Nectric

WOMBAT 2024

WOMBAT 2024: Advanced R Tips & Tricks

Metaprogramming

workshop.nectric.com.au/advr-wombat24

Outline

Outline

Metaprogramming

Metaprogramming is *programming* about programming.

In other words, writing code that can *inspect* and *modify* code.

Metaprogramming

Metaprogramming is *programming* about programming.

In other words, writing code that can *inspect* and *modify* code.

> **A powerful idea**
>
> Unlike most programming languages, R *embraces* metaprogramming and non-standard evaluation (NSE).
> This powers much of the strange but wonderful interface designs in R and its packages.

The rlang package

```r
library(rlang)
```

A package for writing R code that interacts with R code.

! Not a new idea!

Metaprogramming/NSE doesn't need the rlang package.

There are base R equivalents to the functions shown.

NSE is widely used in base R (not just in the tidyverse!)

Parsing code

Every time you run code anywhere in R it needs to be ‘interpreted’ by the parser.

The parser reads unstructured text (your written code) and interprets it as an expression.

```
# parse(text = "seq(1, 10, by = 0.5)")
parse_expr("seq(1, 10, by = 0.5)")
```

```
seq(1, 10, by = 0.5)
```

Deparsing code

Deparsing takes an expression and converts it back to text.

```
my_seq <- parse_expr("seq(1, 10, by = 0.5)")
expr_text(my_seq)
```

```
[1] "seq(1, 10, by = 0.5)"
```

This can be useful for providing informative error messages, or print output for objects which store expressions.

Code is data

Expressions (code) can be used like any other data in R.

```r
my_seq <- parse_expr("seq(1, 10, by = 0.5)")
my_seq
```

```
seq(1, 10, by = 0.5)
```

```r
class(my_seq)
```

```
[1] "call"
```

Code is data

Expressions (code) can be used like any other data in R.

```
my_seq <- parse_expr("seq(1, 10, by = 0.5)")
my_seq
```

```
seq(1, 10, by = 0.5)
```

```
class(my_seq)
```

```
[1] "call"
```

```
eval(my_seq)
```

```
 [1]  1.0  1.5  2.0  2.5  3.0  3.5  4.0  4.5  5.0  5.5  6.
[16]  8.5  9.0  9.5 10.0
```

Inspecting code

R expressions behave exactly like lists

```r
as.list(my_seq)
```

```
[[1]]
seq

[[2]]
[1] 1

[[3]]
[1] 10

$by
[1] 0.5
```

Inspecting code

They can also be subsetted to inspect the functions and arguments.

```
my_seq[[1]]
```

```
seq
```

```
my_seq[["by"]]
```

```
[1] 0.5
```

Modifying code

Expressions can be modified by replacing their elements.

```
my_seq[["by"]] <- 1
my_seq
```

```
seq(1, 10, by = 1)
```

```
eval(my_seq)
```

```
 [1]  1  2  3  4  5  6  7  8  9 10
```

Looking at code

Your turn!

How do infix operators (like `+`, `*`, and `%in%`) get interpreted by the parser?

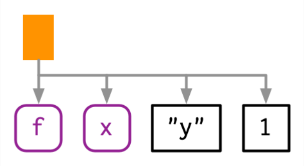
Try to parse `5 + 3 * 7`, and see how the order of operations are represented in the parsed expression.

Bonus: rewrite this expression without infix operators.

Abstract syntax trees

The structure of expressions is commonly known as an abstract syntax tree (AST). We can use `lobstr::ast()` to explore it.

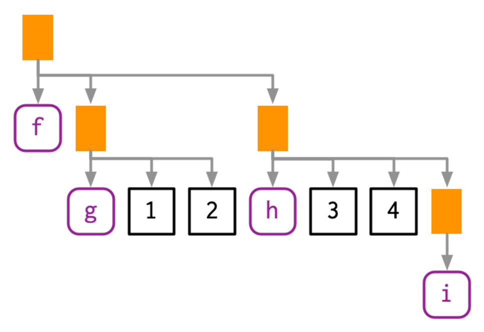
```
lobstr::ast(f(x, "y", 1))
```



Abstract syntax trees

More complicated (nested) code results in a larger/deeper AST.

```r
lobstr::ast(f(g(1, 2), h(3, 4, i())))
```



Abstract syntax trees

Your turn!

