

Wrangling categorical data in R

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ABSTRACT

Data wrangling is a critical foundation of data science, and wrangling of categorical data is an important component of this process. However, categorical data can introduce unique issues in data wrangling, particularly in real-world settings with collaborators and periodically-updated dynamic data. This paper discusses common problems arising from categorical variable transformations in R, demonstrates the use of factors, and suggests approaches to address data wrangling challenges. For each problem, we present at least two strategies for management, one in base R and the other from the ‘tidyverse.’ We consider several motivating examples, suggest defensive coding strategies, and outline principles for data wrangling to help ensure data quality and sound analysis.

Keywords: statistical computing; data derivation; data science; data management

INTRODUCTION

Wrangling skills provide an intellectual and practical foundation for data science. Careless data cleaning operations can lead to errors or inconsistencies in analysis (Hermans and Murphy-Hill, 2015; FitzJohn et al., 2014). The wrangling of categorical data presents particular challenges and is highly relevant because many variables are categorical (e.g., gender, income bracket, U.S. state), and categorical data is often coded with numerical values. It is easy to break the relationship between category numbers and category labels without realizing it, thus losing the information encoded in a variable. If data sources change upstream (for example, if a domain expert is providing spreadsheet data at regular intervals), code that worked on the initial data may not generate an error message, but could silently produce incorrect results.

Statistical and data science tools need to foster good practice and provide a robust environment for data wrangling and data management. This paper focuses on how R deals with categorical data, and showcases best practices for categorical data manipulation in R to produce reproducible workflows. We consider a number of common idioms related to categorical data that arise frequently in data cleaning and preparation, propose some guidelines for defensive coding, and discuss settings where analysts often get tripped up when working with categorical data.

For example, data ingested into R from spreadsheets can lead to problems with categorical data because of the different storage methods possible in both R and the spreadsheets themselves (Wilson et al., 2016). The examples below help flag when these issues arise or avoid them altogether.

To ground our work, we compare and contrast how categorical data are treated in **base** R and the tidyverse (Wickham, 2014, 2016). Tools from the tidyverse, discussed in another paper in this special issue (see <https://github.com/dsscollection/tidyflow>), are designed to make analysis purer, more predictable, and pipeable. Key components of the tidyverse we address in this paper include **dplyr**, **tidyr**, **forcats**, and **readr**. This suite of packages helps facilitate a reproducible workflow where a new version of the data could be supplied in the code with updated results produced (Broman, 2015). While R code written in **base** syntax can also have this quality, a common tendency is to use row or column numbers in code, which makes the result less reproducible. Wrangling of categorical data can make this task even more complex (e.g., if a new level of a categorical variable is added in an updated dataset or inadvertently introduced by a careless error in a spreadsheet to be ingested into R).

Our goal is to make the case that it is better to work with categorical data using tidyverse packages than with **base** R. Tidyverse code is more human readable, which can help reduce errors from the start, and the functions we highlight have been designed to make it harder to accidentally remove relationships

implicit in categorical data. Because these issues are even more salient for new users, we recommend that instructors teach tidyverse approaches from the start.

CATEGORICAL DATA IN R: FACTORS AND STRINGS

Consider a variable describing gender including categories `male`, `female` and `non-conforming`. In R, there are two ways to store this information. One is to use a series of *character strings*, and the other is to store it as a *factor*.

In early versions of R, storing categorical data as a factor variable was considerably more efficient than storing the same data as strings, because factor variables only store the factor labels once (Peng, 2015; Lumley, 2015). However, R now uses a global string pool, so each unique string is only stored once, which means storage is now less of an issue (Peng, 2015). For historical (or possibly anachronistic) reasons, many functions store variables by default as factors.

While factors are important when including categorical variables in regression models and when plotting data, they can be tricky to deal with, since many operations applied to them return different values than when applied to character vectors. As an example, consider a set of decades,

```
x1 <- c(10, 10, 20, 20, 40)
x1f <- factor(x1)
ds <- data.frame(x1, x1f)
library(dplyr)
ds <- ds %>%
  mutate(x1recover = as.numeric(x1f))
ds

##      x1 x1f x1recover
## 1  10   10         1
## 2  10   10         1
## 3  20   20         2
## 4  20   20         2
## 5  40   40         3
```

Instead of creating a new variable with a numeric version of the value of the factor variable `x1f`, the variable is created with a factor number (i.e., 10 is mapped to 1, 20 is mapped to 2, and 40 is mapped to 3). This result is unexpected because `base::as.numeric()` is intended to recover numeric information by coercing a character variable. Compare the following:

```
as.numeric(c("hello"))

## [1] NA

as.numeric(factor(c("hello")))

## [1] 1
```

The factor function has other behavior that feels unexpected. For example, the following code silently makes a missing value, because the values in the data and the levels do not match.

```
factor("a", levels="c")

## [1] <NA>
## Levels: c
```

The unfortunate behavior of factors in R has led to an online movement against the default behavior of many data import functions to make factors out of any variable composed as strings (Peng, 2015; Wickham et al., 2017). The tidyverse is part of this movement, with functions from the **readr** package defaulting to leaving strings as-is. (Others have chosen to add `options(stringAsFactors=FALSE)` into their startup commands.)

Although the storage issues have been solved, and there are problems with defaulting strings to factors, factors are still necessary for some data analytic tasks. The most salient case is in modeling. When you pass a factor variable into `lm()` or `glm()`, R automatically creates indicator (or more colloquially ‘dummy’) variables for each of the levels and picks one as a reference group.

For simple cases, this behavior can also be achieved with a character vector. However, to choose which level to use as a reference level or to order classes, factors must be used. For example, if a factor encodes income levels as `low`, `medium`, `high`, it might make sense to use the lowest income level (`low`) as the reference class so that all the other coefficients can be interpreted in comparison to it. However, R would use `high` as the reference by default because ‘h’ comes before ‘l’ in the alphabet.

While ordering is particularly important when doing ordinal logistic regression and multinomial logistic regression, the use of alphabetic ordering by default means even simple linear regression can be affected.

