

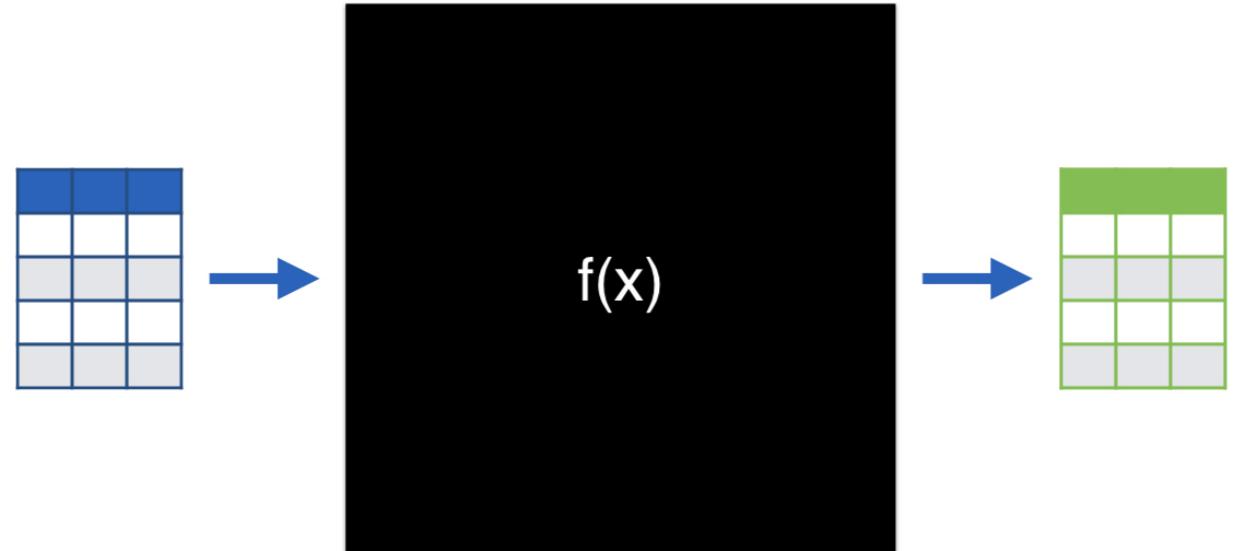
What is Object-Oriented Programming?

