



# R Programming

## Week 2, Class 1

Introduction to Programming

Instructor: Denis Vrdoljak

## R Tutorial



**Module 1 – Introduction to R**

**Module 2 – Importing data and analysis**

**Module 3 – Interpretation of results**

## What is R?

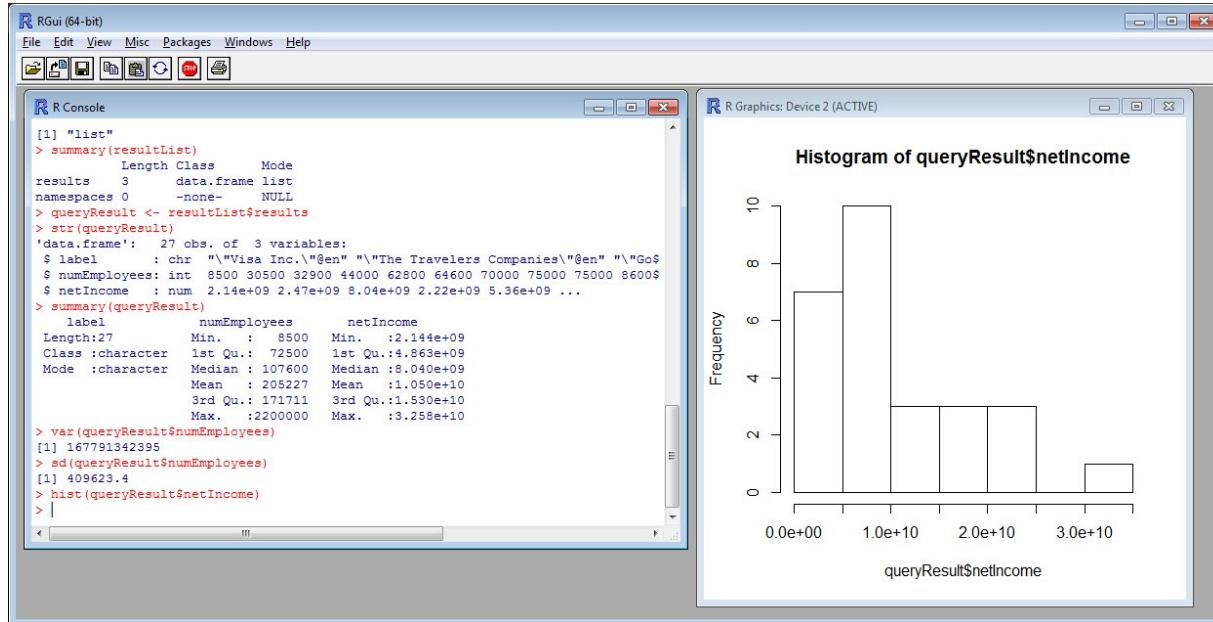
- A suite of operators for calculations on arrays, in particular matrices,
- A large, coherent, integrated collection of intermediate tools for data analysis,
- Graphical facilities for data analysis and display either on-screen or on hardcopy, and
- A well-developed, simple and effective programming language which includes conditionals, loops, user-defined recursive functions and input and output facilities.
- Free, open-source software

# Installing, Running, and Interacting with R

- **How to get R:**
  - <http://www.r-project.org/>
  - Google: "R"
  - Windows, Linux, Mac OS X, source
- **Files for this tutorial:**
  - On the blackboard



# Installing, Running, and Interacting with R



# Installing, Running, and Interacting with R

- **Entering data**
  - ✓ Math
  - ✓ Variables
  - ✓ Arrays
  - ✓ Math on arrays
  - ✓ Functions
- **Getting help**
- **Reading data from files**
- **Selecting subsets of data**



# Installing, Running, and Interacting with R

## Math:

```
> 1 + 1  
[1] 2  
  
> 1 + 1 * 7  
[1] 8  
  
> (1 + 1) * 7  
[1] 14
```

## Variables:

```
> x <- 1  
> x  
[1] 1  
> y = 2  
> y  
[1] 2  
> z -> z  
> z  
[1] 3  
> (x + y) * z  
[1] 9
```



# Installing, Running, and Interacting with R

## Arrays:

```
> x <- c(0,1,2,3,4)
> x
[1] 0 1 2 3 4

> y <- 1:5
> y
[1] 1 2 3 4 5

> z <- 1:50
> z
[1]  1  2  3  4  5  6  7  8  9 10 11 12 13 14 15
[16] 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
[31] 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45
[46] 46 47 48 49 50
```



# Installing, Running, and Interacting with R

Math on arrays:

```
> x <- c(0,1,2,3,4)
> y <- 1:5
> z <- 1:50
> x + y
[1] 1 3 5 7 9
> x * y
[1] 0 2 6 12 20
> x * z
[1] 0 2 6 12 20 0 7 16 27 40 0
[12] 12 26 42 60 0 17 36 57 80 0 22
[23] 46 72 100 0 27 56 87 120 0 32 66
[34] 102 140 0 37 76 117 160 0 42 86 132
[45] 180 0 47 96 147 200
```