In the context of visualizing data, factors are also relevant because they allow categorical variables to be mapped to aesthetic attributes.

While factors are important, they can often be hard to deal with. Because of the way the group numbers are stored separately from the factor labels, it can be easy to overwrite data in such a way that the original data are lost. They present a steep learning curve for new users. In this paper, we will suggest best practices for working with factor data.

To motivate this process, we will consider data from the General Social Survey (Smith et al., 2015). The General Social Survey is a product of the National Data Program for the Social Sciences, and the survey has been conducted since 1972 by NORC at the University of Chicago. It contains data on many factors of social life, and is widely used by social scientists. (In this paper we consider data from 2014.)

There are some import issues inherent to the data which are not particular to categorical data (see Supplementary Appendix A for details). We’ll work with the data with slightly cleaned up variable names.

```
library(dplyr)
GSS <- read.csv("../data/GSScleaned.csv")
glimpse(GSS)

## Observations: 2,540
## Variables: 16
## $ Year                <int> 2014, 2014, 2014, 2014, 2014, 2014, ...
## $ ID                  <int> 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 1...
## $ LaborStatus          <fctr> Working fulltime, Working fulltime,...
## $ OccupationalPrestigeScore <int> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, ...
## $ MaritalStatus        <fctr> Divorced, Married, Divorced, Marrie...
## $ NumChildren          <int> 0, 0, 1, 2, 3, 1, 2, 2, 4, 3, 2, 0, ...
## $ Age                  <fctr> 53.000000, 26.000000, 59.000000, 56...
## $ HighestSchoolCompleted <int> 16, 16, 13, 16, 17, 17, 12, 17, 10, ...
## $ Sex                  <fctr> Male, Female, Male, Female, Female,...
## $ Race                  <fctr> White, White, White, White, White, ...
## $ ChildhoodFamilyIncome <fctr> Below average, Average, Below avera...
## $ TotalFamilyIncome     <fctr> $25000 or more, $25000 or more, $25...
## $ RespondentIncome      <fctr> $25000 or more, $25000 or more, Not...
## $ PoliticalParty        <fctr> Not str republican, Not str republi...
## $ OpinionOfIncome       <fctr> Above average, Above average, Below...
## $ SexualOrientation      <fctr> Heterosexual or straight, Heterosex...
```

The remainder of this paper is organized around case studies (examples) to carry out four specific and useful tasks:

1. Changing the labels of factor levels,
2. Reordering factor levels,
3. Combining several levels into one (both string-like labels and numeric, probably go together), and
4. Making derived factor variables.

Each case study begins with a problem, and presents several solutions. Typically, we contrast a method that uses the functionality of **base R** with an approach from the tidyverse along with some annotations of the code as needed. We will argue that while both approaches can solve the problem, the tidyverse solution tends to be simpler, easier to learn, and less fragile.

106 CHANGING THE LABELS OF FACTOR LEVELS

107 Our first example works with the `LaborStatus` variable. It is a categorical variable with 9 levels. Most
108 of the labels are spelled out fully, but a few are strangely formatted. We want to change this.

109 This is a specific case of the more general problem of changing the text of factor labels, so they appear
110 more nicely formatted in a plot, for example.

111 There are two typical approaches in **base R**. One is more compact, but depends on the levels of the
112 factor not changing in the data being fed in, and the other is more robust, but extremely verbose. In
113 contrast, the **dplyr** package offers a more human readable method, while also supporting reproducibility.

114 Compact but fragile (base R)

115 To begin this example, we will create a new copy of the variable in question so as to leave the original
116 data for comparison.

```
GSS$BaseLaborStatus <- GSS$LaborStatus
levels(GSS$BaseLaborStatus)

## [1] "Keeping house"      "No answer"          "Other"
## [4] "Retired"            "School"              "Temp not working"
## [7] "Unempl, laid off"   "Working fulltime"    "Working parttime"

summary(GSS$BaseLaborStatus)

##      Keeping house      No answer      Other      Retired
##             263             2             76             460
##      School Temp not working Unempl, laid off Working fulltime
##             90             40             104             1230
## Working parttime      NA's
##             273             2
```

117 Almost all of our code examples start with some examination of the `levels()` and `summary()` of
118 the variable, in order to keep track of what the expected results are. With the counts in mind, the labels
119 can be rephrased for a few categories.

```
levels(GSS$BaseLaborStatus) <- c(levels(GSS$BaseLaborStatus)[1:5],
                                   "Temporarily not working",
                                   "Unemployed, laid off",
                                   "Working full time",
                                   "Working part time")

summary(GSS$BaseLaborStatus)

##      Keeping house      No answer      Other
##             263             2             76
##      Retired      School Temporarily not working
##             460             90             40
## Unemployed, laid off Working full time Working part time
##             104             1230             273
##      NA's
##             2
```

120 This method is less than ideal, because it depends on the data coming in with the factor levels ordered
121 in a particular way. The first five levels are left the same, and the last four are overwritten.

122 We call this a *fragile* process since future datasets may cause a workflow to break (a related concept
123 in computer science is *software brittleness*, where a small change can lead to an error). Why is this
124 fragile? By default, R orders factor levels alphabetically. So, `Keeping house` is first not because
125 it is the most common response, but simply because 'k' comes first in the alphabet. If the data gets
126 changed outside of R, for example so responses currently labeled `Working full time` get labeled
127 `Full time work`, the code above will not generate an error message, but will mislabel all the data
128 such that the `BaseLaborStatus` variable is essentially meaningless.

129 The issue of alphabetic ordering becomes even more relevant when considering strings that include
130 non-ASCII characters, where the default order levels may vary from locale to locale. This means that
131 code could create different results based on where it was run.

132 The workflow will also fail if additional factor levels are added after the fact. In our experience, both
 133 with students and scientific collaborators, spreadsheet data can be easily changed in these ways. Others
 134 have noted this concern (Leek, 2016).

