Data frames, Lists, Matrices

AND the Apply Family of Functions

Stat 133, Feb 9 2015

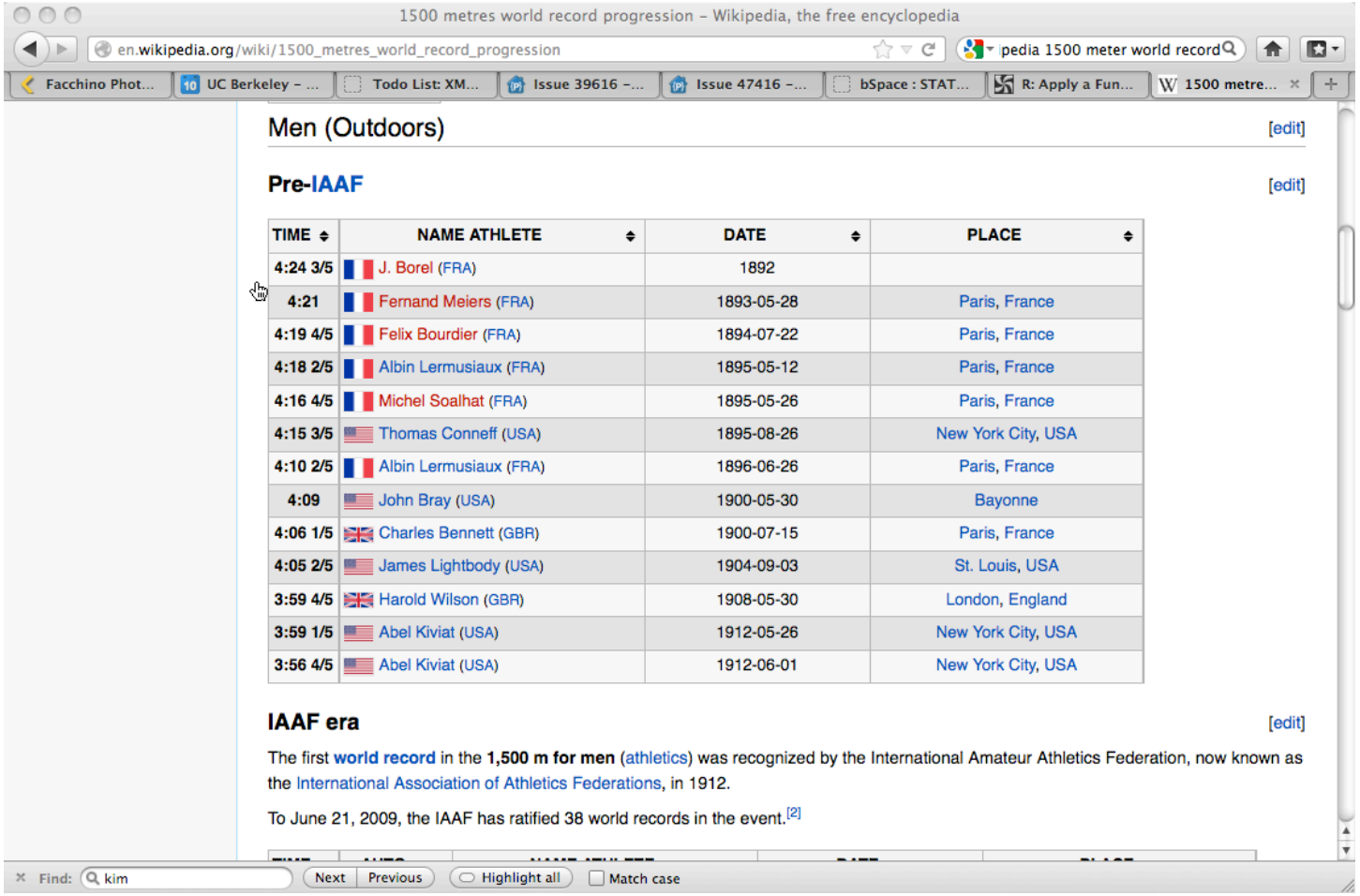
2012 Summer Olympics

Used in next week's homework assignment

World Record in the Men's 1500 meter

How have the times changed?

How much faster are today's runners?



```
> url = http://en.wikipedia.org/wiki/1500_metres_world_record_progression

> tab1 = readHTMLTable(url, which = 1, colClasses = "character")

> head(tab1)
      TIME            NAME ATHLETE       DATE                PLACE
1 4:24 3/5         J. Borel (FRA)       1892
2     4:21   Fernand Meiers (FRA) 1893-05-28      Paris, France
3 4:19 4/5   Felix Bourdier (FRA) 1894-07-22      Paris, France
4 4:18 2/5 Albin Lermusiaux (FRA) 1895-05-12      Paris, France
5 4:16 4/5   Michel Soalhat (FRA) 1895-05-26      Paris, France
6 4:15 3/5   Thomas Conneff (USA) 1895-08-26 New York City, USA
```

