Classes for record linkage of big data sets

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As of version 0.3, the package RecordLinkage includes extensions to overcome the problem of high memory consumption that arises when processing a large number of records (i.e. building record pairs out of $\geq 1000$ records without blocking). In versions 0.3.\_\_\_, this was achieved by blockwise on-demand creation of comparison patterns in an embedded SQLite database (through package RSQLite). Package version 0.4 replaces this mechanism by using file-based data structures from package ff. This approach restricts the amount of data pairs to the available disk space but speeds up execution and facilitates the implementation of methods that need to process the whole set of record pairs (e.g. calculation of optimal classification thresholds).

The interface to the big data methods has is compatible to code written for version 0.3.\_\_\_, so users familiar with these can stick to their existing workflow (unless access to internal structures like object slots is involved). Therefore, the following text sticks to the vignette already included in versions before 0.4 and only technical details are changed to reflect the different implementation.

In order to facilitate a tidier design, S4 classes and methods were used to implement the extensions. In favor of backward compatibility and development time, plans of a complete transition to S4 were dismissed. Nevertheless, the existing functions were joined with their new counterparts, resulting in methods which dispatch on the new S4 as well as on the existing S3 classes. This approach combines two advantages: First, existing code using the package still works, second, the new classes and methods offer (nearly) the same interface, i.e. the necessary function calls for a linkage task differ only slightly. An exception is `getPairs`, whose arguments differ from the existing version (see man page).

1 Defining data and comparison parameters

The existing S3 class "RecLinkData" is supplemented by the S4 classes "RLBigDataLinkage" and "RLBigDataDedup" for linking two datasets and deduplication of one dataset respectively. Both share the common abstract superclass "RLBigData".

```r
library(RecordLinkage)

## Warning: package 'DBI' was built under R version 3.6.2
## Warning: package 'RSQLite' was built under R version 3.6.2
## Warning: package 'ff' was built under R version 3.6.2
## Warning: package 'bit' was built under R version 3.6.2
showClass("RLBigData")
```
## Virtual Class "RLBigData" [package "RecordLinkage"]
##
## Slots:
##
## Name: frequencies blockFld excludeFld strcmpFld
## Class: numeric list numeric numeric
##
## Name: strcmpFun phoneticFld phoneticFun pairs
## Class: character numeric character ffddf
##
## Name: Wdata WdataInd M U
## Class: ff_vector ff_vector ff_vector ff_vector
##
## Known Subclasses: "RLBigDataDedup", "RLBigDataLinkage"

showClass("RLBigDataDedup")

## Class "RLBigDataDedup" [package "RecordLinkage"]
##
## Slots:
##
## Name: data identity frequencies blockFld
## Class: data.frame factor numeric list
##
## Name: excludeFld strcmpFld strcmpFun phoneticFld
## Class: numeric numeric character numeric
##
## Name: phoneticFun pairs Wdata WdataInd
## Class: character ffddf ff_vector ff_vector
##
## Name: M U
## Class: ff_vector ff_vector
##
## Extends: "RLBigData"

showClass("RLBigDataLinkage")

## Class "RLBigDataLinkage" [package "RecordLinkage"]
##
## Slots:
##
## Name: data1 data2 identity1 identity2
## Class: data.frame data.frame factor factor
##
## Name: frequencies blockFld excludeFld strcmpFld
## Class: numeric list numeric numeric
##
## Name: strcmpFun phoneticFld phoneticFun pairs
## Class: character numeric character ffddf
For the two non-virtual classes, the constructor-like function `RLBigDataDedup` and `RLBigDataLinkage` exist, which correspond to `compare.dedup` and `compare.linkage` for the S3 classes and share most of their arguments.

The following example shows the basic usage of the constructors, for details consult their documentation.

```r
# deduplicate with two blocking iterations and string comparison
data(RLdata500)
data(RLdata10000)
rpairs1 <- RLBigDataDedup(RLdata500,
    identity = identity.RLdata500,
    blockfld = list(1,3), strcmp = 1:4)

# link two datasets with phonetic code
s1 <- 471:500
s2 <- sample(1:10000, 300)
identity2 <- c(identity.RLdata500[s1], rep(NaN, length(s2)))
dataset <- rbind(RLdata500[,1], RLdata10000[,s2])
rpairs2 <- RLBigDataLinkage(RLdata500, dataset,
    identity1 = identity.RLdata500,
    identity2 = identity2, phonetic = 1:4,
    exclude = "lname_c2")
```

2 Supervised classification

The existing function `classifySupv` was transformed to a S4 method which handles the old S3 object ("RecLinkData") as well as the new classes. However, at the moment a classifier can only be trained with an object of class "RecLinkData".

```r
train <- getMinimalTrain(compare.dedup(RLdata500,
    identity = identity.RLdata500,
    blockfld = list(1,3)))
rpairs1 <- RLBigDataDedup(RLdata500,
    identity = identity.RLdata500)
classif <- trainSupv(train, "rpart", minsplit=2)
result <- classifySupv(classif, rpairs1)
```

The result is an object of class "RLResult" which contains the classification result along with the data object.
A contingency table can be viewed via `getTable`, various error measures are calculated by `getErrorMeasures`.