135 Robust but verbose (base R)

136 Another (more robust method) to recode this variable in **base R** is to use subsetting to overwrite particular
 137 values in the data.

```
GSS$BaseLaborStatus <- GSS$LaborStatus
summary(GSS$BaseLaborStatus)

##      Keeping house      No answer      Other      Retired
##             263             2             76             460
##      School Temp not working Unempl, laid off Working fulltime
##             90             40             104             1230
## Working parttime      NA's
##             273             2

GSS$BaseLaborStatus <- as.character(GSS$BaseLaborStatus)
GSS$BaseLaborStatus[GSS$BaseLaborStatus == "Temp not working"] <-
  "Temporarily not working"
GSS$BaseLaborStatus[GSS$BaseLaborStatus == "Unempl, laid off"] <-
  "Unemployed, laid off"
GSS$BaseLaborStatus[GSS$BaseLaborStatus == "Working fulltime"] <-
  "Working full time"
GSS$BaseLaborStatus[GSS$BaseLaborStatus == "Working parttime"] <-
  "Working part time"
GSS$BaseLaborStatus <- factor(GSS$BaseLaborStatus)
summary(GSS$BaseLaborStatus)

##      Keeping house      No answer      Other
##             263             2             76
##      Retired      School Temporarily not working
##             460             90             40
## Unemployed, laid off Working full time Working part time
##             104             1230             273
##      NA's
##             2
```

138 This second approach is more robust, because if the labels or ordering of levels changes before this
 139 code is run it will not overwrite labels on the incorrect data. However, this approach has a number of
 140 limitations in addition to being tedious and error prone. It is possible to miss cases, and misspelling and
 141 cut-and-paste errors can mean pieces of the code do not actually do anything.

142 Direct and robust (tidyverse)

143 The `recode()` function in the **dplyr** package is a vectorized function, which combines the robustness
 144 of the second **base R** approach while also reducing the verbosity. It still suffers from the problem of
 145 misspelling and cut-and-paste errors, because it will not generate an error message if you try to recode a
 146 non-existent level.

```
GSS <- GSS %>%
  mutate(tidyLaborStatus =
    recode(LaborStatus,
      `Temp not working` = "Temporarily not working",
      `Unempl, laid off` = "Unemployed, laid off",
      `Working fulltime` = "Working full time",
      `Working parttime` = "Working part time"))
summary(GSS$tidyLaborStatus)

##      Keeping house      No answer      Other
##             263             2             76
##      Retired      School Temporarily not working
##             460             90             40
## Unemployed, laid off Working full time Working parttime
##             104             1230             273
##      NA's
##             2
```

147 In the above example, notice the trailing space in ``Working parttime `` in the `recode()` call.
 148 Because of this typo (the original factor level is actually ``Working parttime``), the original factor
 149 level persists after the recode.

150 Aside – Editing whitespace out of levels

151 A more general problem sometimes arises due to extra spaces included when data are ingested. Such
 152 whitespace can be dealt with when data is read, or addressed later using string operations. This latter
 153 approach can be carried out using the `trimws()` function in **base R**.

```
gender <- factor(c("male ", "male ", "male ", "male"))
levels(gender)

## [1] "male"      "male "    "male "    "male "
```

```
gender <- factor(trimws(gender))
levels(gender)

## [1] "male"
```

154 REORDERING FACTOR LEVELS

155 Often, factor levels have a natural ordering to them. However, the default in **base R** is to order levels
 156 alphabetically. So, users must have a way to impose order on their factor variables.

157 Again, there is a fragile way to reorder the factor levels in **base R**, and a more robust method in the
 158 **tidyverse**.

159 Fragile method (base R)

160 One common way to make this sort of change is to pass an argument to `levels` within the `factor()`
 161 function. However, this is fragile with respect to spelling issues and trailing whitespace.

```
GSS$BaseOpinionOfIncome <- GSS$OpinionOfIncome
summary(GSS$BaseOpinionOfIncome )
```

##	Above average	Average	Below average	Don't know
##	483	1118	666	21
##	Far above average	Far below average	No answer	NA's
##	65	179	6	2

```
GSS$BaseOpinionOfIncome <-
  factor(GSS$BaseOpinionOfIncome,
    levels = c("Far above average", "Above average", "Average ", "Below Average",
      "Far below average", "Don't know", "No answer"))
summary(GSS$BaseOpinionOfIncome )
```

##	Far above average	Above average	Average	Below Average
##	65	483	0	0
##	Far below average	Don't know	No answer	NA's
##	179	21	6	1786

162 Note that many of the category totals come through appropriately, but several totals get set to 0
 163 (Average because of the trailing whitespace and Below Average because of the mistaken capitaliza-
 164 tion). These errors can be exceedingly frustrating to troubleshoot.

165 An approach that looks similar upon inspection but actually does not work is to overwrite the
 166 `levels()` of the factor outside the `factor()` command. It is tempting for new analysts to write code
 167 such as the following, which completely breaks the association between rows and factor labels the data
 168 set.

```
badApproach <- GSS$OpinionOfIncome
```

```
summary(badApproach)

##      Above average      Average      Below average      Don't know
##           483           1118           666           21
## Far above average Far below average      No answer      NA's
##           65           179           6           2

levels(badApproach) <- c("Far above average", "Above average",
                        "Average", "Below Average", "Far below average",
                        "Don't know", "No answer")

summary(badApproach)

## Far above average      Above average      Average      Below Average
##           483           1118           666           21
## Far below average      Don't know      No answer      NA's
##           65           179           6           2
```

169 Notice that no errors were generated, but the labels have been clobbered and the counts do not match
 170 up anymore. Instead of Far above average having 65 observations, it has 483.

