



# ETC4500/ETC5450 Advanced R programming

Week 9: Object-oriented programming (vctrs)



- 1 Programming paradigms
- 2 Object oriented programming

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#### Functional programming (W5)

- Functions are created and used like any other object.
- Output should only depend on the function's inputs.

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#### Object-oriented programming (W6-W7)

- Functions are associated with object types.
- Methods of the same 'function' produce object-specific output.

#### Literate programming (W7)

- Natural language is interspersed with code.
- Aimed at prioritising documentation/comments.
- Now used to create reproducible reports/documents.

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- Natural language is interspersed with code.
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#### Reactive programming (W8)

- Objects are expressed using code based on inputs.
- When inputs change, the object's value updates.

- 1 Programming paradigms
- 2 Object oriented programming

## **Object oriented programming**

#### S3

- The OO system used by most of CRAN.
- Very simple (and 'limited') compared to other systems.

## Object oriented programming

#### **S**3

- The OO system used by most of CRAN.
- Very simple (and 'limited') compared to other systems.

#### vctrs

- Builds upon S3 to make creating vectors easier.
- Good practices inherited by default.

#### S3 Recap: Objects and methods

Unlike most OO systems where methods belong to **objects/data**, S3 methods *belong* to 'generic' **functions**.

Recall that functions in R are objects like any other.

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Self awareness

In S3, there is no concept of 'self' since the relevant objects are available as function arguments.

However S3 is self-aware of registered methods, allowing NextMethod() to call the S3 method of the inherited class.

## S3 Recap: S3 dispatch

To use S3, we call the generic function (e.g. plot()).

plot

```
function (x, y, ...)
UseMethod("plot")
<bytecode: 0x5716ffbb04b0>
<environment: namespace:base>
```

#### S3 Recap: S3 dispatch

stats:::plot.densitv

This function looks at the inputs and dispatches (uses) the appropriate method for the input variable class/type.

```
function (x, main = NULL, xlab = NULL, ylab = "Density", type = "l".
    zero.line = TRUE, ...)
    if (is.null(xlab))
        xlab <- paste("N =", x$n, " Bandwidth =", formatC(x$bw))</pre>
    if (is.null(main))
        main <- sub("[.]default", "", deparse(x$call))</pre>
    plot.default(x, main = main, xlab = xlab, ylab = ylab, type = type,
        ...)
    if (zero.line)
        abline(h = 0, lwd = 0.25, col = "gray")
    invisible(NULL)
```

#### S3 Recap: S3 dispatch

xlabel <- if (!missing(x))</pre> deparse1(substitute(x)) vlabel <- if (!missing(v))</pre>

...)

If there isn't a registered method for the object, the default

```
method for the generic will be used.
graphics:::plot.default
function (x, y = NULL, type = "p", xlim = NULL, ylim = NULL,
   log = "", main = NULL, sub = NULL, xlab = NULL, ylab = NULL,
```

ann = par("ann"), axes = TRUE, frame.plot = axes, panel.first = NULL,

panel.last = NULL, asp = NA, xgap.axis = NA, ygap.axis = NA,

localAxis <- function(..., col, bg, pch, cex, lty, lwd) Axis(...)</pre> localBox <- function(..., col, bg, pch, cex, lty, lwd) box(...)</pre>

localTitle <- function(..., col, bg, pch, cex, lty, lwd) title(...)</pre>

## Creating an S3 generic

S3 generics are work like any ordinary function, but they include UseMethod() which calls the appropriate method.



Your turn!

Create an S3 generic called "reverse".

This function will reverse objects. For example,

- reverse("stressed") becomes "desserts",
- reverse(7919) **becomes** 9197,
- reverse(1.9599) becomes 9959.1.

#### **Writing S3 methods**

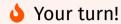
#### An S3 method is an ordinary function with some constraints:

- The function's name is of the form <generic>.<class>,
- The function's arguments match the generic's arguments,
- The function is registered as an S3 method (for packages).

#### This looks like:

```
#' Documentation for the method
#' @method <generic> <class>
<generic>.<class> <- function(<generic args>, <method args>, ...) {
    # The code for the method
}
```

## **Writing S3 methods**



Write methods for reversing character, integer, and double objects.

- reverse("stressed") becomes "desserts",
- reverse(7919L) becomes 9197L,
- reverse(1.9599) **becomes** 9959.1.

Hint: stringi::stri\_reverse() will reverse a string.

The integer and double methods should return an integer and double respectively.

## **Writing S3 defaults**

What if we tried to reverse the current date; reverse(Sys.Date())?

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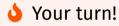


Your turn!

Question: what should the default behaviour be?

