Dot-Pipe: an S3 Extensible Pipe with R Expression Semantics

by John Mount and Nina Zumel

Abstract Pipe notation is popular with a large league of R users, with **magrittr** being the dominant realization. However, this should not be enough to consider piping in R as a completely settled topic that is not subject to further discussion, experiments, or the possibility of improvement. To promote innovation opportunities we describe **wrapr** "dot-pipe", a well behaved sequencing operator with R expression semantics and `S3` extensibility. In this article we include a number of examples of using this pipe to interact with and extend other R packages.

Introduction

Using pipes to sequence operations has a number of advantages. Piping is analogous to representing function composition as a left to right flow of values, which is a natural direction for western readers, and is much more legible than composition represented as nesting.

Pipe notation is a popular topic in the R community. Related work includes:

magrittr Bache and Wickham (2014) the very popular pipe used in **dplyr** (Wickham et al., 2017).

future Bengtsson (2017) a powerful distributed processing package with pipe notation.

rmonad Arendsee (2017) a monadic operator package, capturing exceptions in addition to managing composition and values.

pipeR Ren (2016) a collection of sequencing methods including pipes and method chaining.

backpipe Brown (2016) a right to left pipe operator.

drake Landau (2018) A work-flow/graph toolkit for reproducible code and high-performance computing.

This article will discuss using **wrapr** (Mount and Zumel, 2018) "dot-pipe" both in user code and in packages. dot-pipe has R expression based semantics, is compatible with many other meta-programming paradigms, and is `S3` extensible.

Pipe notations

In and out of R there are a number of common pipe notations:

- Mathematical function composition or application: One can write "`a ∘ b`" to denote "`b(a)`".
- **magrittr** pipe: "`a %>% b(...)`" most commonly is used to denote "`[. <- a; b(., ...)]`".[1] The square braces indicate the dot assignment is happening in a temporary environment that **magrittr** introduces to reduce visible side-effects.
- `F#`'s forward pipe operator often defined as "`a |> b`" means `b a`" (uses `F#`'s partial application feature).
- The dot-pipe (topic of this article) where "`a %.>% b`" is intended to mean "`{. <- a; b}`". Dot-pipe emphasizes sequencing expressions, not function composition or introducing function arguments.

Using `%.>%` to sequence operations

In this section, we demonstrate the use of **wrapr** "dot-pipe" `%.>%` and some of its merits.

The intended semantics of `%.>%` are:

> "`a %.>% b`" is nearly equivalent to "`{. <- a; b}`".

Where `a` and `b` are taken to be R expressions, presumably with "`.`" occurring as a unbound (or free) symbol in `b`.

For example:

[1] To observe the use of dot in **magrittr** one can try the example "`5 %>% (function(x) substitute(x))`".

```
   library("wrapr")
   5 %.>% sin(.)

[1] -0.9589243

   print(.)

[1] 5
```

Notice the **wrapr** dot-pipe leaves the most recent left-hand side value in the variable named ".". While this is a visible side-effect of this pipe which can conflict with other uses of ".", we feel these explicit semantics are sensible, easy to teach, and easy to work with.

We can also write "`5 %.>% sin`", as the dot-pipe looks up functions by name as a user convenience. This function lookup is a non referentially transparent special case, as names are deliberately treated differently than values. However it is an important capability that we will discuss later and greatly expand using R `S3` object oriented dispatch. Dot-pipe's default service does not work with the expression "`5 %.>% sin()`" and throws an informative error message ("please use 'sin(.)'"). Maintaining an explicit distinction between "`sin`" (a name), "`sin()`" (an expression with no free-use of "."), and "`sin(.)`" (an expression with free-use of "."), has benefits, some of which we will demonstrate in the "Extending the sequencer" section. In general, for dot-pipe the explicit expression "`sin(.)`" is preferred to "`sin`" under the rubric "dot-pipe has lots of dots."

Additional dot-pipe examples include:

```
   5 %.>% {1 + .}

[1] 6

   5 %.>% (1 + .)

[1] 6
```

Notice dot-pipe treated the last two statements similarly. We warn the reader that in R the expression "`5 %.>% 1 + .`" is read as "`(5 %.>% 1) + .`", as special operators (those using "%") have higher operator precedence than binary arithmetic operators R Core Team (2018).