Inspect the AST for the following code:

- `5 + 3 * 7`
- `mtcars |> select(cyl)`
- `mtcars |> mutate(wt/hp)`

How does R structure these expressions?

Bonus: does `-2^2` yield 4 or -4? Why?

Analysing code

How would you programmatically analyse code from hundreds of packages?

- Regular expressions on the source code? Maybe…
- Traverse the parsed source code's AST? Yes!

This however can be tricky, requiring recursive algorithms that explore the AST using breadth/depth first search (BFS/DFS).

Coding code

You can also write code that creates code. For this we use the `call2()` function

```
# call("seq", 1, 10, by = 0.5)
call2("seq", 1, 10, by = 0.5)
```

```
seq(1, 10, by = 0.5)
```

Coding code

You can also write code that creates code. For this we use the `call2()` function

```
# call("seq", 1, 10, by = 0.5)
call2("seq", 1, 10, by = 0.5)
```

```
seq(1, 10, by = 0.5)
```

> **! parse_expr() or call2()?**
>
> You might be tempted to `parse()` code that you `paste()` together, but this is unsafe and unreliable! Why?

Metaprogramming

Coding code

Metaprogramming allows us to create code with code!
It also allows us to take code, and change how it is ran.

Outline

Code evaluation

Standard evaluation

- The code and environment is unchanged.
- The result is evaluated as expected.

Code evaluation

Standard evaluation

- The code and environment is unchanged.
- The result is evaluated as expected.

Non-standard evaluation (NSE)

- The code and/or the environment is changed.
- Leading to the evaluated result changing.

Standard or non-standard evaluation?

Your turn!

Do these expressions use standard evaluation or NSE?

- `library(rlang)`

Standard or non-standard evaluation?

Your turn!

Do these expressions use standard evaluation or NSE?

- `library(rlang)`
- `a + b * c`

Standard or non-standard evaluation?

Your turn!

Do these expressions use standard evaluation or NSE?

- `library(rlang)`
- `a + b * c`
- `mtcars |> select(cyl)`

Standard or non-standard evaluation?

Your turn!

Do these expressions use standard evaluation or NSE?

- `library(rlang)`
- `a + b * c`
- `mtcars |> select(cyl)`
- `read_csv("data/study.csv")`

Standard or non-standard evaluation?

Your turn!

Do these expressions use standard evaluation or NSE?

- `library(rlang)`
- `a + b * c`
- `mtcars |> select(cyl)`
- `read_csv("data/study.csv")`
- `ggplot() + geom_line()`

Standard or non-standard evaluation?

Your turn!

Do these expressions use standard evaluation or NSE?

- `library(rlang)`
- `a + b * c`
- `mtcars |> select(cyl)`
- `read_csv("data/study.csv")`
- `ggplot() + geom_line()`
- `mtcars |> mutate(wt/hp)`

Standard or non-standard evaluation?

Your turn!

Do these expressions use standard evaluation or NSE?

- `library(rlang)`
- `a + b * c`
- `mtcars |> select(cyl)`
- `read_csv("data/study.csv")`
- `ggplot() + geom_line()`
- `mtcars |> mutate(wt/hp)`
- `with(mtcars, wt/hp)`

The building blocks of code evaluation

There are four building blocks used in evaluating code.

- **Constants**: A specific value like `1` or `"data/study.csv"`.
- **Symbols**: A name of an object, like `pi`.
- **Expressions**: Code structured as an AST.
- **Environments**: The place where named objects are found.

The building blocks of code evaluation

There are four building blocks used in evaluating code.

- **Constants**: A specific value like `1` or `"data/study.csv"`.
- **Symbols**: A name of an object, like `pi`.
- **Expressions**: Code structured as an AST.
- **Environments**: The place where named objects are found.

> **Question?**
>
> How are these building blocks used together to construct and evaluate code?

