Advanced R Programming - Lecture 4

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(slides based on Leif Jonsson's and Måns Magnusson's)

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Today

Linear algebra using R

Dynamic Documentation with knitr and R-Markdown

ggplot2

Object orientation

Questions since last time?

Big Bang Theory!

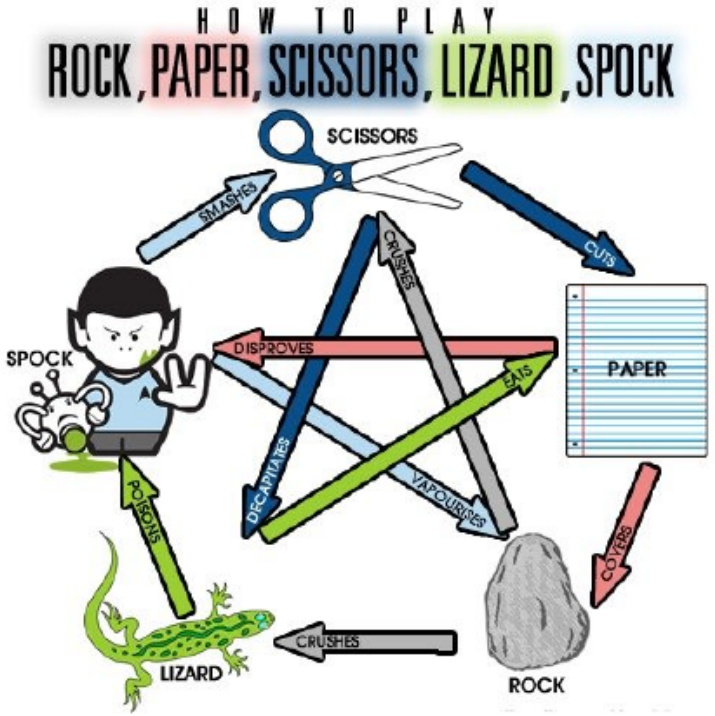


Figure: Rock-paper-scissors according to Sheldon!

http://www.fanpop.com/clubs/the-big-bang-theory/images/34015104/title/rock-paper-scissors-lizard-spock-fanart

sheldon_game (idea, not full solution)

```
sheldon_game <- function(player1, player2){
  alt <- c("rock", "lizard", "spock", "scissors", "paper")
  stopifnot(player1 %in% alt, player2 %in% alt)
  alt1 <- which(alt %in% player1)
  alt2 <- which(alt %in% player2)

  if(any((alt1 + c(1,3)) %% 5 == alt2)) {
        return("Player 1 wins!")
  } else {
        return("Player 2 wins!")
  }
  return("Draw!")
}
```

Linear algebra in R

Basics in base

Uses LINPACK or LAPACK

Extra functionality : Matrix package
(extra LAPACK functionality)

(symbolic algebra e.g. `caracas` package)

Linear algebra

```
# Create matrix
A <- matrix(1:9,ncol=3)

# Block matrices
cbind(A,A); rbind(A,A)

# Transpose
t(A)

# Addition and subtraction
A + A; A - A

# Matrix multiplication; scalar product
A%*%A; t(x)%*%x

# Matrix inversion; solving Ax=b
solve(A); solve(A,b)
```

Linear algebra

```
# Eigenvalues
eigen(A)

# Determinants
det(A)

# Matrix factorization
svd(A)
qr(A)

# Cholesky decomposition
chol(A)
```

Donald E. Knuth, Literate Programming, 1984

"Let us change our traditional attitude to the construction of programs: Instead of imagining that our main task is to instruct a computer what to do, let us concentrate rather on explaining to humans what we want the computer to do."

