

Introduction to the R Language

Scoping Rules

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A Diversion on Binding Values to Symbol

How does R know which value to assign to which symbol? When I type

```
> lm <- function(x) { x * x }
> lm
function(x) { x * x }
```

how does R know what value to assign to the symbol 1m? Why doesn't it give it the value of 1m that is in the *stats* package?

A Diversion on Binding Values to Symbol

When R tries to bind a value to a symbol, it searches through a series of environments to find the appropriate value. When you are working on the command line and need to retrieve the value of an R object, the order is roughly

- 1. Search the global environment for a symbol name matching the one requested.
- 2. Search the namespaces of each of the packages on the search list

The search list can be found by using the search function.

Binding Values to Symbol

- The *global environment* or the user's workspace is always the first element of the search list and the *base* package is always the last.
- The order of the packages on the search list matters!
- User's can configure which packages get loaded on startup so you cannot assume that there will be a set list of packages available.
- When a user loads a package with library the namespace of that package gets put in position
 2 of the search list (by default) and everything else gets shifted down the list.
- Note that R has separate namespaces for functions and non-functions so it's possible to have an object named c and a function named c.

Scoping Rules

The scoping rules for R are the main feature that make it different from the original S language.

- · The scoping rules determine how a value is associated with a free variable in a function
- · R uses *lexical scoping* or *static scoping*. A common alternative is *dynamic scoping*.
- Related to the scoping rules is how R uses the search list to bind a value to a symbol
- Lexical scoping turns out to be particularly useful for simplifying statistical computations

Consider the following function.

```
f <- function(x, y) {
     x^2 + y / z
}</pre>
```

This function has 2 formal arguments x and y. In the body of the function there is another symbol z. In this case z is called a *free variable*. The scoping rules of a language determine how values are assigned to free variables. Free variables are not formal arguments and are not local variables (assigned insided the function body).

Lexical scoping in R means that

the values of free variables are searched for in the environment in which the function was defined.

What is an environment?

- An environment is a collection of (symbol, value) pairs, i.e. x is a symbol and 3.14 might be its
 value.
- Every environment has a parent environment; it is possible for an environment to have multiple "children"
- the only environment without a parent is the empty environment
- A function + an environment = a *closure* or *function closure*.

Searching for the value for a free variable:

- If the value of a symbol is not found in the environment in which a function was defined, then the search is continued in the *parent environment*.
- The search continues down the sequence of parent environments until we hit the *top-level* environment; this usually the global environment (workspace) or the namespace of a package.
- After the top-level environment, the search continues down the search list until we hit the *empty environment*. If a value for a given symbol cannot be found once the empty environment is arrived at, then an error is thrown.

Why does all this matter?

- Typically, a function is defined in the global environment, so that the values of free variables are just found in the user's workspace
- · This behavior is logical for most people and is usually the "right thing" to do
- · However, in R you can have functions defined inside other functions
 - Languages like C don't let you do this
- Now things get interesting In this case the environment in which a function is defined is the body of another function!

```
make.power <- function(n) {
    pow <- function(x) {
        x^n
    }
    pow
}</pre>
```

This function returns another function as its value.

```
> cube <- make.power(3)
> square <- make.power(2)
> cube(3)
[1] 27
> square(3)
[1] 9
```

Exploring a Function Closure

What's in a function's environment?

```
> ls(environment(cube))
[1] "n" "pow"
> get("n", environment(cube))
[1] 3

> ls(environment(square))
[1] "n" "pow"
> get("n", environment(square))
[1] 2
```

Lexical vs. Dynamic Scoping

```
y <- 10

f <- function(x) {
        y <- 2
        y^2 + g(x)
}

g <- function(x) {
        x*y
}</pre>
```

What is the value of

```
f(3)
```

Lexical vs. Dynamic Scoping

- With lexical scoping the value of y in the function g is looked up in the environment in which the function was defined, in this case the global environment, so the value of y is 10.
- · With dynamic scoping, the value of y is looked up in the environment from which the function was called (sometimes referred to as the calling environment).
 - In R the calling environment is known as the *parent frame*
- So the value of y would be 2.