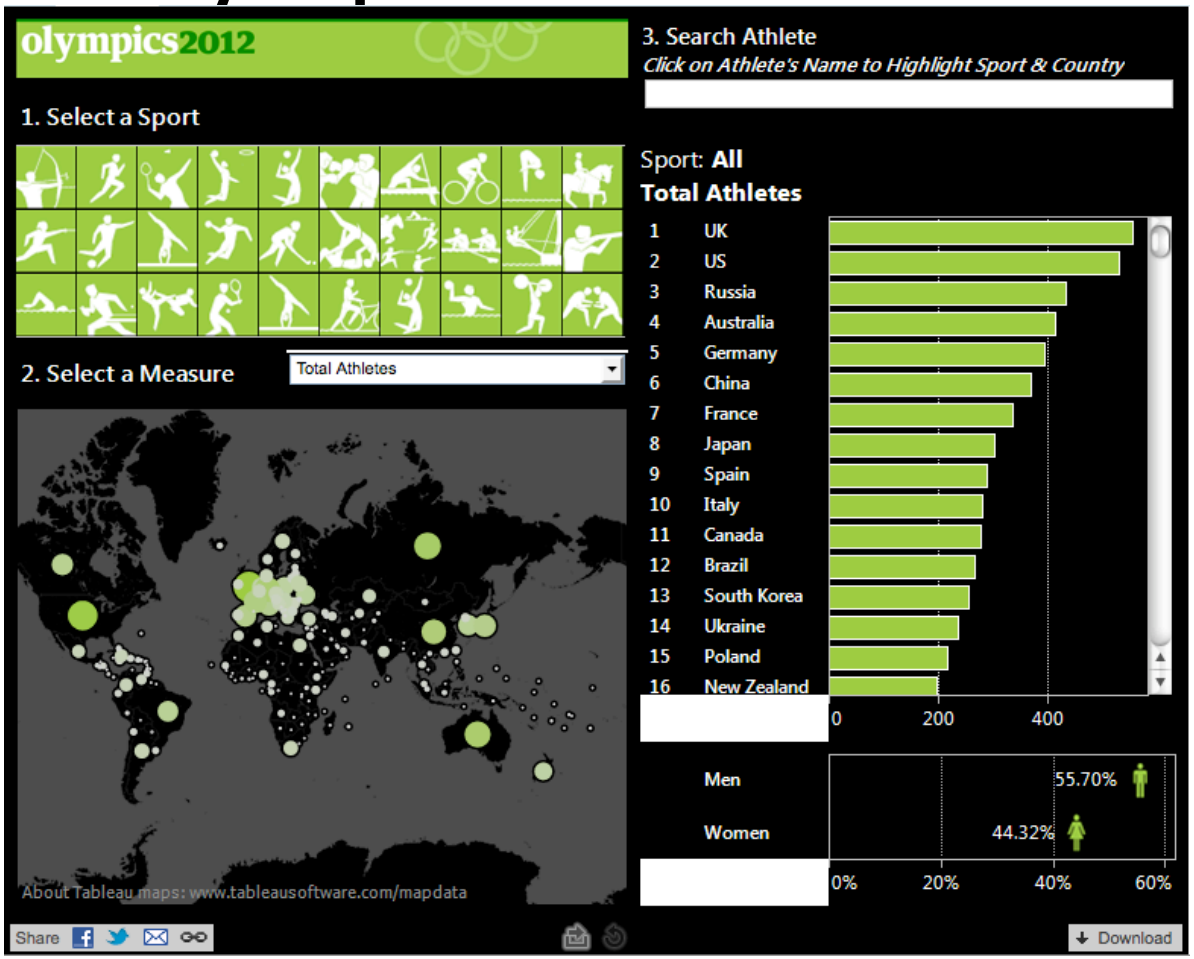
We need to:

turn “3/5” into .6 and add it to 24;

split the country from the athlete’s name, etc.

2012 Olympic Athlete's

Craig Bloodworth at the Information Lab made this data explorer for the Guardian. It includes data on all athletes competing in the Olympics



http://www.guardian.co.uk/sport/datablog/2012/jul/27/london-olympic-athletes-full-list

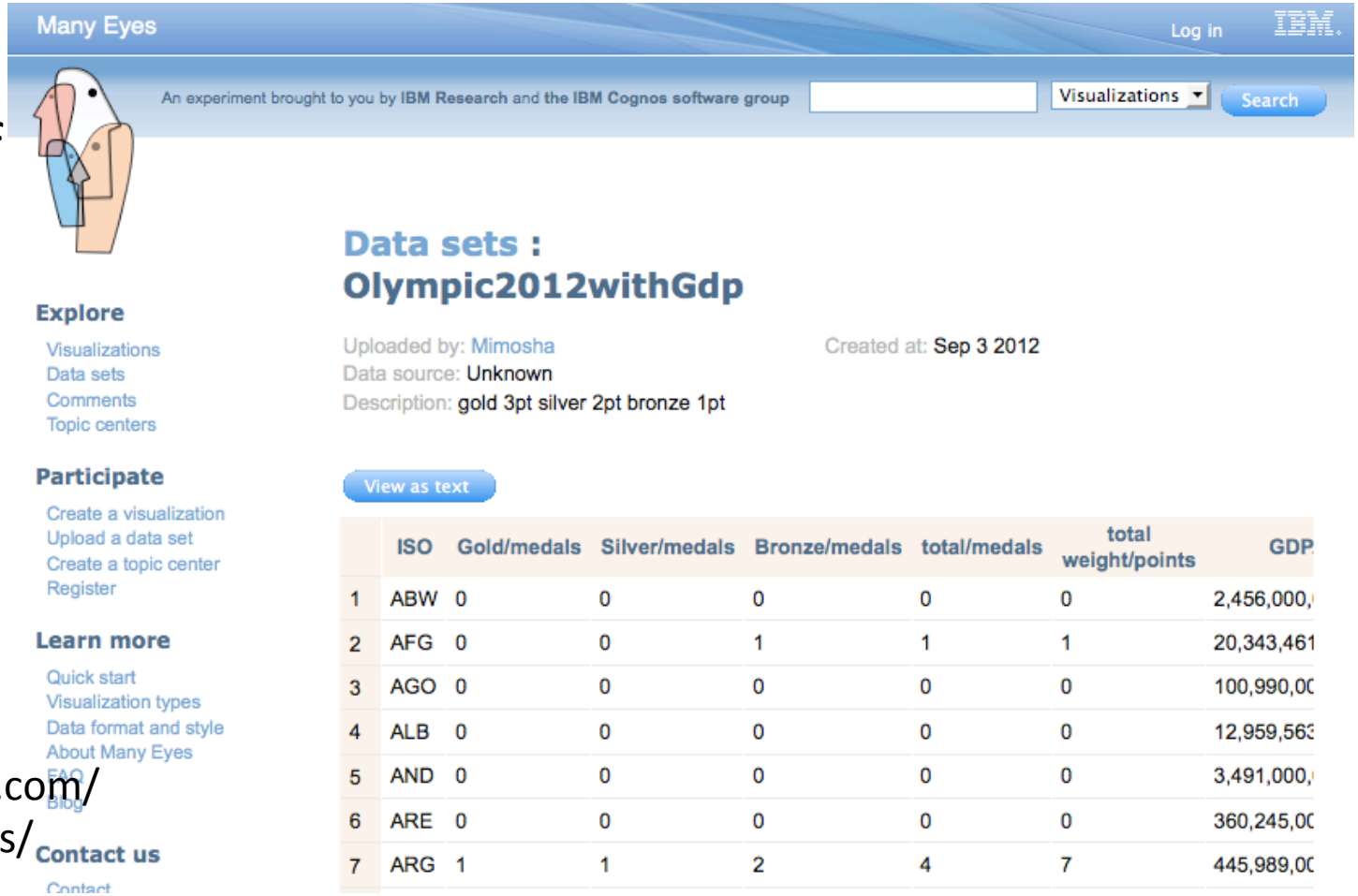
We download the data as a csv file and read it into R with read.csv