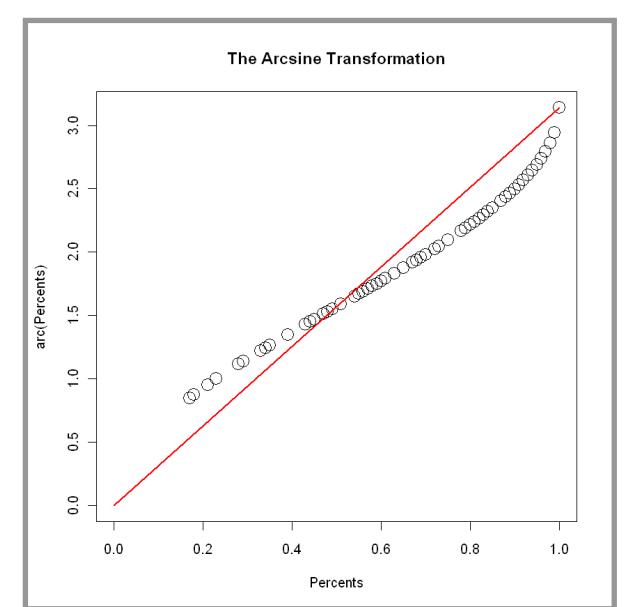


# Installing, Running, and Interacting with R

## Functions:

```
> arc <- function(x) 2*asin(sqrt(x))  
> arc(0.5)  
[1] 1.570796  
> x <- c(0,1,2,3,4)  
> x <- x / 10  
> arc(x)  
[1] 0.0000000 0.6435011 0.9272952  
[4] 1.1592795 1.3694384
```

```
> plot(arc(Percents)~Percents,  
+ pch=21,cex=2,xlim=c(0,1),ylim=c(0,pi),  
+ main="The Arcsine Transformation")  
> lines(c(0,1),c(0,pi),col="red",lwd=2)
```

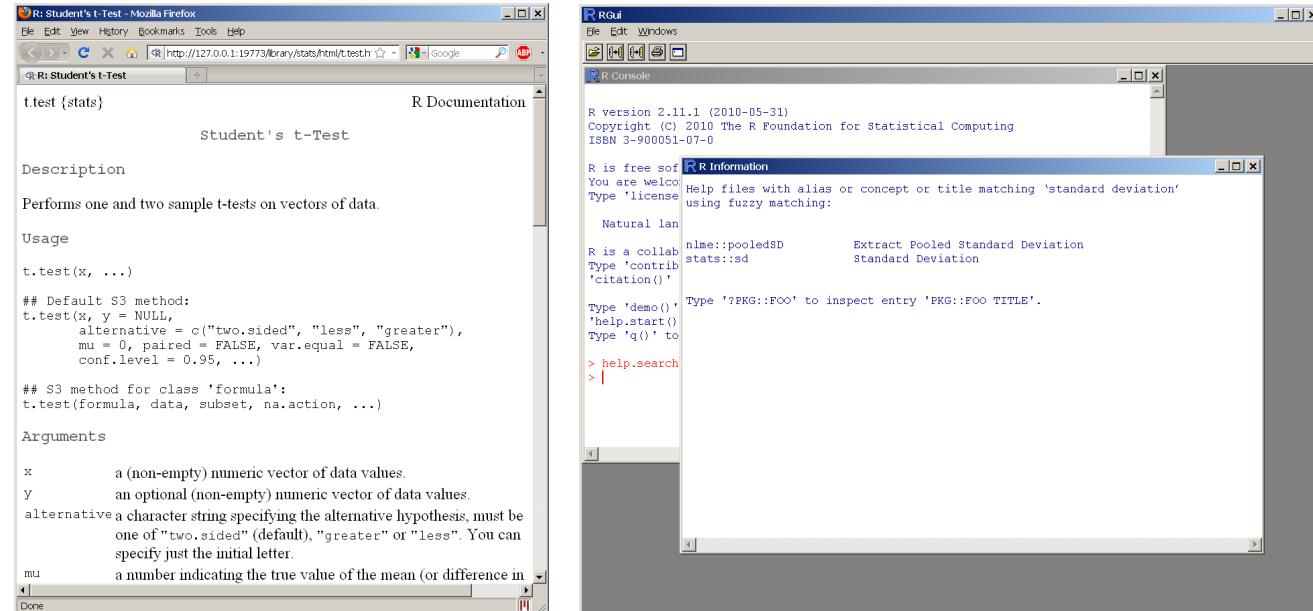




# Installing, Running, and Interacting with R

## Getting help:

```
> help(t.test)
> help.search("standard deviation")
```



The screenshot shows two windows side-by-side. On the left is a Mozilla Firefox browser window titled "R: Student's t-Test - Mozilla Firefox". It displays the R Documentation page for the `t.test` function. The page includes the function's description, usage, and detailed arguments with their descriptions. On the right is the R GUI window, which contains the R Console. The R Console shows the command `> help.search("standard deviation")` being entered. A modal dialog box titled "R Information" is open over the console, providing instructions on how to search for help files.