# **Writing S3 defaults**

What if we tried to reverse the current date; reverse(Sys.Date())?



Question: what should the default behaviour be?

- Raise an error?
- Return a reversed string?
- Something else entirely?

S3 methods are (mostly) dispatched based on the class().

```
class("stressed")

[1] "character"

class(7919L)

[1] "integer"

class(1.9599)

[1] "numeric"
```

To create an S3 object, we add a class to an object.

This is usually done with structure(), for example:

```
e <- structure(list(numerator = 2721, denominator = 1001), class = "fraction")
e

$numerator
[1] 2721

$denominator
[1] 1001

attr(,"class")
[1] "fraction"</pre>
```

The structure() function is usually only used within other functions made for end-users. For example,

- Im() returns a list with class "lm", and
- tibble() returns a data.frame (list) with classes "tbl\_df",
  "tbl", and "data.frame".

The structure() function is usually only used within other functions made for end-users. For example,

- Im() returns a list with class "lm", and
- tibble() returns a data.frame (list) with classes "tbl\_df",
  "tbl", and "data.frame".
- Your turn!

Create fraction(), which returns fraction objects.
This function should check that the inputs are suitable

The fraction class doesn't yet have any methods, so it inherits methods from its list type.

Usually we would create a method for printing S3 objects.

```
print.fraction <- function(x, ...) {
  paste(x$numerator, x$denominator, sep = "/")
}
e</pre>
```

2721/1001



Your turn!

Create a reverse() method for the fraction object class, which inverts the numerator and denominator.

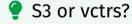
Finished early?

Write a method for converting a fraction into a number.

## **Creating your own S3 vectors (with vctrs)**

The *vctr*s package is helpful for creating custom vectors.

It is built upon S3, so the same approach for creating S3 generics and S3 methods also applies to vctrs.



- Regular S3 is useful for creating singular objects
- vctrs is useful for creating vectorised objects

#### **Creating your own S3 vectors (with vctrs)**

Why vctrs?

vctrs simplifies the complicated parts in creating vectors

- easy subsetting
- nice printing
- predictable recycling
- casting / coercion
- tidyverse compatibility

#### Examples of vctrs packages

#### Lots of vctrs including:

- IP addresses
- Spatial geometries
- Time
- uncertainty

https://github.com/krlmlr/awesome-vctrs

#### Some packages I've made that use vctrs

- distributionalDistributions of various shapes in vectors
- mixtimeTime points/intervals of various granularities in vectors
- graphvecGraph factors, storing graph edges between levels.
- fabletools
  Custom data frames 'mable', 'fable', and 'dable'.

The basic way to produce a vctr is with vctrs::new\_vctr().

Just like structure(), you provide an object and its new class.

```
attendance <- vctrs::new_vctr(c(80, 70, 75, 50), class = "percent")
attendance</pre>
```

```
<percent[4]>
[1] 80 70 75 50
```

As with S3, functions provide ways for users to create vectors.

```
percent <- function(x) {
    vctrs::new_vctr(x, class = "percent")
}
attendance <- percent(c(80, 70, 75, 50))
attendance
<percent[4]>
[1] 80 70 75 50
```

Instead, it has type <character>.

Don't forget to check the inputs, vctrs provides helpful functions to make this easier and provide informative errors.

```
percent <- function(x) {
   vctrs::vec_assert(x, numeric())
   vctrs::new_vctr(x, class = "percent")
}
percent("80%")

Error in `percent()`:
! `x` must be a vector with type <double>.
```

It's useful to provide default arguments in this function which creates a length 0 vector (similar to how empty vectors are created with numeric() and character()).

```
percent <- function(x = numeric()) {
   vctrs::vec_assert(x, numeric())
   vctrs::new_vctr(x, class = "percent")
}
percent()</pre>
```

<percent[0]>

## **Creating a new vctr**

While vctrs provides a nice print method, we need to specify how our vector should be formatted.

```
format.percent <- function(x, ...) {
   paste0(vctrs::vec_data(x), "%")
}
attendance

<percent[4]>
[1] 80% 70% 75% 50%
```

## The rcrd type

A special type of vctr is a record (rcrd).

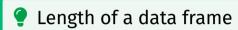
A record is a list containing equal length vectors, and its size is the length its vectors rather than its list.



Record indexing

Usually in R, indexing happens across the list. With the record type, indexing happens within the list's vectors.

