Bayesian Statistics and Hierarchical Bayesian Modeling for Psychological Science

Lecture 02 + 03

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https://github.com/lei-zhang/BayesCog_Wien

universität wien
Fakultät für Psychologie

Bayesian warm-up?

BASICS OF R PROGRAMMING

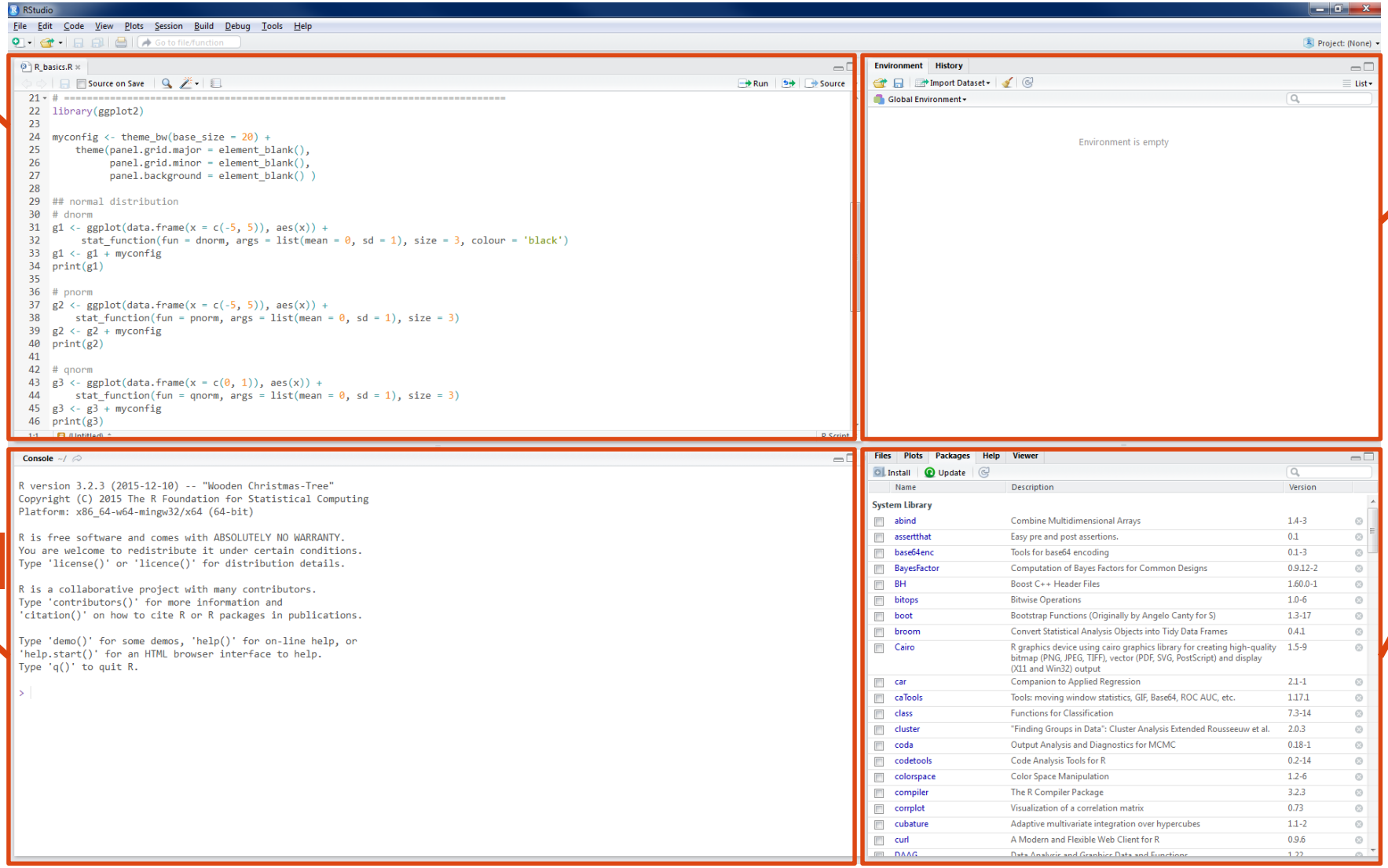
RStudio®

R Basics

- R
  - a programming language for statistical computing
  - R has its own user interface
  - freely available on Windows, Mac, and Linux

- R Studio
  - integrated development environment (IDE) for R
  - a more sophisticated R-friendly editor, with helpful syntax highlight

script editor



console

environment/
command history

file/pkg/img/
etc.

Know your R

```
>R.version

               _
platform       x86_64-w64-mingw32
arch           x86_64
os             mingw32
system         x86_64, mingw32
status
major          3
minor          5.1
year           2018
month          07
day            02
svn rev        74947
language       R
version.string R version 3.5.1 (2018-07-02)
nickname       Feather Spray
```

R Console as a Calculator

cognitive model
statistics
computing

Addition and Subtraction

```
> 3+2
[1] 5

> 3-2
[1] 1
```

Multiplication and Division

```
> 3*2
[1] 6

> 3/2
[1] 1.5
```

Exponents in R

```
> 3^2
[1] 9

> 2^3
[1] 8
```

Constants in R

```
> pi
[1] 3.141593

> exp(1)
[1] 2.718282
```

base of the natural logarithm

Special values

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statistics
computing

Infinite Values

```
> Inf
[1] Inf

> 1+Inf
[1] Inf
```

Empty Values

```
> NULL
NULL

> 1+NULL
numeric(0)
```

Machine Epsilon

```
> .Machine$double.eps
[1] 2.220446e-16

> 0>.Machine$double.eps
[1] FALSE
```

Missing Values

```
> NA
[1] NA

> 1+NA
[1] NA
```

Storing and manipulating variables

Define objects `x` and `y` with values of 3 and 2, respectively:

```
> x=3
> y=2
```

Some calculations with the defined objects `x` and `y`:

```
> x+y
[1] 5

> x*y
[1] 6
```

Warning: R is case sensitve, so `x` and `X` are not the same object.

