collapse is a C/C++ based package for data transformation and statistical computing in R. Among other features it introduces an excellent and highly efficient architecture for grouped (and weighted) statistical programming in R. This post briefly explains this architecture and demonstrates:

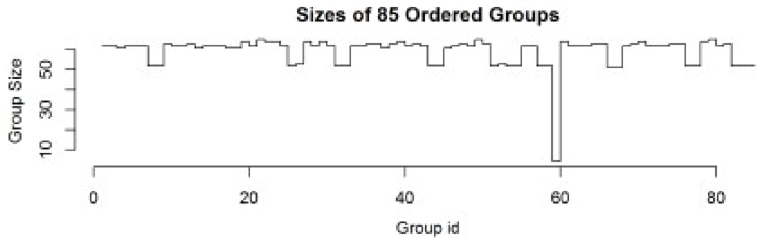
1. How to program highly efficient grouped statistical computations and data manipulations in R using the grouped functions supplied by *collapse*.
2. How to use the grouping mechanism of *collapse* with custom C/C++ code to create further efficient grouped functions/operations in R.

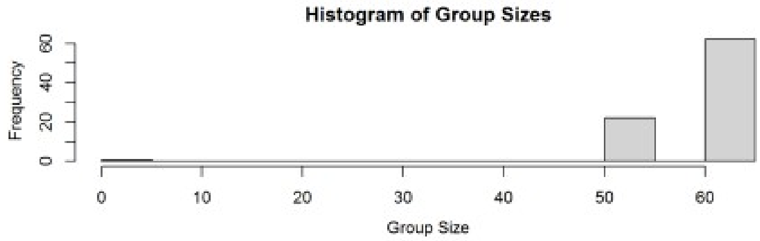
Essentials: *collapse* Grouping Objects

collapse uses grouping objects as essential inputs for grouped computations. These objects are created from vectors or lists of vectors (i.e. data frames) using the function `GRP()`:

```
library(collapse)
# A dataset supplied with collapse providing sectoral value added (VA) and
employment (EMP)
head(GGDC10S, 3)
##   Country Regioncode             Region Variable Year AGR MIN MAN PU CON WRT
TRA FIRE GOV OTH SUM
## 1     BWA        SSA Sub-saharan Africa       VA 1960  NA  NA  NA NA  NA  NA
NA   NA  NA  NA  NA
## 2     BWA        SSA Sub-saharan Africa       VA 1961  NA  NA  NA NA  NA  NA
NA   NA  NA  NA  NA
## 3     BWA        SSA Sub-saharan Africa       VA 1962  NA  NA  NA NA  NA  NA
NA   NA  NA  NA  NA
fdim(GGDC10S)
## [1] 5027   16

# Creating a grouping object (by default return.order = FALSE as the ordering is
typically not needed)
g <- GRP(GGDC10S, c("Country", "Variable"), return.order = TRUE)
# Printing it
print(g)
## collapse grouping object of length 5027 with 85 ordered groups
##
## Call: GRP.default(X = GGDC10S, by = c("Country", "Variable"), return.order =
TRUE), X is unordered
##
## Distribution of group sizes:
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##    4.00   53.00   62.00   59.14   63.00   65.00
##
## Groups with sizes:
## ARG.EMP  ARG.VA BOL.EMP  BOL.VA BRA.EMP  BRA.VA
##      62      62      61      62      62      62
##   ---
## VEN.EMP  VEN.VA ZAF.EMP  ZAF.VA ZMB.EMP  ZMB.VA
##      62      63      52      52      52      52
# Plotting it
plot(g)
```





Grouping is done very efficiently using radix-based ordering in C (thanks to *data.table* source code). The structure of this object is shown below:

```
str(g)
## List of 8
##  $ N.groups   : int 85
##  $ group.id   : int [1:5027] 8 8 8 8 8 8 8 8 8 8 ...
##  $ group.sizes: int [1:85] 62 62 61 62 62 62 52 52 63 62 ...
##  $ groups     :'data.frame': 85 obs. of  2 variables:
##   ..$ Country : chr [1:85] "ARG" "ARG" "BOL" "BOL" ...
##   .. ..- attr(*, "label")= chr "Country"
##   .. ..- attr(*, "format.stata")= chr "%9s"
##   ..$ Variable: chr [1:85] "EMP" "VA" "EMP" "VA" ...
##   .. ..- attr(*, "label")= chr "Variable"
##   .. ..- attr(*, "format.stata")= chr "%9s"
##  $ group.vars : chr [1:2] "Country" "Variable"
##  $ ordered    : Named logi [1:2] TRUE FALSE
##   ..- attr(*, "names")= chr [1:2] "GRP.sort" "initially.ordered"
##  $ order      : int [1:5027] 2583 2584 2585 2586 2587 2588 2589 2590 2591
2592 ...
##   ..- attr(*, "starts")= int [1:85] 1 63 125 186 248 310 372 424 476 539 ...
##   ..- attr(*, "maxgrpn")= int 65
##   ..- attr(*, "sorted")= logi FALSE
##  $ call       : language GRP.default(X = GGDC10S, by = c("Country",
"Variable"), return.order = TRUE)
##  - attr(*, "class")= chr "GRP"
```