Reading data into R

- Many data sets are stored in text files.
- The easiest way to read these into R is using either the `read.table()` or `read.csv()` function, both of which return a data frame.
- There are quite a few options that can be changed. Some of the important ones are
  - file - name or URL
  - header - are column names at the top of the file?
  - sep - what divides elements of the table
  - na.strings - symbol for missing values, like 9999
  - skip - number of lines at the top of the file to ignore

Country-level data

What's the relationship between GDP, population, and number of Olympic medals?



	ISO	Gold/medals	Silver/medals	Bronze/medals	total/medals	total weight/points	GDP
1	ABW	0	0	0	0	0	2,456,000,
2	AFG	0	0	1	1	1	20,343,461
3	AGO	0	0	0	0	0	100,990,00
4	ALB	0	0	0	0	0	12,959,563
5	AND	0	0	0	0	0	3,491,000,
6	ARE	0	0	0	0	0	360,245,00
7	ARG	1	1	2	4	7	445,989,00

http://www-958.ibm.com/software/data/cognos/manyeyes/datasets/olympic2012withgdp/versions/1.txt

```
> ctry = read.csv("http://www-958.ibm.com/software/
data/cognos/manyeyes/datasets/olympic2012withgdp/
versions/1.txt",
skip = 1, sep = "\t", header = FALSE,
colClasses = c("character", rep("numeric", 5),
                rep("character", 3)))
```

```
> head(ctry)
   V1 V2 V3 V4 V5 V6                   V7          V8          V9
1 ABW  0  0  0  0  0    2,456,000,000.00     108,000 22740.7407
2 AFG  0  0  1  1  1   20,343,461,030.00 34,385,000   591.6377
3 AGO  0  0  0  0  0 100,990,000,000.00 19,082,000  5292.4222
4 ALB  0  0  0  0  0   12,959,563,902.00  3,205,000  4043.5457
5 AND  0  0  0  0  0    3,491,000,000.00     84,864 41136.4065
6 ARE  0  0  0  0  0 360,245,000,000.00  7,512,000 47955.9372
```

Need to:

Clean up the GDP and POP by removing “,” and converting to numeric;

Adding latitude and longitude for each country

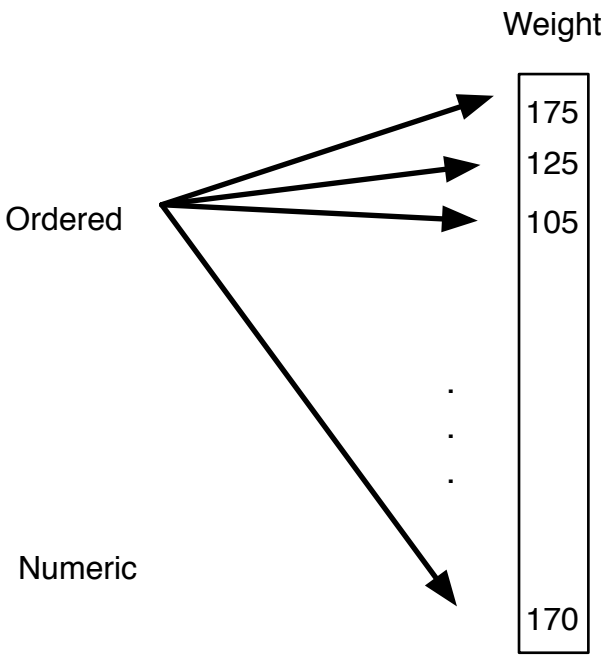
You now have 3 data sets to play with

- Athlete – level data for 2012 Olympics
- World records for the 1500 meter
- Country – level data for the 2012 Olympics and general measures of size and economy and location

Review Data Structures

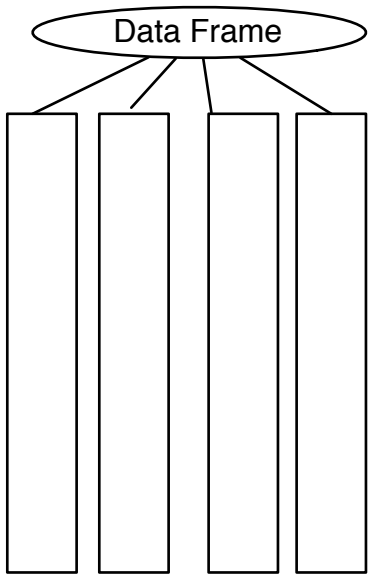
Review: Vector

- *Ordered* container of literals
- Elements must be *same type*



Review: Data Frame

- *Ordered* container of vectors
- Vectors must all be the *same length*
- Vectors can be *different types*