- Donald E. Knuth, Literate Programming, 1984

Motivation

- Good documentation is **essential** for code to remain relevant
- Programmes are sometimes so complex that comments within source code do not adequately describe the author's thoughts - **programme maintenance** and **reproducible research**, on the other hand, do require detailed documentation
- Moreover, several practical use-cases require **well formatted** code documentation
- **Dynamic Documentation** allows for the embedding of code within documentation, thus helping create well-formatted documents that explain what specific code segments do

R Markdown for Dynamic Documentation with R Code (and more)

- The main workhorse of dynamic documentation containing R code is the **knitr** package
- **knitr** supports the embedding of code in various programming languages (R, Python, SQL etc.) in various document formats (markdown, LaTeX, HTML, etc.)
- Another package, **Pandoc**, converts markdown documents (and others) into a number of different formats, including PDF, Word, HTML etc.
- **R Markdown** combines the functionalities of **knitr** & **Pandoc**
- **R Studio** provides a convenient interface for developing, previewing and knitting R Markdown files

R Markdown Workflow

(a) User builds .rmd (R Mark-down) file

(b) User knits .rmd files using **knitr**

(c) **knitr** produces markdown output

(d) **Pandoc** converts markdown into final format of user's choice

Basic Components of an R Markdown file: Metadata

- Metadata are optional, but when written, they are typically found at the beginning of a .rmd file
- Demarcated with three dashes '—' at their beginning and end
- Written in YAML (https://en.wikipedia.org/wiki/YAML)
- A simple example:

```
---
title: "Untitled"
author: "John Doe"
date: '2022-06-13'
output:
  pdf_document: default
  html_document:
    df_print: paged
---
```

See https://bookdown.org/yihui/bookdown/r-markdown.html for more details

Basic Components of an R Markdown file: Text

- Text (the narrative behind the code/report) are to be written in Markdown
- A number of in-line formatting options available: Boldface text through **text**, italics through *text* or _text_, subscripts through ~, superscripts through ^etc.
- Organise header levels through # for Header Level 1, ## for Header Level 2, etc.
- Write math/equations through LaTeX syntax within a pair of dollar signs: e.g., write $\alpha_0 = 10^2$ to produce $\alpha_0 = 10^2$
- References can be done similarily as in LaTeX, with a .bib file and in text as [@refid]

See https://bookdown.org/yihui/rmarkdown/markdown-syntax.html for more details

Basic Components of an R Markdown file: Code

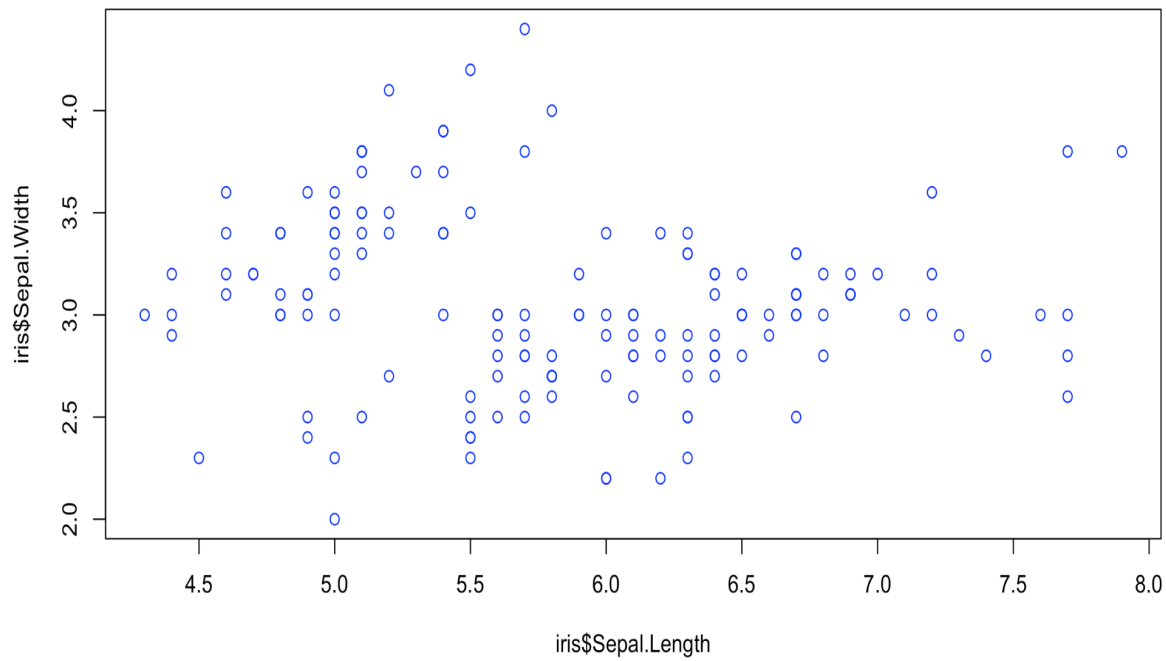
- Code are written in 'chunks' demarcated by three backticks ``` at their beginning and end
- The first set of three backticks in a code chunk must be followed by a mandatory keyword, the language of code (e.g. R) enclosed in curly braces
- Thereafter, optional 'chunk' parameters may also be specified by name within the curly braces, each specification separated by a comma
- Inline code is demarcated by a single backtick ` at the beginning and end

