

# Module 4: Deterministic Blocking

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# Reading

- ▶ Binette and Steorts (2020)
- ▶ Steorts, Ventura, Sadinle, Fienberg (2014)
- ▶ Murray (2016)
- ▶ Christen (2012), Chapter 4

# Agenda

- ▶ Data Cleaning Pipeline
- ▶ Blocking
- ▶ Traditional Blocking
- ▶ Probabilistic Blocking
- ▶ Evaluation Metrics
- ▶ Examples

# Load R packages and data

```
knitr::opts_chunk$set(echo = TRUE,  
                        fig.width=4,  
                        fig.height=3,  
                        fig.align="center")  
  
library(RecordLinkage)  
library(blink)  
library(italy)  
library(tidyverse)  
library(assert)  
data(italy08)  
data(italy10)  
data(RLdata500)
```

# Data Cleaning Pipeline



Figure 1: Data cleaning pipeline.

# Blocking

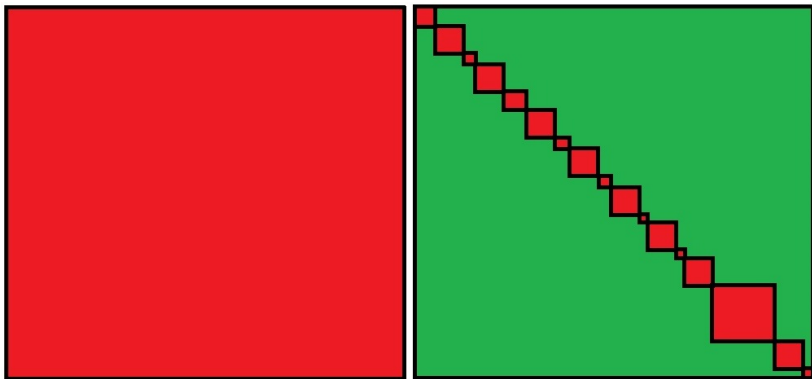


Figure 2: Left: All to all record comparison. Right: Example of resulting blocking partitions.

# Blocking

- ▶ Blocking places similar records into partitions/blocks.
- ▶ ER (typically) is only performed within each block.

# Traditional Blocking

- ▶ A deterministic (fixed) partition is formed based upon the data.
- ▶ A partition is created by treating certain fields that are thought to be nearly error-free as fixed.

Example: Blocking on date of birth year.



# Traditional Blocking

- ▶ Benefits: simple, easy to understand, and fast to implement.
- ▶ Downsides: the blocks are treated as error free, which is not usually accurate and can lead to errors in the ER task that cannot be accounted for.

# Probabilistic Blocking

- ▶ A probability model is used to cluster the data into blocks/partitions.

Example: Fellegi-Sunter (1969), or Locality Sensitive Hashing

Under both blocking approaches, record pairs that do not meet the blocking criteria are automatically classified as non-matches.

# Evaluation Metrics

Evaluation metrics are important for ER as they help us evaluate our proposed methodology (as long as some notion of ground truth exists).

The three that we will focus on in this module are:

- ▶ reduction ratio
- ▶ precision
- ▶ recall
- ▶ f-measure

# Reduction Ratio

The reduction ratio (RR) measures the relative reduction of the comparison space from the de-duplication or hashing technique.

See Christen (2012), Steorts, Ventura, Sadinle, Fienberg (2014) for a formal definition.

## Pairwise Precision and Recall

Let's now turn to formally defining the pairwise precision and recall.

# The confusion matrix

1. Pairs of data can be linked in both the handmatched training data (which we refer to as "truth") and under the estimated linked data. We refer to this situation as true positives (TP).
2. Pairs of data can be linked under the truth but not linked under the estimate, which are called false negatives (FN).
3. Pairs of data can be not linked under the truth but linked under the estimate, which are called false positives (FP).
4. Pairs of data can be not linked under the truth and also not linked under the estimate, which we refer to as true negatives (TN).

# The confusion matrix

		Model	
		M	N
Ground Truth	M	TP (true match)	FN <i>match under GT but not under the model</i>
	N	FP <i>match under the model but not under ground truth</i>	TN <i>(a true non match)</i>

## Pairwise evaluation metrics

$$\text{Recall} = \frac{TP}{TP + FN} = 1 - \text{FNR}.$$

$$\text{Precision} = \frac{TP}{TP + FP} = 1 - \text{FDR}.$$

$$\text{F-measure} = 2 \times \frac{(\textit{precision} \times \textit{recall})}{(\textit{precision} + \textit{recall})}.$$



# Recall

- ▶ For blocking, it is critical the recall be as close a possible to 1.
- ▶ To think about why, what does it mean if we have a blocking criterion where our recall is 0.5?