Wireless Data

- There are 5 wireless access points in a building
- A laptop emits a signal and the strength of the signal is recorded as each access point.
- Also recorded is the location of the laptop in the building.
- Measurements are taken at 254 locations

```
w = read.table("http://
www.stat.berkeley.edu/users/nolan/
data/wireless.txt", header=TRUE)
```

Helpful Functions for finding information out about the data frame

```
> class(w)
[1] "data.frame"

> names(w)
[1] "x"  "y"  "S1" "S2" "S3" "S4" "S5"

> dim(w)
[1] 259   7
```

```
> head(w)
      x   y  S1  S2  S3  S4  S5
1 225.0 144 -92 -78 -49 -92 -92
2   0.0 144 -75 -92 -87 -47 -92
3 111.0 132 -92 -92 -80 -70 -65
4 110.7 132 -87 -92 -67 -67 -62
5 105.0 132 -92 -92 -79 -66 -61
6  99.0 132 -92 -92 -79 -70 -61
```

```
> summary(w$S1)
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
 -92.00  -90.00  -80.00  -77.41  -71.00  -33.00
```

```
> w[w$x > 200, c("S2")]
 [1] -78 -74 -35 -43 -46 -43 -41 -48 -68 -71 -67 -70 -58 -61
[15] -64 -73 -71 -67 -68 -61 -60 -57 -58 -56 -48 -51 -68 -54
[29] -51 -48 -46 -35 -67
```

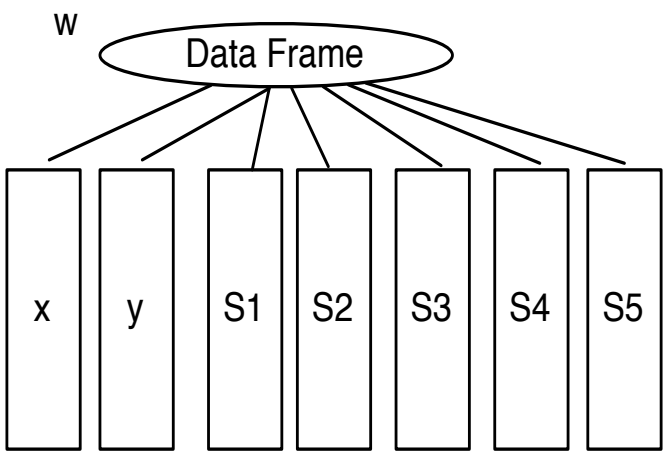
We subset rows and columns of data frames

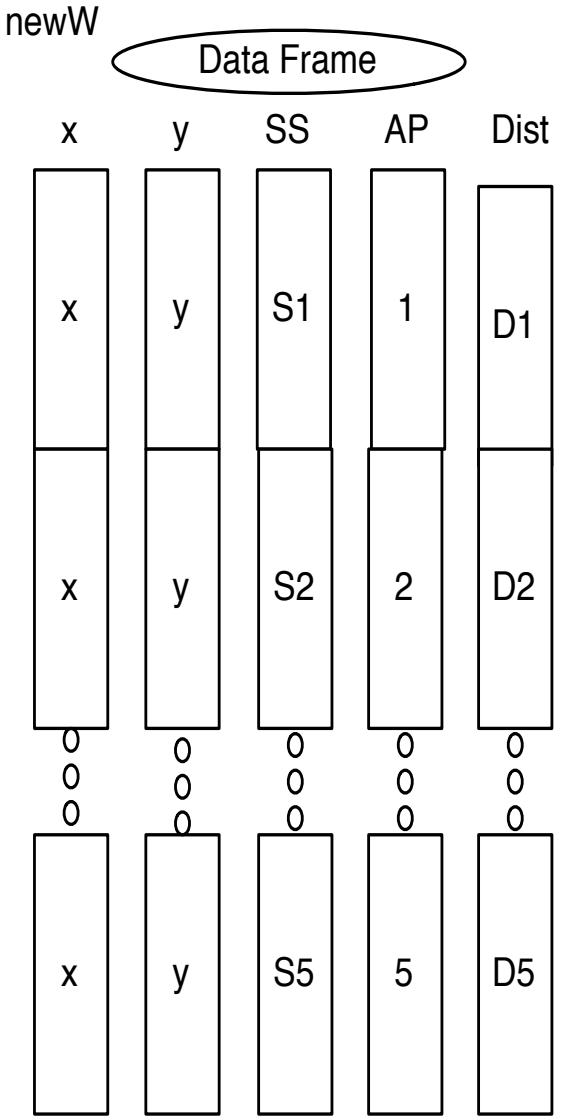
We subset by **position**, **exclusion, logical, name**, and **all**

Now it’s your turn to work with the wireless data

We need to reformat the data frame into another data frame

Revise the Structure





Data Frame ap has five rows and 2 columns (x, y) with the locations of the five access points

Create newW

```
X = rep(w$x, 5)
Y = rep(w$y, 5)
AP = rep(1:5, each = nrow(w))
SS = c(w$S1, w$S2, w$S3, w$S4, w$S5)
D1 = sqrt((w$x – ap[1, "x"] )^2 +
          (w$y – ap[1, "y”])^2 )
Dist = c(D1, D2, D3, D4, D5)
newW = data.frame(x = X, y = Y,
                  AP, SS, Dist)
```

Lists

- Data frames are actually a special kind of *list*.
- Unlike a data frame each element can have a different length.

```
> Ingredients = list(cheese = c("Cheddar", "Swiss"),
+                    meat = c("Ham","Turkey", "Bologna”))
> Ingredients
$cheese
[1] "Cheddar" "Swiss"
$meat
[1] "Ham"     "Turkey"  "Bologna"
```

- Note that the elements are not associated with one another by position, as they were in a given row of a data frame.

