSV

Many times data will be read in from a comma delimited ,("CSV"), file exported from Excel. The file can be read from local storage or from the Web.

```
url <- "http://steviep42.bitbucket.org/bios545r/DATA.DIR/hsb2.csv"

data1 <- read.table(url,header=T,sep=",")

head(data1)
  gender  id race ses schtyp  prgtype read write math science socst
1      0  70    4   1      1  general   57    52   41      47    57
2      1 121    4   2      1   vocati   68    59   53      63    61
3      0  86    4   3      1  general   44    33   54      58    31
4      0 141    4   3      1   vocati   63    44   47      53    56
5      0 172    4   2      1 academic   47    52   57      53    61
6      0 113    4   2      1 academic   44    52   51      63    61
```

Data Frames - Reading CSV

Look at the follow info on World Populations
`http://en.wikipedia.org/wiki/World_population`

We want to get the table that looks like the following, which seems to be the 4th table on the page

The 10 countries with the largest total population:

Rank	Country / Territory	Population	Date	% of world population	Source
1	China[note 2]	1,353,430,000	October 1, 2012	19.2%	[71]
2	India	1,210,193,422	March 2011	17%	[72]
3	United States	314,490,000	October 1, 2012	4.47%	[73]
4	Indonesia	238,400,000	May 2010	3.33%	[74]
5	Brazil	197,067,000	October 1, 2012	2.8%	[75]
6	Pakistan	180,819,000	October 1, 2012	2.57%	[76]
7	Nigeria	170,123,740	July 2012	2.42%	[77]
8	Bangladesh	161,083,804	July 2012	2.29%	[78]
9	Russia	141,927,297	January 1, 2010	2.015%	[79]
10	Japan	127,610,000	May 1, 2012	1.81%	[80]

Data Frames - Reading CSV

We want to get the table that looks like the following, which seems to be the 4th table on the page

```
library(XML)
url <- "http://en.wikipedia.org/wiki/World_population"
table.four <- readHTMLTable(url, which=4)

head(table.four,4)
Rank Country / Territory    Population    Date  \% of world\npopulation  Source
1       China[note 2] 1,353,430,000 October 1, 2012           19.2%        [71]
2               India 1,210,193,422      March 2011           17%          [72]
3       United States   314,490,000 October 1, 2012            4.47%       [73]
4           Indonesia   238,400,000        May 2010            3.33%       [74]
```

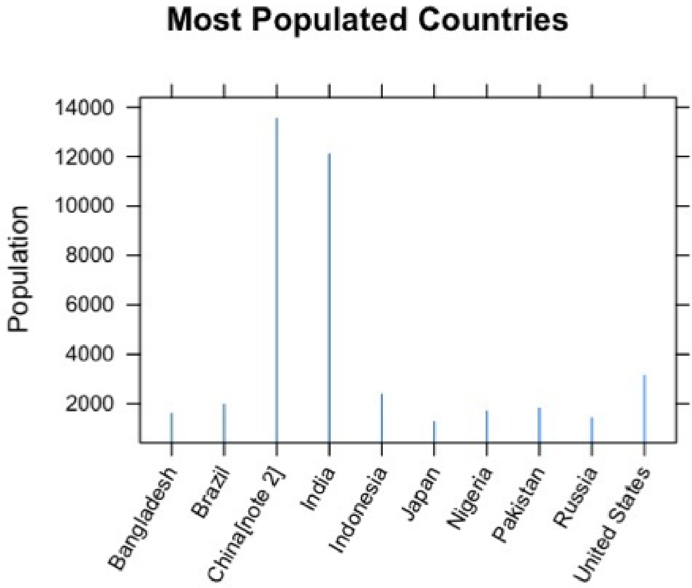
But there are problems here. Everything is a factor including the population, Date, and percent population. We can fix these of course