OBJECT-ORIENTED PROGRAMMING WITH S3 AND R6 IN R

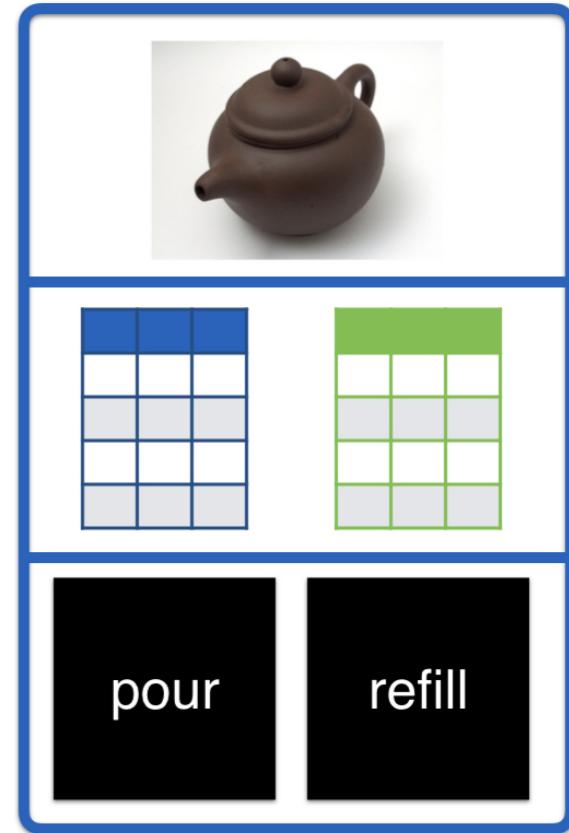


Richie Cotton

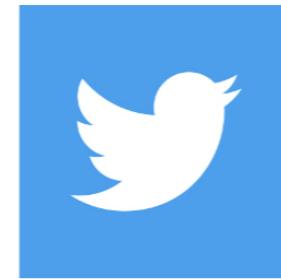
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```
calculate_something <- function(x, y, z) {  
  # do something  
  return(the_result)  
}
```



**A method is just a function, talked about
in an OOP context**



WIKIPEDIA



CDC Weekly Case Count

Disease Name
Salmonellosis

Choose date range
2015-01-01 to 2016-10-25

Location Type

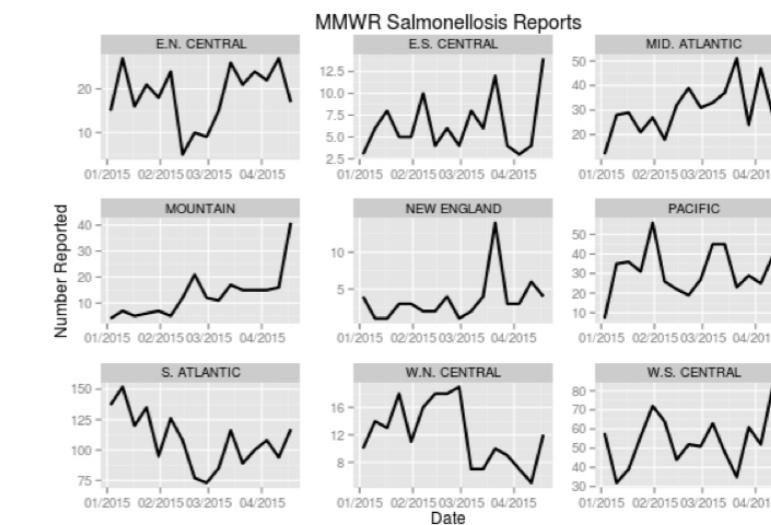
- State
- Single region
- All states within a region
- All regions
- Country

Plot Type

- Weekly data
- Weekly data by year
- Cumulative data by year

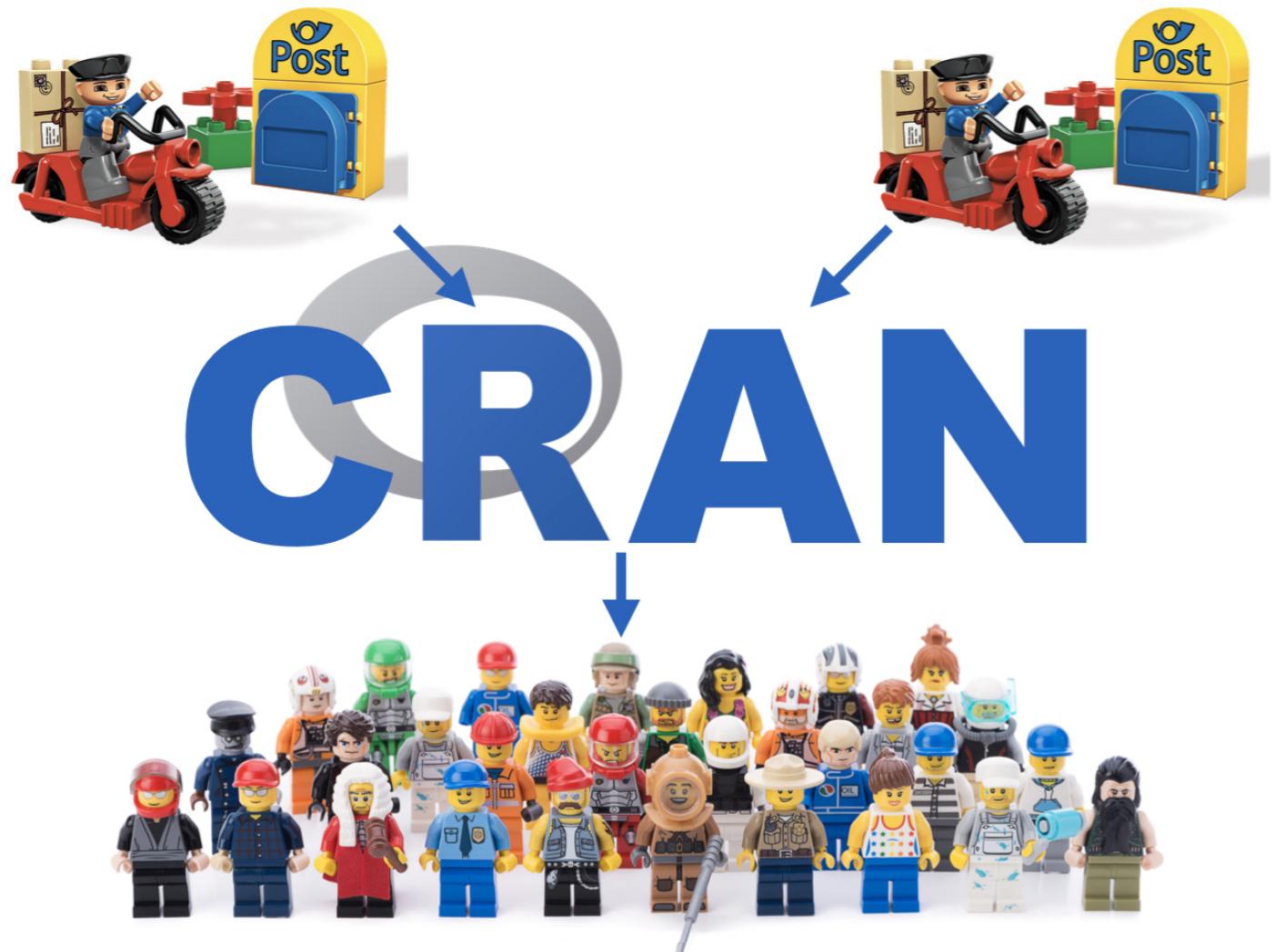
Plot Options

- Include alert thresholds (experimental)
- Force same scale for y-axis



Summary

- With **functional programming**, think about the **functions first**.
- With **object-oriented programming (OOP)** think about the **data structures first**.
- **Don't** use OOP for **general purpose data analyses**.
- **Do** use OOP when you have a **limited number of complex objects**.



Summary

- Use **S3** regularly
- Use **R6** when you need **more power**
- Use **S4** for **Bioconductor**
- Maybe use **ReferenceClasses**

How does R Distinguish Variables?

- `class()` is your **first choice** for determining the kind of variable
- `typeof()` is also **occasionally useful**
- `mode()` and `storage.mode()` are old functions; **don't use them**

```
(x <- rexp(10))
```

```
0.195051 2.191040 0.498703 0.976122 0.299001  
0.105187 0.090073 2.328233 3.043201 2.129631
```

```
class(x) <- "random_numbers"
```

```
x
```

```
0.195051 2.191040 0.498703 0.976122 0.299001  
0.105187 0.090073 2.328233 3.043201 2.129631
```