171 Another **base** approach that will not suffer from spelling mistakes is to use numeric indexing to
 172 reorder the levels. Again, the indexing must take place within a `factor()` call.

```
GSS$BaseOpinionOfIncome <- GSS$OpinionOfIncome
summary(GSS$BaseOpinionOfIncome)

##      Above average      Average      Below average      Don't know
##           483           1118           666           21
## Far above average Far below average      No answer      NA's
##           65           179           6           2

GSS$BaseOpinionOfIncome <-
  factor(GSS$BaseOpinionOfIncome,
        levels=levels(GSS$BaseOpinionOfIncome)[c(5,1:3,6,4,7)])
summary(GSS$BaseOpinionOfIncome)

## Far above average      Above average      Average      Below average
##           65           483           1118           666
## Far below average      Don't know      No answer      NA's
##           179           21           6           2
```

173 This is both verbose and depends on the number and order of the levels staying the same. If another
 174 factor level is added to the dataset, the above code will generate an error message because the number of
 175 levels differs. This example illustrates why it is sometimes dangerous to replace an old version of a data
 176 frame with a new version.

177 Again, if you try this approach outside of a `factor()` call, no errors are generated but the levels get
 178 clobbered.

```
badApproach <- GSS$OpinionOfIncome
summary(badApproach)

##      Above average      Average      Below average      Don't know
##           483           1118           666           21
## Far above average Far below average      No answer      NA's
##           65           179           6           2

levels(badApproach) <- levels(badApproach)[c(5,1:3,6,4,7)]
summary(badApproach)

## Far above average      Above average      Average      Below average
##           483           1118           666           21
## Far below average      Don't know      No answer      NA's
##           65           179           6           2
```

179 Notice that once again, Far above average has been given the wrong number of observations.
 180 Here, **base** methods for reordering factor levels are very fragile. Approaches that appear functional and
 181 do not generate error messages can easily lead to garbled data.

182 Robust method (tidyverse)

183 Because of the fragility and potential for frustration and mistakes associated with reordering levels in
184 base R, we recommend the use of a tidyverse package.

185 The package **forcats** (where the name is an anagram of the word factors!) is included in the tidy-
186 verse (Wickham, 2017). It includes a `fct_relevel()` function that allows for robust reordering of
187 factor levels. It takes a specification of the order of factor levels (either completely or partially) and is
188 robust to re-running code in an interactive session.

```
# devtools::install_github("hadley/forcats")
library(forcats)
summary(GSS$OpinionOfIncome)

##      Above average      Average      Below average      Don't know
##           483           1118           666           21
## Far above average Far below average      No answer      NA's
##           65           179           6           2

GSS <- GSS %>%
  mutate(tidyOpinionOfIncome =
    fct_relevel(OpinionOfIncome,
      "Far above average",
      "Above average",
      "Average",
      "Below average",
      "Far below average"))
summary(GSS$tidyOpinionOfIncome)

## Far above average      Above average      Average      Below average
##           65           483           1118           666
## Far below average      Don't know      No answer      NA's
##           179           21           6           2
```

189 Notice the levels unmentioned in the function call end up at the back end of the ordering, but all the
190 counts are appropriate.

191 COMBINING SEVERAL LEVELS INTO ONE

192 Combining discrete levels

193 This is another common task. Maybe you want fewer coefficients in your model, or the data-generating
194 process makes a finer distinction between categories than your research. For whatever the reason, you
195 want to group together levels that are currently separate.

196 Fragile method (base R)

197 This method overwrites the labels of factor levels with repeated labels in order to group levels together.

```
GSS$BaseMarital <- GSS$MaritalStatus
summary(GSS$BaseMarital)

##      Divorced      Married Never married      No answer      Separated
##           411           1158           675           4           81
##      Widowed      NA's
##           209           2

levels(GSS$BaseMarital) <- c("Not married", "Married",
  "Not married", "No answer",
  "Not married", "Not married", NA)
summary(GSS$BaseMarital)

## Not married      Married      No answer      NA's
##           1376           1158           4           2
```

198 As before, this is fragile because it depends on the order of the factor levels not changing, and on a
199 human accurately counting the indices of all the levels they wish to change.

200 **Robust method (tidyverse)**

201 In the tidyverse, the `recode()` function performs recoding more robustly.

```
summary(GSS$MaritalStatus)

##      Divorced      Married Never married      No answer      Separated
##          411          1158          675           4           81
##      Widowed      NA's
##          209           2

GSS <- GSS %>%
  mutate(tidyMaritalStatus = recode(MaritalStatus,
    Divorced = "Not married",
    `Never married` = "Not married",
    Widowed = "Not married",
    Separated = "Not married"))
summary(GSS$tidyMaritalStatus)

## Not married      Married      No answer      NA's
##          1376          1158           4           2
```

202 In contrast to the **base** approach, the tidyverse approach allows the analyst to only mention the levels
203 that need to be recoded. The levels do not need to be presented in the order they originally appeared (note
204 that `Widowed` appears earlier in the list than it does in the `summary()`).

205 **Combining numeric-type levels**

206 Combining numeric-type levels is a frequently-occurring problem even when
207 `stringsAsFactors = FALSE`. Often variables like age or income are right-censored, so there is a
208 final category that lumps the remainder of people into one group. This means the data is necessarily at
209 least a character string if not a factor. However, it may be more natural to work with numeric expressions
210 when recoding this data.

211 In this data, age is provided as an integer for respondents 18-88, but also includes the possible answers
212 89 or older, No answer and NA.

213 A common data wrangling task might be to turn this into a factor variable with two levels: 18-65, and
214 over 65. In this case, it would be easier to deal with a conditional statement about the numeric values,
215 rather than writing out each of the numbers as a character vector.