See https://bookdown.org/yihui/rmarkdown/basics.html for more details

Basic Components of an R Markdown file: Code

- A simple example:

````
```{r, fig.height=2, fig.width = 4}
data(iris)
plot(iris$Sepal.Length, iris$Sepal.Width, col = 'blue')
```
````



ggplot2

popular visualization package

"The grammar of graphics"
- the language of visualization

flexible

ggplot examples:
`http://shiny.stat.ubc.ca/r-graph-catalog/`

The Grammar

Create a graph layer by layer

Store as object (print to plot)

Three (main) parts:

`data`	The dataset with observations to be visualized (data.frame)
`geom`	The geometric representation of data (see subsequent slides)
`aes`	The mapping of colors/shape to data (see subsequent slides)

geom

`geom_histogram`	Histograms (Continuous Univariate Analysis)
`geom_density`	Density Plots (Continuous Univariate Analysis)
`geom_bar`	Barchart (Discrete Univariate Analysis)
`geom_point`	Scatterplots (Continuous Bivariate Analysis)
`geom_boxplot`	Boxplot (Discrete-Continuous Bivariate Analysis)
`geom_density_2d`	2D Density Plots (Continuous Bivariate Analysis)
`geom_contour`	Contour Plots (Continuous Trivariate Analysis)
`geom_line`	Lineplots (Versatile)
...	...

See https://raw.githubusercontent.com/rstudio/cheatsheets/main/data-visualization.pdf for more ideas

aes

`x`	String; X-axis variable; name of column in data
`y`	Optional; String; Y-axis variable; name of column in data
`size`	Optional; Integer; width of line (if applicable) in mm.
`colour`	Optional; Colour corresponding to `geom`
`shape`	Optional; Shape corresponding to `geom`
...	...

See https://ggplot2.tidyverse.org/articles/ggplot2-specs.html for more details

Special aes

geom	Special aes
geom_point	point shape, point size
geom_line	line type, line size
geom_bar	y min, y max, fill color, outline color
...	...