Basic R functions

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Combine

```
> c(1,3,-2)
[1]  1  3 -2
```

```
> c("a","a","b","b","a")
[1] "a" "a" "b" "b" "a"
```

Variance and Std. Dev.

```
> var(c(1,3,-2))
[1] 6.333333
```

```
> sd(c(1,3,-2))
[1] 2.516611
```

Sum and Mean

```
> sum(c(1,3,-2))
[1] 2
```

```
> mean(c(1,3,-2))
[1] 0.6666667
```

Minimum and Maximum

```
> min(c(1,3,-2))
[1] -2
```

```
> max(c(1,3,-2))
[1] 3
```

Basic R functions (cont.)

Define objects `x` and `y`:

```
> x=c(1,3,4,6,8)
> y=c(2,3,5,7,9)
```

Calculate the correlation:

```
> cor(x,y)
[1] 0.988765
```

Calculate the covariance:

```
> cov(x,y)
[1] 7.65
```

Combine as columns

```
> cbind(x,y)
     x y
[1,] 1 2
[2,] 3 3
[3,] 4 5
[4,] 6 7
[5,] 8 9
```

Combine as rows

```
> rbind(x,y)
  [,1] [,2] [,3] [,4] [,5]
x    1    3    4    6    8
y    2    3    5    7    9
```

Basic Commands

```
getwd()
setwd('E:/teaching/BayesCog_Wien/')
dir() # folders/files in the wd
ls()  # anything in the environment/workspace
print('Hello World!')
cat('Hello', 'World!')
paste0('C:/', 'Group1')
help(func)
? func # and Google!
a <- 5
a = 5
head(d) # first 6 entries
tail(d) # last 6 entries
save(varname, file = "pathname/varname.RData")
load("pathname/varname.RData")
rm(list = ls())
q()
```

RStudio - Shortcuts

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statistics
computing

Ctrl + L: clean console

Ctrl + Shift + N: create a new script

↑: command history

Ctrl(hold) + ↑: command history with certain starts

Ctrl + Enter: execute selected codes (in a script)

Editor (WIN general) - Shortcuts

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statistics
computing

Ctrl + home/Pos1: go to the very top of a script

Ctrl + end/Ende: go to the very end of a script

Shift(hold) + ↑/↓: select line(s)

Ctrl(hold) + ←/→: select word(s)

Data Classes

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statistics
computing

```
numeric: 1.1 2.0
integer: 1 2 3
character / string: "hello world!"
logical: TRUE FALSE
factors: "male" / "female"
(complex: 1+2i)
```

Data Types

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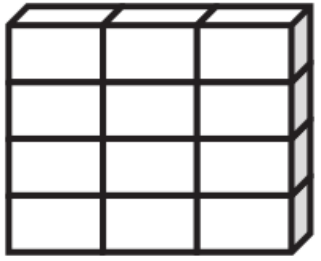
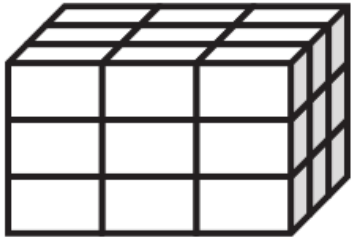
(a) Vector

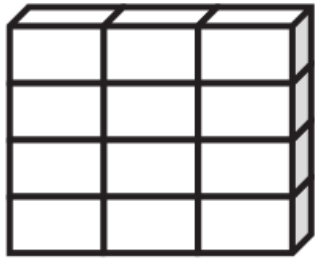
(b) Matrix



(c) Array



(d) Data frame



Columns can be different modes

(e) List

- Vectors
- Arrays
- Data frames
- Lists

Kabacoff (2015)

Exercise I

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computing

…/01.R_basics/_scripts/R_basics.R

up to “Control Flow”

TASK: practise basic R commands and data type

TIP: `class()`, `str()`

Side note: folder structure

click this to start each exercise,
then no need to set directory

Logical Operators

Operator	Summary
$<$	Less than
$>$	Greater than
$<=$	Less than or equal to
$>=$	Greater than or equal to
$==$	Equal to
$!=$	Not equal to
$!x$	NOT x
$x\|y$	x OR y
$x\&y$	x AND y

Control Flow

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computing

- if-else

```
if (cond) {
    ..statement..
}
```

```
if (cond) {
    ..statement..
} else {
    ..statement..
}
```

```
if (cond) {
    ..statement..
} else if (cond) {
    ..statement..
} else {
    ..statement..
}
```

