PRASC

Project for the Regional Advancement of Statistics in the Caribbean

Projet régional pour l'avancement de la statistique dans les Caraïbes

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Canada

Record Linkage

As Presented to the Central Statistical Office of Trinidad & Tobago

Project for the Regional Advancement of Statistics in the Caribbean (PRASC)

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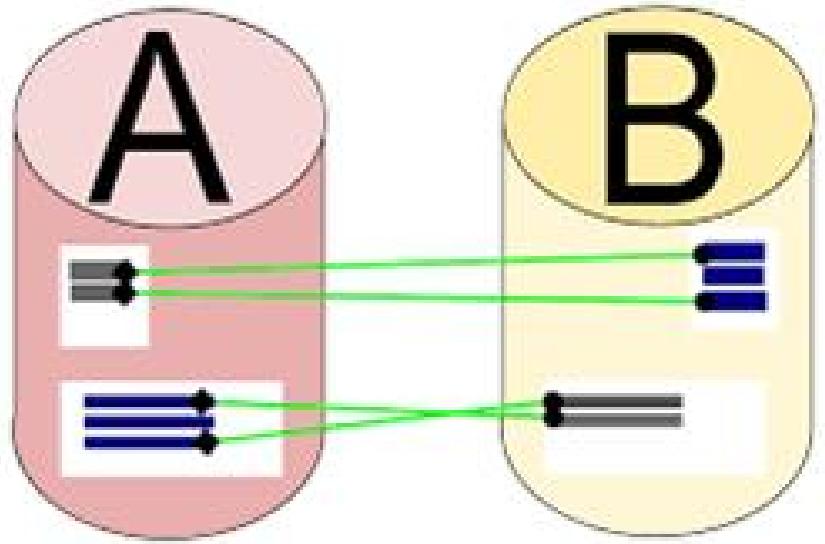
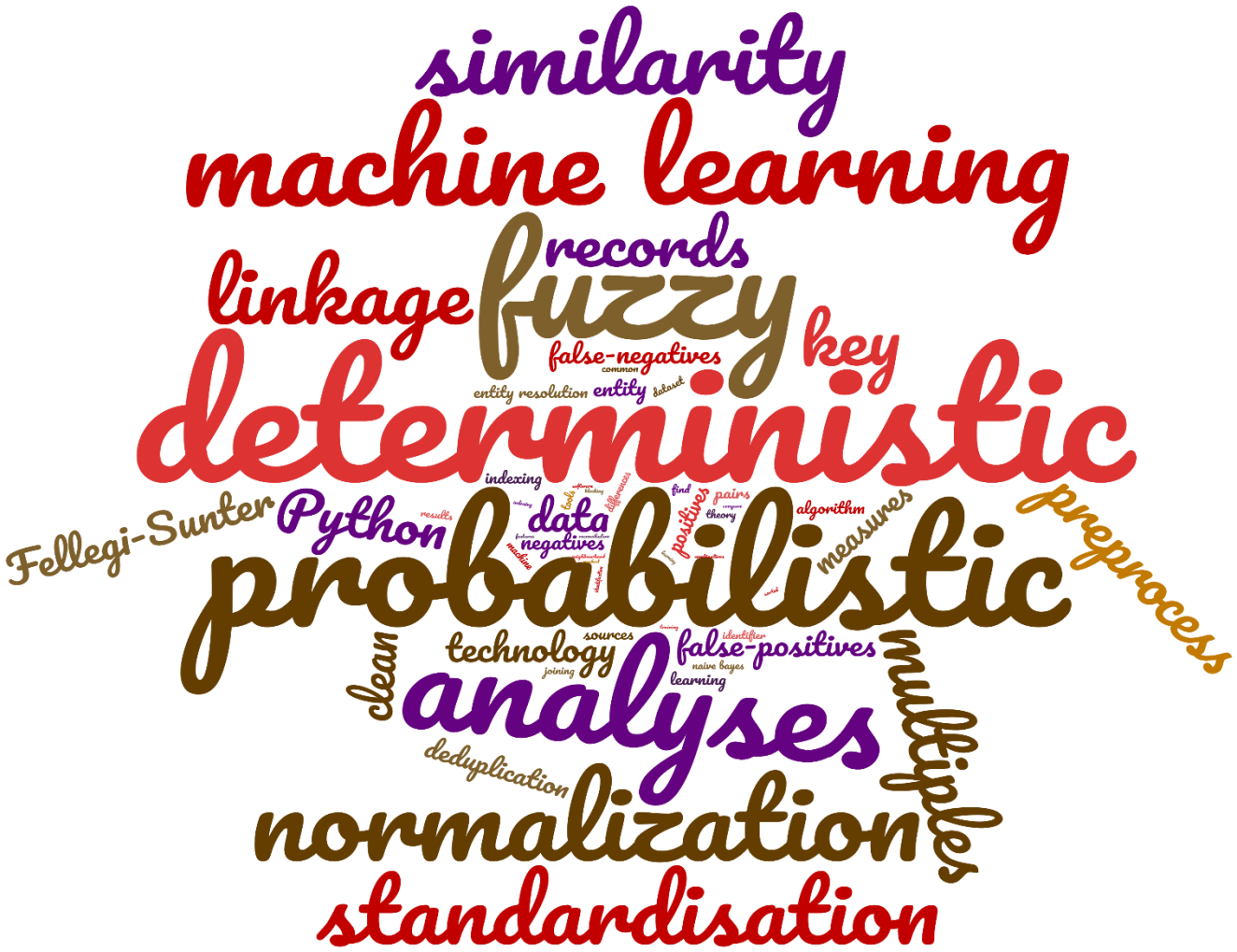
Delivering insight through data, for a better Canada