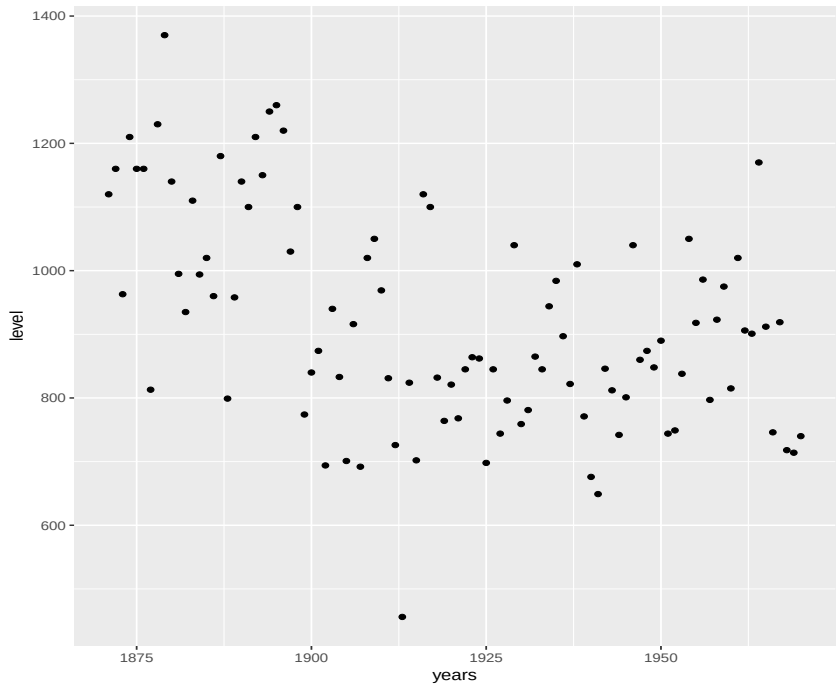
GGPlot2: Example

```
library(ggplot2)

# Preprocessing
data(Nile)
Nile <- as.data.frame(Nile)
colnames(Nile) <- "level"
Nile$years <- 1871:1970
Nile$period <- "- 1900"
Nile$period[Nile$years>=1900]<-"1900 - 1945"
Nile$period[Nile$years > 1945] <- "1945 +"
Nile$period <- as.factor(Nile$period)
```

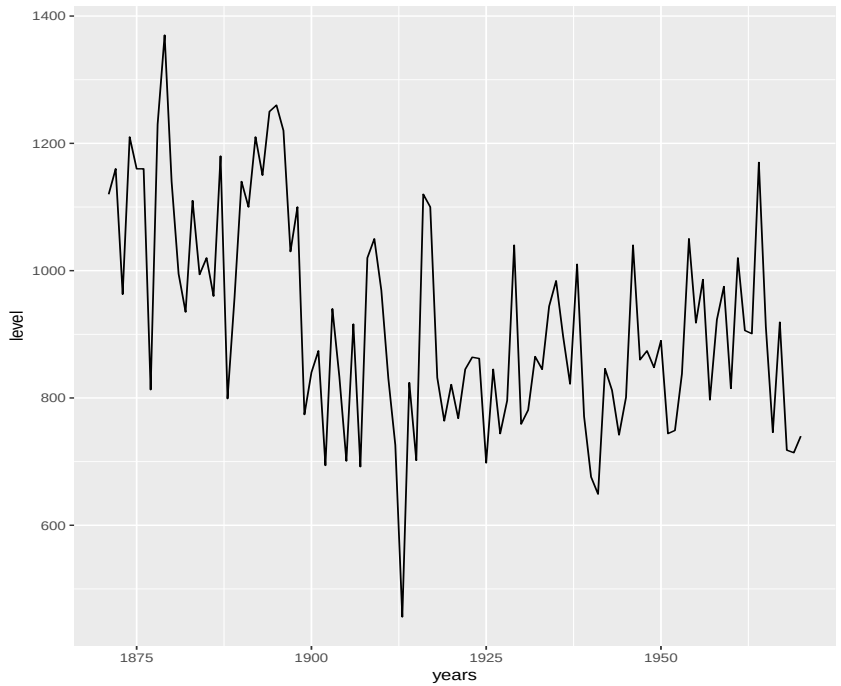
GGPlot2: geom_point

```
pl <-
        ggplot(data=Nile) +
        aes(x=years, y=level) +
        geom_point()
pl
```



