Introduction to Blocking and Classical Record Linkage

Brenda Betancourt and Rebecca C. Steorts

Department of Statistical Science, affiliated faculty in Computer Science, Biostatistics and Bioinformatics, the information initiative at Duke (iiD) and the Social Science Research Institute (SSRI)
Duke University and U.S. Census Bureau
beka@stat.duke.edu
Population Dynamics and Health Program Workshop, University of Michigan

July 10, 2019

Blocking and Classical Record Linkage

1. Blocking

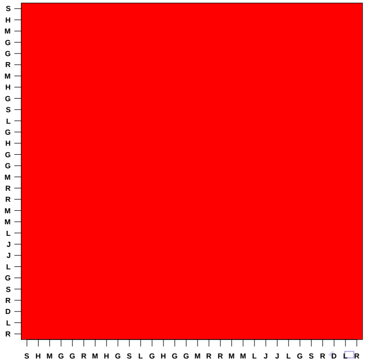
 - Focus will be on deterministic blocking

2. Classical Record Linkage Methods

 - Exact Matching
 - String Matching
 - Fellegi and Sunter (1969); Newcombe (1959).

Computational challenge of entity resolution

- Given a total of M records in two databases, one must perform M^2 record comparisons.
- We must make all-to-all records comparisons, which is very inefficient.
- Example: suppose we have two databases with 5,000 total records $\rightarrow$ 25,000,000 comparisons!



Blocking: dimensionality trick

- Blocking seeks to create partitions, blocks, or bins such that similar records are placed in the same bin.
- Filter out dissimilar record pairs that are extremely unlikely to be matches.
    - Perform record linkage only within blocks

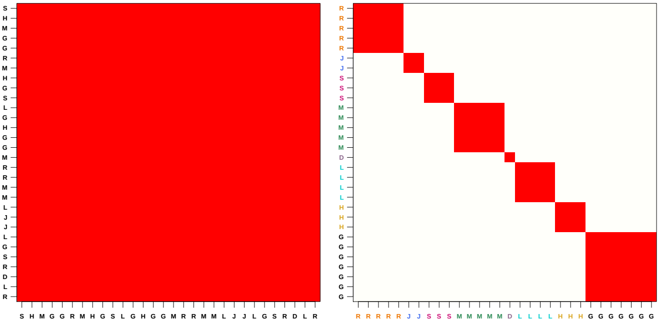
Traditional (Deterministic) Blocking

- Traditional blocking : compare record pairs that match on one or more features.
  - Creates a deterministic partition of the data

- Record pairs that do not meet the blocking criteria are automatically classified as non-matches.

Example: Traditional blocking

All-to-all record comparisons (left) versus partitioning records into blocks by lastname initial and comparing records only within each partition (right).



Example: RLdata500

```
library(RecordLinkage)
data(RLdata500)
head(RLdata500)
```

```
##   fname_c1 fname_c2 lname_c1 lname_c2   by bm bd
## 1  CARSTEN     <NA>    MEIER     <NA> 1949  7 22
## 2     GERD     <NA>    BAUER     <NA> 1968  7 27
## 3   ROBERT     <NA> HARTMANN     <NA> 1930  4 30
## 4   STEFAN     <NA>    WOLFF     <NA> 1957  9  2
## 5     RALF     <NA>  KRUEGER     <NA> 1966  1 13
## 6  JUERGEN     <NA>   FRANKE     <NA> 1929  7  4
```

Continuation: RLdata500

```r
# Record pairs for comparison
choose(500,2)
```

```
## [1] 124750
```

```r
# Blocking by last name initial
last_init <- substr(RLdata500[,"lname_c1"], 1, 1)
head(last_init)
```

```
## [1] "M" "B" "H" "W" "K" "F"
```

```r
# Number of blocks
length(unique(last_init))
```

```
## [1] 20
```

Continuation: RLdata500

```
# Number of records per block
tbl <- table(last_init)
head(tbl)
```

```
## last_init
##  A  B  D  E  F  G
##  5 56  2  6 38 12
```

```
# Block sizes can vary a lot
summary(as.numeric(tbl))
```

```
##    Min. 1st Qu.  Median    Mean 3rd Qu.    Max.
##    2.00    5.75    8.00   25.00   40.00  115.00
```

Continuation: RLdata500

```r
# Number of records pairs per block
sapply(tbl, choose, k=2)
```

```
##    A    B    D    E    F    G    H    J    K    L    M
##   10 1540    1   15  703   66  496   28 1035   78 2850
##    S    T    V    W    Z
## 6555    1   21 1326   10
```

```r
# Reduction on comparison space
sum(sapply(tbl, choose, k=2))
```

```
## [1] 14805
```

Continuation: RLdata500

What is the reduction from the overall space to the reduced space?