Presentation Outline

- Overview of Record Linkage
- Types of Matching
- Pre-Processing of Linkage Variables
- Deterministic Matching with Example
- Ongoing BR Update Processes
- Conclusions




similarity
machine learning
records
linkage
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false-negatives
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entity resolution
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robust
deterministic
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data
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identifier
technology
false-positives
clean
naive bayes
learning
analyses
multiples
deduplication
normalization
standardisation

Overview of Record Linkage

- The process of matching files together to:
  - Identify records in each file that represent the same person, business, object or event
  - Identify duplicates within a file by matching it to itself (deduplication)
  - Produce datasets for analysis, production of statistics, initialization or maintenance of Statistical Business Register (SBR)
- Essential when using administrative data from various sources
  - Lack of unique common identifiers
  - Poor quality of unique common identifiers
  - Lack of standardized formats
  - Contain typographical errors
  - Large volume of records

Overview of Record Linkage (cont.)

- In National Statistics Offices (NSO), this exercise is essential due to the increased use of multiple administrative data sources

    - Business Register / Frame creation
    - Replacement of collected survey data
    - Coherency and data confrontation analysis

Overview of Record Linkage (cont.)

- Links records that represent the same entity (person, object, event, etc.)
- Assumes that the same entity is on both files
- Matching is done using one or more common variables

- Each file should contain a unique identifier
  - Permits the entity within future files (from the same sources) to be quickly and easily linked
  - For example: registration number, tax identification number, etc..
  - Administrative sources often assign their own unique identifier for their particular program

    National Insurance (National Insurance Reg. No./Employer Reg. No.)
    Value Added Tax (VAT registration No.)
    Annual Income Tax (BIR File No./PAYE)
    Business Registration (Certificate No.)
    Business Licence

Overview of Record Linkage (cont.)

- The relationships of the unique identifiers from each source are stored in an accumulated links file for future use
  - Often called a concordance file

Example:

STATID	BIRID	NIBID	VATID
S001	T123	E234	V346
S002	T124	E244	V456
S003		E255	V366

Overview of Record Linkage (cont.)

- Data matching has three primary approaches
  - Deterministic
  - Probabilistic
  - Machine Learning

- All matches should be reviewed in some manner to minimize false matches (false positives)
  - Of particular interest ➔ Multiple links to the same record

Types of Matching, Deterministic Record Linkage

Used to match the same or similar values from different sources using a series of defined rules (test for equality)

- ☑ Quick to run (low computational)
- ☑ No special software required
- ☑ Powerful if a number of matching variables are available
- ☑ Easy to understand and interpret
- ☑ Usually results in very high quality matches

- ☒ Can be more manually intensive to develop and implement business rules
- ☒ Lacks robustness/flexibility
- ☒ Depending on data, can yield low match rates

Types of Matching, Deterministic Record Linkage (cont.)