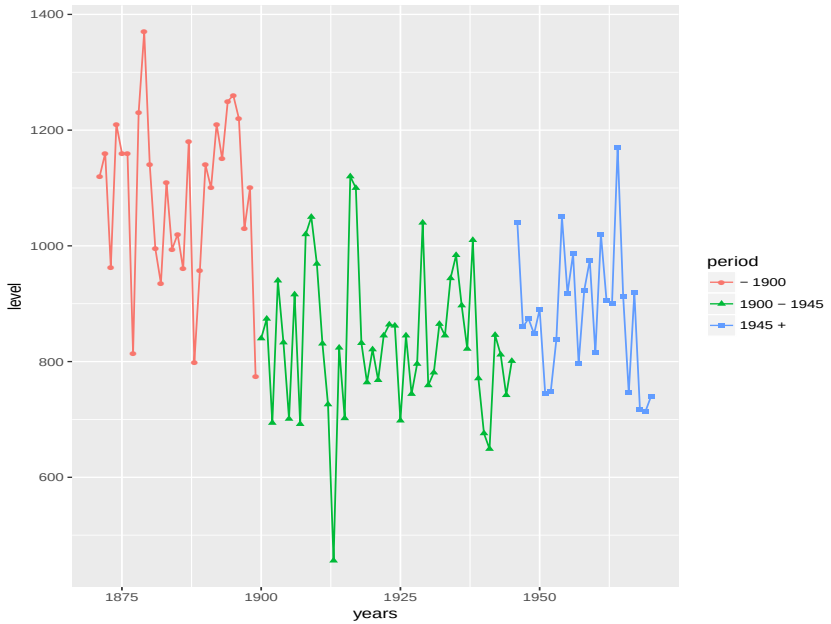
GGPlot2: geom_line

```
pl <-
        ggplot(data=Nile) +
        aes(x=years, y=level) +
        geom_line()
pl
```



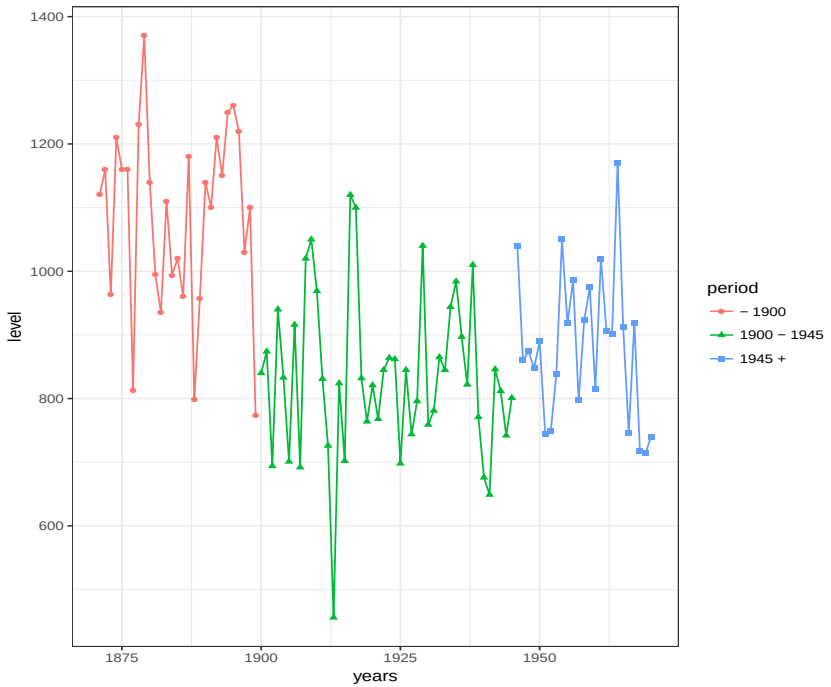
GGPlot2: geom_point + geom_line + colors!

```
pl <-
        ggplot(data=Nile) +
        aes(x=years, y=level, color=period) +
        geom_line(aes(type=period)) +
        geom_point(aes(shape=period))
pl
```