The dot-pipe works well with many packages, including **dplyr** (example taken from a known **dplyr**/**magrittr** incompatibility: various (2018a)):

```
   library("dplyr")
   disp <- 4
   mtcars %.>% filter(., .data$cyl == .env$disp) %.>% nrow(.)

[1] 11
```

Extending the sequencer

Dot-pipe's primary dispatch is user extensible. As we said, it treats "`a %.>% b`" as "`{. <- a; b}`". However, it does this through `S3` dispatch through a method of the form "`apply_left(a,b,pipe_environment,pipe_name)`". User or package code can override this method to add custom effects. For example one can extend dot-pipe to be a **ggplot2** layer compositor as we show below.[2]

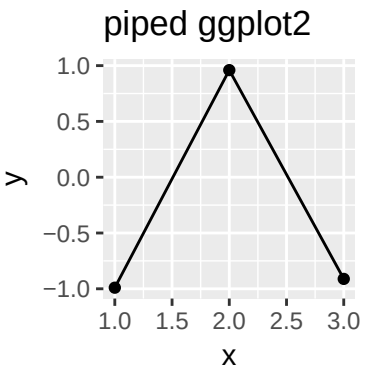
```
  library("ggplot2")
  apply_left.gg <- function(pipe_left_arg,
                            pipe_right_arg,
                            pipe_environment,
                            left_arg_name,
                            pipe_string,
                            right_arg_name) {
    pipe_right_arg <- eval(pipe_right_arg,
                           envir = pipe_environment,
                           enclos = pipe_environment)
    pipe_left_arg + pipe_right_arg
   }
  d <- data.frame(x = 1:3, y = 11:13)
```

[2] For context please see various (2018b).

We have defined an implementation of `apply_left.gg`, as this is the class used by `ggplot2` to recognize its own objects (i.e., `ggplot2` works by defining `` `+`.gg ``). Essentially `apply_left.gg(a,b)` is implemented as "`a + b`", the only detail being "`b`" is passed as a un-evaluated language argument, so it must be evaluated before being used as a regular value (a detail discussed in the package documentation).

We can now easily write a pipeline that combines sequencing **dplyr** transformation steps and combining **ggplot2** geom objects.

```
d %.>%
  mutate(., y = cos(3*x)) %.>%
  ggplot(., aes(x = x,  y = y)) %.>%
  geom_point() %.>%
  geom_line() %.>%
  ggtitle("piped ggplot2")
```



As before the data processing steps (e.g. `mutate()`) require "`.`" as a free symbol to specify where the piped values go. However, the **ggplot2** steps do not use such a "`.`" argument, as these functions do not expect previous steps as arguments.

Dot-pipe was able add capabilities (`S3` based piping) to the **ggplot2** package without requiring any changes to the **ggplot2** package. This extension capability is important.

Treating names as functions

If an object on the right hand side of a dot-pipe stage is an R language name, then the object referred to by that name can be applied as a function (if it refers to a function), or declare a surrogate function (via `S3` dispatch on the class of the *second* or right hand side argument) to be applied as a function. That is `a %.>% b` is treated as `b(a)` or $f_{\texttt{class(b)}}$`(a,b)`. Notice `f` is chosen by `S3` dispatch based on the run-time class of the second or right hand side argument "`b`".

A good example use of this capability is extending the **rquery** package (Mount, 2018) to allow relational operator trees (from that package) to be used both as inspectable objects and as functions that can be applied directly to data. In the following example, we create an operator tree that adds the column `y` to a data frame `d`.

```
library("rquery")
optree <- table_source("d", colnames(d)) %.>%
    extend_nse(., y = cos(2*x))
```

We can treat `optree` as an object as we show below.

```
class(optree)
```

```
[1] "relop_extend" "relop"
```

```
print(optree)
```

```
[1] "table('d'; x, y) %.>% extend(., y := cos(2 * x))"
```

```
column_names(optree)
```

```
[1] "x" "y"
```

```
   columns_used(optree)

$d
[1] "x"
```

Or we can pipe into it as if it were an expression or function, as we now demonstrate.

```
   # get a databse connection
   db = DBI::dbConnect(RSQLite::SQLite(),
                       ":memory:")
   # make our db connection available to rquery package
   options(list("rquery.rquery_db_executor" = list(db = db)))
   # show the apply_right method
   print(rquery::apply_right)

function(pipe_left_arg,
                       pipe_right_arg,
                       pipe_environment,
                       left_arg_name,
                       pipe_string,
                       right_arg_name) {
  UseMethod("apply_right", pipe_right_arg)
}
<bytecode: 0x7ff16c8fe788>
<environment: namespace:wrapr>

   d %.>% optree # apply optree to d as if optree were a function

  x          y
1 1 -0.4161468
2 2 -0.6536436
3 3  0.9601703
```

In this example we defined the function stand-in for the right hand side pipe argument. To be beastly about it: `apply_right` "verbifies nouns."[3] Any user or package can extend the dot-pipe to suit their needs, just as we have shown here. If **rquery** were to include a function such as `apply_right.relop` then dot-pipe users would see this benefit with no extra effort on their own part. We strongly encourage package developers to start including a few "extra effects" for **wrapr** users.