The building blocks of code evaluation

In `rlang`, we have three main building block functions:

- `sym("pi")`: a symbol/name like `pi`
- `expr(1/pi)`: an expression for `1/pi`
- `quo(1/pi)`: a *quosure* (expression **and** environment)

The building blocks of code evaluation

In `rlang`, we have three main building block functions:

- `sym("pi")`: a symbol/name like `pi`
- `expr(1/pi)`: an expression for `1/pi`
- `quo(1/pi)`: a *quosure* (expression **and** environment)

Follow along!

Use `call2()` and these building blocks to construct and evaluate `mtcars |> mutate(wt/hp)`.

Hint: `x |> f(y)` is parsed as `f(x, y)`.

The building blocks of code evaluation

Your turn!

Spot the difference.

How do the results of the following functions differ?

- `sym("2 * pi")`
- `expr(2 * pi)`
- `quo(2 * pi)`

Capturing code

More often than not, NSE involves capturing user code that was used in your function. This is done with `en*()` functions:

- `ensym(x)`: capture a symbol
- `enexpr(x)`: capture an expression
- `enquo(x)`: capture a quosure

Capturing code

More often than not, NSE involves capturing user code that was used in your function. This is done with `en*()` functions:

- `ensym(x)`: capture a symbol
- `enexpr(x)`: capture an expression
- `enquo(x)`: capture a quosure

These must be used inside functions, for example:

```
capture_expr <- function(x) {
  enexpr(x)
}
capture_expr(1/pi)
```

Unquoting (bang-bang!!)

Why doesn't the following code work?

```
log_expr <- function(x) {
  # Capture expression
  x <- enexpr(x)
  # Return new expression with log()
  expr(log(x))
}
log_expr(1/pi)
```

```
log(x)
```

Unquoting (bang-bang!!)

To use captured code in our functions, we need to unquote it.

```
log_expr <- function(x) {
  # Capture expression
  x <- enexpr(x)
  # Return new expression with log()
  expr(log(!!x))
}
log_expr(1/pi)
```

```
log(1/pi)
```

`expr(log(!!x))` will create an expression (`expr()`) that replaces `x` with its value (`1/pi`).

Unquoting (bang-bang!!)

Unquoting in analysis

Unquoting replaces the object's name with its value.
This is also useful when using NSE functions.

How can `!!` be useful with dplyr?

Unquoting (bang-bang!!)

Suppose we wanted to programmatically `filter()` `mtcars$cyl`:

```
cyl <- 4
mtcars |>
  filter(cyl == cyl)
```

What's the problem? How can unquoting help?

Embracing inputs ({{curly-curly}})

The pattern `!!enquo(x)` is so often in functions that it has a special shortcut known as 'embrace' or 'curly-curly'. The code `{x}` is identical to `!!enquo(x)`.

Consider this function for summarising a value's range:

```
var_summary <- function(data, var) {
  data |>
    summarise(n = n(), min = min({{ var }}), max = max({{ var }}))
}
mtcars |>
  group_by(cyl) |>
  var_summary(mpg)
```

Why is `enquo()` important here?

Unquote-splicing (bang-bang-bang!!!)

It is sometimes useful to unquote multiple code elements across multiple arguments of a function.

This is done with unquote-splicing using `!!!` on a list of symbols, expressions, or quosures.

Unquote-splicing (bang-bang-bang!!!)

It is sometimes useful to unquote multiple code elements across multiple arguments of a function.

This is done with unquote-splicing using `!!!` on a list of symbols, expressions, or quosures.

A list symbols, expressions, or quosures can be:

- created with `syms()`, `exprs()`, `quos()`
- captured with `ensyms()`, `enexprs()`, `enquos()`

This is often used to capture, modify and pass on dots (`...`).

Unquote-splicing (bang-bang-bang!!!)

For example, the `var_summary()` function can be extended to accept multiple variables (or expressions) via dots (`...`).

```
var_summaries <- function(data, ...) {
  vars <- enquos(...)
  .min <- purrr::map(vars, ~ expr(min(!!.)))
  .max <- purrr::map(vars, ~ expr(max(!!.)))
  data |>
    summarise(n = n(), !!!.min, !!!.max)
}
mtcars |>
  group_by(cyl) |>
  var_summaries(mpg, wt)
```

Tidy dots (:=)

Tidy dots (`:=`) allow the argument names to be unquoted too.