Indexing lists

- Lists can be indexed by name, using $.
- They can also be indexed like vectors, using []. The result will be another list of length 1.

```
> Ingredients[2]
$meat
[1] "Ham"     "Turkey"  "Bologna”
> class(Ingredients[2])
[1] "list”
```

Indexing lists

- To extract individual elements of a list, enclose the index in [[]]. The result will be coerced to a simpler structure, depending on the element.

```
> Ingredients[[2]]
[1] "Ham"     "Turkey"  "Bologna"
> class(Ingredients[[2]])
[1] "character”
```

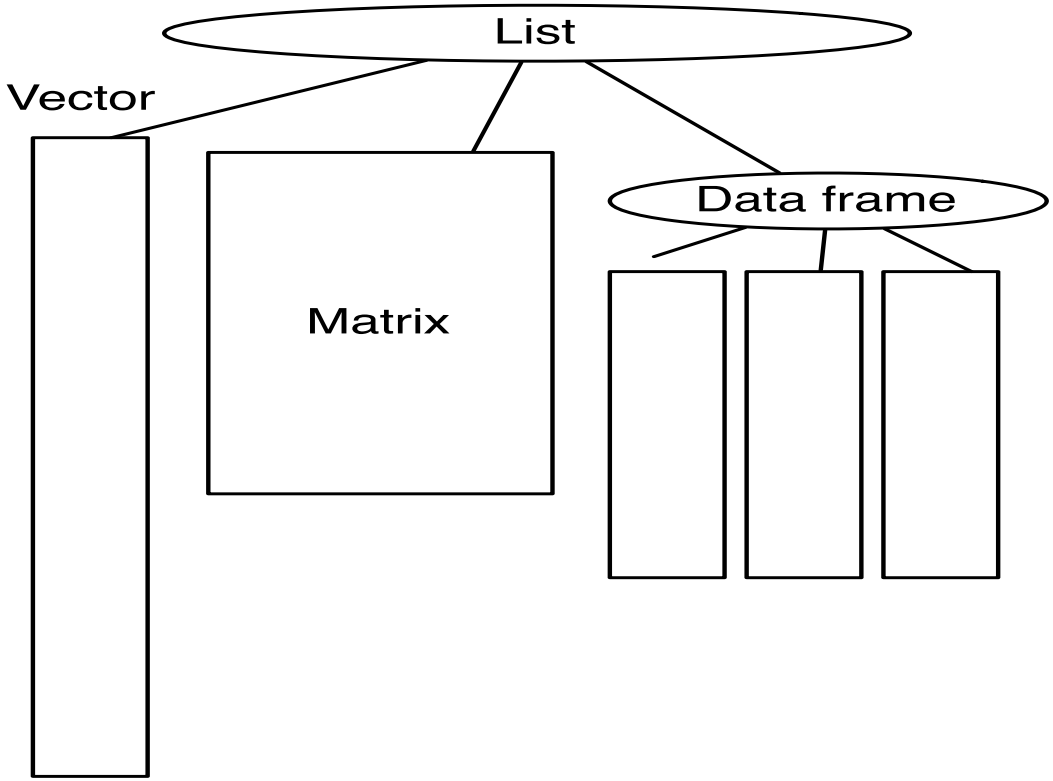
- You will often encounter lists as return values of function calls in R.

```
> x = 1:100
> y = x * 3 + rnorm(100)
> regression.results = lm(y~x) # Regress y on x
> is.list(regression.results)
[1] TRUE
> names(regression.results)
 [1] "coefficients"  "residuals"     "effects"
 [4] "rank"          "fitted.values" "assign"
 [7] "qr"            "df.residual"   "xlevels"
[10] "call"          "terms"         "model"
> regression.results$coef # Note partial matching
(Intercept)           x
  0.2433211   2.9950379
```

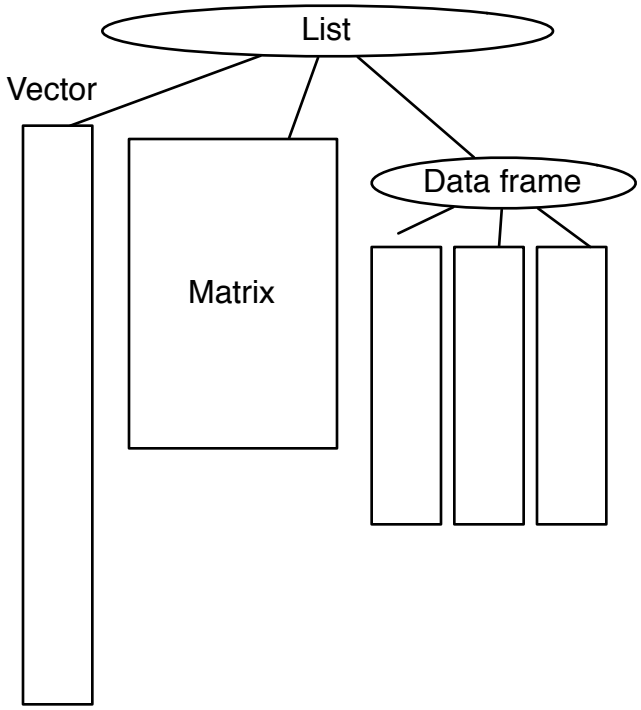
Lists

Lists

- *Ordered* container of objects
- Objects can be anything, vector, data frame, list, etc.