## The rcrd type



Usually the length of data refers to the number of rows, but in R it is the number of columns since it is a list.

```
length(mtcars)
```

[1] 11

In vctrs, data is a record so we get the number of rows.

```
vctrs::vec_size(mtcars)
```

[1] 32

### **Creating a new rcrd**

#### A record is created with the vctrs::new\_rcrd() function.

```
wallet <- vctrs::new_rcrd(
   list(amt = c(10, 38), unit = c("AU$", "\text{\text{\text{"}}}")), class = "currency"
)
format.currency <- function(x, ...) {
   paste0(vctrs::field(x, "unit"), vctrs::field(x, "amt"))
}
wallet
<currency[2]>
```

<currency[2]>
[1] AU\$10 ¥38

## **Creating a new rcrd**



Your turn!

Rewrite the fraction() function to use the rcrd data type.

You will also need to update the methods:

- Obtain the numerator and denominator with field().
- Replace the print method with a format method.
- Remove the print.fraction method with rm().

### The list\_of type

 $\Gamma\Gamma\Lambda$ 

```
list of() vectors require list elements to be the same type.
It can be created with list_of(), or more easily converted to
with as list of(). It behaves identically to new vctr().
vctrs::as_list_of(list(80, 70, 75, 50), .ptype = numeric())
t of<double>[4]>
\lceil \lceil 1 \rceil \rceil
Γ1 | 80
[[2]]
Γ17 70
[[3]]
[1] 75
```

### **Prototypes**

Notice the .ptype when we used as\_list\_of()?

ptype is shorthand for prototype, which is a size-0 vector.



Prototype attributes!

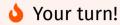
Prototypes contains all relevant attributes of the object, such as class, dimension, and levels of factors.

### **Prototypes**

#### Obtain prototypes of a vector with vctrs::vec\_ptype().

```
vctrs::vec_ptype(1:10)
integer(0)
vctrs::vec ptype(rnorm(10))
numeric(0)
vctrs::vec_ptype(factor(letters))
factor()
Levels: abcdefghijklmnopqrstuvwxyz
vctrs::vec_ptype(attendance)
<percent[0]>
```

## vctr, rcrd, or list\_of?



What's better? The vctr type or list\_of?

## vctr, rcrd, or list\_of?

Your turn!

What's better? The vctr type or list\_of?

It depends! If your vector is based on...

- a single atomic vector (like percent) then vctr,
- two or more atomic vectors (like fraction), then rcrd,
- complicated objects (like lm), then list\_of.

#### That's it! You have created a new vector for R!

i Time to celebrate with a break!

Ask questions, try using your new vector in various ways.

#### **Methods for vctrs**

While our new vectors looks pretty and fits right in with our tidy tibbles, it isn't very useful vet.



Adding features

Since vctrs is built upon S3, the same approach for creating generic functions and methods applies to vctrs.

#### **Methods for vctrs**

While our new vectors looks pretty and fits right in with our tidy tibbles. it isn't very useful vet.



Adding features

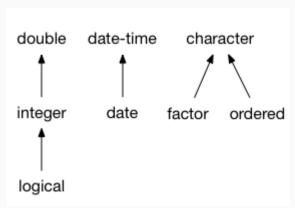
Since vctrs is built upon S3, the same approach for creating generic functions and methods applies to vctrs.

However there are also some important vector specific **methods** which should be written to improve usability.

We saw earlier how R coerces vectors of different types.

```
c("desserts", 10)
[1] "desserts" "10"
c(pi, OL)
[1] 3.14 0.00
c(-1, TRUE, FALSE)
\lceil 1 \rceil -1 \quad 1 \quad 0
c(1, Sys.Date())
[1]
    1 20153
```

When combining or comparing vectors of different types, R will (usually) *coerce* to the 'richest' type.



vctrs doesn't make any assumptions about how to coerce your vector, and instead raises an error.

```
library(vctrs)
vec_c(attendance, 0.8)

Error in `vec_c()`:
! Can't combine `..1` <percent> and `..2` <double>.
```

We can specify what the common ('richest') type is by writing vctrs::vec\_ptype2() methods.

```
#' @export
vec_ptype2.percent.double <- function(x, y, ...) {</pre>
  percent() # Prototype since this produces size-0
vctrs::vec ptvpe2(attendance, 0.8)
<percent[0]>
vctrs::vec_ptype2(0.8, attendance)
Error:
! Can't combine `0.8` <double> and `attendance` <percent>.
```

Common typing uses double-dispatch.

We need to define the common type in both directions.

```
#' @export
vec_ptype2.double.percent <- function(x, y, ...) {
   percent() # Prototype since this produces size-0
}
vctrs::vec_ptype2(attendance, 0.8)
<percent[0]>
vctrs::vec_ptype2(0.8, attendance)
<percent[0]>
```

4



Your turn!