Examples:

- Matching by common unique identifiers assigned by administrative sources
- Exact matching on a data item (or combination of data items) that are expected to produce an accurate match (example: Business Name)
- Matching on transformed or normalized data allowing similar data items to be linked which in combination with other data items produce an accurate match
- Using the concordance file to reuse matches found in the past

Types of Matching, Probabilistic Record Linkage

Used to match similar values from different sources using a series of calculated weights for each data item based on its estimated ability to correctly identify a match or a non-match (test for similarity)

- ☑ Minimal preprocessing of matching variables
- ☑ Offers flexibility and robustness (partial/varying degree of matching)
- ☑ Can increase match rates over deterministic matching
- ☑ Valuable method in the absence of a common identifier and reduced quality of data

- ☒ Special software is required
- ☒ Increased computational requirements vs. deterministic matching
- ☒ Increased runtime, can be slow for larger datasets*
- ☒ Match results harder to interpret
- ☒ Potential to increase noise in the match result set
- ☒ Must include some review of matches

Types of Matching, Probabilistic Record Linkage (cont.)

- Uses a measure of similarity of each matching variable
  - Edit based – Generalize Edit Distance, Levenshtein, Jaro/Jaro-Winkler
  - Token based – Cosine similarity, Jaccard Coefficient, etc
  - Other – Locality Sensitive Hashing (LSH), MinHash, etc.

Example use case: ‘Andrew Martin Smith’ vs ‘Andy Martin Smith’

given some measure of similarity: 90% similar*

Example tools:

- Fuzzy Match add-in for Microsoft Excel (Free)
- G-Link, developed by Statistics Canada
- Python: Record Linkage Toolkit, Scikit-learn, Jellyfish (open source)

Types of Matching, Machine Learning

Extension of probabilistic linkage theory that uses a mathematical model to determine likely matches between data sets.

- ☑ Can be very powerful at identifying difficult to make matches
- ☑ Can be beneficial when data and volume warrants

- ☒ Often requires adequate training data or a 'truth' file to achieve quality results
- ☒ Transparency of match results (black box)
- ☒ Specialized software required
- ☒ Expertise required to understand and successfully apply models
- ☒ Computational and resource intensive

*Not typically used by National Statistics Offices for frame creation

Pre-processing of Linkage Variables

- It is important to properly assess and prepare each file for linkage
  - All linkage variables should be standardized/normalized across files
  - Keep only the fields needed for linkage
    - Reduces execution time and space required

Pre-processing of Linkage Variables (cont.)

- Analyse & Prepare data
  - Identify Linkage Variables
    - Business names: Legal Name, Trade Name
    - Addresses
    - Telephone numbers
    - Etc.
  - Formatting Files
    - Standardize values
    - Rename Variables to Identify Source

Pre-processing of Linkage Variables (cont.)

- Standardizing business names
  - Convert to upper case
  - Standardize common strings
    - A/C ➔ AIR CONDITIONING
    - ST-, ST., SAINT-, SAINT. ➔ ST
    - **Found by reviewing values**
  - Remove punctuation and spaces
    - MOM's FAST FOOD ➔ MOMSFASTFOOD
    - CO-OP ➔ COOP

Pre-processing of Linkage Variables (cont.)

- Standardizing business names (cont.)
  - Drop trivial words/letters
    - LTD, LIMITED
    - CO, COMPANY
    - INC, INCORPORATED
    - AND, OF, THE

- Standardize addresses by data field
  - Address – number, thoroughfare name and type
  - District/village
  - City

- Standardize geographical names
  - District/village names
  - Thoroughfare types

Pre-processing of Linkage Variables (cont.)

- Algorithms exist for standardizing or creating alternate representations for some fields

  - Strings:
    - Direct Match Key (DMK) (useful for business names)
    - Soundex (phonetic)
    - MatchRatingCodex (phonetic)
    - Metaphone (phonetic, targeted at person names)
    - NYSIIS (phonetic, targeted at person names)

    ….
  - Others:
    - Postal
    - Hashing

    ….

Jeff’s Bakery Limited → JFBKR

Jeff’s Bakery Limited → J121

Jeff’s Bakery Limited → JF’MTD

Sean Shawn Steven Stephan → SN PHN

Sean Shawn Steven Stephan → SAN SAN STAFAN STAFAN

Deterministic Matching

- An iterative approach
- Multiple passes with different matching criteria
- Start with the most stringent criteria and move to less stringent ones
- When determining the most stringent criteria, consider
  - The ability to find true pairs
  - The ability to reject false pairs

Deterministic Matching (cont.)

- Typically starts with:
  - Raw values then moves towards preprocessed values
    - The raw values can have some minor preprocessing such as the removal of accents and case conversions
  - Deterministic matches then moves towards less precise matches using transformed data
    - Allows deterministic matching to quickly find the most likely links
    - Smaller files of remaining unlinked records are entered into the rules requiring more computing intensive transformations

  - The art of record linkage is to find the best order to execute the various possible combinations of variables and approaches

Deterministic Matching (cont.)