Data Frames - Reading CSV

We want to get the table that looks like the following, which seems to be the 4th table on the page

```
table.four <- table.four[,-4:-6]  # Eliminate the 4th-6th column
table.four
   Rank Country / Territory    Population
1     1           China[73] 1,352,190,000
2     2               India 1,210,193,422

# Get rid of the commas in the numbers

table.four$Population <- as.numeric(gsub(",","",table.four$Population))/100000

# Give the columns new names

names(table.four) <- c("Rank","Country","Population")

# Plot the data
library(lattice)

xyplot(Population ~ Country,table.four,scales = list(x = c(rot=60)),
       type="h",main="Most Densely Populated Countries")
```

Data Frames - Reading CSV



Data Frames - Reading CSV

There is a way to convert columns to the desired format as we are reading it. We use the **colClasses** argument in the **read.table()** function. It works for most formats except perhaps for dates given the wide variety of date formats

```
classes <- c("integer","character","FormattedNumber","character",
             "Percent","character")

poptable <- readHTMLTable(url,which=4,colClasses=classes,
                          stringsAsFactors=F)

str(poptable)
'data.frame':  10 obs. of  6 variables:
$ Rank                : int  1 2 3 4 5 6 7 8 9 10
$ Country / Territory : chr  "China[note 2]" "India" "United States" "Indonesia" ..
$ Population          : num  1.37e+09 1.26e+09 3.19e+08 2.52e+08 2.04e+08 ...
$ Date                : chr  "December 15, 2014" "December 15, 2014" "December 15, 2
$ Approx. % of world population: num  19 17.5 4.43 3.5 2.82 2.61 2.48 2.18 2.03 1.7
$ Source              : chr  "[83]" "[84]" "[85]" "[86]" ...
```

Data Frames - Chicago Crime - Supplemental

- The City of Chicago let's you download lots of different data for analysis

https://data.cityofchicago.org/

Data Frames - Chicago Crime - Supplemental

- I got a file from this site and put it on a server if you want to download it and give it a whirl. This a about 82 MB so don't try reading it over a home-based connection.
- Also, my laptop has 4GB of RAM. I suspect if you have 2GB of RAM on your laptop you will be okay but I cannot be sure. On campus it took about 1 minute for R to read and process it.

```
url <- "http://steviep42.bitbucket.org/bios545r/DATA.DIR/chi_crimes.csv"

chi <- read.table(url, header=T, sep=",")
```

- I tried reading this file into Excel. While it ultimately loaded the file it took a long time and response was very slow on my laptop
- Part of the problem is that Excel loads the whole thing for purposes of display when in reality it might not be necessary to see everything. In fact with 300K records it is impractical to want to see every record

Data Frames - Chicago Crime - Supplemental

A better approach is to first download the file to your computer using the "download.file" function and then using read.table.

This way R won't simultaneously be downloading and reading the file which can sometimes cause trouble

```
url <- "http://steviep42.bitbucket.org/bios545r/DATA.DIR/chi_crimes.csv"

download.file(url,"chi_crimes.csv")
trying URL 'http://steviep42.bitbucket.org/bios560rs2014/DATA.DIR/chi_crime
Content type 'text/csv' length 85753091 bytes (81.8 Mb)
opened URL
==================================================
downloaded 81.8 Mb
```

Data Frames - Chicago Crime - Supplemental

The file relates to all calls to the Chicago Police Department in 2012

```
system("ls -lh chi*")
-rw-r--r--@ 1 fender  staff    82M Sep 13 06:20 chi_crimes.csv

system("wc -l chi*")         # 334,142 lines !!
  334142 chi_crimes.csv

# It takes about 25 seconds to read this in on my laptop

system.time(mychi <- read.table("chi_crimes.csv",header=T,sep=","))
   user  system elapsed
 25.026   0.323  25.417

nrow(mychi)
[1] 334141

ncol(mychi)
[1] 22
```

Data Frames - Chicago Crime - Supplemental

```
names(chi)
 [1] "Case.Number"          "ID"
 [3] "Date"                 "Block"
 [5] "IUCR"                 "Primary.Type"
 [7] "Description"          "Location.Description"
 [9] "Arrest"               "Domestic"
[11] "Beat"                 "District"
[13] "Ward"                 "FBI.Code"
[15] "X.Coordinate"         "Community.Area"
[17] "Y.Coordinate"         "Year"
[19] "Latitude"             "Updated.On"
[21] "Longitude"            "Location"
[23] "month"
```