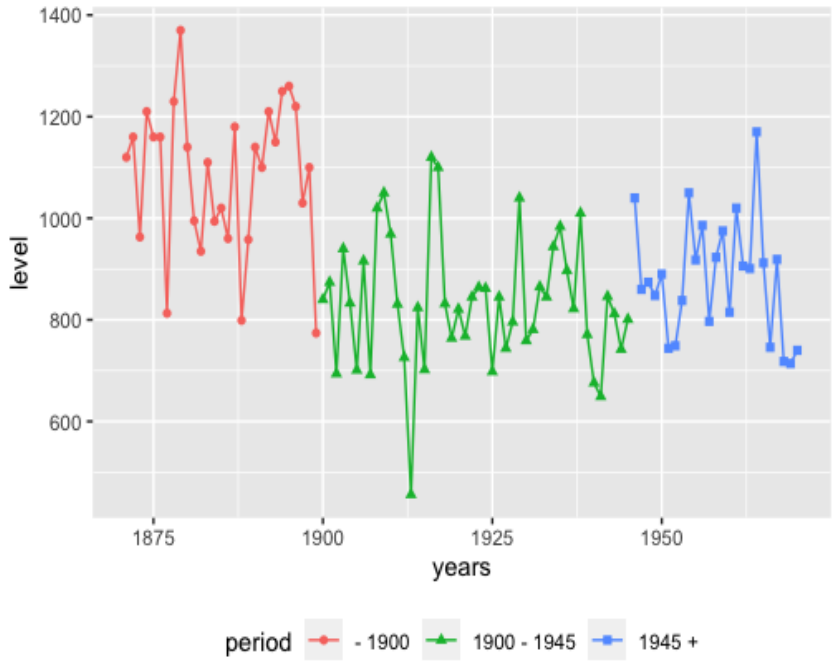
GGPlot2: use BW theme

```
pl + theme_bw()
```



GGPlot2: Change Legend Position

```
pl + theme(legend.position="bottom")
```



Object orientation

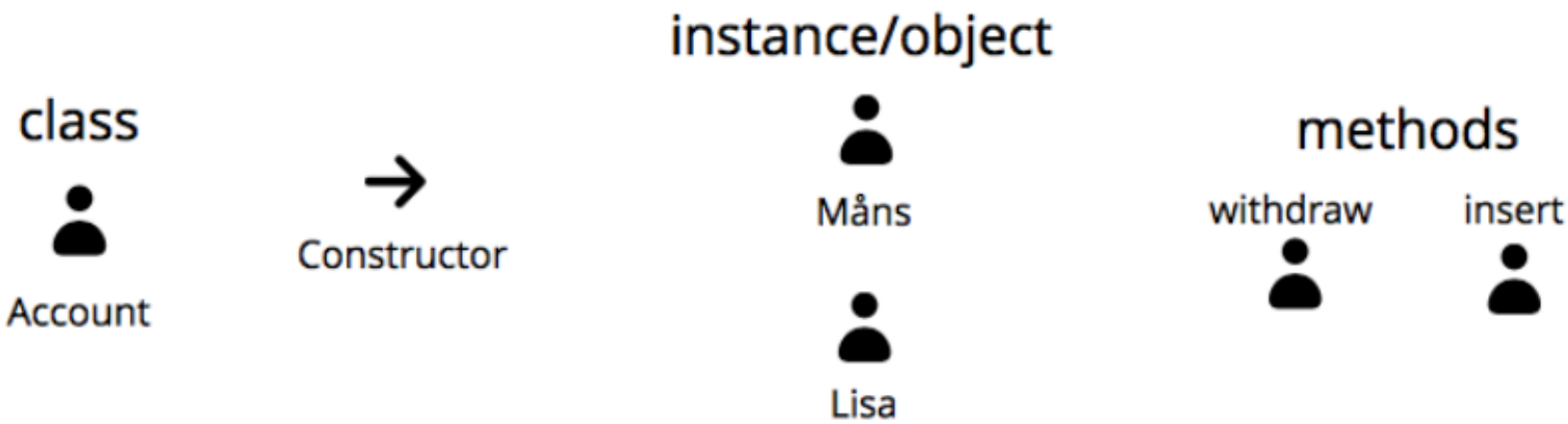
Programming paradigm

Mutable states

Key abstraction is "an object"