# Installing, Running, and Interacting with R

- **Example experiment:**
  - Subjects learning to perform a new task:
  - Two groups of subjects
    - (“A” and “B”; high and low aptitude learners)
      - Two types of training paradigm
        - (“High variability” and “Low variability”)
      - Four pre-training assessment tests
- **Example data in “R\_Tutorial\_Data.txt” @Blackboard**



# Installing, Running, and Interacting with R

## Reading data from files:

```
> myData <- read.table("R_Tutorial_Data.txt",
+ header=TRUE, sep="\t")
> myData
   Condition Group  Pre1  Pre2  Pre3  Pre4 Learning
1       Low     A  0.77  0.91  0.24  0.72      0.90
2       Low     A  0.82  0.91  0.62  0.90      0.87
3       Low     A  0.81  0.70  0.43  0.46      0.90
4       .
5       .
6       .
61      High    B  0.44  0.41  0.84  0.82      0.29
62      High    B  0.48  0.56  0.83  0.85      0.48
63      High    B  0.61  0.82  0.88  0.95      0.28
```

Screenshot of OpenOffice.org Calc showing the data from "R\_Tutorial\_Data.txt". The data is in a single column, and the software has automatically detected the tab-separated values and created a table with columns: Condition, Group, Pre1, Pre2, Pre3, Pre4, and Learning.

Condition	Group	Pre1	Pre2	Pre3	Pre4	Learning
Low	A	0.77	0.91	0.24	0.72	0.90
Low	A	0.82	0.91	0.62	0.90	0.87
Low	A	0.81	0.70	0.43	0.46	0.90
Low	A	0.88	0.89	0.2	0.63	0.85
Low	A	0.78	0.68	0.25	0.73	0.93
Low	A	0.74	0.9	0.99	0.99	0.93
Low	A	0.78	0.86	0.79	0.78	0.89
Low	A	0.76	0.76	0.61	0.85	0.8
Low	A	0.93	0.82	0.99	0.99	0.98
Low	A	0.82	0.78	0.28	0.75	0.88
Low	A	0.91	0.73	0.87	0.72	0.88
Low	A	0.96	0.69	0.69	0.59	0.94
Low	A	0.97	0.86	0.89	0.9	0.99
Low	A	0.89	0.54	0.79	0.96	0.92
Low	A	0.76	0.94	0.81	0.95	0.83
Low	A	0.84	0.85	0.97	0.86	0.65
Low	B	0.62	0.82	0.43	0.56	0.57

Screenshot of Notepad showing the data from "R\_Tutorial\_Data.txt". The data is in a single column, and the software has automatically detected the tab-separated values and created a table with columns: Condition, Group, Pre1, Pre2, Pre3, Pre4, and Learning.

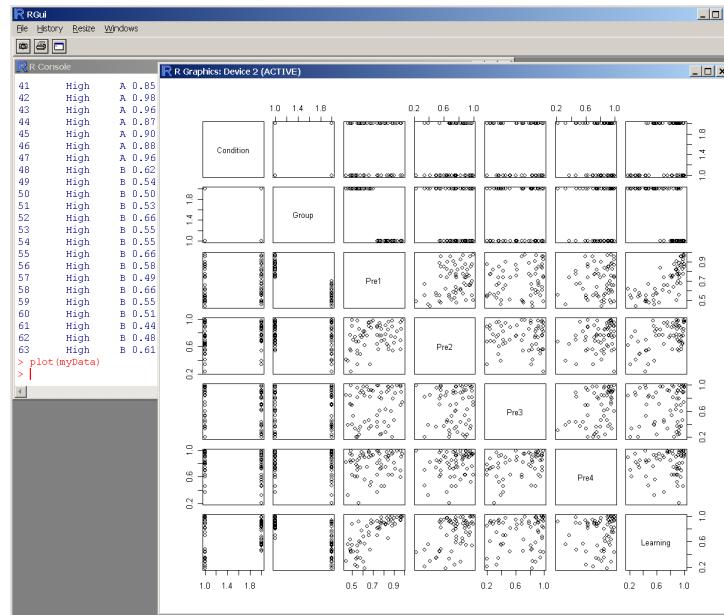
Condition	Group	Pre1	Pre2	Pre3	Pre4	Learning
Low	A	0.77	0.91	0.24	0.72	0.90
Low	A	0.82	0.91	0.62	0.9	0.87
Low	A	0.81	0.7	0.43	0.46	0.9
Low	A	0.88	0.89	0.2	0.63	0.85
Low	A	0.78	0.68	0.25	0.73	0.93
Low	A	0.74	0.9	0.99	0.99	0.93
Low	A	0.78	0.86	0.79	0.78	0.89
Low	A	0.76	0.76	0.61	0.85	0.8
Low	A	0.93	0.82	0.99	0.99	0.98
Low	A	0.82	0.78	0.28	0.75	0.88
Low	A	0.91	0.73	0.87	0.72	0.88
Low	A	0.96	0.69	0.69	0.59	0.94
Low	A	0.97	0.86	0.89	0.9	0.99
Low	A	0.89	0.54	0.79	0.96	0.92
Low	A	0.76	0.94	0.81	0.95	0.83
Low	A	0.84	0.85	0.97	0.86	0.65
Low	B	0.62	0.82	0.43	0.56	0.57