Dot-pipe semantics

We have been describing dot-pipe semantics by introducing transformed code that we ask to be considered equivalent to the dot-pipe pipeline. Think of that as the specification. Dot-pipe's implementation is not by code substitution but through execution of rules we outline here.

In R, special operators (those written with `%`) are left to right associative (meaning "`a %.>% b %.>% c`" is taken to mean "`(a %.>% b) %.>% c`") with fairly high operator precedence (meaning they are applied earlier than some other operators).

The dot-pipe semantics are realized by the following processing rules. "`a %.>% b`" is processed as follows:

Def. We choose the default "control on the left case" (or "L case") if the second or right hand side argument "`b`" is not a R language name or other de-referencable entity, otherwise we take the "control on right case" (or "R case"). We then continue with one of these two cases.

L case. `S3` dispatch is performed on `apply_left(a,b,env,nm)`, with "`a`" being the class determining argument, and "`b`" an un-evaluated R language object. The default implementation of `apply_left(a,b,env,nm)` is "`. <-a ; eval(b)`" (performed in the calling environment).

R case. We look-up or de-reference the second or right hand side argument "`b`" and then branch as follows.

i. If the second or right hand side argument "`b`" is now a function, the value `b(a)` is returned.

[3] This is a joke for English speakers: "practically any noun can be verbed in English" Peterson (1984).

ii. Otherwise S3 dispatch is performed on `apply_right(a,b,env,nm)` using `b` as the class determining argument (`env` being the environment we want to be working in). We call this "class(b) choosing a surrogate function." The default implementation of `apply_right(a,b,env,nm)` itself S3 dispatches via `apply_left(a,b,env,nm)`.

This may seem involved, but it is in fact quite regular with only one exception: a dereference triggers right-dispatch. Roughly the rule is: "treat the second or right hand side argument as an expression, unless it is a name." The intent is for dot-pipe to have simple semantics that are capable of being combined many ways to allow rich emergent behavior.

Example Applications

Both R users and package developers can achieve a great number of useful effects by adding S3 implementations for `apply_left()` or for `apply_right()`. Some possibilities include:

- Enabling `%.>%` as layering function for **ggplot2** (as a replacement for "+", as we demonstrated).
- Enabling auto-application of **rquery** operation trees to `"data.frame"`s (as we demonstrated).
- Enabling auto-application of models by mapping `apply_right.model_class` to the appropriate `predict` method.

```
d <- data.frame(x=1:5, y = c(1, 1, 0, 1, 0))
model <- glm(y~x, family = binomial, data = d)
apply_right.glm <-
     function(pipe_left_arg,
              pipe_right_arg,
              pipe_environment,
              left_arg_name,
              pipe_string,
              right_arg_name) {
   predict(pipe_right_arg,
           newdata = pipe_left_arg,
           type = 'response')
 }
d %.>% model
```

```
       1         2         3         4         5
0.9428669 0.8472400 0.6508301 0.3851524 0.1739107
```

Notice we can pipe new data directly into the model for prediction. The S3 `apply_right` extensions give us a good opportunity to regularize model predictions functions to take the same arguments and have the desired default behaviors.

- Enabling pipe notation for SQL.

```
apply_right.SQLiteConnection <-
     function(pipe_left_arg,
              pipe_right_arg,
              pipe_environment,
              left_arg_name,
              pipe_string,
              right_arg_name) {
   DBI::dbGetQuery(pipe_right_arg, pipe_left_arg)
 }
"SELECT * FROM sqlite_temp_master"   %.>%   db
```

```
[1] type     name     tbl_name rootpage sql
<0 rows> (or 0-length row.names)
```

Here we piped SQL code directly into the database connection.

- A string concatenation operator.

```
apply_left.character <- function(pipe_left_arg,
                                 pipe_right_arg,
                                 pipe_environment,
                                 left_arg_name,
                                 pipe_string,
```

```
                                    right_arg_name) {
    pipe_right_arg <- eval(pipe_right_arg,
                           envir = pipe_environment,
                           enclos = pipe_environment)
    paste0(pipe_left_arg, pipe_right_arg)
  }
 `%+%` <- wrapr::`%.>%`
 "a" %+% "b" %+% "c"
```

```
[1] "abc"
```

One can, of course, define a string concatenation operator directly- but this is a good example of the use of the dot-pipe as a sort of compound constructor.