Hint: The original space of comparisons was

```
choose(500,2)
```

```
## [1] 124750
```

and we have reduced the number of comparisons to

```
sum(sapply(tbl, choose, k=2))
```

```
## [1] 14805
```

Blocking caveats

- Features often contain errors, noise, etc. and may not be suitable for determistic blocking.
- Why? A noisy feature used for determisitic blocking can miss a large proportion of matches (i.e. increased false negatives rates).
- The frequency distribution of the values of the blocking features will affect the block sizes.
- There is a trade off between the size of the blocks and computational efficency.
  - If the blocks are too big, then the computational speed increases.
  - If the blocks are too small, then true matches may be missed.

How to choose the blocking features (variables or keys)

- Fields containing the fewest errors or missing values should be chosen as blocking variables e.g. clinical diagnosis in EHR.
- Understand the kind of errors that are unlikely for a certain field or a combination of them.
- More complex blocking schemes can be constructed using conjunctions.
  - Retain only pairs which agree on last name initial and zip code.

Classical Record Linkage: Exact matching

- Exact matching: Exact matching is a method that says two records are a match if they agree on every feature.
- Performing exact matching is very common in the social and health sciences in practice, however, this is not common in statistics, computer science, or machine learning.
- Other types of matching or merging are used, where records are called to be a match if they agree based upon a similarity comparison or a probabilitistic model.
- Examples include: string matching, Fellegi-Sunter method, semi-supervised methods, and hash techniques.

Classical Record Linkage: Similarity metrics

- Levenshtein (edit) (1966): minimum number of substitutions required to transform one string into another e.g. Adam vs Alan has a distance $L = 2$, normalized as $1 - \frac{L}{maxLength} = 0.5$ for similarity.

- Jaro-Winkler (1990): The Jaro distance (1989) considers common characters and character transpositions. The JW similarity measure is:

$$JW(A, B) = J(A, B) + 0.1p(1 - J(A, B))$$

where p is the # of the first four characters that agree exactly e.g. Adam vs Alan: p=1, J= 0.67 and JW=0.7.

These work well on English names that are less than 7 characters.

Example: RLdata500

```r
library(RecordLinkage)
data(RLdata500)
```

```
##      fname_c1 lname_c1   by bm bd
## 314    RENATE   SCHUTE 1940 12 29
## 407    RENATE  SCHULTE 1940 12 29
## 289 CHRISTINE   PETERS 1993  2  5
## 399 CHRISTINE   PETERS 1993  2  6
## 402   CHRISTA  SCHWARZ 1965  7 13
## 462  CHRISTAH  SCHWARZ 1965  7 13
```

Example: RLdata500

```r
# Levenshtein similarity
levenshteinSim("SCHUTE", "SCHULTE")
```

```
## [1] 0.8571429
```

```r
levenshteinSim("CHRISTA", "CHRISTAH")
```

```
## [1] 0.875
```

```r
# Jaro-Winkler similarity
jarowinkler(c("SCHUTE","CHRISTA"),
            c("SCHULTE","CHRISTAH"))
```

```
## [1] 0.9714286 0.9750000
```

Similarity metrics (continued)

- The Soundex algorithm generates a code representing the phonetic pronunciation of a word.
- This is typicall more useful on non-English names or longer names.
- The Soundex code for a name consists of a letter followed by three numerical digits:
  - the letter is the first letter of the name,
  - the digits encode the remaining consonants.
- Consonants at a similar place of articulation share the same digit
  - The consonants B, F, P and V are each encoded by a 1.

Example: Soundex algorithm

```
##        fname_c1 lname_c1   by bm bd
## 314      RENATE   SCHUTE 1940 12 29
## 407      RENATE  SCHULTE 1940 12 29
## 289 CHRISTINE   PETERS 1993  2  5
## 399 CHRISTINE   PETERS 1993  2  6
## 402    CHRISTA  SCHWARZ 1965  7 13
## 462   CHRISTAH  SCHWARZ 1965  7 13
```

```r
tail(soundex(dup_set$fname_c1))
```

```
## [1] "R530" "R530" "C623" "C623" "C623" "C623"
```

```r
tail(soundex(dup_set$lname_c1))
```

```
## [1] "S300" "S430" "P362" "P362" "S620" "S620"
```

Example: Soundex algorithm

```
##       fname_c1 lname_c1   by bm bd
## 130  MICHAEL     MEYER 1988  1 31
## 147  MICHAEL      MYER 1988  1 31
## 217    HORST     MEIER 1977  6  6
## 248    HORST     MEIER 1972  6  6
## 34     HEINZ     BOEHM 1938 12 20
## 111    HEINZ    BOEHMR 1938 12 20
```

```
head(soundex(dup_set$lname_c1))
```

```
## [1] "M600" "M600" "M600" "M600" "B500" "B560"
```

Blocking by disjunctions

- Produces overlapping blocks of the data.
  - Disjunction: records match on field A or field B

- Using multiple keys to consider typographical or measurement errors that would exclude true matches.
  - Blocking by last name initial or zip code

1.	Mary Clain	123 Oak St	90210
2.	Mary Klein	123 Oak Street	90210
3.	Mary Klain	123 Oak St	50210

- Reduction in false negative rates.