# Installing, Running, and Interacting with R

## Examining datasets:

```
> plot(myData)
```





# Installing, Running, and Interacting with R

## Selecting subsets of data:

```
> myData$Learning
[1] 0.90 0.87 0.90 0.85 0.93 0.93 0.89 0.80 0.98
[10] 0.88 0.88 0.94 0.99 0.92 0.83 0.65 0.57 0.55
[19] 0.94 0.68 0.89 0.60 0.63 0.84 0.92 0.56 0.78
[28] 0.54 0.47 0.45 0.59 0.91 0.98 0.82 0.93 0.81
[37] 0.97 0.95 0.70 1.00 0.90 0.99 0.95 0.95 0.97
[46] 1.00 0.99 0.18 0.33 0.88 0.23 0.75 0.21 0.35
[55] 0.70 0.34 0.43 0.75 0.44 0.44 0.29 0.48 0.28
> myData$Learning [myData$Group=="A"]
[1] 0.90 0.87 0.90 0.85 0.93 0.93 0.89 0.80 0.98
[10] 0.88 0.88 0.94 0.99 0.92 0.83 0.65 0.98 0.82
[19] 0.93 0.81 0.97 0.95 0.70 1.00 0.90 0.99 0.95
[28] 0.95 0.97 1.00 0.99
```



# Installing, Running, and Interacting with R

Selecting subsets of data:

```
> myData$Learning
[1] 0.90 0.87 0.90 0.85 0.93 0.93 0.89 0.80 0.98
[10] 0.88 0.88 0.94 0.99 0.92 0.83 0.65 0.57 0.55
[19] 0.94 0.68 0.89 0.60 0.63 0.84 0.92 0.56 0.78
[28] 0.54 0.47 0.45 0.59 0.91 0.98 0.82 0.93 0.81
[37] 0.97 0.95 0.70 1.00 0.90 0.99 0.95 0.95 0.97
[46] 1.00 0.99 0.18 0.33 0.88 0.23 0.75 0.21 0.35
[55] 0.70 0.34 0.43 0.75 0.44 0.44 0.29 0.48 0.28
> attach(myData)
> Learning
[1] 0.90 0.87 0.90 0.85 0.93 0.93 0.89 0.80 0.98
[10] 0.88 0.88 0.94 0.99 0.92 0.83 0.65 0.57 0.55
[19] 0.94 0.68 0.89 0.60 0.63 0.84 0.92 0.56 0.78
[28] 0.54 0.47 0.45 0.59 0.91 0.98 0.82 0.93 0.81
[37] 0.97 0.95 0.70 1.00 0.90 0.99 0.95 0.95 0.97
[46] 1.00 0.99 0.18 0.33 0.88 0.23 0.75 0.21 0.35
[55] 0.70 0.34 0.43 0.75 0.44 0.44 0.29 0.48 0.28
```



# Installing, Running, and Interacting with R

Selecting subsets of data:

```
> Learning[Group=="A"]
 [1] 0.90 0.87 0.90 0.85 0.93 0.93 0.89 0.80 0.98
[10] 0.88 0.88 0.94 0.99 0.92 0.83 0.65 0.98 0.82
[19] 0.93 0.81 0.97 0.95 0.70 1.00 0.90 0.99 0.95
[28] 0.95 0.97 1.00 0.99
> Learning[Group!="A"]
 [1] 0.57 0.55 0.94 0.68 0.89 0.60 0.63 0.84 0.92
[10] 0.56 0.78 0.54 0.47 0.45 0.59 0.91 0.18 0.33
[19] 0.88 0.23 0.75 0.21 0.35 0.70 0.34 0.43 0.75
[28] 0.44 0.44 0.29 0.48 0.28
> Condition[Group=="B"&Learning<0.5]
 [1] Low Low High High High High High High High
[10] High High High High High
Levels: High Low
```

# Statistics and Data Analysis

- **Parametric Tests**
  - Independent sample t-tests
  - Paired sample t-tests
  - One sample t-tests
  - Correlation
- **Nonparametric tests**
  - Shapiro-Wilks test for normality
  - Wilcoxon signed-rank test (Mann-Whitney U)
  - Chi square test
- **Linear Models and ANOVA**