- After each pass ➔ important to review the links
  - If the first 100 links are valid, consider accepting all links from the pass
  - If the first 100 links are invalid, consider rejecting all links from the criteria

- All true links are saved to the concordance file
- All unlinked records enter the next pass of the strategy

- Final Check: Multiple links with the same record should be reviewed
  - Determine which are likely true links
  - If more than one link appears valid, determine how to resolve

Deterministic Matching (cont.)

Pass 1	Pass 2	Pass 3	Pass 4
Legal Name	Legal Name		
Operating Name		Operating Name	Operating Name
Street Name	Street Name	Street Name	
City	City	City	City
Telephone Number	Telephone Number	Telephone Number	Telephone Number

Legal name = Enterprise
Operating name = Establishment

Deterministic Matching

Example

Deterministic Matching Example

BIR File

BIRID	Legal Name	Trade Name	Address	Tel#	Revenue
T001	123 Bahamas	Goulet and St. Louis Ltd	123 Main Street	123-234-0202	1,000,000
T002	Fresh Air Inc.	Fresh Air Inc.	22 Cool Street	123-234-1111	500,000
T003	Bahamas Hotel	Beach Front Hotel	5 Beach Street	123-234-2525	5,000,000
T004	1202 Bahamas	Island Steak House	10 George Street	123-234-1010	2,000,000
T005		Cycle Repair	15 Cloud Street	123-234-2345	10,000

National Insurance File

NIBID	Legal Name	Trade Name	Address	Tel#	Emp.
E010	123 Bahamas	Goulet & St-Louis Limited	123 Main	123-234-0202	100
E020	Fresh Air Inc.	Fresh Air Inc.	22 Cool Street	123-235-1111	50
E030	Bahamas Hotel	Beach Front Hotel	5 Beach Street	123-234-2525	75
E040	1202 Bahamas	Island Steak House	10 George Street	123-234-1010	20

Deterministic Matching Example (Cont.)

BIR File

BIRID	Legal Name	Trade Name	Address	Tel#	Revenue
T001	123 Bahamas	Goulet and St-Louis Ltd	123 Main Street	123-234-0202	1,000,000
T002	Fresh Air Inc.	Fresh Air Inc.	22 Cool Street	123-234-1111	500,000
T003	Bahamas Hotel	Beach Front Hotel	5 Beach Street	123-234-2525	5,000,000
T004	1202 Bahamas	Island Steak House	10 George Street	123-234-1010	2,000,000
T005		Cycle Repair	15 Cloud Street	123-234-2345	10,000

National Insurance File

NIBID	Legal Name	Trade Name	Address	Tel#	Emp.
E010	123 Bahamas	Goulet & St-Louis Limited	123 Main	123-234-0202	100
E020	Fresh Air Inc.	Fresh Air Inc.	22 Cool Street	123-235-1111	50
E030	Bahamas Hotel	Beach Front Hotel	5 Beach Street	123-234-2525	75
E040	1202 Bahamas	Island Steak House	10 George Street	123-234-1010	20

Matched Result File #1

BIRID	NIBID	Legal Name	Trade Name	Address	Tel#	Revenue	Emp.
T003	E030	Bahamas Hotel	Beach Front Hotel	5 Beach Street	123-234-2525	5,000,000	75
T004	E040	1202 Bahamas	Island Steak House	10 George Street	123-234-1010	2,000,000	20

Deterministic Matching Example (Cont.)

BIR File

BIRID	Legal Name	Trade Name	Address	Tel#	Revenue
T001	123 Bahamas	Goulet and St.Louis Ltd	123 Main Street	123-234-0202	1,000,000
T002	Fresh Air Inc.	Fresh Air Inc.	22 Cool Street	123-234-1111	500,000
T005		Cycle Repair	15 Cloud Street	123-234-2345	10,000

National Insurance File

NIBID	Legal Name	Trade Name	Address	Tel#	Emp.
E010	123 Bahamas	Goulet & St-Louis Limited	123 Main	123-234-0202	100
E020	Fresh Air Inc.	Fresh Air Inc.	22 Cool Street	123-235-1111	50

Pre-processed BIR File

BIRID	Legal Name	Trade Name	Address	Tel#	Revenue
T001	123BAHAMAS	GOULETSTLOUIS	123 Main	123-234-0202	1,000,000
T002	FRESHAIR	FRESHAIR	22 Cool	123-234-1111	500,000
T005		CYCLEREPAIR	15 Cloud	123-234-2345	10,000

Pre-processed National Insurance File

NIBID	Legal Name	Trade Name	Address	Tel#	Emp.
E010	123BAHAMAS	GOULETSTLOUIS	123 Main	123-234-0202	100
E020	FRESHAIR	FRESHAIR	22 Cool	123-235-1111	50

Deterministic Matching Example (Cont.)