- A formula term collector.

```
 apply_left.formula <- function(pipe_left_arg,
                                pipe_right_arg,
                                pipe_environment,
                                left_arg_name,
                                pipe_string,
                                right_arg_name) {
    pipe_right_arg <- eval(pipe_right_arg,
                           envir = pipe_environment,
                           enclos = pipe_environment)
    pipe_right_arg <- paste(pipe_right_arg, collapse = " + ")
    update(pipe_left_arg, paste(" ~ . +", pipe_right_arg))
  }
 `%+%` <- wrapr::`%.>%`
 (y~a) %+% c("b", "c", "d") %+% "e"
```

```
y ~ a + b + c + d + e
```

We anticipate motivated package authors can find many special cases that the dot-pipe can streamline for their users. The value will be when many packages add effects on the same pipe, so users know by using that pipe they will simultaneously have many powerful features made available.

We have found it profitable to roughly think of `apply_left()` as a "programmable comma" and `apply_right()` as "automatic execution."[4]

Conclusion

We have demonstrated a well-behaved, `S3` extensible tool for sequencing or pipe-lining operations in R. The left-dispatch of `apply_left()` method is useful in assembling composite structures such as building a `ggplot2` plot up from pieces. The right-dispatch `apply_right()` is unusual, but a natural extension of the "pipes write functions on the right" idea. The goal of dot-pipe is to supply simple semantics (in the R style) that can later be composed into powerful specific applications. The dot-pipe can be used to extend packages, or to add user desired effects. We would like **wrapr** dot-pipe to be a testing ground both for pipe-aware package extensions and for experimenting with the nature of piping in R itself.

Bibliography

Z. Arendsee. *rmonad: A Monadic Pipeline System*, 2017. URL https://CRAN.R-project.org/package=rmonad. R package version 0.4.0. [p1]

S. M. Bache and H. Wickham. *magrittr: A Forward-Pipe Operator for R*, 2014. URL https://CRAN.R-project.org/package=magrittr. R package version 1.5. [p1]

H. Bengtsson. *future: Unified Parallel and Distributed Processing in R for Everyone*, 2017. URL https://CRAN.R-project.org/package=future. R package version 1.6.2. [p1]

C. Brown. *backpipe: Backward Pipe Operator*, 2016. URL https://CRAN.R-project.org/package=backpipe. R package version 0.1.8.1. [p1]

[4]Obviously these are vague terms, but they capture some sliver of the differences in semantics of the seen between the two patterns.

W. M. Landau. *drake: Data Frames in R for Make*, 2018. URL https://CRAN.R-project.org/package=drake. R package version 5.0.0. [p1]

J. Mount. *rquery: Relational Query Generator for Data Manipulation*, 2018. URL https://CRAN.R-project.org/package=rquery. R package version 0.3.0. [p3]

J. Mount and N. Zumel. *wrapr: Wrap R Functions for Debugging and Parametric Programming*, 2018. https://github.com/WinVector/wrapr, http://winvector.github.io/wrapr/. [p1]

P. L. Peterson. Semantic indeterminacy and scientific underdetermination. *Philosophy of Science*, 51(3): 464–487, September 1984. [p4]

R Core Team. R language definition, 2018. URL https://cran.r-project.org/doc/manuals/r-release/R-lang.html. [p2]

K. Ren. *pipeR: Multi-Paradigm Pipeline Implementation*, 2016. URL https://CRAN.R-project.org/package=pipeR. R package version 0.6.1.3. [p1]

various. dplyr issue 3286: .env pronoun error, only when piped, 2018a. URL https://github.com/tidyverse/dplyr/issues/3286. [p2]

various. Why can't ggplot2 use %>%?, 2018b. URL https://community.rstudio.com/t/why-cant-ggplot2-use/4372. [p2]

H. Wickham, R. Francois, L. Henry, and K. Müller. *dplyr: A Grammar of Data Manipulation*, 2017. URL https://CRAN.R-project.org/package=dplyr. R package version 0.7.4. [p1]

John Mount
Win-Vector LLC
552 Melrose Ave., San Francisco CA, 94127
USA
jmount@win-vector.com

Nina Zumel
Win-Vector LLC
552 Melrose Ave., San Francisco CA, 94127
USA
nzumel@win-vector.com