# Basic parametric inferential statistics

## Independent sample t-tests:

```
> t.test(Pre2[Group=="A"],  
+ Pre2[Group=="B"],  
+ paired=FALSE)
```

Welch Two Sample t-test

```
data: Learning[Group == "A"] and Learning[Group == "B"]  
t = 1.6117, df = 53.275, p-value = 0.1129  
alternative hypothesis: true difference in means is not equal to 0  
95 percent confidence interval:  
-0.0179193 0.1645725  
sample estimates:  
mean of x mean of y  
0.7764516 0.7031250
```



# Basic parametric inferential statistics

## Independent sample t-tests:

```
> t.test(Pre2[Group=="A"],  
+ Pre2[Group=="B"],  
+ paired=FALSE,  
+ var.equal=TRUE)
```

Welch Two Sample t-test

```
data: Learning[Group == "A"] and Learning[Group == "B"]  
t = 1.601, df = 61, p-value = 0.1145  
alternative hypothesis: true difference in means is not equal to 0  
95 percent confidence interval:  
-0.0179193 0.1645725  
sample estimates:  
mean of x mean of y  
0.7764516 0.7031250
```



## Basic parametric inferential statistics

### Independent sample t-tests:

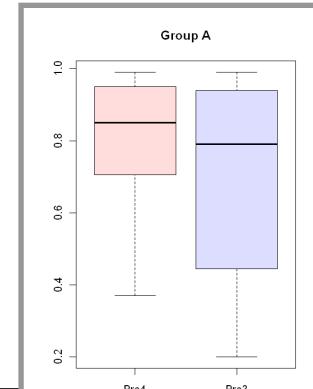
```
> t.test(Pre2[Group=="A"],  
+ Pre2[Group=="B"],  
+ paired=FALSE,  
+ var.equal=TRUE,  
+ alternative="greater")  
  
Welch Two Sample t-test  
  
data: Learning[Group == "A"] and Learning[Group == "B"]  
t = 1.601, df = 61, p-value = 0.5727  
alternative hypothesis: true difference in means is greater than 0  
95 percent confidence interval:  
-0.003169388 Inf  
sample estimates:  
mean of x mean of y  
0.7764516 0.7031250
```



# Basic parametric inferential statistics

## Paired sample t-test:

```
> t.test(Pre4[Group=="A"],  
+ Pre3[Group=="A"],  
+ paired=TRUE)  
  
Paired t-test  
  
data: Pre4[Group == "A"] and Pre3[Group == "A"]  
t = 2.4054, df = 30, p-value = 0.02253  
alternative hypothesis: true difference in means is not equal to 0  
95 percent confidence interval:  
 0.01641059 0.20100876  
sample estimates:  
mean of the differences  
 0.1087097  
  
> boxplot(Pre4[Group=="A"],  
+ Pre3[Group=="A"],  
+ col=c("#ffdddd", "#ddffff"),  
+ names=c("Pre4", "Pre3"), main="Group A")
```





# Basic parametric inferential statistics

## One sample t-test:

```
> t.test(Learning[Group=="B"], mu=0.5, alternative="greater")
```

```
One Sample t-test
```

```
data: Learning[Group == "B"]
t = 1.5595, df = 31, p-value = 0.06452
alternative hypothesis: true mean is greater than 0.5
95 percent confidence interval:
```

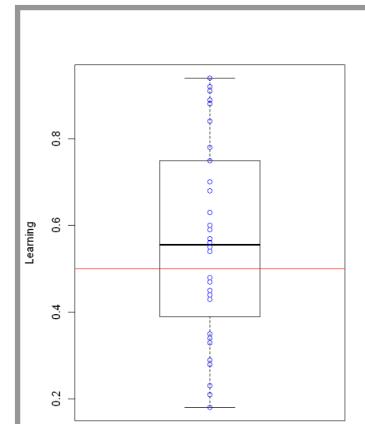
```
0.4945469      Inf
```

```
sample estimates:
```

```
mean of x
```

```
0.5625
```

```
> boxplot(Learning[Group=="B"],
+ names="Group B", ylab="Learning")
> lines(c(0,2), c(0.5, 0.5), col="red")
> points(c(rep(1,length(Learning[Group=="B"]))),
+ Learning[Group=="B"], pch=21, col="blue")
```





# Basic parametric inferential statistics

## Correlation:

```
> cor.test(Pre1, Learning, method="pearson")
```

Pearson's product-moment correlation

data: Pre1 and Learning

t = 9.2461, df = 61, p-value = 3.275e-13

alternative hypothesis: true correlation is not equal to 0

95 percent confidence interval:

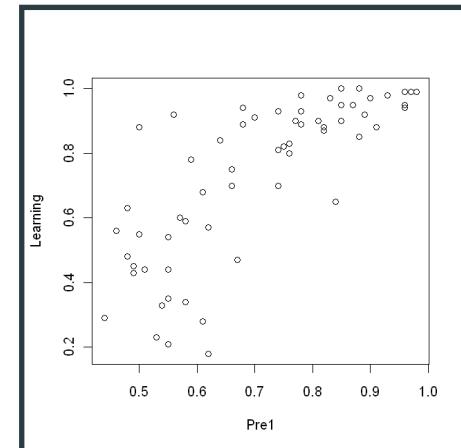
0.6366698 0.8506815

sample estimates:

cor

0.7639292

```
> plot(Pre1, Learning)
```

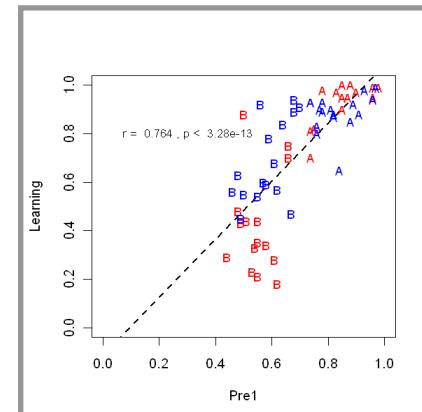




# Basic parametric inferential statistics

## Correlation (fancier plot example):

```
> cor.test(Pre1, Learning, method="pearson")  
  
Pearson's product-moment correlation  
  
data: Pre1 and Learning  
t = 9.2461, df = 61, p-value = 3.275e-13  
alternative hypothesis: true correlation is not equal to 0  
95 percent confidence interval:  
 0.6366698 0.8506815  
sample estimates:  
cor  
0.7639292  
  
> plot(Learning~Pre1, ylim=c(0,1), xlim=c(0,1), ylab="Learning", xlab="Pre1", type="n")  
> abline(lm(Learning~Pre1), col="black", lty=2, lwd=2)  
> points(Learning[Group=="A"&Condition=="High"]~Pre1[Group=="A"&Condition=="High"],  
+ pch=65, col="red", cex=0.9)  
> points(Learning[Group=="A"&Condition=="Low"]~Pre1[Group=="A"&Condition=="Low"],  
+ pch=65, col="blue", cex=0.9)  
> points(Learning[Group=="B"&Condition=="High"]~Pre1[Group=="B"&Condition=="High"],  
+ pch=66, col="red", cex=0.9)  
> points(Learning[Group=="B"&Condition=="Low"]~Pre1[Group=="B"&Condition=="Low"],  
+ pch=66, col="blue", cex=0.9)  
> legend(2.5,1.0, c("LV Training", "HV Training"), pch=c(19), col=c("blue","red"), bty="y")  
> yCor <- cor.test(Pre1, Learning, method="pearson")  
> text(0.3,0.8, paste("r = ", format(myCor$estimate,digits=3),", p < ", format(myCor$p.value,digits=3)), cex=0.8)
```





# Statistics and Data Analysis

## Are my data normally distributed?

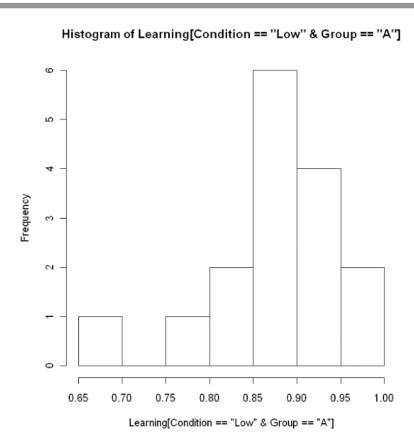
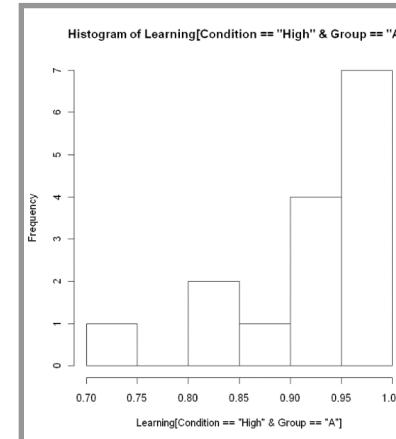
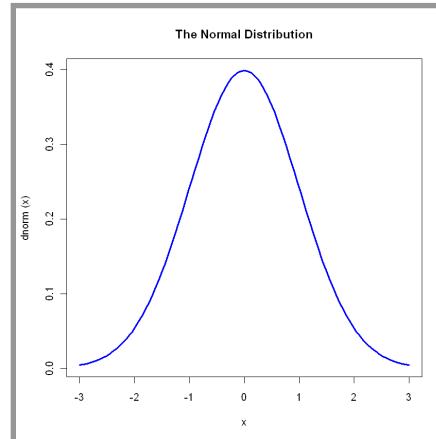
```
> t.test(Learning[Condition=="High"&Group=="A"] ,  
+ Learning[Condition=="Low"&Group=="A"] )  
  
Welch Two Sample t-test  
  
data: Learning[Condition == "High" & Group == "A"] and  
Learning[Condition == "Low" & Group == "A"]  
t = 1.457, df = 28.422, p-value = 0.1561  
alternative hypothesis: true difference in means is not equal to 0  
95 percent confidence interval:  
 -0.01764821  0.10481488  
sample estimates:  
mean of x mean of y  
0.9273333 0.8837500
```