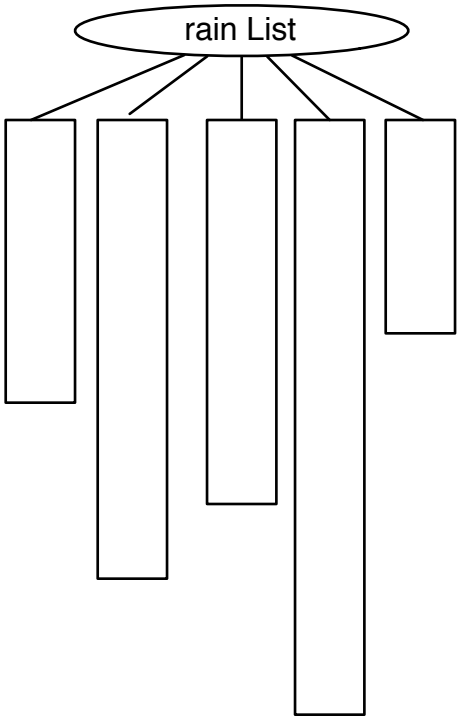


- Data frames are actually a special kind of *list*.
- Unlike a data frame each element in a list can have a different length.
- Actually, each element can be either a list, data frame, vector, matrix, …



Rainfall

- Daily rainfall collected at 5 weather stations
- **rain** is a list of length 5
  - One element for each station
  - Each element is a numeric vector of rain measurements
  - Stations not in operation for the same length of time



```
load(url("http://www.stat.berkeley.edu/users/nolan/data/rainfallCO.rda"))
```

```
> class(rain)
[1] "list"
> length(rain)
[1] 5
> names(rain)
[1] "st050183" "st050263" "st050712"
"st050843" "st050945"
```

Indexing lists

- Lists can be indexed by name, using $.

```
> class(rain$st050183)
[1] "numeric"
> length(rain$st050183)
[1] 9878
> head(rain$st050183)
[1]  0 10 11  1  0  0
```

- Or by [[ ]] with position or name

```
> class(rain[["st050945"]])
[1] "numeric"
> length(rain[["st050945"]])
[1] 3692
> head(rain[[5]])
[1]  0  0  1  0 26  0
```

Indexing lists

- Lists can also be indexed like vectors, using []. The result will be another list.

```
> class(rain["st050183"])
[1] "list"
> length(rain["st050183"])
[1] 1
```

Indexing lists

- To extract individual elements of a list, enclose the index in [[ ]]. The result will an object of the same type as the element of the list. You can only use one value in [[ ]].

```
> class(rain[[1]])
[1] "numeric"
> head(rain[[1]])
[1]  0 10 11  1  0  0
```

Matrices and Arrays

Matrices and Arrays

- Rectangular collection of elements
- Dimensions are two, three, or more
- Homogeneous primitive elements (e.g., all numeric or all character)

- You can create a matrix in R using the `matrix` function.
- By default, matrices in R are assigned by *column-major* order.
- You can assign them by *row-major* order by setting the `byrow` argument to TRUE. Note that the first argument to `matrix` is a vector, so all elements must be of the same type (numeric, character, or logical).

```
> m = matrix(1:6, nrow = 2)
> m
     [,1] [,2] [,3]
[1,]    1    3    5
[2,]    2    4    6
> m = matrix(1:6, nrow = 2, byrow = TRUE)
 m
     [,1] [,2] [,3]
[1,]    1    2    3
[2,]    4    5    6
```

- Assign names to the rows and columns of a matrix:

```
> rownames(m) = letters[1:2]
> colnames(m) = letters[1:3]
> m
  a b c
a 1 2 3
b 4 5 6
```

- Find the dimensions of a matrix:

```
> dim(m); nrow(m); ncol(m)
[1] 2 3
[1] 2
[1] 3
```

- Exchange rows and columns:

```
> t(m)  # t for transpose
  a b
a 1 4
b 2 5
c 3 6
```

- To index elements of a matrix, use the same five methods of indexing we use for vectors, but with the first index for rows and the second for columns.

```
> m
  a b c
a 1 3 5
b 2 4 6
```

What will each line return?

```
> m[-1, 2]
[1] 4
> m["a",]
[1] 1 3 5
> Sl = c(TRUE, TRUE, FALSE)
> m[, Slog]
  a b
a 1 3
b 2 4
```

- Aside: by default the result is coerced to a vector if possible, rather than a matrix with a single row or column. To override, use drop = FALSE.

```
> m[1, ]
[1] 1 3 5
> class(m[1, ])          # Class is not matrix
[1] "integer"
> m[1, , drop = FALSE]  # Class will stay matrix
     [,1] [,2] [,3]
[1,]    1    3    5
> class(m[1, , drop = FALSE])
[1] "matrix"
```

- Aside: Matrices and arrays are actually stored as vectors with shape information so our discussions of "vectorized" calculations hold for matrices as well.

```
> mm = matrix(1:6, ncol = 2, byrow = TRUE)
> mm
     [,1] [,2]
[1,]    1    2
[2,]    3    4
[3,]    5    6
> mm[4]
[1] 2
> length(mm)
[1] 6
> (mm + 17)[1, ]
[1] 18 19
```

Arrays – matrices in higher dimensions

```
> x = array(1:30, c(4, 3, 2))
> x
, , 1
     [,1] [,2] [,3]
[1,]    1    5    9
[2,]    2    6   10
[3,]    3    7   11
[4,]    4    8   12

, , 2
     [,1] [,2] [,3]
[1,]   13   17   21
[2,]   14   18   22
[3,]   15   19   23
[4,]   16   20   24
```

- The integers 1, 2, … , 30 are arranged in a 3-dimensional array
- The array has:
  - 4 rows
  - 3 columns
  - 2 panels