- for-loop

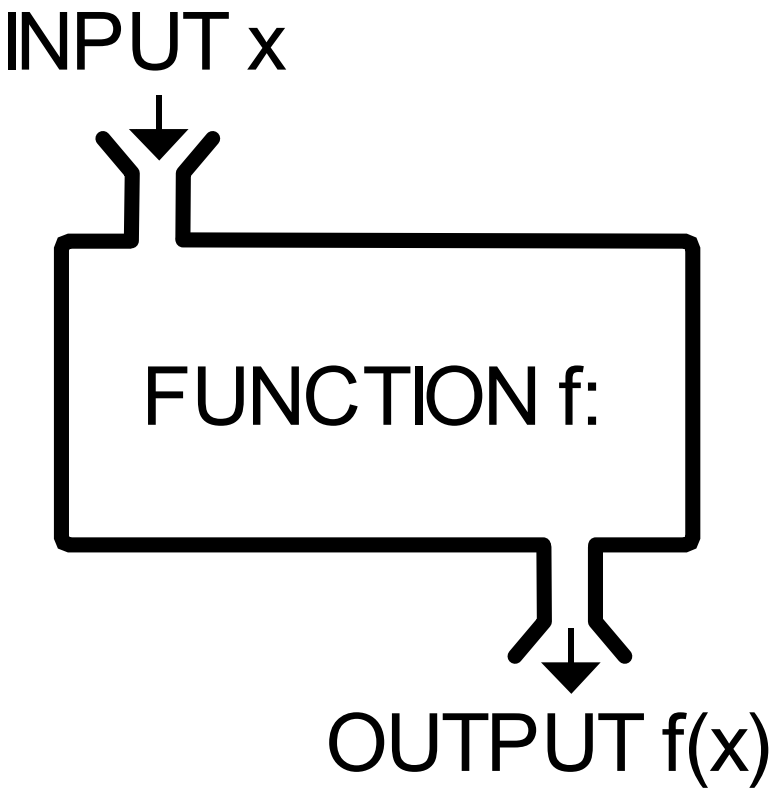
```
for ( j in 1:J) {
    ..statement..
}
```

```
for ( j in 1:J ) {
    for ( k in 1:K ) {
        ..statement..
    }
}
```

Functions

The operation(s) to obtain some quantity, based on another quantity.

- built-in functions
- external functions (packages)
- user-defined functions



User-defined Function

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computing

```
funname <- function (input_arges) {
    .. function body ..
    .. function body ..
    return(output_arges)
}
```

$$sem = \sqrt{\frac{s^2}{n-1}}$$

```
sem <- function(x) {
    sqrt( var(x,na.rm=TRUE) / (length(na.omit(x))-1) )
}
```

Exercise II

cognitive model
statistics
computing

```
…/01.R_basics/_scripts/R_basics.R
```

TASK: practise control flow and user-defined function

Exercise II

cognitive model
statistics
computing

- Generate a random number between 0 and 1
- Compare it against 1/3 and 2/3
- Print the random number and its position relative to 1/3 and 2/3.

```r
# if-else
t <- runif(1) # random number between 0 and 1
if (t <= 1/3) {
    cat("t =", , ", t <= 1/3. \n")
} else if () {
    cat("t =", t, ", t > 2/3. \n")
} else {
    cat("t =", t, ", 1/3 < t <= 2/3. \n")
}
```

Example outcome:

```
t = 0.895 , t > 2/3.
```

- Get the name of each month
- Print it one by one

```r
# for-loop
month_name <- format(ISOdate(2018,1:12,1),"%B")
for (j in 1:length(month_name) ) {
    cat()
}
```

```
The month is January
The month is February
The month is March
The month is April
The month is May
The month is June
The month is July
The month is August
The month is September
The month is October
The month is November
The month is December
```

Packages in R

R packages are collections of functions and data sets developed by the community, to make your life a lot easier!

```
install.packages('ggplot2')
library(ggplot2)
detach('package:ggplot2')
```

Visualization

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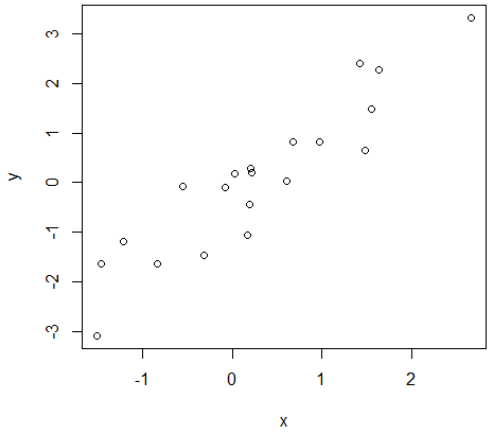
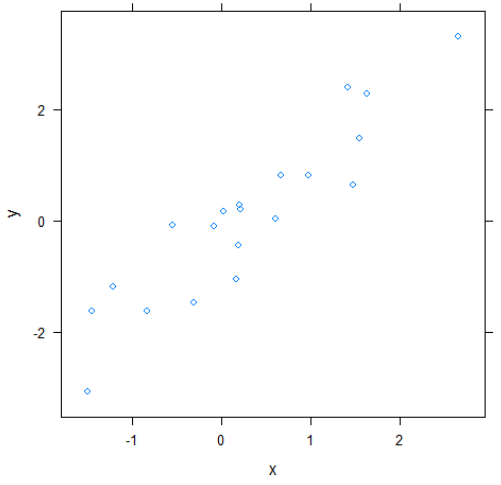
computing

- built-in plotting functions – first attempt / quick look / exploratory
- {lattice} – making nicer, similar to basic plotting functions (takes lm formulae)
- {ggplot2} – making nicer, a layering philosophy