Lexical vs. Dynamic Scoping

When a function is *defined* in the global environment and is subsequently *called* from the global environment, then the defining environment and the calling environment are the same. This can sometimes give the appearance of dynamic scoping.

```
> g <- function(x) {
+ a <- 3
+ x+a+y
+ }
> g(2)
Error in g(2) : object "y" not found
> y <- 3
> g(2)
[1] 8
```

Other Languages

Other languages that support lexical scoping

- · Scheme
- · Perl
- Python
- Common Lisp (all languages converge to Lisp)

Consequences of Lexical Scoping

- In R, all objects must be stored in memory
- · All functions must carry a pointer to their respective defining environments, which could be anywhere
- In S-PLUS, free variables are always looked up in the global workspace, so everything can be stored on the disk because the "defining environment" of all functions is the same.

Application: Optimization

Why is any of this information useful?

- Optimization routines in R like optim, nlm, and optimize require you to pass a function whose argument is a vector of parameters (e.g. a log-likelihood)
- However, an object function might depend on a host of other things besides its parameters (like data)
- When writing software which does optimization, it may be desirable to allow the user to hold certain parameters fixed

Maximizing a Normal Likelihood

Write a "constructor" function

```
make.NegLogLik <- function(data, fixed=c(FALSE,FALSE)) {
    params <- fixed
    function(p) {
        params[!fixed] <- p
        mu <- params[1]
        sigma <- params[2]
        a <- -0.5*length(data)*log(2*pi*sigma^2)
        b <- -0.5*sum((data-mu)^2) / (sigma^2)
        -(a + b)
    }
}</pre>
```

Note: Optimization functions in R *minimize* functions, so you need to use the negative log-likelihood.

Maximizing a Normal Likelihood

Estimating Parameters

```
> optim(c(mu = 0, sigma = 1), nLL)$par

mu sigma

1.218239 1.787343
```

Fixing $\sigma = 2$

```
> nLL <- make.NegLogLik(normals, c(FALSE, 2))
> optimize(nLL, c(-1, 3))$minimum
[1] 1.217775
```

Fixing $\mu = 1$

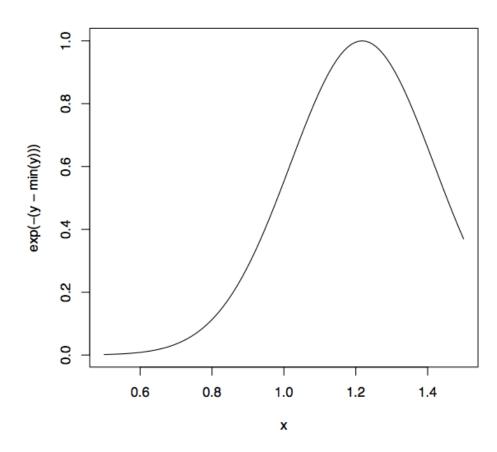
```
> nLL <- make.NegLogLik(normals, c(1, FALSE))
> optimize(nLL, c(1e-6, 10))$minimum
[1] 1.800596
```

Plotting the Likelihood

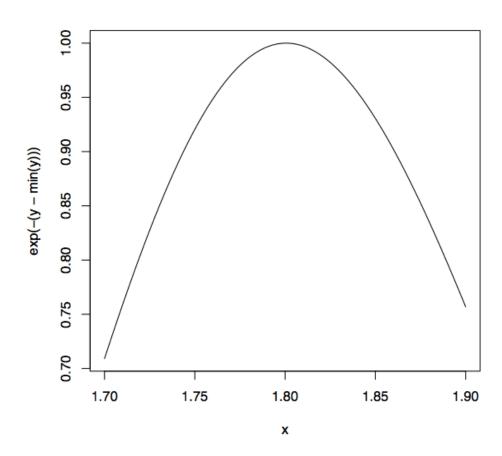
```
nLL <- make.NegLogLik(normals, c(1, FALSE))
x <- seq(1.7, 1.9, len = 100)
y <- sapply(x, nLL)
plot(x, exp(-(y - min(y))), type = "l")

nLL <- make.NegLogLik(normals, c(FALSE, 2))
x <- seq(0.5, 1.5, len = 100)
y <- sapply(x, nLL)
plot(x, exp(-(y - min(y))), type = "l")</pre>
```

Plotting the Likelihood



Plotting the Likelihood



Lexical Scoping Summary

- · Objective functions can be "built" which contain all of the necessary data for evaluating the function
- · No need to carry around long argument lists useful for interactive and exploratory work.
- · Code can be simplified and cleand up
- Reference: Robert Gentleman and Ross Ihaka (2000). "Lexical Scope and Statistical Computing,"
 JCGS, 9, 491–508.