Data Frames - Chicago Crime - Supplemental

```
sapply(chi, function(x) length(unique(x)))
        Case.Number                    ID                  Date
             334114                334139                121480
              Block                  IUCR          Primary.Type
              28383                   358                    30
        Description  Location.Description                Arrest
                296                   120                     2
           Domestic                  Beat              District
                  2                   302                    25
               Ward              FBI.Code          X.Coordinate
                 51                    30                 60704
     Community.Area          Y.Coordinate                  Year
                 79                 89895                     1
           Latitude            Updated.On             Longitude
             180396                  1311                180393
           Location                 month
             178534                    12
```

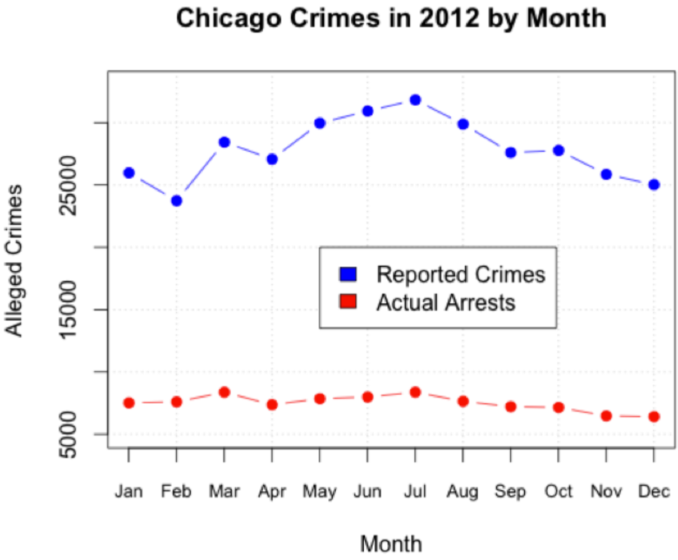
Data Frames - Chicago Crime - Supplemental

```
# Make the date a "real date"
hi$Date <- strptime(chi$Date,"%m/%d/%Y %r")
chi$month <- months(chi$Date)
chi$month <- factor(chi$month,levels=c("January","February","March",
                   "April","May","June","July","August", "September",
                   "October","November","December"),ordered=TRUE)

# Okay how many crimes were committed in each Month of the year ?

plot(1:12,as.vector(table(chi$month)),type="n",xaxt="n",
     ylab="Alleged Crimes",xlab="Month",
     main="Chicago Crimes in 2012 by Month", ylim=c(5000,33000))
     grid()

axis(1,at=1:12,labels=as.character(sapply(levels(chi$month),
     function(x) substr(x,1,3))),cex.axis=0.8)

points(1:12,as.vector(table(chi$month)),type="b",pch=19,col="blue")

points(1:12,as.vector(table(chi$month,chi$Arrest)[,2]),col="red",
       pch=19,type="b")
```

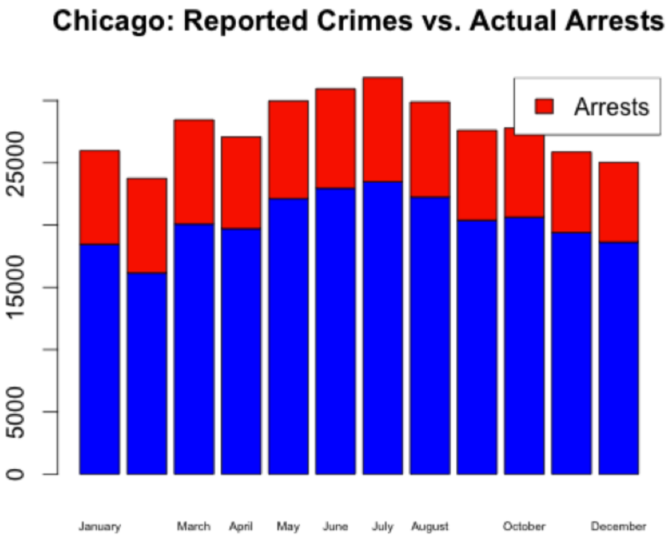
Data Frames - Chicago Crime - Supplemental

```
# Might look better in a barplot

barplot(table(chi$Arrest,chi$month),col=c("blue","red"),cex.names=0.5,
        main="Chicago: Reported Crimes vs. Actual Arrests")

legend("topright",c("Arrests"),fill="red")

# Even easier to do

rev(sort(table(chi$month)))

barplot(rev(sort(hold)),horiz=F,las=1,cex.names=0.5,col=heat.colors(12),
        main="Chicago: Reported Crimes in 2012 by Month")

# Looks like the Summer is when more crimes are committed
```