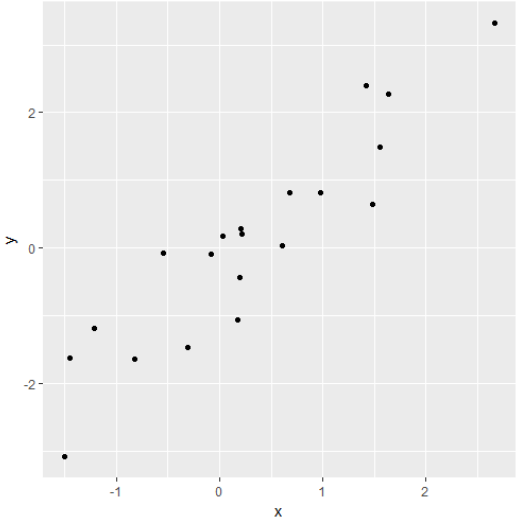
`plot(x,y)`



`lattice::xyplot(y~x)`



`ggplot2::qplot(x,y)`



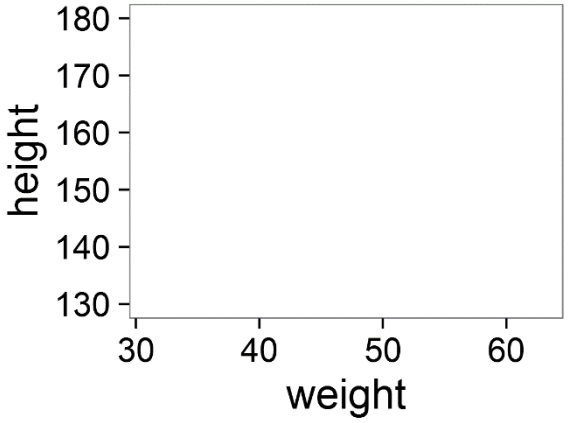
Brief Intro to ggplot2

cognitive model
statistics
computing

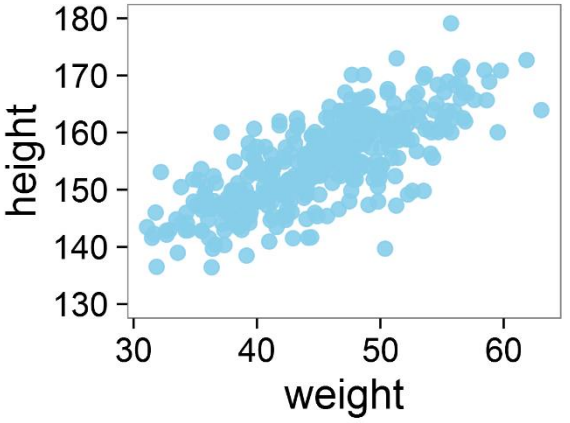
```
plot = geometric (points, lines, bars) + aesthetic (color, shape, size)
```

game of adding layers!