See Shrivastava and Steorts (2018) and Chen, Shrivastava, Steorts (2018) for further regarding about blocking criterion using human rights data.

## Example: Traditional blocking

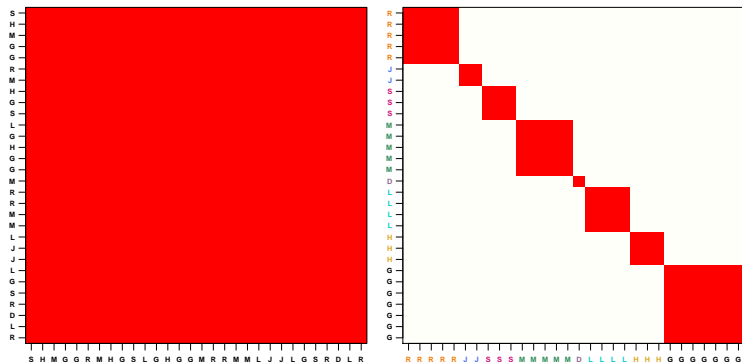


Figure 4: All-to-all record comparisons (left) versus partitioning records into blocks by lastname initial and comparing records only within each partition (right).

## Example: 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

## RLdata500 (Continued)

```
# Total number of all to all record comparisons  
choose(500,2)
```

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

## RLdata500 (Continued)

```
# Block by last name initial
```

```
last_init <- substr(RLdata500[, "lname_c1"], 1, 1)  
head(last_init)
```

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

```
# Total number of blocks
```

```
length(unique(last_init))
```

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

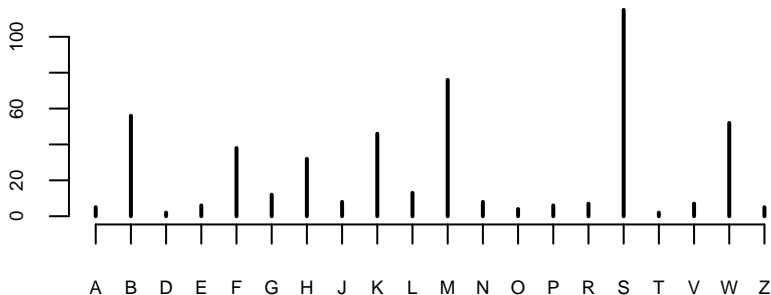
## RLdata500 (Continued)

```
# Total number of records per block  
recordsPerBlock <- table(last_init)  
head(recordsPerBlock)
```

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

## RLdata500 (Continued)

```
# Block sizes can vary  
plot(recordsPerBlock,  
      cex.axis=0.6, xlab="", ylab="")
```



## RLdata500 (Continued)

What is the overall dimension reduction from the original space to the reduced space induced by blocking?



## RLdata500 (Continued)

Recall the total number of all-to-all record comparisons made was:

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

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

Using blocking, we have reduced the comparison space to the following:

```
sum(choose(recordsPerBlock, 2))
```

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

## How do we calculate the reduction ratio (RR)?

The reduction ratio is

RR = % comparisons eliminated by blocking.

```
(choose(500, 2) - sum(choose(recordsPerBlock, 2))) /  
choose(500, 2)
```

```
## [1] 0.8813226
```

## How do we calculate the RR (via a function)?

```
reduction.ratio <- function(block.labels) {  
  n_all_comp = choose(length(block.labels), 2)  
  n_block_comp = sum(choose(table(block.labels), 2))  
  
  (n_all_comp - n_block_comp) / n_all_comp  
}  
  
reduction.ratio(last_init)
```

```
## [1] 0.8813226
```

## Reduction Ratio

In summary, we have reduced the comparison space by roughly 88 percent.

# Evaluation metrics

Let's now code up the evaluation metrics for pairwise precision and recall.

## Pairwise Precision

```
clusters = split(1:length(last_init), identity.RLdata500)

# Number of matching pairs among blocks
n_matches = sapply(clusters, function(records) {
  # Number of matches in that block
  sum(choose(table(identity.RLdata500[records]), 2))
})

# Total number of pairs
n_pairs = sum(choose(table(last_init), 2))

sum(n_matches) / n_pairs

## [1] 0.003377237
```

## Pairwise Precision

```
precision <- function(block.labels, IDs) {  
  assert(length(block.labels) == length(IDs))  
  
  clusters = split(1:length(block.labels), block.labels)  
  
  # Number of matching pairs among blocks  
  n_matches = sapply(clusters, function(records) {  
    sum(choose(table(IDs[records]), 2))  
  })  
  
  # Total number of pairs  
  n_pairs = sum(choose(table(block.labels), 2))  
  
  sum(n_matches) / n_pairs  
}
```