```
attr(, "class")
```

```
class(x)
```

```
"random_numbers"
```

```
typeof(x)
```

```
"double"
```

Generics and Methods

OBJECT-ORIENTED PROGRAMMING WITH S3 AND R6 IN R



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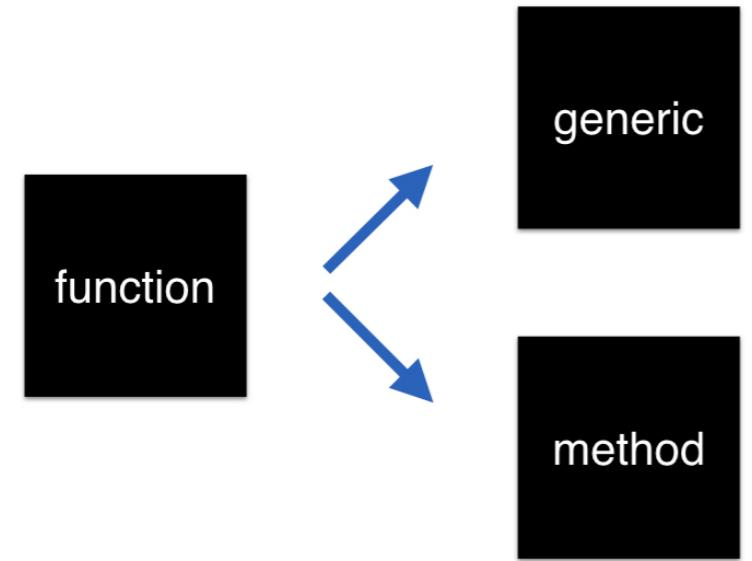
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```
summary(c(TRUE, FALSE, NA, TRUE))
```

Mode	FALSE	TRUE	NA's
logical	1	2	1

```
summary(rgamma(1000, 1))
```

Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
0.000354	0.276500	0.690300	1.020000	1.384000	9.664000



**function overloading = input-dependent
behavior**

print

```
function (x, ...)  
UseMethod("print")  
<bytecode: 0x1062f0870>  
<environment: namespace:base>
```

Methods are named generic.class

- print.Date
- summary.factor
- unique.array

Method signatures contain generic signatures

```
args(print)
```

```
function (x, ...)  
NULL
```

```
args(print.Date)
```

```
function (x, max = NULL, ...)  
NULL
```

**pass arguments between methods with ...
include it in both generic and methods**

print.function

```
function (x, useSource = TRUE, ...)  
.Internal(print.function(x, useSource, ...))
```

print.Date

```
function (x, max = NULL, ...)  
{  
  if (is.null(max))  
    max <- getOption("max.print", 9999L)  
  if (max < length(x)) {  
    print(format(x[seq_len(max)]), max = max, ...)  
    cat("[ reached getOption(\"max.print\") -- omitted",  
        length(x) - max, "entries ]\n")  
  }  
  else print(format(x, max = max, ...))  
  invisible(x)  
}
```

Summary

- Functions **split** into **generic + method**
- Methods named `generic.class`
- Method args **contain generic args (if generic has an arg method must have it also)**
- Include a `...` arg
- Use `lower_snake_case` or `lowerCamelCase`
- `sloop::is_s3_generic("print")` checks if print uses s3
`sloop::is_s3_method("print.Date")` checks that `print.Date` is used by `print` general function

We can use `generic.default()` to create a default method

we can use `ls.str` to explore the workspace

Methodical Thinking

OBJECT-ORIENTED PROGRAMMING WITH S3 AND R6 IN R



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```
methods("mean") # or methods(mean)
```

```
mean.Date      mean.default  mean.difftime mean.POSIXct
```

```
mean.POSIXlt
```

```
see '?methods' for accessing help and source code
```

```
methods(class = "glm") # or methods(class = glm)
```

```
add1           anova          coerce  
confint        cooks.distance deviance  
drop1          effects         extractAIC  
family         formula         influence  
initialize     logLik          model.frame  
nobs           predict         print  
residuals      rstandard       rstudent  
show            slotsFromS3    summary  
vcov            weights
```

see '?methods' for accessing help and source code

```
.S3methods(class = "glm")
```

```
add1           anova          confint  
cooks.distance deviance       drop1  
effects        extractAIC    family  
formula        influence      logLik  
model.frame   nobs           predict  
print           residuals     rstandard  
rstudent       summary       vcov
```

weights

see '?methods' for accessing help and source code

```
.S4methods(class = "glm")
```

```
coerce      initialize  show      slotsFromS3  
see '?methods' for accessing help and source code
```

Method Lookup for Primitive Generics

OBJECT-ORIENTED PROGRAMMING WITH S3 AND R6 IN R

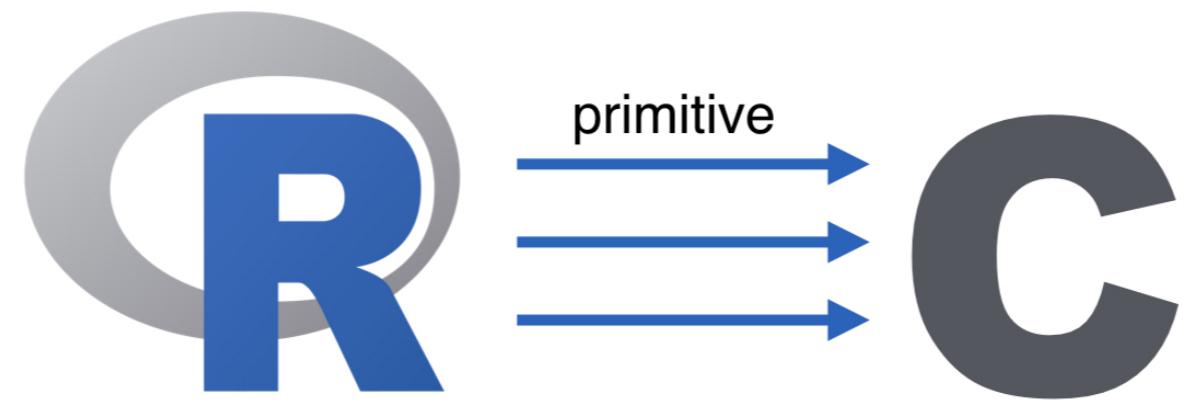


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R vs. C

- C code often runs faster
- R code is usually easier to **write**
- ... and easier to **debug**



exp