Data Frames - Chicago Crime - Supplemental

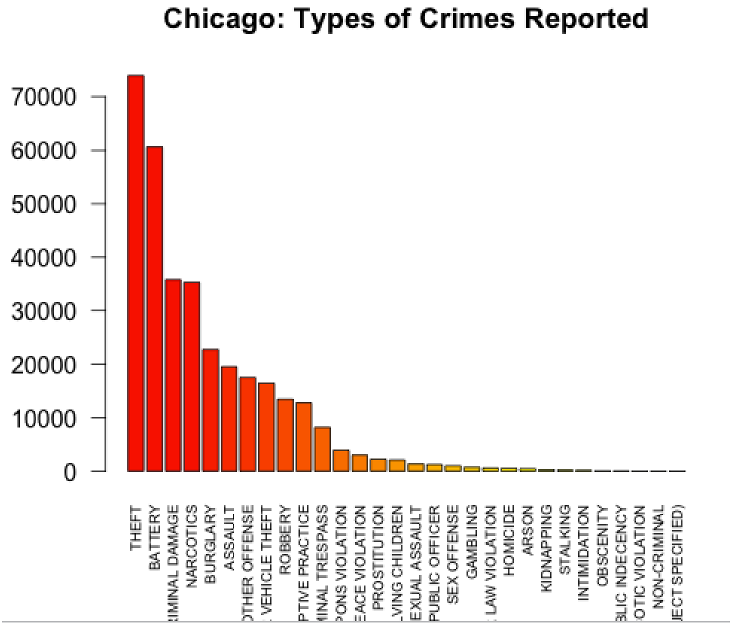


Data Frames - Chicago Crime - Supplemental

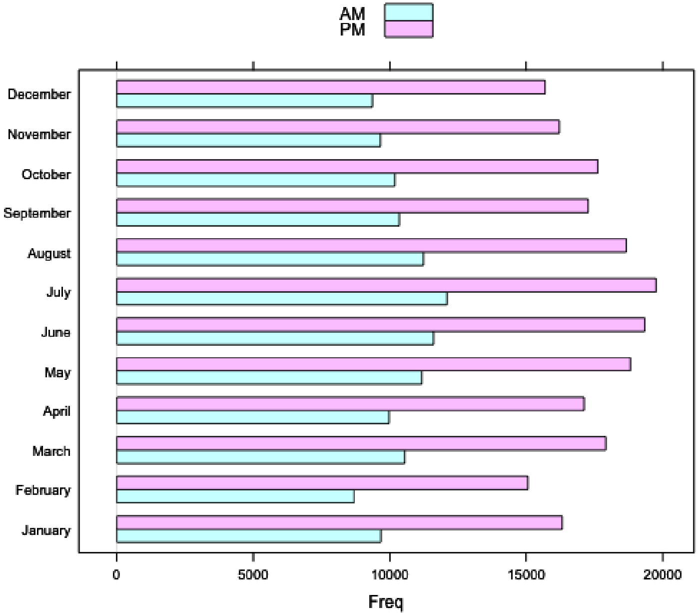


Data Frames - Chicago Crime - Supplemental

```
# Find out number of alleged crimes by type

categories <- rev(sort(sapply(unique(as.character(chi$Primary.Type)),
              function(x) { nrow(chi[chi$Primary.Type==x,]) })))

categories <- rev(sort(table(chi$Primary.Type)))

barplot(categories,horiz=F,las=1,cex.names=0.6,col=heat.colors(30),
        las=2, main="Chicago: Types of Crimes Reported")
```