## Pairwise Recall

```
recall <- function(block.labels, IDs) {  
  assert(length(block.labels) == length(IDs))  
  
  precision(IDs, block.labels)  
}
```



# Pairwise Precision and Recall

```
precision(last_init, identity.RLdata500)
```

```
## [1] 0.003377237
```

```
recall(last_init, identity.RLdata500)
```

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

# Italian Survey on Household and Wealth (SHIW)

We will now explore a case study to the SHIW

# SHIW

- ▶ The Italian Survey on Household and Wealth (SHIW) is a sample survey 383 households conducted by the Bank of Italy every two years (2008 and 2010).
- ▶ The data set is anonymized to remove first and last name (and other sensitive information).

# SHIW

The following attribute information is available:

- ▶ PARENT (parental status)
- ▶ GENDER
- ▶ ANASC (year of birth)
- ▶ NASCREG (working status)
- ▶ CIT (employment status)
- ▶ ACOM4C (branch of activity)
- ▶ STUDIO (town size)
- ▶ Q (quality of life status)
- ▶ QUAL (whether or not Italian national)
- ▶ SETT (highest educational level obtained)
- ▶ IREG (region of Italy)

# Explore Data

```
head(italy08) # first year of SHIW
```

##	id	PARENT	SEX	ANASC	NASCREG	CIT	ACOM4C	STUDIO	Q	QUAL	SETT	IREG
## 1	1040021	1	2	1948	16	1	0	5	1	2	3	16
## 2	1040022	10	2	1952	16	1	0	7	1	2	3	16
## 3	1110521	1	1	1972	20	1	2	5	1	1	4	20
## 4	1110522	3	1	1935	20	1	2	2	3	6	5	20
## 5	1110523	3	2	1941	20	1	2	3	3	6	5	20
## 6	119401	1	1	1941	7	1	0	4	3	6	5	7

# Explore Data

```
head(italy08) # second year of SHIW
```

##	id	PARENT	SEX	ANASC	NASCREG	CIT	ACOM4C	STUDIO	Q	QUAL	SETT	IREG
## 1	1040021	1	2	1948	16	1	0	5	1	2	3	16
## 2	1040022	10	2	1952	16	1	0	7	1	2	3	16
## 3	1110521	1	1	1972	20	1	2	5	1	1	4	20
## 4	1110522	3	1	1935	20	1	2	2	3	6	5	20
## 5	1110523	3	2	1941	20	1	2	3	3	6	5	20
## 6	119401	1	1	1941	7	1	0	4	3	6	5	7

# Reformat Data

```
id08 <- italy08$id
id10 <- italy10$id
id <- c(italy08$id, italy10$id) # combine the id
italy08 <- italy08[-c(1)] # remove the id
italy10 <- italy10[-c(1)] # remove the id
italy <- rbind(italy08, italy10)
head(italy)
```

##	PARENT	SEX	ANASC	NASCREG	CIT	ACOM4C	STUDIO	Q	QUAL	SETT	IREG
## 1	1	2	1948	16	1	0	5	1	2	3	16
## 2	10	2	1952	16	1	0	7	1	2	3	16
## 3	1	1	1972	20	1	2	5	1	1	4	20
## 4	3	1	1935	20	1	2	2	3	6	5	20
## 5	3	2	1941	20	1	2	3	3	6	5	20
## 6	1	1	1941	7	1	0	4	3	6	5	7

## Your turn

- ▶ Construct a blocking criterion for the SHIW data set.
- ▶ Provide code to construct the blocks
- ▶ Are your blocks well balanced?
- ▶ What is the reduction ratio?
- ▶ What is the pairwise recall and precision?
- ▶ Would you recommend your blocking criterion for an ER task?  
Why or why not.

Hint: You might consider blocking on gender, regions (in Italy), or combinations of these. What do you find?



## Your turn solution

Let's block on gender.

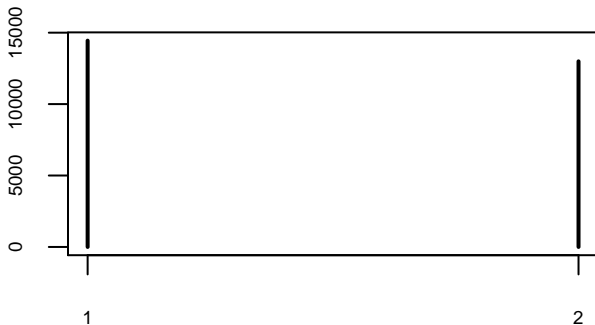
```
# block by gender  
blockByGender <- italy$SEX  
recordsPerBlock <- table(blockByGender)  
head(recordsPerBlock)
```

```
## blockByGender  
##      1      2  
## 14442 12993
```

## Your turn solution

The block sizes are similar. But note, they are still quite large.

```
# Checking block sizes  
plot(recordsPerBlock,  
      cex.axis=0.6, xlab="", ylab="")
```



## Your turn solution

```
print(rr <- reduction.ratio(blockByGender))
```

```
## [1] 0.4986234
```

We have reduced the overall space by roughly 50 percent.