```
function (x) .Primitive("exp")
```

+

```
function (e1, e2) .Primitive("+")
```

if

```
.Primitive("if")
```

sin

```
function (x) .Primitive("sin")
```

-

```
function (e1, e2) .Primitive("-")
```

for

```
.Primitive("for")
```

.S3PrimitiveGenerics

```
"anyNA"           "as.character"    "as.complex"
"as.double"        "as.environment" "as.integer"
"as.logical"       "as.call"          "as.numeric"
"as.raw"           "c"                 "dim"
"dim<-"           "dimnames"         "dimnames<-
"is.array"         "is.finite"        "is.infinite"
"is.matrix"        "is.na"             "is.nan"
"is.numeric"       "length"           "length<-
"levels<-"        "names"            "names<-
"rep"              "seq.int"          "xtfrm"
```

```
all_of_time <- c("1970-01-01", "2012-12-21")  
as.Date(all_of_time)
```

```
"1970-01-01" "2012-12-21"
```

```
class(all_of_time) <- "date_strings"  
as.Date(all_of_time)
```

as.Date isn't a primitive generic

```
Error in as.Date.default(all_of_time) :  
  do not know how to convert 'all_of_time' to class "Date"
```

```
length(all_of_time)
```

length is a primitive generic

```
2
```

Summary

- Some R functions are actually **written in C**
- The **primitive** interface gives **best performance**
- `.S3PrimitiveGenerics` lists **primitive S3 generics**
- Primitive generics **don't throw an error** when no method is found

To confirm that method hasn't been created we can use `exists("function.class")`

When no method is found, the C-code function is called.

Too Much Class

OBJECT-ORIENTED PROGRAMMING WITH S3 AND R6 IN R



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```
x <- c(1, 3, 6, 10, 15)
class(x) <- c(
  "triangular_numbers", "natural_numbers", "numeric"
)
```

It is important to write classes from the most specificity to the most general.

```
is.numeric(x)
```

```
TRUE
```

```
inherits(x, "triangular_numbers")
```

```
TRUE
```

```
what_am_i.triangular_numbers <- function(x, ...) {  
  message("I'm triangular numbers")  
  NextMethod("what_am_i")  
}
```

```
what_am_i.natural_numbers <- function(x, ...) {  
  message("I'm natural numbers")  
  NextMethod("what_am_i")  
}
```

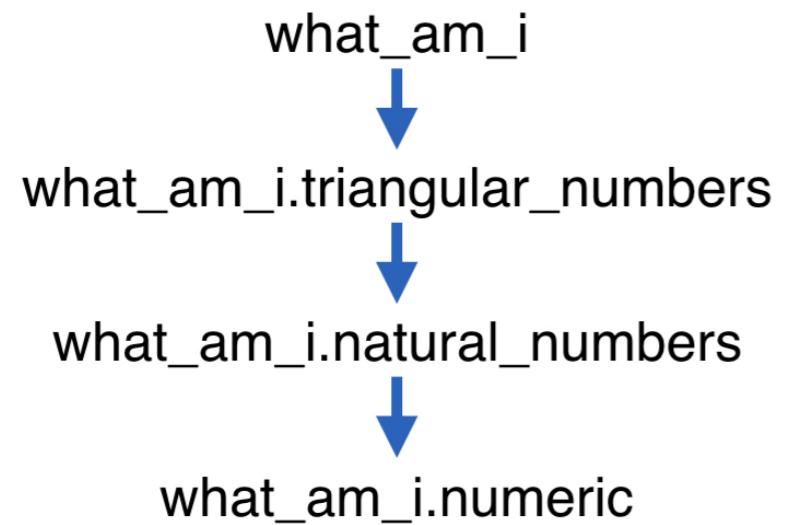
```
what_am_i.numeric <- function(x, ...) {  
  message("I'm numeric")  
}
```

`what_am_i(x)`

I'm triangular numbers

I'm natural numbers

I'm numeric



Summary

- **Multiple classes** are allowed
- Use `inherits()` to test for **arbitrary classes**
- Use `NextMethod()` to **chain method calls**

The Object Factory

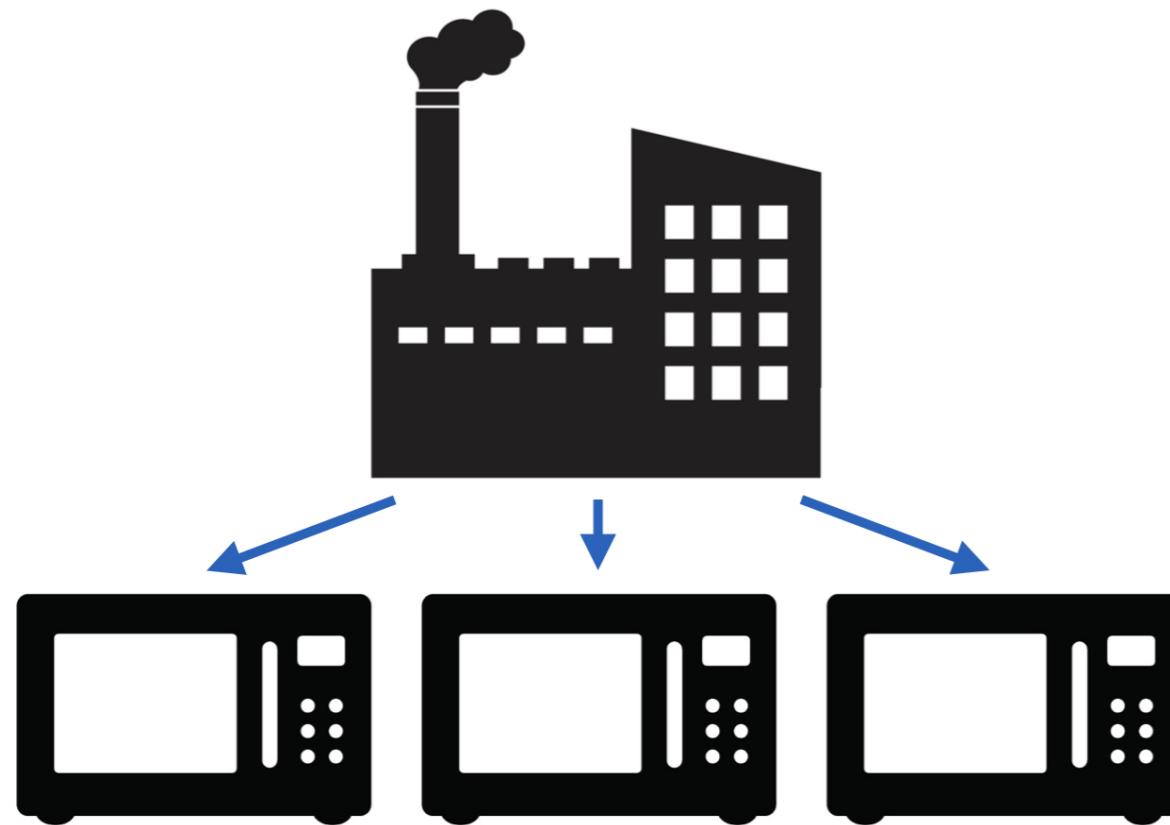
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class generators are templates for objects a.k.a. factories