The first three slots of this object provide the number of unique groups, a group-id matching each value/row to a group[1], and a vector of group-sizes. The fourth slot provides the unique groups (default `return.groups = TRUE`), followed by the names of the grouping variables, a logical vector showing whether the grouping is ordered (default `sort = TRUE`), and the ordering vector which can be used to sort the data alphabetically according to the grouping variables (default `return.order = FALSE`).

Grouped Programming in R

collapse provides a whole ensemble of C++ based generic statistical functions that can use these 'GRP' objects to internally perform (column-wise) grouped (and weighted) computations on vectors, matrices and data frames in R. Their names are contained in the global macro `.FAST_FUN`:

```
.FAST_FUN
##  [1] "fmean"      "fmedian"    "fmode"      "fsum"       "fprod"      "fsd"
"fvar"
##  [8] "fmin"       "fmax"       "fnth"       "ffirst"     "flast"      "fNobs"
```

```
"fNdistinct"
## [15] "fscale"     "fbetween"    "fwithin"     "fHDbetween" "fHDwithin"   "flag"
"fdiff"
## [22] "fgrowth"
```

Additional functions supporting grouping objects are `TRA` (grouped replacing and sweeping out statistics), `BY` (split-apply-combine computing) and `collap` (advanced data aggregation with multiple functions).

To provide a brief example, we can compute a grouped mean of the above data using:

```
head(fmean(GGDC10S[6:16], g))
##                  AGR         MIN         MAN           PU         CON
WRT         TRA
## ARG.EMP  1419.8013    52.08903   1931.7602   101.720936   742.4044
1982.1775   648.5119
## ARG.VA  14951.2918  6454.94152  36346.5456  2722.762554  9426.0033
26633.1292 14404.6626
## BOL.EMP   964.2103    56.03295    235.0332     5.346433   122.7827
281.5164   115.4728
## BOL.VA   3299.7182  2846.83763   3458.2904   664.289574   729.0152
2757.9795  2727.4414
## BRA.EMP 17191.3529   206.02389   6991.3710   364.573404  3524.7384
8509.4612  2054.3731
## BRA.VA  76870.1456 30916.64606 223330.4487 43549.277879 70211.4219
178357.8685 89880.9743
##                  FIRE         GOV        OTH         SUM
## ARG.EMP    627.79291    2043.471   992.4475   10542.177
## ARG.VA    8547.37278   25390.774  7656.3565  152533.839
## BOL.EMP     44.56442          NA   395.5650    2220.524
## BOL.VA    1752.06208          NA  4383.5425   22619.177
## BRA.EMP   4413.54448    5307.280  5710.2665   54272.985
## BRA.VA  183027.46189 249135.452 55282.9748 1200562.671
```

By default (`use.g.names = TRUE`), group names are added as names (vectors) or row-names (matrices and data frames) to the result. For data frames we can also add the grouping columns again using[2]:

```
head(add_vars(g[["groups"]], fmean(get_vars(GGDC10S, 6:16), g, use.g.names =
FALSE)))
##   Country Variable        AGR         MIN         MAN           PU         CON
WRT         TRA
## 1     ARG      EMP  1419.8013    52.08903   1931.7602   101.720936   742.4044
1982.1775   648.5119
## 2     ARG       VA 14951.2918  6454.94152  36346.5456  2722.762554  9426.0033
26633.1292 14404.6626
## 3     BOL      EMP   964.2103    56.03295    235.0332     5.346433   122.7827
281.5164   115.4728
## 4     BOL       VA  3299.7182  2846.83763   3458.2904   664.289574   729.0152
2757.9795  2727.4414
## 5     BRA      EMP 17191.3529   206.02389   6991.3710   364.573404  3524.7384
8509.4612  2054.3731
## 6     BRA       VA 76870.1456 30916.64606 223330.4487 43549.277879 70211.4219
178357.8685 89880.9743
##          FIRE        GOV        OTH        SUM
## 1   627.79291   2043.471   992.4475   10542.177
## 2  8547.37278  25390.774  7656.3565  152533.839
## 3    44.56442         NA   395.5650    2220.524
## 4  1752.06208         NA  4383.5425   22619.177
## 5  4413.54448   5307.280  5710.2665   54272.985
```

```
## 6 183027.46189 249135.452 55282.9748 1200562.671
```