## Your turn solution

```
precision(blockByGender, id)
```

```
## [1] 3.599727e-05
```

```
recall(blockByGender, id)
```

```
## [1] 0.9113109
```

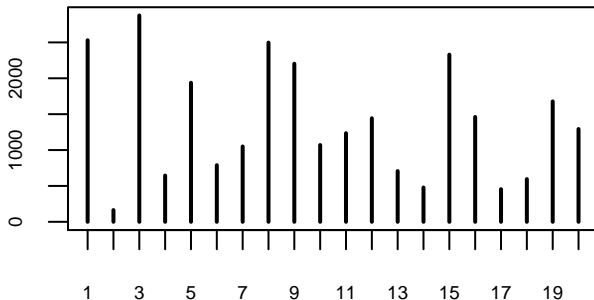
This is not an optimal blocking criterion as ideally, we would want both the precision and recall to be close to 1.

# Your turn solution

Let's block on the twenty regions in Italy.

```
blockRule <- (italy$IREG)
(recordsPerBlock <- table(blockRule))
```

```
## blockRule
##   1   2   3   4   5   6   7   8   9  10  11  12  13  14  15  16
## 2530 164 2875 645 1938 789 1050 2497 2203 1070 1235 1443 707 478 2329 1461
##   17  18  19  20
##  455  595 1678 1293
plot(recordsPerBlock,
     cex.axis=0.6, xlab="", ylab="")
```



```
print(rr <- reduction.ratio(blockRule))
```

```
## [1] 0.9339148
precision(blockRule, id)
```

## Your turn solution

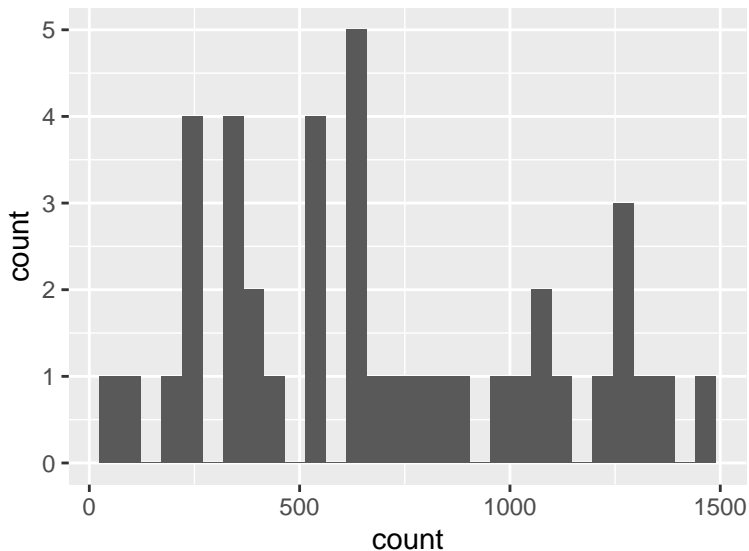
Let's block on a combination of gender and region.

Hint: Use `tidyverse`.

The histogram is not printing now for some reason.

## Your turn solution

```
italy %>%  
  group_by(IREG, SEX) %>%  
  summarise(count = n(), .groups="drop") %>%  
  ggplot() +  
  geom_histogram(aes(count))
```



# Your turn solution

```
blockIDs = paste(italy$IREG, italy$SEX, sep="_")
table(blockIDs)
```

```
## blockIDs
##  1_1  1_2 10_1 10_2 11_1 11_2 12_1 12_2 13_1 13_2 14_1 14_2 15_1 15_2 16_1 16_2
## 1282 1248 536 534 624 611 772 671 368 339 249 229 1310 1019 846 615
## 17_1 17_2 18_1 18_2 19_1 19_2 2_1 2_2 20_1 20_2 3_1 3_2 4_1 4_2 5_1 5_2
## 246 209 333 262 969 709 91 73 634 659 1489 1386 324 321 1056 882
## 6_1 6_2 7_1 7_2 8_1 8_2 9_1 9_2
## 418 371 517 533 1254 1243 1124 1079
```

```
print(rr <- reduction.ratio(blockIDs))
```

```
## [1] 0.9667954
```

```
precision(blockIDs, id)
```

```
## [1] 0.0005429847
```

```
recall(blockIDs, id)
```

```
## [1] 0.9103717
```