CLASS GENERATOR

Is a template that describes:

- * What data can be stored in the object
- * What functions can be applied to the object.

```
library(R6)
thing_factory <- R6Class(
  "Thing", (name of the class in UpperCamelCase)
  private = list(
    a_field = "a value",
    another_field = 123
  )
)
```

```
a_thing <- thing_factory$new()
```

```
another_thing <- thing_factory$new()
```

Summary

- Load the **R6** package to work with R6!
- Define **class generators** with `R6Class()`
- Class names should be **UpperCamelCase**
- **Data fields** stored in `private` list
- Create objects with factory's `new()` method

Hiding Complexity with Encapsulation

OBJECT-ORIENTED PROGRAMMING WITH S3 AND R6 IN R

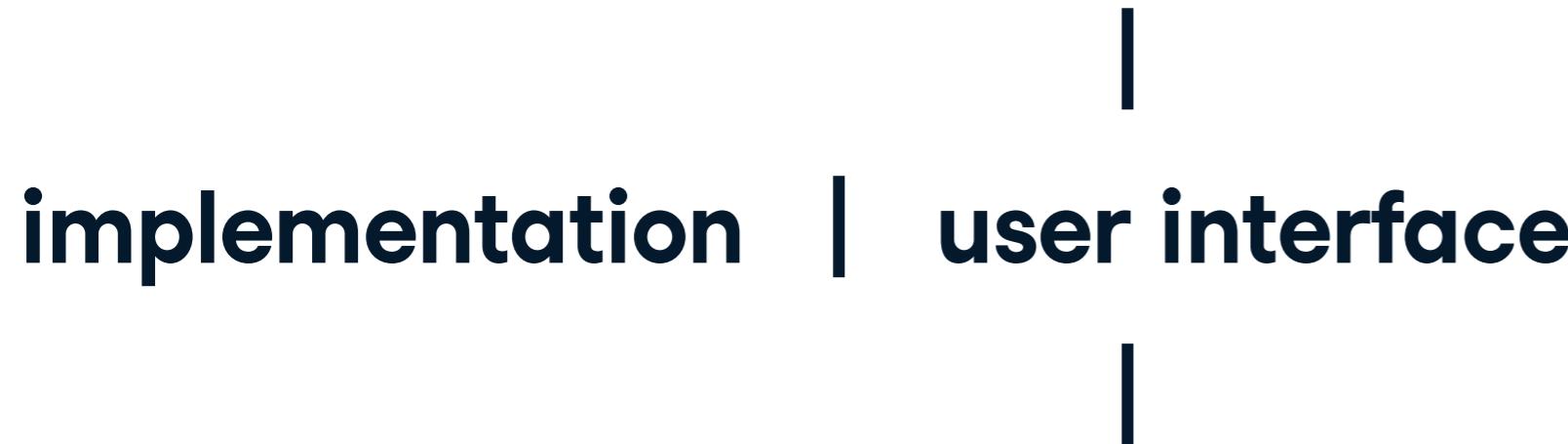


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Encapsulation

Separating the implementation of the object from its user interface is called "encapsulation".



```
microwave_oven_factory <- R6Class(  
  "MicrowaveOven",  
  private = list(  
    power_rating_watts = 800,  
    door_is_open = FALSE  
)  
  ,  
  public = list(  
    open_door = function() {  
      private$door_is_open <- TRUE  
    }  
)  
)
```

```
initialize = function(power_rating_watts, door_is_open) {  
  if(!missing(power_rating_watts)) {  
    private$power_rating_watts <- power_rating_watts  
  }  
  if(!missing(door_is_open)) {  
    private$door_is_open <- door_is_open  
  }  
}
```

We can create the function initialize to edit the behavior of new function as in the example to change private values when create the obj.

```
# Make a microwave
a_microwave_oven <-
microwave_oven_factory$new(power_rating_watts = 650,
                           door_is_open = TRUE)
```

private\$ accesses **private** elements

... and `self$` accesses **public** elements

`super$` accesses **public** methods in **parent**

```
# Create microwave oven object  
a_microwave_oven <- microwave_oven_factory$new()  
  
# Call cook method for 1 second  
a_microwave_oven$cook(1)
```

Getting and Setting with Active Bindings

OBJECT-ORIENTED PROGRAMMING WITH S3 AND R6 IN R



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CONTROLLED ACCESS ZONE

Active Bindings

defined like functions

accessed like data variables

getting = read the data field
setting = write the data field

```
thing_factory <- R6Class(  
  "Thing",  
  private = list(  
    ..a_field = "a value",  
    ..another_field = 123  
,  
  active = list(  
    a_field = function() {  
      if(is.na(private$..a_field)) {  
        return("a missing value")  
      }  
      private$..a_field  
    },  
    another_field = function(value) {  
      if(missing(value)) {  
        private$..another_field  
      } else {  
        assert_is_a_number(value)  
        private$..another_field <- value  
      }  
    }  
  )  
)
```