Write methods that define the common (proto)type between fraction and double as fraction -> double.

Unfortunately c() from base R can't (yet) be changed to support double-dispatch with S3. Usually this isn't a problem,

```
c(attendance, attendance)

<percent[8] >
[1] 80% 70% 75% 50% 80% 70% 75% 50%

c(attendance, 0.8)

<percent[5] >
[1] 80% 70% 75% 50% 0.8%
```

but if your class isn't used in the first argument...

```
c(0.8, attendance)
```

```
[1] 0.8 80.0 70.0 75.0 50.0
```

... your common (proto)type will be ignored!

vctrs uses double dispatch when needed, and using vctrs::vec\_c() fixes many coercion problems in R.

```
vctrs::vec_c(0.8, attendance)

<percent[5]>
[1] 0.8% 80% 70% 75% 50%

vctrs::vec_c(1, Sys.Date())

Error in `vctrs::vec_c()`:
! Can't combine `..1` <double> and `..2` <date>.
```

i Double dispatch inheritence

Double dispatch in vctrs doesn't work with inheritance and so:

- NextMethod() can't be used
- Default methods aren't inherited/used.

Converting percentages

Notice earlier how combining percentages with numbers gave the incorrect result?

This is because we haven't written a method for converting numbers into percentages.

The vctrs::vec\_cast() generic is used to convert/coerce ('cast') one type into another. Time to write more methods!

vec\_cast(percent(80), double())

vctrs::vec\_cast() also uses double dispatch.

```
vec_cast.double.percent <- function(x, to, ...) {</pre>
  vec data(x)/100
vec_cast.percent.double <- function(x, to, ...) {</pre>
  percent(x*100)
vec_cast(0.8, percent())
<percent[1]>
[1] 80%
```

[1] 0.8

With both vec\_ptype2() and vec\_cast() methods for percentages and doubles it is now possible to combine them.

```
vctrs::vec_c(0.8, attendance)

<percent[5]>
[1] 80% 80% 70% 75% 50%
```

We can also use coercion to easily perform comparisons.

```
attendance > 0.7
```

[1] TRUE FALSE TRUE FALSE



Your turn!

Write a method for casting from a fraction to a double. Does this work with as.numeric()?

Methods also need to be written for math and arithmetic.

vec\_math() implements mathematical functions like

```
mean(attendance)

<percent[1] >
[1] 68.75%

vec_arith() implements arithmetic operations like

attendance + percent(0.1)

Error in `vec_arith()` at vctrs/R/type-vctr.R:650:5:
! <percent> + <percent> is not permitted
```

Since attendance is a simple numeric, the default vec\_math method works fine. The default vec\_math function is essentially:

```
vec_math.percent <- function(.fn, .x, ...) {
  out <- vec_math_base(.fn, .x, ...)
  vec_restore(out, .x)
}</pre>
```

- Apply the math to the underlying numbers
- Restore the percentage class

Unlike double dispatch in vec\_ptype2() and vec\_cast(), we currently need to implement our own secondary dispatch for vec\_arith().

```
vec_arith.percent <- function(op, x, y, ...) {
   UseMethod("vec_arith.percent", y)
}
vec_arith.percent.default <- function(op, x, y, ...) {
   stop_incompatible_op(op, x, y)
}</pre>
```

#### Then we can create methods for arithmetic.

```
vec_arith.percent.percent <- function(op, x, y, ...) {
  out <- vec_arith_base(op, x, y)
  vec_restore(out, to = percent())
}
percent(40) + percent(20)

<pre>cent[1]>
[1] 60%
```

#### Then we can create methods for arithmetic.

```
vec_arith.percent.numeric <- function(op, x, y, ...) {</pre>
  out <- vec_arith_base(op, x, vec_cast(y, percent()))</pre>
  vec_restore(out, to = percent())
percent(40) + 0.3
<percent[1]>
「1 70%
0.3 + percent(40)
Error in `vec_arith()` at vctrs/R/type-vctr.R:650:5:
! <double> + <percent> is not permitted
```

#### Then we can create methods for arithmetic.

```
vec_arith.numeric.percent <- function(op, x, y, ...) {</pre>
  out <- vec arith base(op, vec cast(x, percent()), y)</pre>
  vec_restore(out, to = percent())
percent(40) + 0.3
<percent[1]>
「1 70%
0.3 + percent(40)
<percent[1]>
「1 70%
```



Your turn!

Add support for math and arithmetic for the fraction class.

Hint: cast your fraction to a double and then use the base math/arith function, returning a double is fine.

Finished early?

Try to extend vec\_arith() so that it retains the fraction class for +, -, \*, / operations.