COMP20008 Elements of Data Processing

Data linkage and privacy

Announcements

- Friday May 5th guest lecturer: Scott Thomson from Google
- Feedback on phase2A submissions will be released this Thursday (May 4th).

Outline

- **Last week**
  - How to define similarity between records?
  - How to efficiently do linkage when matching two large databases
  - Blocking

- **Today: How to maintain privacy when doing data linkage?**
  - Why is privacy important?
  - An example method for privacy preserving linkage

Data Linkage and Privacy

- If data matching is being conducted within a single organisation and is using databases within the organisation, privacy/ confidentiality is generally not a concern.
  – Can assume individuals doing the matching are authorised, aware of policies and don't have malicious intent
  – E.g. University of Melbourne: administrator who is matching student academic results database against database of applicants for PhD study

- On the other hand, problems can arise if
  – Matched data is being passed to another organisation or being made public
  – Data matching is being conducted across databases from different organisations

Example 1: Need for privacy in public health

- Research team investigating effects of car accidents on the public health system. Research questions
  - Most common injuries for what types of car accident?
  - When and where accidents occurred, the road and weather conditions at time of accident and health of people involved in accident, as well as two years later?
- Data needed
  - Hospital data on patients
  - Private health insurance data
  - Police
  - Road traffic authorities
- *These organisations can't share all their data with the research team.*

Example 2: Need for privacy - business

- Two businesses wish to co-operate
  - Find how many customers and suppliers in common
  - *Don't want to share all their confidential data with another*
  - Need techniques for sharing such that
    - Only records in the two databases that are similar with each other (according to some similarity function) are identified.
    - The identities of these records and their similarities are revealed to both organisations
    - Neither of the two parties must be able to learn anything else about the other party's confidential data (the non similar records)

Example 3: Need for privacy – national security

- National crime investigation unit analysing crimes of national significance (significance to all of Australia)
- Wants to link its own database about suspicious individuals to different databases around Australia
  - Tax
  - Law enforcement
  - Financial institutions
- *Only linked records should be available to the unit*
  - It should not get access from the bank to financial data about non-suspicious individuals
  - It should not get access to tax records about non-suspicious individuals

Privacy Preserving Data Linkage: Problem Statement

- How can we perform data linkage for two databases, each from a different organisation
  - Without revealing any information about individuals who do not get linked across the databases (i.e. individuals who occur in one database and not in the other)

- We will need
  - Methods for computing similarity of records, without revealing the record values
    - Hashing: an important tool

Hashing

- A hash function H maps a data item of arbitrary size to a data item of fixed size
- Example 1
  - H(James) = 10
  - H(Kate)   = 11
  - H(The quick brown fox jumped over the lazy dog) = 20
  - [take first letter of the string, ‘J’, ‘K’ or ‘T’]
- Example 2
  - H(32)=2
  - H(20)=2
  - H(6)=0
  - H(7)=1
  - [remainder when dividing by 3]

Non invertible (one way) hash function

- Non invertible hash function. Given the output H(X), extremely hard to reconstruct X. Examples
  - MD5 hash function (produces a 32 digit hex number)
    - H(James)= d52e32f3a96a64786814ae9b5279fbe5
    - H(I love data wrangling)= 614416fa9d994aa8225ebd7c50f22060
    - H(12345678)= 25d55ad283aa400af464c76d713c07ad
  - SHA-3-512 hash function (produces a 64 digit hex number)
    - H(James)=02c56351888fa73ff825ffd65526b264ebefe7916fa5d8d5c58e766bfdd1de8e85b68bf12599b9d21eca6683d4abfa8616acfa6834e7c478e394374a7b015898
    - H(12345678)=8a56bac869374c669443a1626ff0967af258123f83faf6b55e31dd541e6bbd90308a3385713294bf2e8861bc8cf8f8feda41f9c4db19d5811a6b5de85eac9870

Hash function Demo

- http://emn178.github.io/online-tools/sha3_512.html

Hash encoding for exact matching: 2 party protocol

- Each organisation
  - Applies a (one way) hash function to the attribute used to join the databases
  - Shares its hashed values with the other organisation. Each checks which ones match. These are the linked records.

Org. A

Name	H(Name)
Jill	8347
Jane	6992

Org. B

Name	H(Name)
Bob	2332
Jane	6992

Exact matching: 2 party protocol

- Form groups of 4-5:
  - You need one laptop that is connected to the internet
  - Open *lecture17.ipynb* (available via LMS)
  - Create a dictionary with Student name as its key & student's favorite movie as its value (first name only)
  - Use capital letters to start the name
  - Email the output to enaghi@unimelb.edu.au

Small changes in input, large change in output

- Disadvantage 1: What about single character differences in the original value? E.g. MD5 hash function
  - H(James)= d52e32f3a96a64786814ae9b5279fbe5
  - H(Jamex)= c3bfa7fa6ad2b987619bb4c932e65b4a
  - Single character difference results in a completely different output. This is generally true for one way hash functions such as MD5, SHA ....