1. Define private variables names starting with ..

2. Define a read-only active binding

3. Define an editable active binding

Read-only behavior

```
a_thing <- thing_factory$new()  
a_thing$a_field
```

```
"a value"
```

```
a_thing$a_field <- "a new value"
```

```
Error in (function (value) : a_field is read-only.
```

Restriction example when changing private value

```
a_thing$another_field <- 456
```

```
a_thing$another_field <- "456"
```

```
Error in (function (value) : is_a_number :  
value is not of class 'numeric'; it has class 'character'.
```

Propagating Functionality with Inheritance

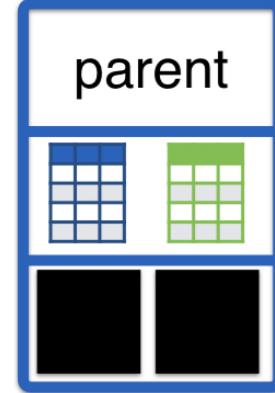
OBJECT-ORIENTED PROGRAMMING WITH S3 AND R6 IN R



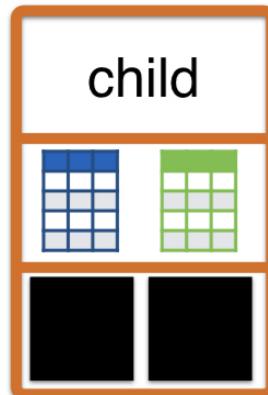
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```
thing_factory <- R6Class(  
  "Thing",  
  private = list(  
    a_field = "a value",  
    another_field = 123  
  public = list(  
    do_something = function(x, y, z) {  
      # do something here  
    }  
  )  
)
```



the class you inherit from



the class that inherits
fields and methods

```
a_thing <- thing_factory$new()  
class(a_thing)
```

"Thing" "R6"

```
child_thing_factory <- R6Class(  
  "ChildThing",  
  inherit = thing_factory  
  public = list(  
    do_something_else = function() {  
      # more functionality  
    }  
  })  
)
```

```
a_child_thing <- child_thing_factory$new()  
class(a_child_thing)
```

"ChildThing" "Thing" "R6"

Embrace, Extend, Override

OBJECT-ORIENTED PROGRAMMING WITH S3 AND R6 IN R



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`private$` accesses **private** fields

`self$` accesses **public** methods in **self**

`super$` accesses **public** methods in **parent** if they were overwritten

```
child_thing_factory <- R6Class(  
  "ChildThing",  
  inherit = thing_factory,  
  public = list(  
    do_something = function() {  
      message("the child do_something method")  
    },  
    do_something_else = function() {  
      message("the child do_something_else method")  
      self$do_something()  
      super$do_something()  
    }  
  )  
)
```

```
a_child_thing <- child_thing_factory$new()
```

```
a_child_thing$do_something_else()
```

the child do_something_else method
the child do_something method
the parent do_something method

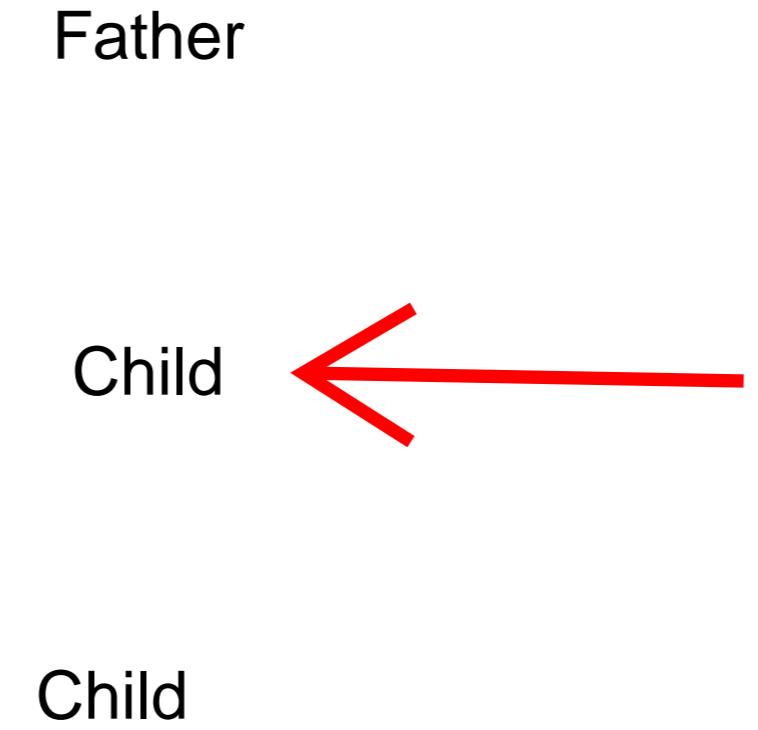
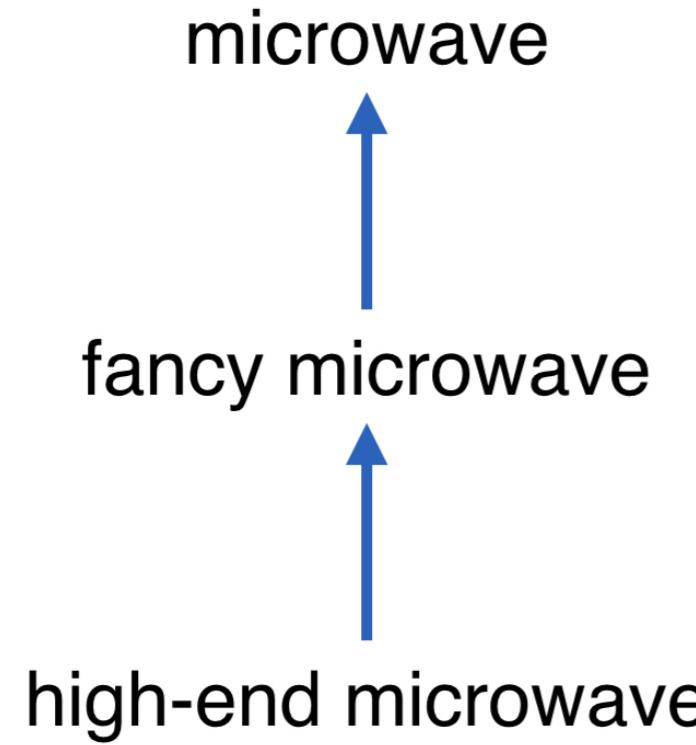
Multiple Levels of Inheritance

OBJECT-ORIENTED PROGRAMMING WITH S3 AND R6 IN R



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```
child_thing_factory <- R6Class(  
  "ChildThing",  
  inherit = thing_factory,  
  public = list(  
    do_something = function() {  
      message("the child do_something method")  
    }  
)  
  active = list(  
    super_ = function() super  
  )  
)
```

```
grand_child_thing_factory <- R6Class(  
  "GrandChildThing",  
  inherit = child_thing_factory,  
  public = list(  
    do_something = function() {  
      message("the grand-child do_something method")  
      super$do_something()  
      super$super_$do_something()  
    }  
  )  
)
```

```
a_grand_child_thing <- grand_child_thing_factory$new()  
a_grand_child_thing$do_something()
```