The execution cost of all of these functions is extremely small, so the performance is essentially limited by C++, not by R.

```
library(microbenchmark)
microbenchmark(call = add_vars(g[["groups"]], fmean(get_vars(GGDC10S, 6:16), g,
use.g.names = FALSE)))
## Unit: microseconds
##  expr     min      lq     mean   median      uq     max neval
##  call 257.931 271.765 368.8147 369.2695 384.889 987.545   100
```

We can use these functions to write very efficient grouped code in R. This shows a simple application in panel data econometrics comparing a pooled OLS to a group means, a between and a within estimator computed on the demeaned data[3]:

```
Panel_Ests <- function(formula, data, pids) {
  # Get variables as character string, first variable is dependent variable
  vars <- all.vars(formula)
  # na_omit is a fast replacement for na.omit
  data_cc <- na_omit(get_vars(data, c(vars, pids)))
  g <- GRP(data_cc, pids, return.groups = FALSE, call = FALSE)
  # qM is a faster as.matrix
  data_cc <- qM(get_vars(data_cc, vars))
  # Computing group means
  mean_data_cc <- fmean(data_cc, g, use.g.names = FALSE)
  # This computes regression coefficients
  reg <- function(x) qr.coef(qr(cbind(Intercept = 1, x[, -1L, drop = FALSE])),
x[, 1L])

  qM(list(Pooled = reg(data_cc),
          Means = reg(mean_data_cc),
          # This replaces data values with the group-mean -> between-group
estimator
          Between = reg(TRA(data_cc, mean_data_cc, "replace_fill", g)),
          # This subtracts the group-means -> within-group estimator
          Within = reg(TRA(data_cc, mean_data_cc, "-", g))))
}

library(magrittr)  # Pipe operators

# Calculating Value Added Percentage Shares (data is in local currency)
VA_shares <- fsubset(GGDC10S, Variable == "VA") %>% ftransformv(6:16, `*`,
100/SUM)

# Value Added data (regressing Government on Agriculture, Manufactoring and
Finance & Real Estate)
Panel_Ests(GOV ~ AGR + MAN + FIRE, VA_shares, "Country") %>% round(4)
##            Pooled   Means Between  Within
## Intercept 25.8818 26.6702 26.5828  0.0000
## AGR       -0.3425 -0.3962 -0.3749 -0.2124
## MAN       -0.2339 -0.1744 -0.2215 -0.2680
## FIRE      -0.2083 -0.3337 -0.2572 -0.0742

# Employment data
fsubset(GGDC10S, Variable == "EMP") %>% ftransformv(6:16, `*`, 100/SUM) %>%
  Panel_Ests(formula = GOV ~ AGR + MAN + FIRE, "Country") %>% round(4)
##            Pooled   Means Between  Within
```

```
## Intercept 33.2047 34.6626 35.4332  0.0000
## AGR       -0.3543 -0.3767 -0.3873 -0.2762
## MAN       -0.4444 -0.4595 -0.4790 -0.4912
## FIRE      -0.1721 -0.3097 -0.2892 -0.1087
```

It would be easy to add an option for sampling weights as `fmean` also supports weighted grouped computations. A benchmark below shows that this series of estimators is executed very efficiently and scales nicely to large data (quite a bit faster than using `plm` to do it).

```
# Benchmark on VA data
microbenchmark(call = Panel_Ests(SUM ~ AGR + MIN + MAN, VA_shares, "Country"))
## Unit: milliseconds
##  expr      min       lq     mean  median       uq      max neval
##  call 1.643975 2.203792 3.119572 2.72077 3.583589 10.44576   100
```

There are lots and lots of other applications that can be devised in R using the `.FAST_FUN` and efficient programming with grouping objects.