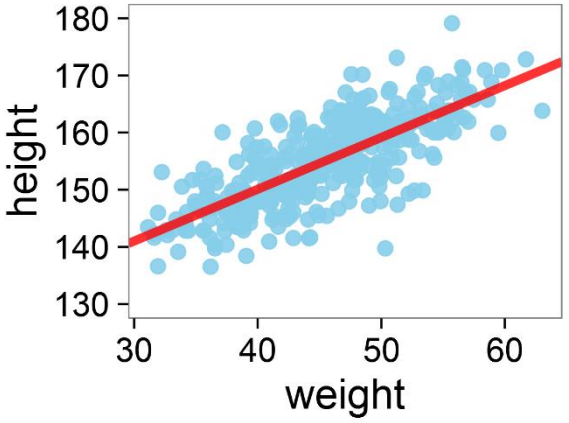
background



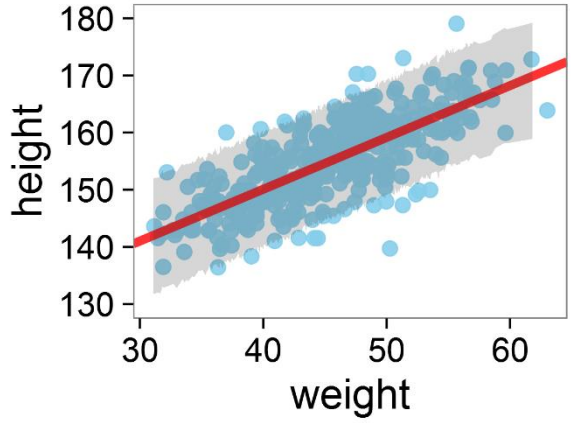
add scatters



add regression line

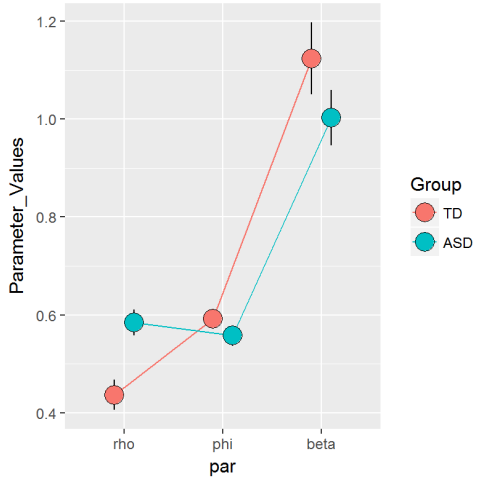


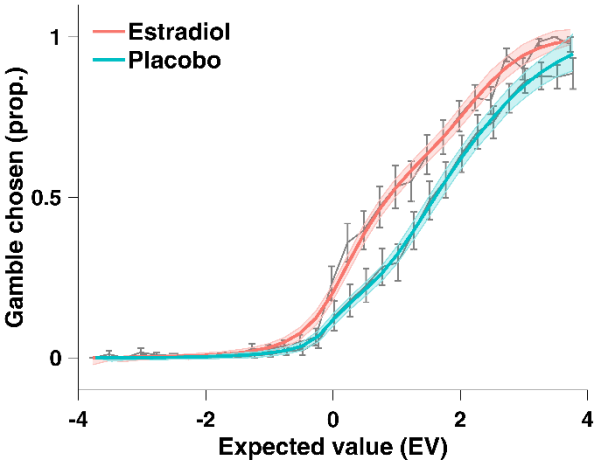
add uncertainty

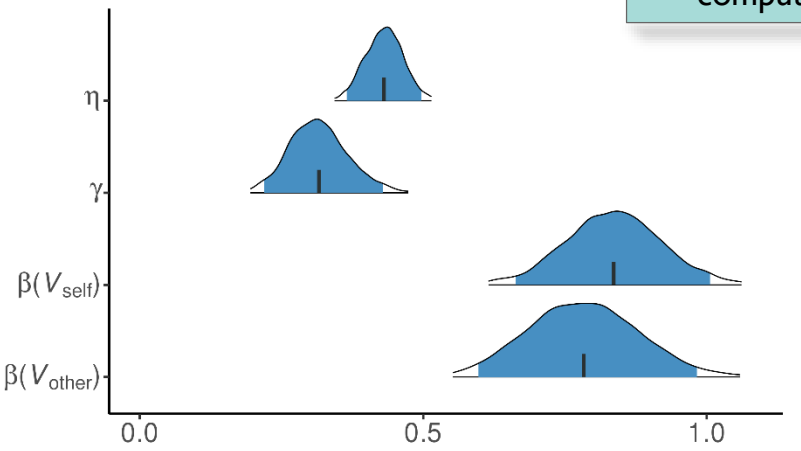


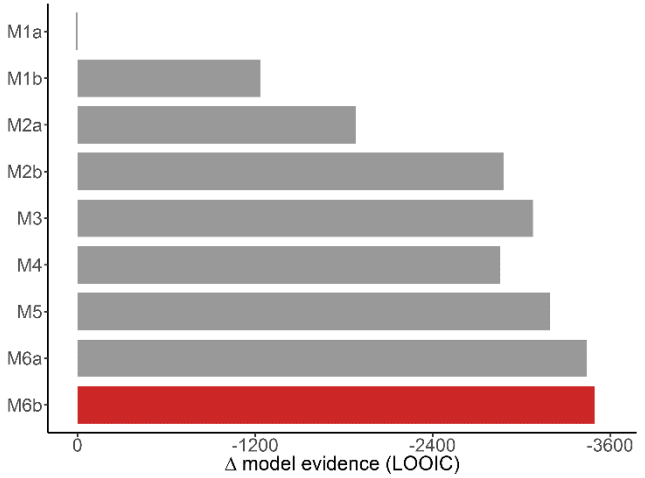
A taste of ggplot2