the grand-child do_something method
the child do_something method
the parent do_something method

Environments, Reference Behavior, & Shared Fields

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```
env <- new.env()
```

```
lst <- list(x = pi ^ (1:5), y = matrix(month.abb, 3))
```

```
env$x <- pi ^ (1:5)  
env[["y"]] <- matrix(month.abb, 3)
```

```
lst
```

```
$x  
3.141593 9.869604 31.006277 97.409091 306.019685
```

```
$y
```

```
 [,1] [,2] [,3] [,4]  
[1,] "Jan" "Apr" "Jul" "Oct"  
[2,] "Feb" "May" "Aug" "Nov"  
[3,] "Mar" "Jun" "Sep" "Dec"
```

```
env
```

```
<environment: 0x103f3dfc8>
```

```
ls.str(lst)
```

```
x : num [1:5] 3.14 9.87 31.01 97.41 306.02  
y : chr [1:3, 1:4] "Jan" "Feb" "Mar" "Apr" "May" ...
```

```
ls.str(env)
```

```
x : num [1:5] 3.14 9.87 31.01 97.41 306.02  
y : chr [1:3, 1:4] "Jan" "Feb" "Mar" "Apr" "May" ...
```

```
lst2 <- lst  
(lst$x <- exp(1:5))
```

```
2.718282 7.389056 20.085537 54.598150 148.413159
```

```
lst2$x
```

```
3.141593 9.869604 31.006277 97.409091 306.019685
```

```
identical(lst$x, lst2$x)
```

```
FALSE
```

```
env2 <- env  
(env$x <- exp(1:5))
```

```
2.718282 7.389056 20.085537 54.598150 148.413159
```

```
env2$x
```

```
2.718282 7.389056 20.085537 54.598150 148.413159
```

```
identical(env$x, env2$x)
```

```
TRUE
```

```
env <- list2env(lst)
```

```
thing_factory <- R6Class(  
  "Thing",  
  private = list(  
    shared = {  
      e <- new.env()  
      e$a_shared_field = 123  
      e  
    }  
,  
    active = list(  
      a_shared_field = function(value) {  
        if(missing(value)) {  
          private$shared$a_shared_field  
        } else {  
          private$shared$a_shared_field <- value  
        }  
      }  
    )  
)
```

```
a_thing <- thing_factory$new()  
another_thing <- thing_factory$new()
```

```
a_thing$a_shared_field
```

```
123
```

```
another_thing$a_shared_field
```

```
123
```

```
a_thing$a_shared_field <- 456  
another_thing$a_shared_field
```

```
456
```

Cloning R6 Objects

OBJECT-ORIENTED PROGRAMMING WITH S3 AND R6 IN R



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```
thing_factory <- R6Class(  
  "Thing",  
  private = list(  
    ..a_field = 123  
> ),  
  active = list(  
    a_field = function(value) {  
      if(missing(value)) {  
        private$..a_field  
      } else {  
        private$..a_field <- value  
      }  
    }  
> )  
> )
```

```
a_thing <- thing_factory$new()  
a_copy <- a_thing  
a_thing$a_field <- 456
```

```
a_copy$a_field
```

```
456
```

```
a_clone <- a_thing$clone()
```

```
a_thing$a_field <- 789  
a_clone$a_field
```

```
456
```

```
container_factory <- R6Class(  
  "Container",  
  private = list(  
    ..thing = thing_factory$new()  
> ),  
  active = list(  
    thing = function(value) {  
      if(missing(value)) {  
        private$..thing  
      } else {  
        private$..thing <- value  
      }  
    }  
> )  
> )
```

```
a_container <- container_factory$new()  
a_clone <- a_container$clone()
```

```
a_container$thing$a_field <- "a new value"  
a_clone$thing$a_field
```

```
"a new value"
```

```
a_deep_clone <- a_container$clone(deep = TRUE)
```

```
a_container$thing$a_field <- "a different value"  
a_deep_clone$thing$a_field
```

```
"a new value"
```