Dictionary attack

- Disadvantage 2: An organisation could mount a dictionary attack to “invert” the hash function. E.g. Organisation A generates a hash dictionary by computing hashes for all words of length 4
  - H(aaaa)=…
  - H(aaab)= …
  - H(aaac)= …
  - H(aaad)= …
  - …..
  - H(zzzz)= …
- Organisation A then scans the hashed values received from Organisation B. Checks if any match its hash dictionary. If yes, privacy is lost for those items.
- Could also generate dictionary for all known words, pairs of words, …. [up to some limit of feasibility]
- d077f244def8a70e5ea758bd8352fcd8 example

2 party protocol: Disadvantages

- Back to the previous example

Hash encoding for exact matchine: 3 party protocol

- Possible solution
  - Involve a trusted 3rd party (Organisation C)
  - Organisations A and B send their hashed values to Organisation C, who then checks for matches.
  - What if Organisation C is malicious?
    - Organisation C could mount a dictionary attack and guess the hashed values
    - Solution: A and B perform "dictionary attack resistant" hashing

3rd Party Protocol using salt

A

Name	H(Name)
Jill+SECRET_KEY	1112
Jane+SECRET Key	9341

B

Name	H(Name)
Bob+SECRET_KEY	2996
Jane+SECRET_KEY	9341

- Organisations A and B concatenate a secret word to every name field in their data before hashing (known as a *salt*). Organisation C does not know what this word is and thus can't perform a dictionary attack to "reverse" the hashed values it receives.

Hashing and salting

- In June 2012 dating site eHarmony was hacked
  - 1.5 million password hashes publicly released
- In June 2012 social networking site LinkedIn was hacked
  - 6.5 million hashed password stolen and publicly released
- *Neither company used a salt when hashing the passwords*
  - Many passwords were thus susceptible to a brute force dictionary attack on the hashed values