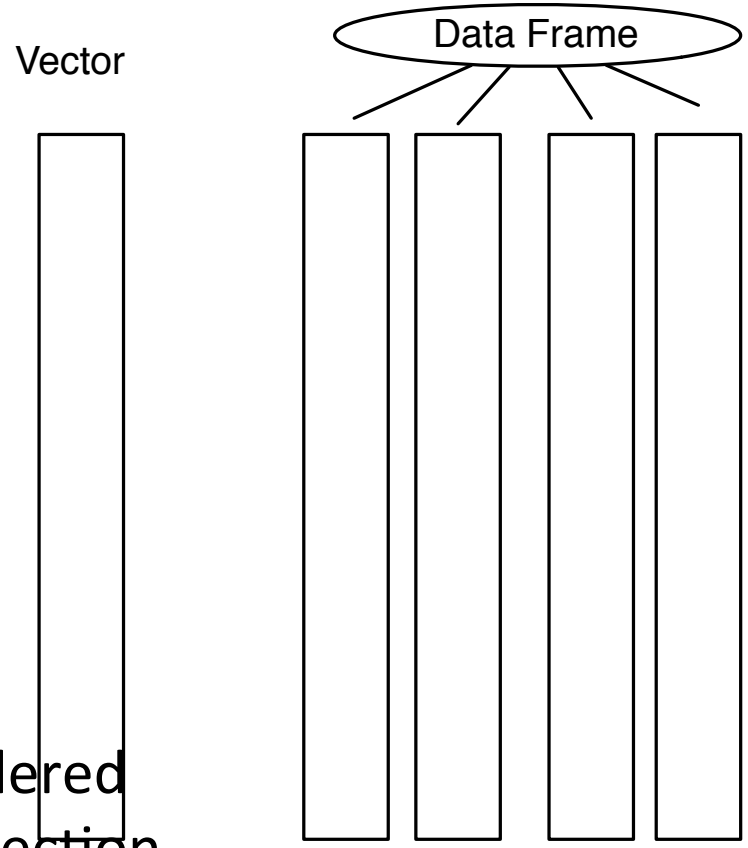
```
> x[1:2, 3, 2]
[1] 21 22

> x[ , 2, 1]
[1] 5 6 7 8

> x[3:4, c(3, 1), 1]
     [,1] [,2]
[1,]   11    3
[2,]   12    4
```

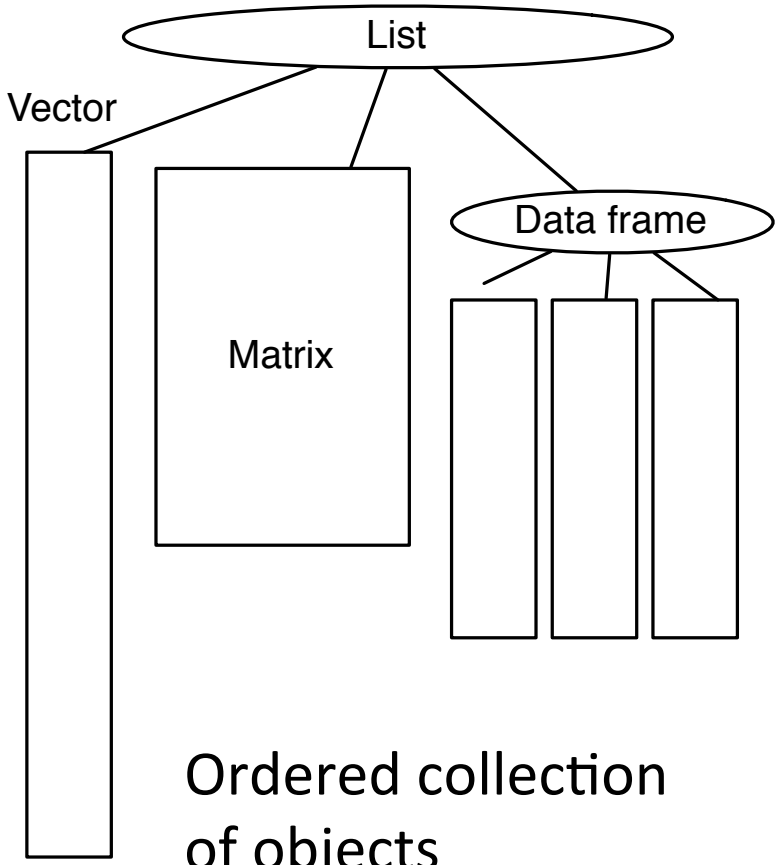
Summary of Data Structures

Types of structures

- To summarize, the data structures we have encountered so far are:
  - vector
  - data frame
  - list
  - matrix

Vector – Data frame - List





Ordered collection of primitive types

Ordered collection of vectors all same length

Ordered collection of objects

Indexing data structures

- Vectors: [index]

```
> x[1:10]
> x[-3]
> x[x>3]
```

- Data frames: [rowindex, colindex] and $name

```
> family$weight
> family[, 3:4]
> family[famiy$height > 70, 2]
```

Returns a vector when possible, unless use drop = FALSE

- Note: both $ can index only *one* element.