# Statistics and Data Analysis

## Are my data normally distributed?

```
> plot(dnorm,-3,3,col="blue",lwd=3,main="The Normal Distribution")
> par(mfrow=c(1,2))
> hist(Learning[Condition=="High"&Group=="A"])
> hist(Learning[Condition=="Low"&Group=="A"])
```





# Statistics and Data Analysis

## Are my data normally distributed?

```
> shapiro.test(Learning[Condition=="High"&Group=="A"])

    Shapiro-Wilk normality test

data: Learning[Condition == "High" & Group == "A"]
W = 0.7858, p-value = 0.002431

> shapiro.test(Learning[Condition=="Low"&Group=="A"])

    Shapiro-Wilk normality test

data: Learning[Condition == "Low" & Group == "A"]
W = 0.8689, p-value = 0.02614
```



## Basic non-parametric inferential statistics

### Wilcoxon signed-rank / Mann-Whitney U tests:

```
> wilcox.test(Learning[Condition=="High"&Group=="A"] ,  
+ Learning[Condition=="Low"&Group=="A"] ,  
+ exact=FALSE ,  
+ paired=FALSE)  
  
Wilcoxon rank sum test with continuity correction  
  
data: Learning[Condition == "High" & Group == "A"] and  
      Learning[Condition == "Low" & Group == "A"]  
W = 173.5, p-value = 0.03580  
alternative hypothesis: true location shift is not equal to 0
```



# Basic non-parametric inferential statistics

## Chi square test:

```
> x <- matrix(c(
+ length(Learning[Group=="A"&Condition=="High"&Gender=="F"]),
+ length(Learning[Group=="A"&Condition=="Low"&Gender=="F"]),
+ length(Learning[Group=="B"&Condition=="High"&Gender=="F"]),
+ length(Learning[Group=="B"&Condition=="Low"&Gender=="F"])),
+ ncol=2)
> x
     [,1]   [,2]
[1,]    4    12
[2,]   10     7
> chisq.test(x)

Pearson's Chi-squared test with Yates' continuity correction

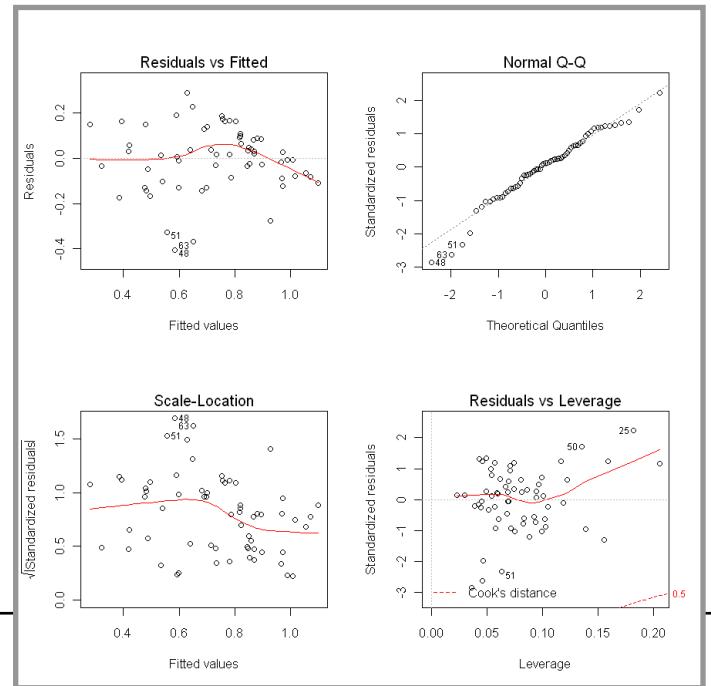
data:  x
X-squared = 2.5999, df = 1, p-value = 0.1069
```



# Linear models and ANOVA

## Linear models:

```
> myModel <- lm(Learning ~ Prel + Pre2 + Pre3 + Pre4)  
> par(mfrow=c(2,2))  
> plot(myModel)
```





# Linear models and ANOVA

## Linear models:

```
> summary(myModel)

Call:
lm(formula = Learning ~ Pre1 + Pre2 + Pre3 + Pre4)

Residuals:
    Min      1Q  Median      3Q     Max 
-0.40518 -0.08460  0.01707  0.09170  0.29074 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)    
(Intercept) -0.22037   0.11536  -1.910 0.061055 .
Pre1         1.05299   0.12636   8.333 1.70e-11 ***
Pre2         0.41298   0.10926   3.780 0.000373 ***
Pre3         0.07339   0.07653   0.959 0.341541  
Pre4        -0.18457   0.11318  -1.631 0.108369  
---
Signif. codes:  0 '****' 0.001 '***' 0.01 '**' 0.05 '*' 0.1 '.' 1 

Residual standard error: 0.1447 on 58 degrees of freedom
Multiple R-squared: 0.6677,    Adjusted R-squared: 0.6448 
F-statistic: 29.14 on 4 and 58 DF,  p-value: 2.710e-13
```