216 **Fragile method (base R)**

217 In order to break this data apart as simply as possible, it needs to be numeric. The first step is to recode
218 the label for 89 or older to read 89.

```
GSS$BaseAge <- GSS$Age
levels(GSS$BaseAge)

## [1] "18.000000" "19.000000" "20.000000" "21.000000" "22.000000"
## [6] "23.000000" "24.000000" "25.000000" "26.000000" "27.000000"
## [11] "28.000000" "29.000000" "30.000000" "31.000000" "32.000000"
## [16] "33.000000" "34.000000" "35.000000" "36.000000" "37.000000"
## [21] "38.000000" "39.000000" "40.000000" "41.000000" "42.000000"
## [26] "43.000000" "44.000000" "45.000000" "46.000000" "47.000000"
## [31] "48.000000" "49.000000" "50.000000" "51.000000" "52.000000"
## [36] "53.000000" "54.000000" "55.000000" "56.000000" "57.000000"
## [41] "58.000000" "59.000000" "60.000000" "61.000000" "62.000000"
## [46] "63.000000" "64.000000" "65.000000" "66.000000" "67.000000"
## [51] "68.000000" "69.000000" "70.000000" "71.000000" "72.000000"
## [56] "73.000000" "74.000000" "75.000000" "76.000000" "77.000000"
## [61] "78.000000" "79.000000" "80.000000" "81.000000" "82.000000"
## [66] "83.000000" "84.000000" "85.000000" "86.000000" "87.000000"
## [71] "88.000000" "89 or older" "No answer"

levels(GSS$BaseAge) <- c(levels(GSS$BaseAge)[1:71], "89", "No answer")
```

219 This code is already fragile because of its reliance on numeric indexing. From the `levels()` output,
220 the first 71 levels correspond to the ages 18-88, and are in the expected order, so these are left as-is. Then

221 89 or older is overwritten with simply 89. Finally, the variable can be converted to a character
 222 vector and then to a numeric one.

```
GSS$BaseAge <- as.numeric(as.character(GSS$BaseAge))
summary(GSS$BaseAge)

##      Min. 1st Qu.  Median    Mean 3rd Qu.    Max.    NA's
##      18.00   34.00   49.00   49.01   62.00   89.00     11
```

223 This avoids the pitfall from the introduction by not using `as.numeric()` on the factor variables
 224 (this would convert 18 to 1, 19 to 2, etc.). This method cheats a little— if the goal were to use this as a
 225 numeric variable in an analysis it would not be appropriate to turn all the 89 or older cases into the
 226 number 89. In this case, the goal is to create a two-level factor, so those cases would be assigned to the
 227 65 and up category one way or the other.

228 Once the variable is numeric, some conditional logic can be applied to split into two cases.

```
summary(GSS$BaseAge)

##      Min. 1st Qu.  Median    Mean 3rd Qu.    Max.    NA's
##      18.00   34.00   49.00   49.01   62.00   89.00     11

GSS$BaseAge <- ifelse(GSS$BaseAge < 65, "18-64", "65 and up")
GSS$BaseAge <- factor(GSS$BaseAge)
summary(GSS$BaseAge)

##      18-64 65 and up    NA's
##      2011      518      11
```

229 **Robust method (tidyverse)**

230 The tidyverse method follows similar logic. However, instead of explicitly overwriting 89 or older
 231 with the number 89 using indexing, the tidyverse solution uses the **readr** `parse_number()` function
 232 to remove the numbers from each factor label. This works for the labels that already look numeric, like
 233 18.000000 as well as for 89 or older. Then conditional logic can be used to split the variable
 234 within a mutate command.

```
library(readr)
GSS <- GSS %>%
  mutate(tidyAge = parse_number(Age)) %>%
  mutate(tidyAge = if_else(tidyAge < 65, "18-65", "65 and up"),
         tidyAge = factor(tidyAge))
summary(GSS$tidyAge)

##      18-65 65 and up    NA's
##      2011      518      11
```

235 Note that this approach requires the analyst to be very sure the strings including a number have a
 236 *relevant* number. If one of the levels was labeled 2 or more people in household it would be
 237 converted to the number 2. This would accidentally add a number that was not meaningful.

238 **CREATING DERIVED CATEGORICAL VARIABLES**

239 Challenges often arise when data scientists need to create derived categorical variables. As an example,
 240 consider an indicator of moderate drinking status. The National Institutes of Alcohol Abuse and Alco-
 241 holism have published guidelines for moderate drinking (NIAAA, 2016). These guidelines state that
 242 women (or men aged 65 or older) should drink no more than one drink per day on average and no more
 243 than three drinks on any single day or at a sitting. Men under age 65 should drink no more than two drinks
 244 per day on average and no more than four drinks on any single day.

245 The `HELPmiss` dataset from the **mosaicData** package includes baseline data from randomized
 246 Health Evaluation and Linkage to Primary Care (HELP) clinical trial (Samet et al., 2003). These subjects
 247 for the study were recruited from a detoxification center, hence those that reported alcohol as their primary
 248 substance of abuse have extremely high rates of drinking.

	variable	description
	sex	gender of subject female or male
249	i1	average number of drinks per day (in last 30 days)
	i2	maximum number of drinks per day (in past 30 days)
	age	age (in years)

250 These guidelines can be used to create a new variable called `abstinent` for those reporting no
 251 drinking based on the value of their `i1` variable and `moderate` for those that do not exceed the NIAAA
 252 guidelines, with all other non-missing values coded as `highrisk`.

```
library(mosaic)
library(mosaicData)
library(dplyr)
library(readr)
```

253 Because missing values can become especially problematic in more complex derivations, we will
 254 make one value missing so we can ensure our data wrangling accounts for the missing value.

```
data(HELPmiss)
HELPsmall <- HELPmiss %>%
  mutate(i1 = ifelse(id == 1, NA, i1)) %>% # make one value missing
  select(sex, i1, i2, age)
head(HELPsmall, 2)

##      sex i1 i2 age
## 1 male NA 26 37
## 2 male 56 62 37
```

255 Fragile method (base R)

```
# create empty vector for new variable
drinkstat <- character(length(HELPsmall$i1))
# create abstinent group
drinkstat[HELPsmall$i1 == 0] = "abstinent"
# create moderate group
drinkstat[(HELPsmall$i1 > 0 & HELPsmall$i1 <= 1 & # find those with moderate levels
  HELPsmall$i2 <= 3 & HELPsmall$sex == "female") |
  (HELPsmall$i1 > 0 & HELPsmall$i1 <= 2 &
  HELPsmall$i2 <= 4 & HELPsmall$sex == "male")] = "moderate"
# create highrisk group
drinkstat[((HELPsmall$i1 > 1 | HELPsmall$i2 > 3) & HELPsmall$sex == "female") |
  ((HELPsmall$i1 > 2 | HELPsmall$i2 > 4) & HELPsmall$sex == "male")] = "highrisk"
# account for missing values
is.na(drinkstat) <- is.na(HELPsmall$i1) | is.na(HELPsmall$i2) |
  is.na(HELPsmall$sex)
drinkstat <- factor(drinkstat)
table(drinkstat, useNA = "always")

## drinkstat
## abstinent highrisk moderate <NA>
##          69       372       28        1
```

256 While this approach works, it is hard to follow, check, or debug. The logical conditions are all
 257 correctly coded, but require many repetitions of `HELPsmall$variable`, and the missing value was
 258 not handled by default (without the `is.na()` call, the missing value would default to be `highrisk`
 259 because of the extreme value for `i2` for that subject).