For example:

```
my_df <- function(x) {
  tibble(!!expr_text(enexpr(x)) := x * 2)
}
my_var <- 10
my_df(my_var)
```

```
# A tibble: 1 x 1
  my_var
   <dbl>
1     20
```

You can alternatively use `!!!` with a named list.

Outline

Tidy evaluation

Tidy evaluation refers to the use of NSE in the tidyverse to make data analysis easier.

NSE is used widely across tidyverse packages, but at the same time it is used sparingly.

Your turn!

Question

Where have you seen NSE used in tidyverse packages?

Tidy evaluation

Tidy evaluation searches the variables of the data first, followed by the search path of the user's environment.

This is a type of NSE, since it changes the environment in which code is ran.

```
mtcars |>
  mutate(mpg/wt)
```

`mpg/wt` would ordinarily error since `mpg` and `wt` aren't found, but `mutate()` uses NSE to first search the dataset.

Tidy evaluation

This is accomplished using `eval_tidy()`, with the arguments:

- `expr`: The expression (code) to evaluate
- `data`: The dataset 'mask' to search first
- `env`: The environment to search next.

Unlike `eval()`, this will:

- Respect the environments of quosures
- Attach *pronouns* for `.data` and `.env`

Tidy evaluation

We can use `eval_tidy()` to create a simple `dplyr::mutate()` function variant.

```r
my_mutate <- function(.data, mutation) {
  mutation <- enquo(mutation)
  result <- eval_tidy(mutation, data = .data, env = caller_env())
  .data[[as_label(mutation)]] <- result
  .data
}
mtcars |>
  my_mutate(mpg/wt)
```

Question: What features are missing in our function compared to `dplyr::mutate()`?

Domain specific languages: tidyselect

The tidyselect package is useful for selecting variables from a dataset using NSE. The code/behaviour is so different it forms a domain specific language (DSL).

> **tidyselect in the wild**
>
> You almost certainly have used tidyselect in the tidyverse. It powers column selection in:
>
> - `dplyr` for `select()`, `across()`, and more.
> - `tidyr` for almost everything.

Domain specific languages: tidyselect

The tidyselect domain specific language (DSL), which uses NSE to identify columns with:

- var1:var10
- matches("x.\\d")
- all_of(<chr>)
- where(<fn>)

Domain specific languages: tidyselect

If you need tidy column selection, simply import and use `tidyselect::eval_select()`.

```
library(tidyselect)
x <- expr(mpg:cyl)
eval_select(x, mtcars)
```

```
mpg cyl
  1   2
```

This function returns the column numbers that were selected.

tidyselect

Putting it all together, we can create our own `dplyr::select()` function variant.

```
my_select <- function(.data, cols) {
  cols <- eval_select(enexpr(cols), .data)
  .data[cols]
}
my_select(mtcars, c(mpg, wt, vs:carb))
```

Your turn!

Modify this function to instead accept the selected columns via the dots (`...`), just like `dplyr::select()`.

Tidyverse design principles

Notice how little NSE the tidyverse uses to great effect.

A lot of thought has gone into designing the tidyverse, which mostly uses standard evaluation: https://design.tidyverse.org/

Tidyverse design principles

Notice how little NSE the tidyverse uses to great effect.

A lot of thought has gone into designing the tidyverse, which mostly uses standard evaluation: https://design.tidyverse.org/

A design compromise

While very appreciated by users, NSE introduces a lot of complexity when programming with tidyverse packages.

Software design with NSE

In most cases you shouldn't use NSE in your code.

Software design with NSE

In most cases you shouldn’t use NSE in your code.

> **❗ Why?**
>
> NSE can be incredibly confusing for others!
> Code might work outside your function, but is completely different when used inside it.

Software design with NSE

In most cases you shouldn't use NSE in your code.

> ❗ Why?
>
> NSE can be incredibly confusing for others!
> Code might work outside your function, but is completely different when used inside it.

Understanding NSE however is very useful for advanced use of tidyverse packages in non-interactive contexts.

Software design with NSE

If you must use NSE, you should:

- Use it sparingly
- Be consistent
- Clearly document it
- Get a lot of design benefit from it
  (not just for slightly less typing!)