R is *not* purely object oriented

Object orientation



Object orientation

Fields

currency : class variable

current_amount : object variable

no_withdraws : object variable

Methods

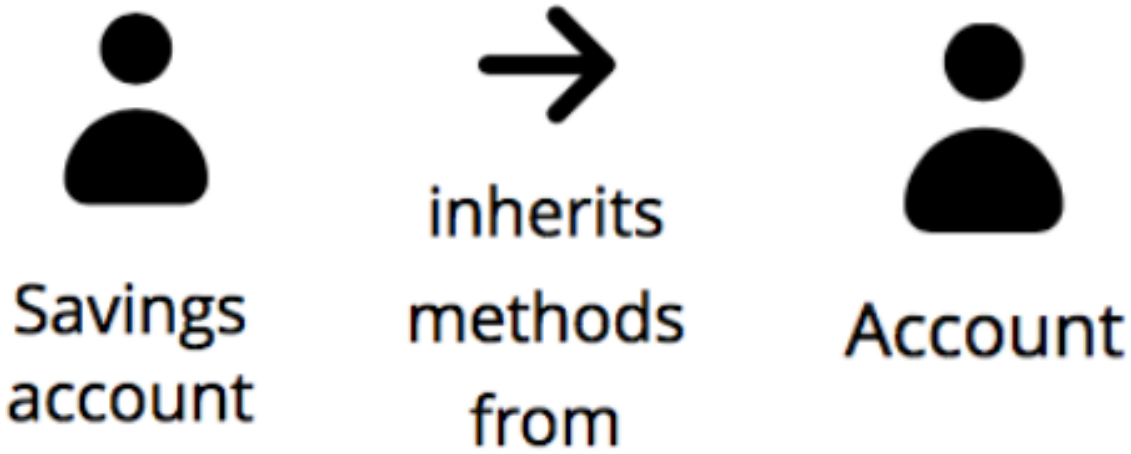
insert()

withdraw()

Object orientation

- **class**: template and generator of objects
- **constructor**: minimal set all fields to default values (organize the memory allocated for the object)
- **interface**: collection of "services" the class/object offers, *public interface*, need to be exported in `NAMESPACE`

Inheritance



Possible from multiple classes, your class can extend more than one class.

Object orientation in R

S3
Simple
Methods belongs to functions

Object orientation in R

S3	S4
Simple	More formal
Methods belongs to functions	Methods belongs to functions
	@Fields
	Parents

Object orientation in R

S3	S4	RC
Simple	More formal	Latest (R 2.12)
Methods belongs to functions	Methods belongs to functions	no copy-on-modify
	@Fields	Methods belongs to objects
	Parents	Objects have Fields and methods $

S3

- "Not really objects, more of a naming convention"
- "Based around the `.` syntax: E.g. for `print`, `print` calls `print.lm` `print.anova`, etc. And if not found, `print.default`"

https://stackoverflow.com/questions/9521651/r-and-object-oriented-programming

```
# Create object
x <- 1:100
class(x) <- "my_numeric"
```

S3

Methods belong to functions (the generic ones)

```
# Create object
x <- 1:100
class(x) <- "my_numeric"

# Create generic function
# S3 classes have own implementation
# of a function called f
f <- function(x) UseMethod("f")
```

S3

`print()` is a generic function

```
# Create object
x <- 1:100
class(x) <- "my_numeric"

# Create generic function
# S3 classes have own implementation
# of a function called f
f <- function(x) UseMethod("f")

# Create method
print.my_numeric <- function(x, ...){
        cat("This is my numeric vector.")
}
```

call: `print(x)`

S3

```
# Create object
x <- 1:100
class(x) <- "my_numeric"

# Create generic function
# S3 classes have own implementation
# of a function called f
f <- function(x) UseMethod("f")

# Create method
print.my_numeric <- function(x, ...){
        cat("This is my numeric vector.")
}
```

Usage of `.` discouraged in names of own functions and objects.
`t.test()`: `t` method for `test` objects?
(typo p.103 of printed book, Ed. 1, online is correct)

S4

```
# Create class with slots (with permitted classes)
setClass("Person",
slots=list(name="character", age="numeric",
 salary="numeric"))
# Create inheriting class, can inherit from multiple
setClass("Employee",
slots=list(boss="Person"),contains="Person")

alice<-new("Person", name="Alice",age=40, salary=100)
alice@age
bob<-new("Employee", name="Bob",age=25, salary=100,
boss=alice)
```