Indexing data structures

- Lists: $name, [index], [[index]]

```
> rain$stationname
> rain[1:2]
> rain[[1]]
```

- Matrices: [rowindex, colindex]

```
> m[1, 2]
> m[1:2, ]
> m[ ,"a", drop = TRUE]
```

- Note: [[ ]] can index only *one* element. Also we can index a matrix as if it were a vector

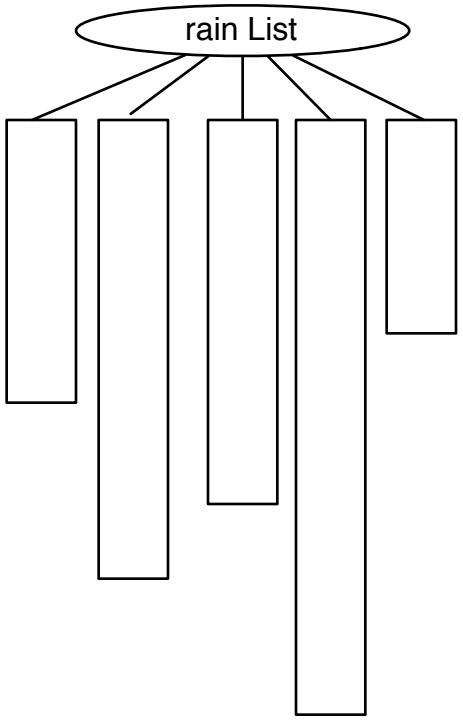
Apply Functions

- Sometimes we want an operation to be applied to each element of a list, to each vector in a data frame, or to individual dimensions of a matrix
- R provides the *apply* mechanism to do this.
- There are several apply functions:
  - sapply() and lapply() for lists and data frames
  - apply() for matrices
  - tapply() for “tables”, i.e. ragged arrays as vectors

- With these functions we can avoid looping, and instead write code that is meaningful in a statistical setting.
- For example with our list of rainfall data, each element represents the measurements taken at a particular weather station and when we think about studying the average rainfall at each station - we don’t think in terms of loops.

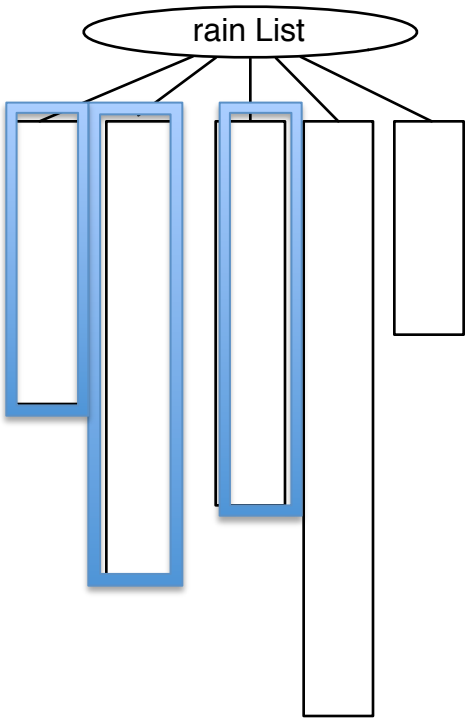
Rainfall

- Daily rainfall collected at 5 weather stations
- **rain** is a list of length 5
  - One element for each station
  - Each element is a numeric vector of rain measurements
  - Stations not in operation for the same length of time



Rainfall

- Apply the mean function to each element of **`rain`**
- Finds: average precipitation of first station,
- Second station,
- Third station,
- Etc.



lapply() and sapply()

- The **lapply** and **sapply** both apply a specified function to each element of a list.
- The former returns a list object and the latter a vector when possible.

Mean rainfall at each station

```
> lapply(rain, mean)
$st050183
[1] 6.631707

$st050263
[1] 3.798993

$st050712
[1] 5.102299

$st050843
[1] 6.084607

$st050945
[1] 4.549296
```

```
> sapply(rain, mean)
st050183 st050263 st050712
6.631707 3.798993 5.102299

st050843 st050945
6.084607 4.549296
```

Additional arguments

```
> lapply(rain, mean, na.rm = TRUE,
          trim = 0.1)
$st050183
[1] 2.393978

$st050263
[1] 0.9875949

$st050712
[1] 0.7895235

$st050843
[1] 1.238481

$st050945
[1] 0.7366283
```

> args(lapply)
function (X, FUN, ...)

X takes the list object

FUN is the function to apply to each element in X

… allows any number of arguments to be passed to FUN

tapply()

- This function is useful to apply a function to subsets of a vector.

```
> x
[1] 1 2 3 4 5 6 7 8 9 10
> v
[1] 1 1 1 0 0 0 1 1 1 0
> tapply(x, v, mean)
0    1
6.25 5.00
> tapply(x, v, median)
0   1
5.5 5.0
```

Now it’s your turn to try it out

Rainfall data

- Maximum rainfall at each station

```
sapply(rain, max)
```

- 99th percentile of rainfall at each station

```
sapply(rain, quantile, probs = 0.99)
```

Rainfall data

- **`day`** is a list with the same structure as **`rain`**
- Check that the number of recordings at each station matches the number of days recorded at the corresponding station

```
all(sapply(rain, length)
          == sapply(day, length))
```

Rainfall data

- Number of years each station is in operation

```
Year = lapply(day, floor)
Uyear = lapply(Year, unique)
OpYear = sapply(Uyear, length)
```

For any one station:

```
length(unique(floor(day[[1]] )))
sapply(day, length(unique(floor(?))) )
```

sapply(day, function(x) length(unique(floor(x))))

- Proportion of days it rained at each station

```
sapply(rain, function(x)
       sum(x > 0)/length(x) )
```

Matrices and Arrays

apply()

- **apply(x, 1, sum)** for the matrix x, the sum function is applied across the columns so that the row dimension (i.e. dim 1) is preserved.

```
> x
     [,1] [,2] [,3]
[1,]    1    3    5
[2,]    2    4    6
> apply(x, 1, sum)
[1]  9 12
```

apply()

- **apply(x, 1, min)** for the matrix x, the min function is applied down the rows so that the column dimension (i.e. dim 2) is preserved.

```
> x
     [,1] [,2] [,3]
[1,]    1    3    5
[2,]    2    4    6
> apply(x, 2, min)
[1] 1 3 5
```