Example: Blocking by disjunctions

```r
# Two records must agree in either first name initial
# or bith year to be compared.
# Only 2709 pairs instead of 124750!

rpairs <- compare.dedup(RLdata500c,
blockfld = list(1, 3), #list with blocking fields
identity = identity.RLdata500)

tail(rpairs$pairs)
```

```
##       id1 id2 fname_c1 lname_c1 by bm bd is_match
## 2704 477 497        1        0  0  0  0        0
## 2705 479 483        0        0  1  1  0        0
## 2706 480 481        1        0  0  0  0        0
## 2707 480 490        1        0  0  0  0        0
## 2708 481 490        1        1  0  1  1        1
## 2709 494 497        0        0  1  1  0        0
```

Example: String comparison and blocking

```
rpairsfuzzy <- compare.dedup(RLdata500c,
               phonetic = FALSE, blockfld = 3,
               strcmp = TRUE, strcmpfun = jarowinkler)

tail(rpairsfuzzy$pairs)
```

```
##       id1 id2  fname_c1  lname_c1 by  bm  bd is_match
## 1540 460 485 0.0000000 0.5396825  1 0.7 0.0       NA
## 1541 464 466 0.4555556 0.5396825  1 0.7 0.0       NA
## 1542 467 472 1.0000000 0.9333333  1 1.0 1.0       NA
## 1543 468 469 0.5777778 0.4666667  1 0.7 0.7       NA
## 1544 479 483 0.4370370 0.5619048  1 1.0 0.0       NA
## 1545 494 497 0.6111111 0.5026455  1 1.0 0.0       NA
```

The Fellegi-Sunter approach (1969)

- Represent every pair of records using vector of features that describe similarity between individual record fields.
  - Use string metrics for names and strings of numbers (Levenshtein or Jaro-Winkler).
- Place feature vectors for record pairs into three classes: matches (M), nonmatches (U), and possible matches.
- Let $P(\gamma|M)$ and $P(\gamma|U)$ be probabilities of observing a feature vector γ for a matched and nonmatched pair, respectively.

The Fellegi-Sunter approach (1969)

- Perform record-pair classification by calculating the ratio $w = (P(\gamma|M)/P(\gamma|U))$ for each candidate record pair.

- Establish two thresholds based on desired error levels to optimally separate the weight values for matches, possible matches, and nonmatches.

- Note: the quality of classification of the Fellegi-Sunter method relies strongly on reasonable estimations of M and U probabilities.

Example: Blocking and Fellegi-Sunter

```r
# tail(rpairs$pairs)
# Using comparison data blocking by first name initial
# and birth year
rpairs1 <- epiWeights(rpairs)

# Weights to compute thresholds for classification
rpairs1$Wdata[1:5]
```

```
## [1] 0.2223402 0.2223402 0.2488181 0.2488181 0.3936336
```

Example: Fellegi-Sunter

```r
summary(rpairs1)
```

Weight distribution:

(0.35,0.4]	(0.4,0.45]	(0.45,0.5]	(0.55,0.6]	(0.6,0.65]
2	10	30	50	8
(0.65,0.7]	(0.7,0.75]	(0.75,0.8]	(0.8,0.85]	(0.85,0.9]
0	0	35	8	3

Example: Fellegi-Sunter

```
result <- epiClassify(rpairs1, 0.7)
summary(result)

alpha error: 0.080000 # False negative rate
beta error: 0.000000  # False positive rate
accuracy: 0.998523

Classification table:

           classification
true status    N    P    L
      FALSE 2659    0    0
      TRUE     4    0   46
```

Summary

- Blocking: reduce comparison space by choosing relatively noise free fields to match records
  - Use conjunctions (and) create a partition of the data or disjunctions (or) to create overlapping blocks.
- Strings: choose a string similarity metric to compare record pairs within blocks.
  - Levenshtein or Jaro-Winkler.
- Record linkage: use Fellegi-Sunter method to classify records as matches, posibble matches or nonmathches.

References

- Sariyar M. and Borg A. (2010), The RecordLinkage Package: Detecting Errors in Data, The R Journal Vol. 2/2. Check big data functions of the package (>=1'000,000 record pairs).
- Steorts et al. (2014) A Comparison of Blocking Methods for Record Linkage. In: Domingo-Ferrer J. (eds) Privacy in Statistical Databases. PSD 2014. Lecture Notes in Computer Science, vol 8744. Springer, Cham.
- Fellegi I.P., Sunter A.B. (1969), A Theory for Record Linkage, Journal of the American Statistical Association 64(328), pp. 1183–1210.
- Dusetzina et al. Linking Data for Health Services Research: A Framework and Instructional Guide. Rockville (MD): Agency for Healthcare Research and Quality (US) (2014). An Overview of Record Linkage Methods. `https://www.ncbi.nlm.nih.gov/books/NBK253312/`
- Entity Resolution and Information Quality, John R. Talburt, Elsevier (2011)