260 Robust method (tidyverse)

```
HELPsmall <- HELPsmall %>%
```

```

mutate(drink_stat = case_when(
  i1 == 0 ~ "abstinent",
  i1 <= 1 & i2 <= 3 & sex == 'female' ~ "moderate",
  i1 <= 1 & i2 <= 3 & sex == 'male' & age >= 65 ~ "moderate",
  i1 <= 2 & i2 <= 4 & sex == 'male' ~ "moderate",
  is.na(i1) ~ "missing", # can't put NA in place of "missing"
  TRUE ~ "highrisk"
))

HELPSmall %>%
  group_by(drink_stat) %>%
  dplyr::count()

## Source: local data frame [4 x 2]
## Groups: drink_stat [4]
##
##   drink_stat      n
##   <chr> <int>
## 1 abstinent    69
## 2 highrisk   372
## 3 missing      1
## 4 moderate    28

```

261 In the robust tidyverse method, the same logic is used, but the conditions are clearer and more
 262 comprehensible. Instead of one complex Boolean condition for `moderate`, three separate lines can be
 263 used to match the different options. While the end result is the same, this code is more human readable
 264 and it is harder to miss special cases.

265 An additional example is provided in Supplementary Appendix B.

266 DEFENSIVE CODING

267 It is always good practice to code in a defensive manner. Investing a little time up front can help avoid
 268 painful errors later. In the context of wrangling categorical data, defensive coding involves running many
 269 `summary()` commands to ensure data operations do not mangle relationships, and might involve adding
 270 conditional testing statements into code creating or modifying factors. These testing statements (such as
 271 those implemented in the **testthat** and **assertthat** packages) can help ensure the data have not changed
 272 from one session to another, or as the result of changes to the raw data.

273 As an example, we might want to check there are exactly three levels for the drinking status variable
 274 in the `HELP` dataset. If there were fewer or more than three levels, something would have gone wrong
 275 with our code. The **assertthat** package can help with this.

```

library(assertthat)
levels(drinkstat)

## [1] "abstinent" "highrisk" "moderate"

assert_that(length(levels(drinkstat)) == 3)

## [1] TRUE

```

276 We also might want to ensure the factor labels are exactly what we were expecting. Perhaps we
 277 want to make sure the `Sex` variable in the `GSS` data has two categories, with particular levels. The
 278 `expect_equivalent()` function from the **testthat** package can be used to make this check.

```

library(testthat)
levels(GSS$Sex)

## [1] "Female" "Male"

expect_equivalent(levels(GSS$Sex), c("Female", "Male"))

```

279 This check will only work if the levels are exactly the same as the strings provided, and are in the
 280 same order. Ideally, `expect_equivalent()` would do level checking without relying on order, but
 281 that is not the current functionality.

282 While assertions of this sort are most commonly used to provide error-checking within functions, we
283 believe that they can and should be incorporated into working code. In this manner they may serve as the
284 basis for a function at some point in the future.

285 CONCLUSION

286 Categorical variables arise commonly in most datasets. Aspects of data wrangling in R involving
287 categorical variables can be problematic and error-prone, particularly when using **base R**. In this paper
288 we have outlined some example case studies where analytic tasks can be simplified and made more robust
289 through use of new tools available in the tidyverse. However, these are only some of the issues categorical
290 data presents.

291 For example, many analysts use testing and training data when working with models. Without careful
292 thought toward levels of categorical variables, there can be a mismatch between the levels present in the
293 training data and those present in the testing data. If a particular level was not present in the training data,
294 the model will not be able to make predictions for the observations in the testing data with that level. Even
295 worse, if the two sets have the same number of levels, the model may produce predictions by matching
296 the order of the levels rather than the labels.

297 We believe further work is needed to continue to make it easier to undertake analyses requiring
298 data wrangling (particularly with respect to categorical data). New tools and an increased emphasis on
299 defensive coding may help improve the quality of data science moving forward.

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303 SUPPLEMENTARY APPENDIX A: LOADING THE DATA

304 Since this is a reproducible special issue, we want to make sure our data ingestion process is as reproducible
305 as possible. We are using the General Social Survey (GSS) data, which includes many years of data
306 (1972-2014) and many possible variables (150-800 variables, depending on the year) (Smith et al., 2015).
307 However, the GSS data has some idiosyncrasies. So, we are attempting good-enough practices for data
308 ingest (Wilson et al., 2016).

309 The major issue related to reproducibility is the fact that the dataset is not available through an API.
310 For SPSS and Stata users, yearly data are available for direct download on the website. For more format
311 possibilities, users must go through an online wizard to select variables and years for the data they wish
312 to download (NORC at the University of Chicago, 2016). For this paper, we selected a subset of the
313 demographic variables and the year 2014. The possible output options from the wizard are Excel (either
314 data and metadata or metadata only), SPSS, SAS, Stata, DDI, or R script. We selected both the Excel and
315 R formats to look at the differences.