S4: Methods: create a generic, then instances

```
setGeneric("salary_change", function(p, i) {
   standardGeneric("salary_change")
 })
setMethod("salary_change",
signature(p = "Person", i = "numeric"),
  function(p, i) {
    p@salary+i
  })
setMethod("salary_change",
signature(p = "Employee", i = "numeric"),
  function(p, i) {
     nsal<-callNextMethod()
     ## method from parent (contained) class
     if (nsal>p@boss@salary){nsal<-p@salary}
     nsal
  })
```

S4: printing

define in S3 style `print.Person()`

BUT

define method `show` for class
(allows for arbitrary, appropriate default displaying, when not calling `print()`)

```
setMethod("show","Person",
     function(object){
     cat(paste0(object@name,":␣",object@age,"y/o"))
     cat("\n")
})
```

RC

```
# Create object with fields and methods
Account <- setRefClass("Account",
        fields = list(balance = "numeric"),
        methods = list(
                withdraw = function(x) {
                        balance <<- balance - x
                },
                deposit = function(x) {
                        balance <<- balance + x
                }
        )
)
```

RC: objects are mutable

```
a<-Account$new(balance=100)

a$balance<-200; a$balance ##output: 200
b<-a;b$balance ##output: 200
a$balance<-0;b$balance ##output: 0

c<-a$copy() ## all RC objects have a copy() method

a$balance<-100;c$balance;a$balance ##output: 0, 100

## S4: if we change something in alice,
## then bob's boss does not change
salary_change(bob,5) ##output: 100
alice@salary<-salary_change(alice,10)
salary_change(bob,5) ##output: 100
bob@boss<-alice; salary_change(bob,5) ##output: 105
```

RC: printing (compare S4), constructor

define in S3 style `print.Account()`

BUT

define method `show` for class
(allows for arbitrary, appropriate default displaying, when not calling `print()`)

```
Account$methods(show=function(){
cat(paste0("Account␣balance:␣",.self$balance,"\n"))})
```

```
Account$methods(initialize=function(balance=0){
.self$balance<<-balance;cat("Account␣created!\n")})
d<-Account(300)
```

Checking class: use `inherits()` **NOT** `class()`

Problem with *multiple class* inheritance

```
x<-1; class(x)<-c("a","b","c")
class(x)
[1] "a" "b" "c"
class(x)=="a"
[1]  TRUE FALSE FALSE
if (class(x)=="a"){}
NULL
Warning message:
In if (class(x) == "a") { :
  the condition has length > 1 and only the
  first element will be used
inherits(x,"a")
[1] TRUE
```

NAMESPACE: exporting **(LABS!)**

S3

`S3method(method, class)`

e.g. `S3method(print, my_numeric)`

S4

in `DESCRIPTION Depends: methods`

`exportClasses(class)`: class publicly avaialable,

`export(class)`: generator publicly avaialable

`http://stat.ethz.ch/R-manual/R-devel/library/methods/html/Introduction.html`

`exportMethods(method)`: "If a package defines methods for generic functions, those methods should be exported if any of the classes involved are exported", e.g. `plot()`

`https://stat.ethz.ch/R-manual/R-patched/library/methods/html/setMethod.html`

RC: same as S4 but typically impossible to be extended outside your package

NAMESPACE: importing **(LABS!)**

S4

```
importClassesFrom(package, ...)
importMethodsFrom(package, ...)
```

http://www.hep.by/gnu/r-patched/r-exts/R-exts_33.html

More OO classes

`https://stackoverflow.com/questions/9521651/r-and-object-oriented-programming`

- Reference classes `?setRefClass`, "Primarily useful to avoid making copies of large objects (pass by reference)"
- proto "Neat concept (prototypes, not classes), but seems tricky in practice"
- R6 ""'Creating an R6 class is similar to the reference class, except that theres no need to separate the fields and methods, and you cant specify the types of the fields.'""
- R.oo

The End... for today.
Questions?
See you next time!