# Linear models and ANOVA

## Linear models:

```
> step(myModel, direction="backward")
Start: AIC=-238.8
Learning ~ Pre1 + Pre2 + Pre3 + Pre4

          Df Sum of Sq    RSS     AIC
- Pre3   1  0.01925 1.2332 -239.81
<none>           1.2140 -238.80
- Pre4   1  0.05566 1.2696 -237.98
- Pre2   1  0.29902 1.5130 -226.93
- Pre1   1  1.45347 2.6675 -191.21

Step: AIC=-239.81
Learning ~ Pre1 + Pre2 + Pre4

          Df Sum of Sq    RSS     AIC
- Pre4   1  0.03810 1.2713 -239.89
<none>           1.2332 -239.81
- Pre2   1  0.28225 1.5155 -228.83
- Pre1   1  1.54780 2.7810 -190.58
```

...

...

```
Step: AIC=-239.89
Learning ~ Pre1 + Pre2
```

	Df	Sum of Sq	RSS	AIC
<none>		1.2713	-239.89	
- Pre2	1	0.24997	1.5213	-230.59
- Pre1	1	1.52516	2.7965	-192.23

Call:

```
lm(formula = Learning ~ Pre1 + Pre2)
```

Coefficients:

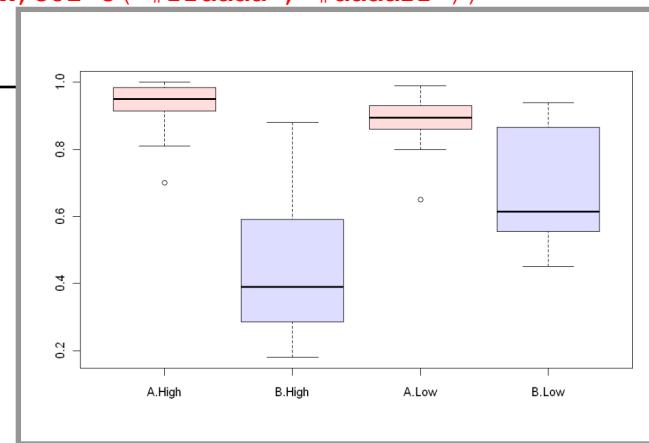
(Intercept)	Pre1	Pre2
-0.2864	1.0629	0.3627



# Linear models and ANOVA

## ANOVA:

```
> myANOVA <- aov(Learning~Group*Condition)
> summary(myANOVA)
      Df Sum Sq Mean Sq F value    Pr(>F)
Group          1 1.8454 1.84537 81.7106 9.822e-13 ***
Condition       1 0.1591 0.15910  7.0448 0.0102017 *
Group:Condition 1 0.3164 0.31640 14.0100 0.0004144 ***
Residuals      59 1.3325 0.02258
---
Signif. codes:  0 '****' 0.001 '***' 0.01 '**' 0.05 '*' 0.1 '.' 1
> boxplot(Learning~Group*Condition,col=c("#ffdddd","#ddffff"))
```



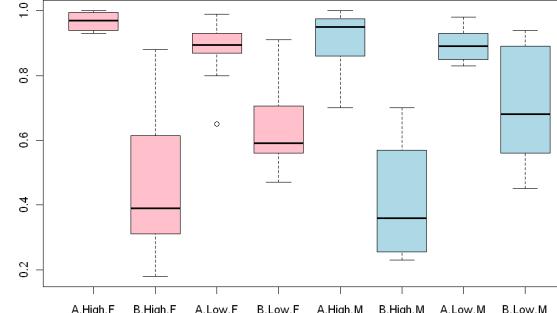


# Linear models and ANOVA

## ANOVA:

```
> myANOVA2 <- aov(Learning~Group*Condition+Gender)
> summary(myANOVA2)
      Df  Sum Sq Mean Sq F value    Pr(>F)
Group        1 1.84537 1.84537 80.3440 1.523e-12 ***
Condition     1 0.15910 0.15910  6.9270  0.010861 *
Gender        1 0.04292 0.04292  1.8688  0.176886
Group:Condition 1 0.27378 0.27378 11.9201  0.001043 **
Residuals    58 1.33216 0.02297
---
Signif. codes:  0 '****' 0.001 '***' 0.01 '**' 0.05 '*' 0.1 '.' 1
```

```
> boxplot(Learning~Group*Condition+Gender,
+ col=c(rep("pink", 4), rep("light blue", 4)))
```





R wiki:

<http://rwiki.sciviews.org/doku.php>

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<http://cran.r-project.org/doc/contrib/Lemon-kickstart/>



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