316 The R format provided by the GSS is actually a Stata file and custom R script using the **foreign**
317 package to do the translation. Here is the result of that process.

```
source(' ../data/GSS.r')
```

```
glimpse(GSS)

## Observations: 2,538
## Variables: 17
## $ YEAR      <int> 2014, 2014, 2014, 2014, 2014, 2014, 2014, 2014, 2014,...
## $ ID_       <int> 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16...
## $ WRKSTAT   <int> 1, 1, 4, 2, 5, 1, 9, 1, 8, 1, 7, 8, 5, 1, 6, 2, 2, 1,...
## $ PRESTIGE  <int> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,...
## $ MARITAL   <int> 3, 1, 3, 1, 1, 1, 1, 1, 1, 5, 1, 1, 5, 3, 1, 5, 1, 3, 5,...
## $ CHILDS    <int> 0, 0, 1, 2, 3, 1, 2, 2, 4, 3, 2, 0, 5, 2, 0, 3, 3, 0,...
## $ AGE       <int> 53, 26, 59, 56, 74, 56, 63, 34, 37, 30, 43, 56, 69, 4...
## $ EDUC      <int> 16, 16, 13, 16, 17, 17, 12, 17, 10, 15, 5, 11, 8, 11,...
## $ SEX       <int> 1, 2, 1, 2, 2, 2, 1, 1, 2, 2, 2, 1, 1, 2, 2, 1, 2, 1,...
## $ RACE      <int> 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 3, 3, 1, 1, 1, 1, 3, 1,...
## $ INCOMI6   <int> 2, 3, 2, 2, 4, 4, 2, 3, 3, 1, 1, 2, 2, 2, 2, 3, 2, 3,...
## $ INCOME    <int> 12, 12, 12, 12, 13, 12, 13, 12, 10, 12, 9, 9, 10, 11,...
## $ RINCOME   <int> 12, 12, 0, 9, 0, 12, 13, 12, 0, 12, 0, 0, 0, 11, 12, ...
## $ INCOME72  <int> 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0,...
## $ PARTYID   <int> 5, 5, 6, 5, 3, 6, 6, 8, 3, 3, 3, 3, 3, 1, 3, 6, 1, 3,...
## $ FINRELA   <int> 4, 4, 2, 4, 3, 4, 9, 3, 2, 3, 8, 5, 1, 1, 3, 3, 2, 3,...
## $ SEXORNT   <int> 3, 3, 3, 3, 3, 9, 0, 0, 3, 3, 3, 3, 3, 0, 3, 3, 0, 0,...
```

318 Obviously, the result is less than ideal. All of the factor variables are encoded as integers, but their
 319 level labels have been lost. We have to look at a codebook to determine if SEX == 1 indicates male or
 320 female. We would rather preserve the integrated level labels. In order to do this, our best option is to use
 321 the Excel file and use the **readxl** package to load it.

```
library(readxl)
GSS <- read_excel("../data/GSS.xls")
glimpse(GSS)

## Observations: 2,540
## Variables: 17
## $ Gss year for this respondent      <dbl> 2014, 2014...
## $ Respondent id number             <dbl> 1, 2, 3, 4...
## $ Labor force status               <chr> "Working f...
## $ Rs occupational prestige score   (1970) <dbl> 0, 0, 0, 0...
## $ Marital status                   <chr> "Divorced"...
## $ Number of children               <dbl> 0, 0, 1, 2...
## $ Age of respondent                <chr> "53.000000...
## $ Highest year of school completed <dbl> 16, 16, 13...
## $ Respondents sex                  <chr> "Male", "F...
## $ Race of respondent               <chr> "White", "...
## $ Rs family income when 16 yrs old <chr> "Below ave...
## $ Total family income              <chr> "$25000 or...
## $ Respondents income              <chr> "$25000 or...
## $ Total family income              <chr> "Not appli...
## $ Political party affiliation       <chr> "Not str r...
## $ Opinion of family income         <chr> "Above ave...
## $ Sexual orientation               <chr> "Heterosex..."
```

322 This is a little better. Now the character strings are preserved. But, the data is not yet usable in an
 323 analysis. One problem is some of the variable names include spaces, so they are hard to use. Also, one
 324 variable name is repeated, perhaps because of an error in the data wizard. To fix these issues, the variables
 325 must be renamed the variables such that all variables have unique names without spaces.

```
names(GSS) <- make.names(names(GSS), unique=TRUE)
```

```
names(GSS)

## [1] "Gss.year.for.this.respondent....."
## [2] "Respondent.id.number"
## [3] "Labor.force.status"
## [4] "Rs.occupational.prestige.score...1970."
## [5] "Marital.status"
## [6] "Number.of.children"
## [7] "Age.of.respondent"
## [8] "Highest.year.of.school.completed"
## [9] "Respondents.sex"
## [10] "Race.of.respondent"
## [11] "Rs.family.income.when.16.yrs.old"
## [12] "Total.family.income"
## [13] "Respondents.income"
## [14] "Total.family.income.1"
## [15] "Political.party.affiliation"
## [16] "Opinion.of.family.income"
## [17] "Sexual.orientation"
```

326 These names are an improvement, but now some are full of periods. For ease of coding, more human
 327 readable names are preferable. As with all the tasks in this paper, there is a fragile way to do this in **base**
 328 **R**, but we'll use the more robust `rename()` function from the **dplyr** package. `rename()`

```
library(dplyr)
GSS <- GSS %>%
  rename(Year = Gss.year.for.this.respondent.....,
         ID = Respondent.id.number,
         LaborStatus = Labor.force.status,
         OccupationalPrestigeScore = Rs.occupational.prestige.score...1970.,
         MaritalStatus = Marital.status,
         NumChildren = Number.of.children,
         Age = Age.of.respondent,
         Sex = Respondents.sex,
         HighestSchoolCompleted = Highest.year.of.school.completed,
         Race = Race.of.respondent,
         ChildhoodFamilyIncome = Rs.family.income.when.16.yrs.old,
         TotalFamilyIncome = Total.family.income,
         RespondentIncome = Respondents.income,
         PoliticalParty = Political.party.affiliation,
         OpinionOfIncome = Opinion.of.family.income,
         SexualOrientation = Sexual.orientation)

names(GSS)

## [1] "Year"
## [3] "LaborStatus"
## [5] "MaritalStatus"
## [7] "Age"
## [9] "Sex"
## [11] "ChildhoodFamilyIncome"
## [13] "RespondentIncome"
## [15] "PoliticalParty"
## [17] "SexualOrientation"

## [2] "ID"
## [4] "OccupationalPrestigeScore"
## [6] "NumChildren"
## [8] "HighestSchoolCompleted"
## [10] "Race"
## [12] "TotalFamilyIncome"
## [14] "Total.family.income.1"
## [16] "OpinionOfIncome"
```

```
GSS <- GSS %>%
  select(~Total.family.income.1)
```