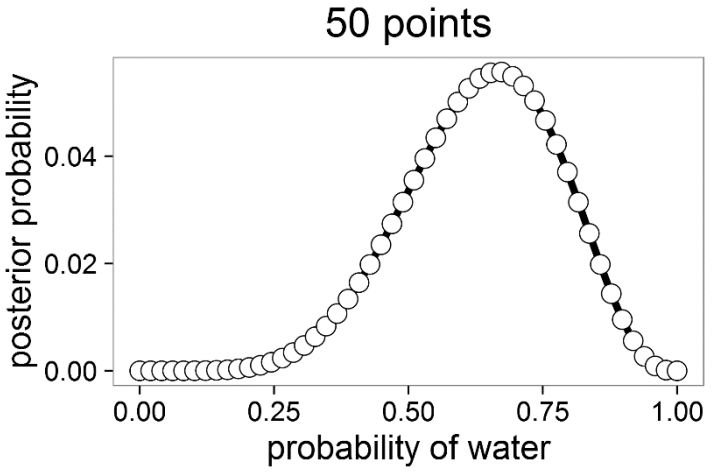
cognitive model
statistics
computing

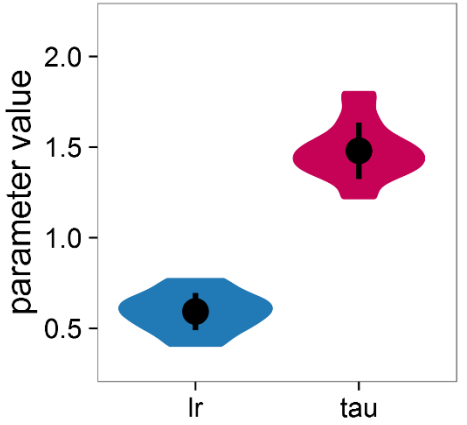






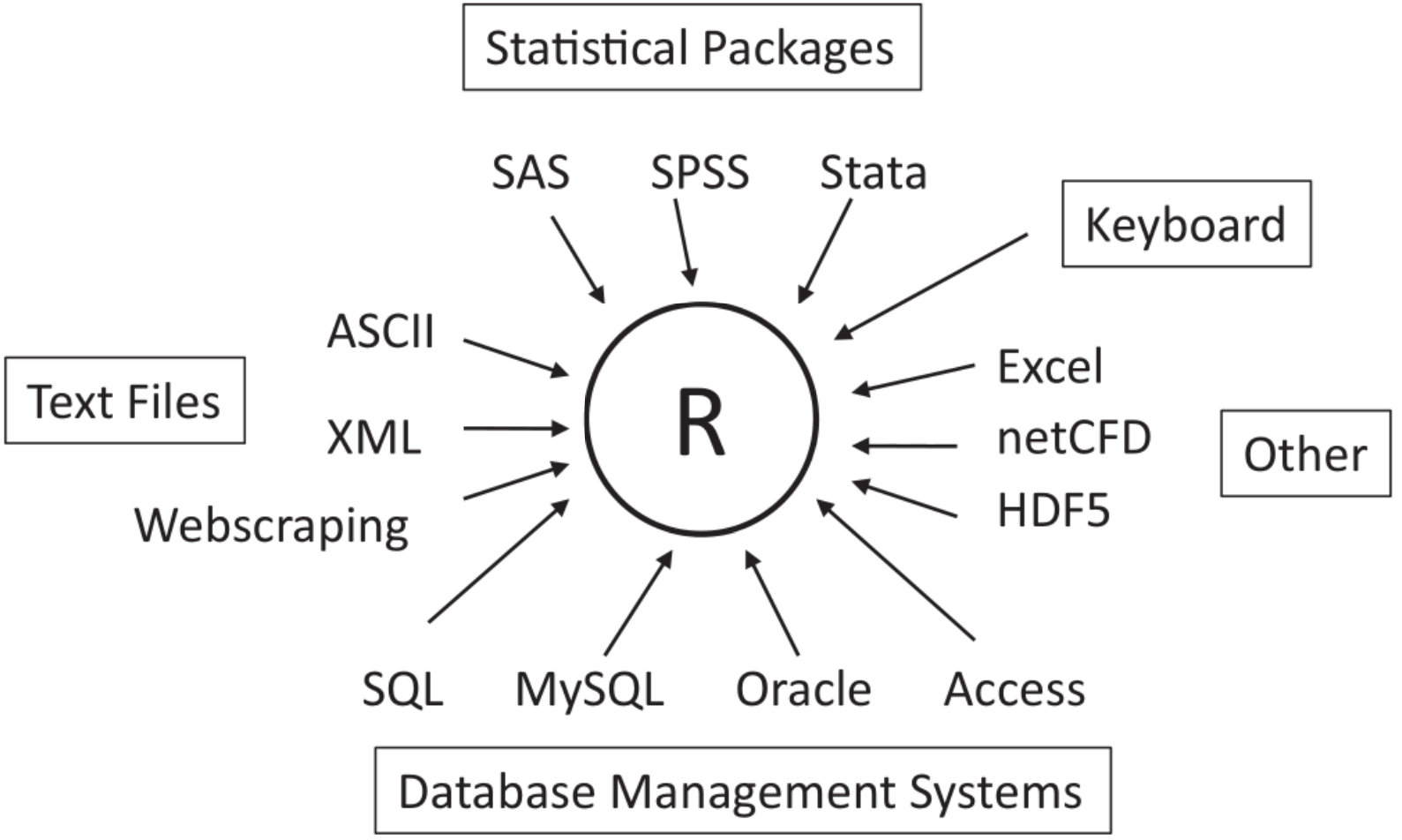






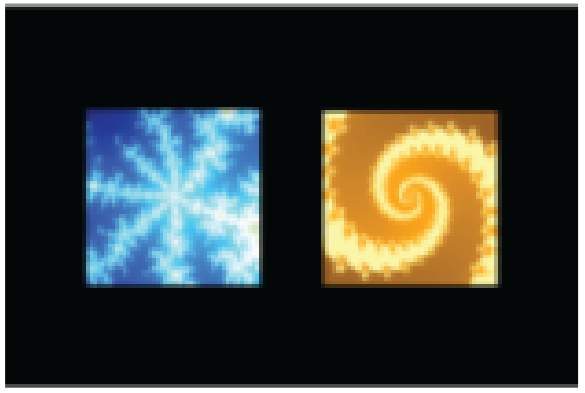
https://www.r-graph-gallery.com/

Data management

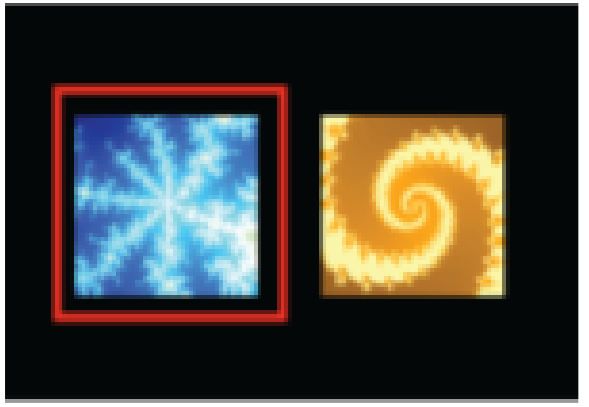


Kabacoff (2015)