### 3 Weight-based classification

As with "RecLinkData" objects, weight-based classification with "RLBigData" classes includes weight calculation and classification based on one or two thresholds, dividing links, non-links and, if desired, possible links. The following example applies classification with Epilink (see documentation of `epiWeights` for details):
rpairs1 <- epiWeights(rpairs1)
result <- epiClassify(rpairs1, 0.5)
getTable(result)
## < table of extent 0 x 0 >

4 Evaluation and results

In addition to `getTable` and `getErrorMeasures`, `getPairs`, which was re-designed as a versatile S4 method, is an important tool to inspect data and linkage results. For example, the following code extracts all links with weights greater or equal than 0.7 from the result set obtained in the last example:

```
getPairs(result, min.weight=0.7, filter.link="link")
```

```
## Warning in min(x, na.rm = na.rm): kein nicht-fehlendes Argument für min; gebe Inf zurück
## Warning in max(x, na.rm = na.rm): kein nicht-fehlendes Argument für max; gebe -Inf zurück
## ============================================================
## id  fname_c1  lname_c1  fname_c2  lname_c2  by  bm  bd
## 1  290  HELGA  BERGER  <NA>  1989  1  18
## 2  466  HELGA  BERGER  <NA>  1989  1  28
## 3
## 4  313  URSULA  MUELLR  <NA>  1940  6  15
## 5  457  URSULA  MUELLER  <NA>  1940  6  15
## 6
## 7  467  ULRIKE  BECKRR  <NA>  1982  8  4
## 8  472  ULRIKE  BECKER  <NA>  1982  8  4
## 9
## is_match  Class  Weight
## 1
## 2  TRUE  L  0.7786012
## 3
## 4
## 5  TRUE  L  0.7293529
## 6
## 7
## 8  TRUE  L  0.7293529
## 9
```

A frequent use case is to inspect misclassified record pairs; for this purpose two shortcuts are included that call `getPairs` with appropriate arguments:

```
getFalsePos(result)
```

```
## Warning in min(x, na.rm = na.rm): kein nicht-fehlendes Argument für min; gebe Inf zurück
```
## Warning in max(x, na.rm = na.rm): kein nicht-fehlendes Argument für max; gebe -Inf zurück

### ---

### id    fname_c1 fname_c2 lname_c1 lname_c2 by bm bd
### 1  388 ANDREA <NA> WEBER <NA> 1945 5 20
### 2  408 ANDREA <NA> SCHMIDT <NA> 1945 2 20
### 3

### is_match Class Weight
### 1
### 2 FALSE   L 0.5067013
### 3

getFalseNeg(result)

## Warning in min(x, na.rm = na.rm): kein nicht-fehlendes Argument für min; gebe Inf zurück
## Warning in min(x, na.rm = na.rm): kein nicht-fehlendes Argument für max; gebe -Inf zurück

### ---

### id    fname_c1 fname_c2 lname_c1 lname_c2 by bm bd
### 1  353 INGE <NA> SEIDEL <NA> 1949 9 4
### 2  355 INGEU <NA> SEIDEL <NA> 1949 8 4
### 3
### 4  285 ERIKA <NA> WEBER <NA> 1995 2 1
### 5  379 ERIKA <NA> WEBER <NA> 1992 2 29
### 6
### 7  127 KARL <NA> KLEIN <NA> 2002 6 20
### 8  142 KARL <NA> KLEIBN <NA> 2002 6 29
### 9
### 10 37 HARTMHUT <NA> HOFFMSNN <NA> 1929 12 29
### 11  72 HARTMUT <NA> HOFFMANN <NA> 1929 12 29
### 12

### is_match Class Weight
### 1
### 2 TRUE    N 0.4948059
### 3
### 4
### 5 TRUE    N 0.4782410
### 6
### 7
### 8 TRUE    N 0.4692532
### 9
### 10
### 11 TRUE    N 0.4081096
### 12