329 With the data loaded and the names adjusted, the cleaned data can be written to a new file for use in
 330 the body of the paper.

```
library(readr)
write_csv(GSS, path="../data/GSScleaned.csv")
```

331 A version of this file is used as our motivating example.

332 SUPPLEMENTARY APPENDIX B: CLOSING EXERCISE

333 We have included the following as a possible supplementary exercise.

334 Subjects in the HELP study were also categorized into categories of primary and secondary drug and
 335 alcohol involvement, as displayed in the following table.

```
HELPhbase <- HELPhfull %>%
  filter(TIME == 0)
tally(~ PRIM_SUB + SECD_SUB, data=HELPhbase)

##          SECD_SUB
## PRIM_SUB 0  1  2  3  4  5  6  7  8
##      1 99  0 57 13  1  3 11  0  1
##      2 51 84  0  6  0  0 15  0  0
##      3 57 28 29  0  0  6  5  1  2
##      6  0  1  0  0  0  0  0  0  0
```

336 The following coding of substance use involvement was used in the study.

	value	description
	0	None
	1	Alcohol
	2	Cocaine
	3	Heroin
337	4	Barbituates
	5	Benzos
	6	Marijuana
	7	Methadone
	8	Opiates

338 Create a new variable called `primsub` combining the primary and secondary substances into
 339 a categorical variable with values corresponding to primary and secondary substances of the form:
 340 alcohol only, cocaine only, heroin only, alcohol-cocaine, cocaine-alcohol,
 341 or other. Code any group with fewer than 5 entries as alcohol-other, cocaine-other, or
 342 heroin-other. If `PRIM_SUB == 6` make the `primsub` variable missing.

343 How many subjects are there in the alcohol-none group? How many subjects are there in the
 344 alcohol-other group? What are the three most common groups?

345 SOLUTION:

```
HELPhbase <- HELPhbase %>%
  mutate(
    primary= recode(PRIM_SUB,
      `1`="alcohol",
      `2`="cocaine",
      `3`="heroin",
      `4`="barbituates",
      `5`="benzos",
      `6`="marijuana",
      `7`="methadone",
      `8`="opiates"),
    second=recode(SECD_SUB,
      `0`="none",
      `1`="alcohol",
      `2`="cocaine",
      `3`="heroin",
      `4`="barbituates",
      `5`="benzos",
      `6`="marijuana",
      `7`="methadone",
      `8`="opiates"),
    title=paste0(primary, "-", second)
  )
```

```
tally(~ primary, data=HELPhbase)
```



```
##
##   alcohol   cocaine   heroin marijuana
##      185      156      128         1

tally(~ second, data=HELPbase)

##
##   alcohol barbituates   benzos   cocaine   heroin   marijuana
##      113         1         9      86      19      31
## methadone      none   opiates
##         1      207         3

counts <- HELPbase %>%
  group_by(primary, second) %>%
  summarise(observed=n())

merged <- left_join(HELPbase, counts, by=c("primary", "second"))

merged <- merged %>%
  mutate(
    title =
      case_when(
        observed < 5 & primary == "alcohol" ~ "alcohol-other",
        observed < 5 & primary == "cocaine" ~ "cocaine-other",
        observed < 5 & primary == "heroin" ~ "heroin-other",
        TRUE ~ title),
    title = ifelse(primary == "marijuana", NA, title))

tally(~ title + observed, data=merged)

##
## title      observed
## title      1  2  3  5  6 11 13 15 28 29 51 57 84 99
## alcohol-cocaine  0  0  0  0  0  0  0  0  0  0  0  0  57  0  0
## alcohol-heroin   0  0  0  0  0  0  13  0  0  0  0  0  0  0  0
## alcohol-marijuana 0  0  0  0  0  11  0  0  0  0  0  0  0  0  0
## alcohol-none     0  0  0  0  0  0  0  0  0  0  0  0  0  99  0
## alcohol-other    2  0  3  0  0  0  0  0  0  0  0  0  0  0  0
## cocaine-alcohol  0  0  0  0  0  0  0  0  0  0  0  0  84  0  0
## cocaine-heroin   0  0  0  0  6  0  0  0  0  0  0  0  0  0  0
## cocaine-marijuana 0  0  0  0  0  0  0  15  0  0  0  0  0  0  0
## cocaine-none     0  0  0  0  0  0  0  0  0  0  51  0  0  0  0
## heroin-alcohol    0  0  0  0  0  0  0  0  28  0  0  0  0  0  0
## heroin-benzos     0  0  0  0  6  0  0  0  0  0  0  0  0  0  0
## heroin-cocaine    0  0  0  0  0  0  0  0  0  29  0  0  0  0  0
## heroin-marijuana  0  0  0  5  0  0  0  0  0  0  0  0  0  0  0
## heroin-none       0  0  0  0  0  0  0  0  0  0  0  57  0  0  0
## heroin-other      1  2  0  0  0  0  0  0  0  0  0  0  0  0  0
## <NA>             1  0  0  0  0  0  0  0  0  0  0  0  0  0  0

tally(~ title == "alcohol-none", data=merged)

##
## TRUE FALSE <NA>
##    99   370     1

tally(~ title == "alcohol-other", data=merged)

##
## TRUE FALSE <NA>
##     5   464     1

sort(tally(~ title, data=merged), decreasing=TRUE)[1:3]

##
## alcohol-none cocaine-alcohol alcohol-cocaine
##           99             84             57
```

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