One simple experiment



choice
presentation



action
selection

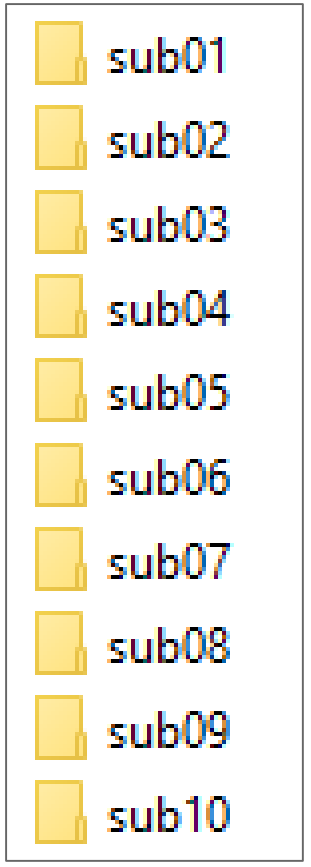
outcome

reward contingency – 80:20

The data

- nSub = 10
- nTrial = 80

./_data/_raw_data/sub01/raw_data_sub01.txt




```
subjID, trialID, choice, outcome, correct
1,1,2,-1,1
1,2,1,1,1
1,3,1,1,1
1,4,1,1,1
1,5,2,-1,1
1,6,1,1,1
1,7,1,1,1
1,8,1,1,1
1,9,1,-1,1
1,10,2,-1,1
1,11,1,1,1
1,12,1,1,1
1,13,1,-1,2
```

Import some data!

```
data_dir = ('_data/RL_raw_data/sub01/raw_data_sub01.txt')
data = read.table(data_dir, header = T, sep = ",")
head(data)
```

```
  subjID trialID choice outcome correct
1      1       1      1       1       1
2      1       2      1       1       1
3      1       3      1       1       1
4      1       4     NA       1       1
5      1       5      1      -1       1
6      1       6      2      -1       1
```

Indexing

```
data[1,1]
data[1,]
data[,1]
data[1:10,]
data[,1:2]
data[1:10, 1:2]
data[c(1,3,5,6), c(2,4)]

data$choice
```

```
> data
   subjID trialID choice outcome correct
1       1       1      1       1       1
2       1       2      1       1       1
3       1       3      1       1       1
5       1       5      1      -1       1
6       1       6      2      -1       1
7       1       7      1       1       1
8       1       8      1       1       1
9       1       9      1       1       1
10      1      10      1       1       1
11      1      11      1       1       1
```

Import some data!

```
data_dir = ('_data/RL_raw_data/sub01/raw_data_sub01.txt')
data = read.table(data_dir, header = T, sep = ",")
head(data)
```

```
  subjID trialID choice outcome correct
1      1       1      1       1       1
2      1       2      1       1       1
3      1       3      1       1       1
4      1       4     NA       1       1
5      1       5      1      -1       1
6      1       6      2      -1       1
```

```
sum(complete.cases(data))   # number of valid trials
data = data[complete.cases(data),]
dim(data[complete.cases(data),])
```

Exercise III

```
…/01.R_basics/_scripts/R_basics.R
```

TASK:

write a for loop

… which reads in each participant's raw data

… and reshape it in the "long format" by subj

TIP: complete line 173

```
for ( j in 1:n ) {
   read.table(file, header = T, sep = ",")
}
```

subID	Choice
sub01	1
sub01	2
…	
sub02	2
sub02	2
…	
sub10	2
sub10	1

Read all the data!

```
ns = 10
data_dir = '_data/RL_raw_data'

rawdata = c();
for (s in 1:ns) {
    sub_file = file.path(data_dir, sprintf('sub%02i/raw_data_sub%02i.txt',s,s))
    sub_data = read.table(sub_file, header = T, sep = ",")
    rawdata = rbind(rawdata, sub_data)
}
rawdata = rawdata[complete.cases(rawdata),]
rawdata$accuracy = (rawdata$choice == rawdata$correct) * 1.0

acc_mean = aggregate(rawdata$accuracy, by = list(rawdata$subjID), mean)[,2]
```

mean choice accuracy across trials, per participant.

Basic stats

```
> as.matrix(acc_mean, 10, 1)
          [,1]
 [1,] 0.8076923
 [2,] 0.7125000
 [3,] 0.6875000
 [4,] 0.6493506
 [5,] 0.7750000
 [6,] 0.7250000
 [7,] 0.7662338
 [8,] 0.8000000
 [9,] 0.7500000
[10,] 0.6750000
```

```
mean(acc_mean)
sd(acc_mean)
sem(acc_mean)

t.test(acc_mean, mu = 0.5) # one sample t-test

        One Sample t-test

data:  acc_mean
t = 13.788, df = 9, p-value = 2.34e-07
alternative hypothesis: true mean is not equal to 0.5
95 percent confidence interval:
 0.6962988 0.7733565
sample estimates:
mean of x
0.7348277
```

Basic correlation

```
load('_data/RL_descriptive.RData')
descriptive$acc = acc_mean
df = descriptive

cor.test(df$IQ, df$acc)

        Pearson's product-moment correlation

data:  df$IQ and df$acc
t = 4.8347, df = 8, p-value = 0.001297
alternative hypothesis: true correlation is not equal to 0
95 percent confidence interval:
 0.5114810 0.9671586
sample estimates:
      cor
0.8631401
```

```
> descriptive
   subjID        IQ      Age    acc
1       1 123.98691 31.07218 0.8125
2       2  87.63187 30.13800 0.7125
3       3  89.39930 23.44219 0.6875
4       4  84.34607 27.44848 0.6500
5       5 134.72208 23.30624 0.7750
6       6  84.60797 25.67858 0.7250
7       7 111.10238 24.36375 0.7750
8       8 117.89599 32.74026 0.8000
9       9  96.88233 22.80211 0.7500
10     10  76.01652 30.44258 0.6750
```