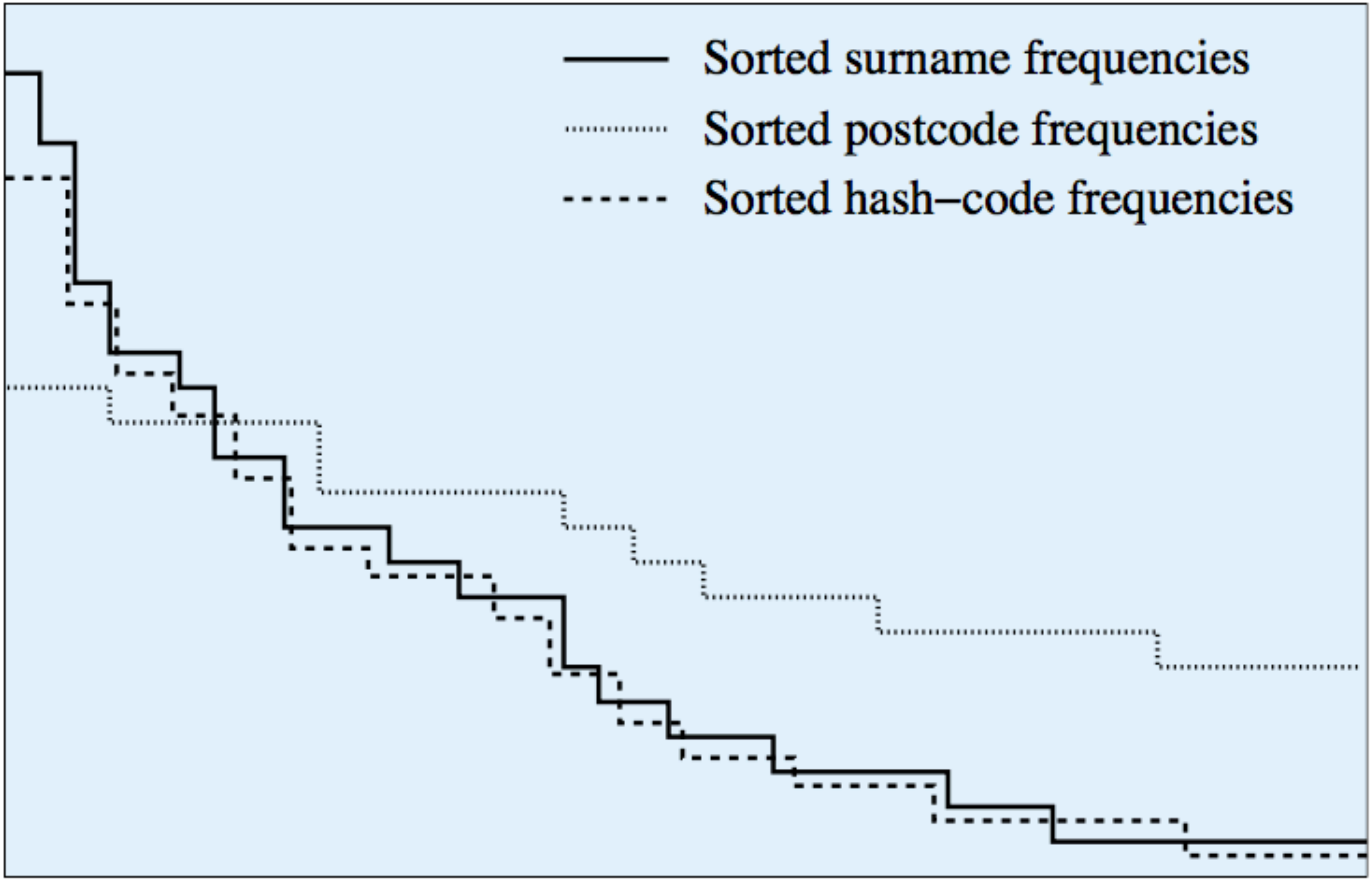
Question

- The two party protocol isn’t robust to a dictionary attack.
  - Why doesn’t adding salt to the hash function help here?

Frequency attack

- This third party scheme prevents a dictionary attack, but may still be susceptible to a frequency attack.
  - 3rd party compares the distribution of hashed values to some known distribution
    - E.g. distribution of surname frequencies in a public database versus distribution of hash values
    - May be able to guess some of the hashed values!
- Organisations A and B could prevent this by adding random records to manipulate the frequency distribution

Frequency attack [slide from Peter Christen]



Summary/ Privacy preserving linkage

- Organisations A and B can determine which records in the two databases are an exact match in a privacy preserving manner by
  - using a trusted third party C, and
  - using one way hash functions with a salt, and
  - adding random records

- A reasonably private scheme (depending on how much the third party is trust)

Challenge 1

- The hash based technique using the 3rd party, can only compute exact similarity between strings in a privacy preserving manner.

- What if we wish to compute approximate similarity between two strings in a privacy preserving manner?
  - To be covered in Monday's lecture

Challenge 2: Public release

- Suppose organisation wishes to make one of its internal datasets public, for social good purposes
  - E.g. NASA releasing images of Mars
  - City of San Francisco, crime data
  - CERN, particle physics data
  - Bank, data on credit scoring and people who experiences financial distress
- Can be very, very difficult to prevent data linkage attacks or reverse engineering of people's identities
  - America Online search logs
  - Medicare Benefits Schedule data (https://pursuit.unimelb.edu.au/articles/understanding-the-maths-is-crucial-for-protecting-privacy)

America Online Search Logs

- In 2006, America Online released a file with 3 months of ``anonymized'' search queries of 658k users.
  - After a public outcry, data quickly taken down, but couldn't be removed completely from the Web
  - Ranked 58 out of the 101 dumbest moments in business by CNNMoney.com
  - http://www.nytimes.com/2006/08/09/technology/09aol.html?_r=0

User id	Time	Search Query
1	..	..
1	…	…
1	…	…
2	…	.
2	…	…
2	..	…
3	…	…

Public release: Solutions

- Don't release the data at all!, or

- Release an obfuscated version of the data (e.g. with noise added to all the records)
  - This is the basis of methods such as k-anonymity and differential privacy (we will likely look at in a couple of weeks)

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Acknowledgements

- Material in this lecture partly adapted from
  - Data Matching: Concepts and Techniques for Record Linkage, Entity Resolution and Duplicate Detection, Peter Christen, Springer, 2012. Available as an e-book for download by University Library
    - Read Sections 1,2, 4.1,4.2,5.4, 8.1, 8.2

What you need to know from this lecture

- be able to explain in what circumstances privacy is an important issue for data linkage -understand the objective of privacy preserving data linkage
- understand the use of one way hashing for exact matching in a 2 party privacy preserving data linkage protocol
- understand the vulnerabilities of 2 party privacy preserving data linkage protocol to i) small differences in input, ii) dictionary attack
- understand the operation of the 3 party protocol for privacy preserving linkage, using hash encoding with salt for exact matching. Understand the disadvantages of this protocol

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Plan for coming lectures

- Next lecture on Friday (May 5^{th}): Scott Thomson from Google
- Next Monday (May 8^{th}): Approximate Privacy-Preserving Matching Techniques