Creating Grouped Functions in C/C++

It is also possible to just use 'GRP' objects as input to new grouped functions written in C or C++. Below I use *Rcpp* to create a generic grouped `anyNA` function for vectors:

```
// [[Rcpp::plugins(cpp11)]]
#include
using namespace Rcpp;

// Inputs:
// x - A vector of any type
// ng - The number of groups - supplied by GRP() in R
// g - An integer grouping vector - supplied by GRP() in R

// Output: A plain logical vector of size ng

template
LogicalVector ganyNACppImpl(Vector x, int ng, IntegerVector g) {
  int l = x.size();
  if(l != g.size()) stop("length(x) must match length(g)");
  LogicalVector out(ng); // Initializes as false

  if(RTYPE == REALSXP) { // Numeric vector: all logical operations on NA/NaN
evaluate to false, except != which is true.
    for(int i = 0; i < l; ++i) {
      if(x[i] != x[i] && !out[g[i]-1]) out[g[i]-1] = true;
    }
  } else { // other vectors
    for(int i = 0; i < l; ++i) {
      if(x[i] == Vector::get_na() && !out[g[i]-1]) out[g[i]-1] = true;
    }
  }

  return out;
}

// Disabling complex and non-atomic vector types
template <>
LogicalVector ganyNACppImpl(Vector x, int ng, IntegerVector) {
  stop("Not supported SEXP type!");
}
```

```
template <>
LogicalVector ganyNACppImpl(Vector x, int ng, IntegerVector) {
  stop("Not supported SEXP type!");
}

template <>
LogicalVector ganyNACppImpl(Vector x, int ng, IntegerVector) {
  stop("Not supported SEXP type!");
}

template <>
LogicalVector ganyNACppImpl(Vector x, int ng, IntegerVector) {
  stop("Not supported SEXP type!");
}

// [[Rcpp::export]]
LogicalVector ganyNACpp(const SEXP& x, int ng = 0, const IntegerVector& g = 0){
  RCPP_RETURN_VECTOR(ganyNACppImpl, x, ng, g);
}
```

On the R side things are then pretty simple:

```
library(Rcpp)
sourceCpp("ganyNA.cpp")

ganyNA <- function(x, g, use.g.names = TRUE) {
  # Option group.sizes = FALSE prevents tabulation of levels if a factor is
passed
  g <- GRP(g, return.groups = use.g.names, group.sizes = FALSE, call = FALSE)
  res <- ganyNACpp(x, g[[1L]], g[[2L]])
  # GRPnames creates unique group names. For vectors they need not be character
typed.
  if(use.g.names) names(res) <- GRPnames(g, force.char = FALSE)
  res
}
```

Strictly speaking there are different options to set this up: `GRP()` is a S3 generic function with a default method applying to atomic vectors and lists / data frames, but also a 'factor' method converting factors to 'GRP' objects. Above I have used the generic `GRP` function with the option `group.sizes = FALSE`, so factors are efficiently converted without tabulating the levels. This provides more efficiency if a factor is passed to `g`, but will not drop unused factor levels. The alternative is to use `g <- GRP.default(g, return.groups = use.g.names, call = FALSE)`, which will get rid of unused factor levels, but using factors for grouping is just as efficient as any other vector.

```
GGDC10S %$% ganyNA(SUM, list(Country, Variable)) %>% head
## ARG.EMP  ARG.VA BOL.EMP  BOL.VA BRA.EMP  BRA.VA
##   FALSE   FALSE   FALSE    TRUE   FALSE    TRUE

# 10 million obs and 1 million groups, 1% of data missing
x <- na_insert(rnorm(1e7), prop = 0.01)
g <- sample.int(1e6, 1e7, TRUE)
system.time(ganyNA(x, g))
##        User      System verstrichen
##        0.56        0.05        0.61
system.time(ganyNA(x, g, use.g.names = FALSE))
##        User      System verstrichen
##        0.42        0.03        0.46
```

```
# Using a factor grouping variable: more efficient but does not drop any unused
levels
f <- qF(g, na.exclude = FALSE) # Efficiently creating a factor (qF is faster
as.factor)
system.time(ganyNA(x, f))
##        User      System verstrichen
##        0.02        0.02        0.03
system.time(ganyNA(x, f, use.g.names = FALSE))
##        User      System verstrichen
##        0.04        0.01        0.05

# We can also efficiently pass a 'GRP' object: both GRP.GRP and GRP.default
simply return it.
g <- GRP(g)
system.time(ganyNA(x, g))
##        User      System verstrichen
##        0.01        0.00        0.01
system.time(ganyNA(x, g, use.g.names = FALSE))
##        User      System verstrichen
##        0.03        0.00        0.03
```

We could additionally add a `TRA` argument and then internally call the `TRA()` function to allow for replacing and sweeping out statistics, but this does not make much sense here.