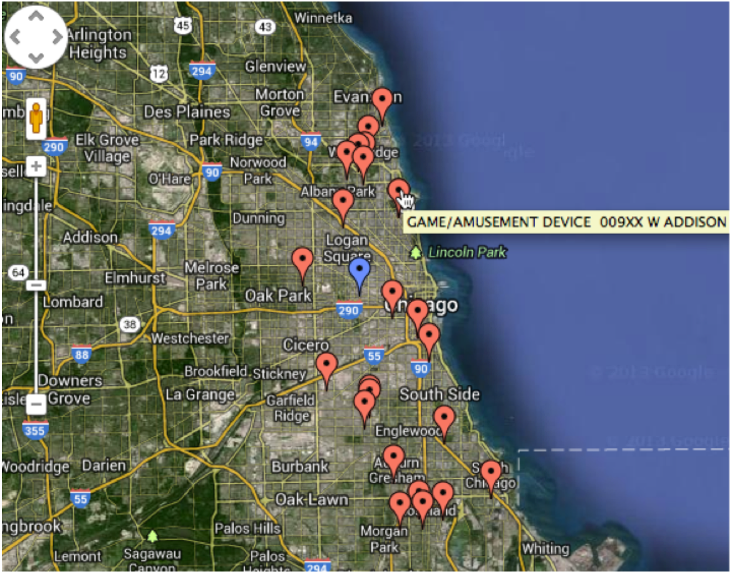

Chicago: Types of Crimes Reported
70000
60000
50000
40000
30000
20000
10000
0
THEFT
BATTERY
RIMINAL DAMAGE
NARCOTICS
BURGLARY
ASSAULT
THER OFFENSE
VEHICLE THEFT
ROBBERY
PTIVE PRACTICE
INAL TRESPASS
PONS VIOLATION
EACE VIOLATION
PROSTITUTION
VING CHILDREN
EXUAL ASSAULT
PUBLIC OFFICER
SEX OFFENSE
GAMBLING
LAW VIOLATION
HOMICIDE
ARSON
KIDNAPPING
STALKING
INTIMIDATION
OBSCENITY
BLIC INDECENCY
OTIC VIOLATION
NON-CRIMINAL
JECT SPECIFIED)

```
library(lattice)
barchart(table(chi$month,chi$ampm),stack=FALSE,auto.key=T,freq=F)
```



Let's map some of these reported crimes. Let's zone in on the reported gambling offenses. Most of these are for Dice games. Let's see the ones that are Gambling but not dice related

```
hold <- chi[chi$Primary.Type == "GAMBLING",]
hold <- chi[chi$Primary.Type == "GAMBLING" & chi$Description != "GAME/DICE",]

nrow(hold) # How many non-Dice related gambling offenses were there ?

# About 26 I think
# Let's plot them on a map

library(googleVis)  # This is an addon package you must install

hold$LatLon <- paste(hold$Latitude,hold$Longitude,sep=":")
hold$Tip <- paste(hold$Description,hold$Locate.Description,hold$Block,
                 "<BR>",sep=" ")
chi.plot <- gvisMap(hold,"LatLon","Tip")

plot(chi.plot)
```


GAME/AMUSEMENT DEVICE 009XX W ADDISON
Winnetka
Arlington Heights
Glenview
Morton Grove
Des Plaines
Park Ridge
Elk Grove Village
O'Hare
Norwood Park
Dunning
Addison
Elmhurst
Melrose Park
Oak Park
Logan
Lincoln Park
Lombard
Westchester
Cicero
Brookfield
Stickney
Downers Grove
La Grange
Garfield Ridge
South Side
Englewood
Woodridge
Darien
Burbank
Oak Lawn
Palos Hills
Morgan Park
Lemont
Whiting