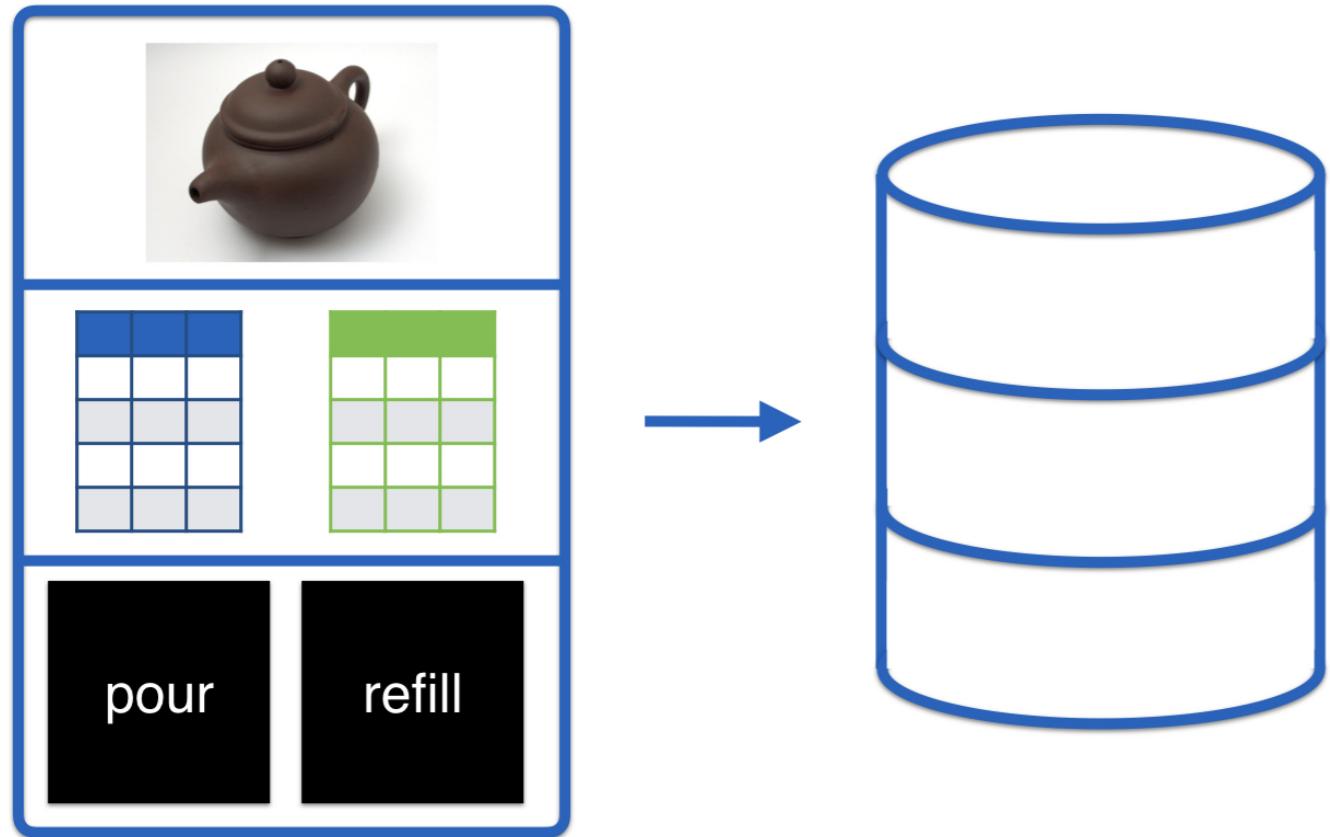
Shut it Down

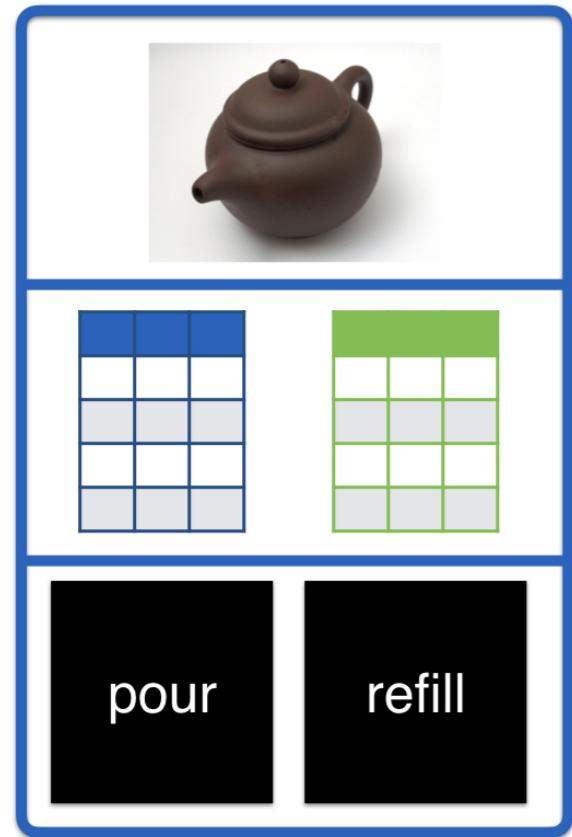
OBJECT-ORIENTED PROGRAMMING WITH S3 AND R6 IN R



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`initialize()` customizes **startup**

`finalize()` customizes **cleanup**

```
thing_factory <- R6Class(  
  "Thing",  
  private = list(  
    ..a_field = 123  
> ),  
  public = list(  
    initialize = function(a_field) {  
      if(!missing(a_field)) {  
        private$a_field = a_field  
      }  
    },  
    finalize = function() {  
      message("Finalizing the Thing")  
    }  
> )  
)
```

```
a_thing <- thing_factory$new()
```

```
rm(a_thing)
```

```
gc()
```

Finalizing the Thing

	used (Mb)	gc trigger (Mb)	max used (Mb)
Ncells	443079	23.7	750400 40.1 592000 31.7
Vcells	718499	5.5	1308461 10.0 1092342 8.4

```
library(RSQLite)
database_manager_factory <- R6Class(
  "DatabaseManager",
  private = list(
    conn = NULL
  ),
  public = list(
    initialize = function(a_field) {
      private$conn <- dbConnect("some-database.sqlite")
    },
    finalize = function() {
      dbDisconnect(private$conn)
    }
  )
)
```

Summary

- `finalize()` **cleans up** after **R6** objects
- It is useful when **working with databases**
- It gets called during **garbage collection**

Let's practice!

OBJECT-ORIENTED PROGRAMMING WITH S3 AND R6 IN R