Exercise IV

```
…/01.R_basics/_scripts/R_basics.R
```

TASK:

Read in the descriptive data: _data/descriptive.RData

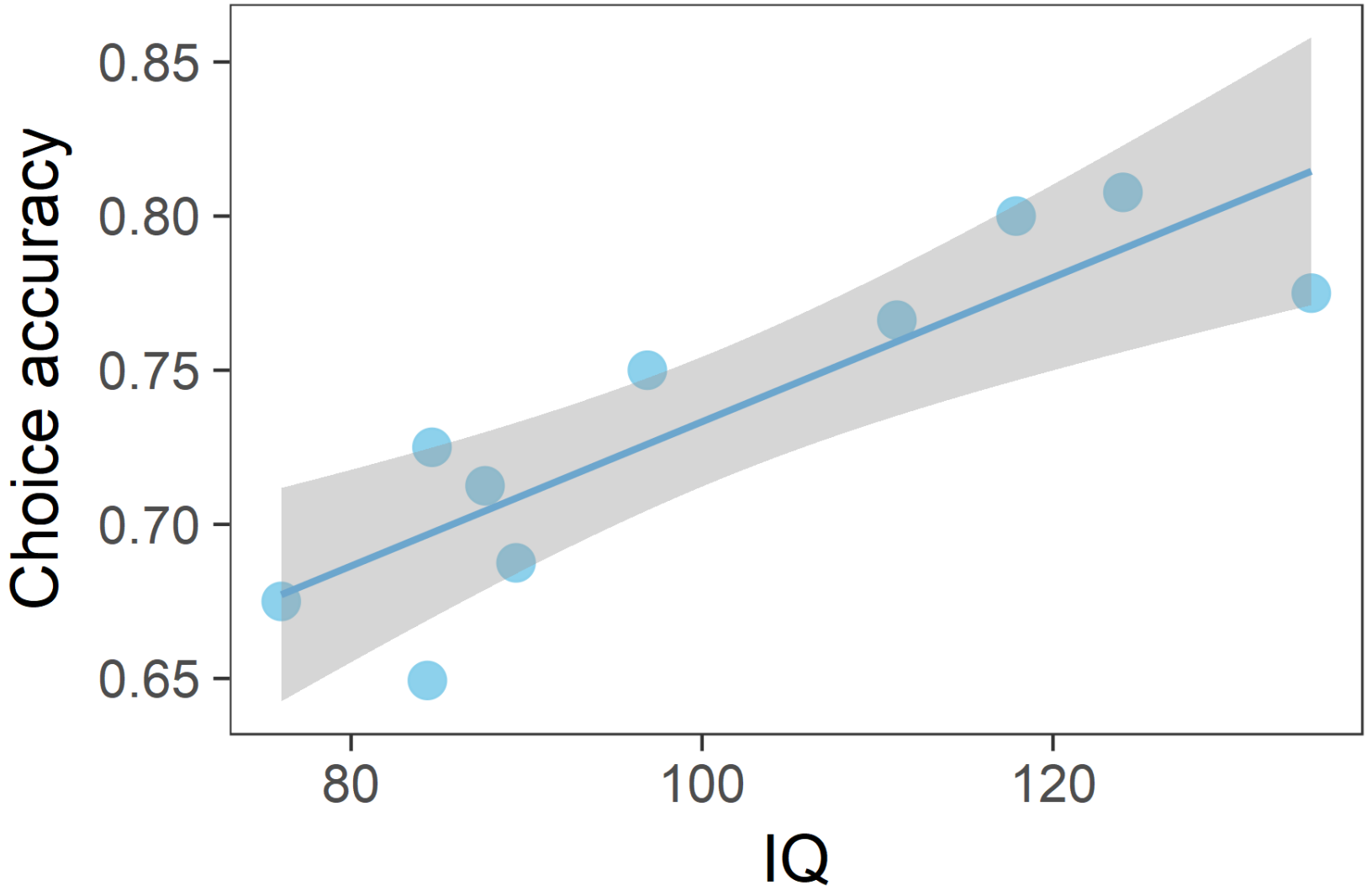
…include ‘acc_mean’ as a new column, and

…rename ‘descriptive’ as df.

Practice all the basic stats.

```
df$new_Col = new_Col
```

A simple linear regression



What is exactly the regression line in R?

$$\mu_i = \alpha + \beta x_i$$

$$y_i = \mu_i + \varepsilon$$

$0.8631^2 = 0.7131$

```
fit1 = lm(acc ~ IQ, data = df)
summary(fit1)

Call:
lm(formula = acc ~ IQ, data = df)

Residuals:
      Min        1Q    Median        3Q       Max
-0.047305 -0.016277  0.007562  0.022577  0.027731

Coefficients:
             Estimate Std. Error t value Pr(>|t|)
(Intercept) 0.499292   0.049565  10.073 8.04e-06 ***
IQ          0.002340   0.000484   4.835   0.0013 **
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.02885 on 8 degrees of freedom
Multiple R-squared:  0.745,  Adjusted R-squared:  0.7131
F-statistic: 23.37 on 1 and 8 DF,  p-value: 0.001297
```

Exercise V

```
…/01.R_basics/_scripts/R_basics.R
```

TASK:

Read and make sense of the ggplot functions,

… experiment make some adjustments (color marker size etc.), and

… run the `lm(acc ~ IQ)`


ANY
QUESTIONS
?

Happy Computing!