Pre-processed BIR File

BIRID	Legal Name	Trade Name	Address	Tel#	Revenue
T001	123BAHAMAS	GOULETSTLOUIS	123 Main	123-234-0202	1,000,000
T002	FRESHAIR	FRESHAIR	22 Cool	123-234-1111	500,000
T005		CYCLEREPAIR	15 Cloud	123-234-2345	10,000

Pre-processed National Insurance File

NIBID	Legal Name	Trade Name	Address	Tel#	Emp.
E010	123BAHAMAS	GOULETSTLOUIS	123 Main	123-234-0202	100
E020	FRESHAIR	FRESHAIR	22 Cool	123-235-1111	50

Matched Result File #2

BIRID	NIBID	Legal Name	Trade Name	Address	Tel#	Revenue	Emp.
T001	E020	123 Bahamas	Goulet and St. Louis Ltd	123 Main Street	123-234-0202	1,000,000	1,000,000

Deterministic Matching Example (Cont.)

Pre-processed BIR File

BIRID	Legal Name	Trade Name	Address	Tel#	Revenue
T002	FRESHAIR	FRESHAIR	22 Cool	123-234-1111	500,000
T005		CYCLEREPAIR	15 Cloud	123-234-2345	10,000

Pre-processed National Insurance File

NIBID	Legal Name	Trade Name	Address	Tel#	Emp.
E020	FRESHAIR	FRESHAIR	22 Cool	123-235-1111	50

Matched Result File #3

BIRID	NIBID	Legal Name	Trade Name	Address	Tel#	Revenue	Emp.
T001	E020	Fresh Air Inc.	Fresh Air Inc.	22 Cool Street	123-234-1111	500,000	50

Deterministic Matching Example (Cont.) - Final result

BIRID	NIBID	Legal Name	Trade Name	Address	Tel#	Revenue	Emp.
T001	E010	123 Bahamas	Goulet and St-Louis Ltd	123 Main Street	123-234-0202	1,000,000	100
T002	E030	Fresh Air Inc.	Fresh Air Inc.	22 Cool Street	123-234-1111	500,000	50
T003	E040	Bahamas Hotel	Beach Front Hotel	5 Beach Street	123-234-2525	5,000,000	75
T004	E050	1202 Bahamas	Island Steak House	10 George Street	123-234-1010	2,000,000	20
T005			Cycle Repair	15 Cloud Street	123-234-2345	10,000	

Ongoing BR Update Processes Using Administrative Data

- Develop linkage process or procedures
  - Possible linkage variables: legal & trade names, addresses, telephone numbers, etc..
  - Final output: Concordance table containing all the unique administrative business IDs and the BR unique business ID

- Identify key variables to be updated or created on the BR
  - Tombstone (legal name, trade name, address, telephone #, etc..)
  - Size variables (revenue, employees etc..)
  - Classification variables (geography, industry, others)

Ongoing BR Update Processes Using Administrative Data (cont.)

- Develop business status rules or procedures (birth, active, inactive and ceased)
- Create “update date” and “source” variables for maintenance purposes

Resources

- https://uwaterloo.ca/networks-lab/blog/post/pre-processing-recordlinkage
  - University of Waterloo: complete tutorial of record linkage work flow using Python Record Linkage Toolkit. Great tutorial that summarizes most of the concepts of record linkage and is a great introduction to this useful library

- **An Overview of Selected International Business Record Linkage Programs**
  - https://www150.statcan.gc.ca/n1/pub/18-001-x/18-001-x2016001-eng.htm
  - Statistics Canada report summarizing record linkage activities including challenges and best practices for a number or NSOs

- Guidelines for Hierarchical Record Linkage (electronic handout, to be provided)
  - Provides a summary of record linkage concepts and as well as example implementation of a DMK
- Excel fuzzy match…

Conclusions

- Record linkage or data integration processes bring many advantages to a statistical organization
  - Reduce the need to contact businesses
  - Reduce costs
  - Replace existing survey modules
  - Develop new data series just based on BR data
  - Help in creating a complete BR
    - Overall population
    - Variable values
- However, need to:
  - Deploy initial effort to develop the processes and procedures to link records for the same businesses from various data sources
  - Apply the procedures at pre-determined frequency to ensure new records get linked and to attempt to link previously unlinked records.

You can contact the PRASC team at:

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