ARX

A Comprehensive Tool for Anonymizing Biomedical Data

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Today’s presenters

Florian Kohlmayer

- Computer scientists, background in IT security and database systems
- Research assistants at the Chair for Biomedical Informatics at TUM
- Core-developers of ARX

Fabian Prasser
Today’s agenda

- Introduction
- Demonstration
- Questions & answers
Motivation: Data sharing in biomedical research

• Data sharing is a core element of biomedical research
  • Wellcome Trust: Sharing research data to improve public health [1]
  • OECD: Principles and guidelines for access to research data from public funding [2]

• Disclosure of data may lead to harm for individuals
  • Data may be person-related and highly sensitive

• Large body of laws & regulations mandates privacy protection
  • US: HIPPA Privacy Rule
  • EU: European Data Protection Regulation
  • DE: German Federal Data Protection Act

• Safeguards
  • Access control, policies, agreements, …
  • De-identification / anonymization
Overview: De-identification / anonymization

• **Controlling interactive data analysis**
  • **Subject:** query results, …
  • **Methods:** differential privacy, query-set-size control, …
  • **Implementations:** Fuzz, PINQ, Airavat, HIDE

• **Masking identifiers in unstructured data**
  • **Subject:** clinical notes, …
  • **Methods:** machine learning, regular expressions, …
  • **Implementations:** MIST, MITdeid, NLM Scrubber

• **Transforming structured data (focus of ARX)**
  • **Subject:** tabular data, …
  • **Methods:** generalization, suppression, …
  • **Implementations:** ARX, sdcMicro, PARAT
Background: Transforming structured data

- **Basic idea**: transform datasets in such a way that they adhere to a set of formal privacy guarantees

- **Typical transformations**
  - **Generalization**: Germany $\rightarrow$ Europe (often applied to individual values)
  - **Suppression**: Germany $\rightarrow$ * (often applied to whole entries)

- **Example generalization hierarchies**
Background: Transforming structured data (cont.)

- **Representation of gen. hierarchies**

  ![Tree diagram]

- **Full-domain generalization**: all values of an attribute are generalized to the same level of the associated generalization hierarchy

- **Search space**: combinations of all generalization levels (lattice)

  **Tabular representation**

<table>
<thead>
<tr>
<th>Level 0</th>
<th>Level 1</th>
<th>Level 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>&lt;50</td>
<td>*</td>
</tr>
<tr>
<td>2</td>
<td>&lt;50</td>
<td>*</td>
</tr>
<tr>
<td>...</td>
<td>&lt;50</td>
<td>*</td>
</tr>
<tr>
<td>50</td>
<td>≥50</td>
<td>*</td>
</tr>
<tr>
<td>51</td>
<td>≥50</td>
<td>*</td>
</tr>
<tr>
<td>...</td>
<td>≥50</td>
<td>*</td>
</tr>
</tbody>
</table>

   **Schema:**

<table>
<thead>
<tr>
<th>Age</th>
<th>Gender</th>
<th>Zip code</th>
</tr>
</thead>
</table>

   Level 0 for attribute “gender”
   Level 0 for attribute “age”
   Level 1 for attribute “zip code”
Background: Privacy models

- **Well-known models**: k-anonymity, ℓ-diversity, t-closeness, δ-presence

- **Example**: k-anonymity
  - Proposed by Samarati and Sweeney in 1998 [3]
  - Attacker model: linkage via a set of quasi-identifiers (identity disclosure)
  - Mitigated by: building groups of indistinguishable data entries
  - Adherence can be achieved with generalization and suppression

<table>
<thead>
<tr>
<th>Age</th>
<th>Gender</th>
<th>Zip code</th>
</tr>
</thead>
<tbody>
<tr>
<td>34</td>
<td>male</td>
<td>81667</td>
</tr>
<tr>
<td>45</td>
<td>female</td>
<td>81675</td>
</tr>
<tr>
<td>34</td>
<td>female</td>
<td>81931</td>
</tr>
<tr>
<td>45</td>
<td>male</td>
<td>81925</td>
</tr>
<tr>
<td>70</td>
<td>female</td>
<td>81931</td>
</tr>
<tr>
<td>70</td>
<td>male</td>
<td>81931</td>
</tr>
<tr>
<td>66</td>
<td>male</td>
<td>80931</td>
</tr>
</tbody>
</table>

Age | Gender | Zip code
---|--------|----------
< 50 | *      | 816**    |
< 50 | *      | 816**    |
< 50 | *      | 819**    |
< 50 | *      | 819**    |
≥ 50 | *      | 819**    |
≥ 50 | *      | 819**    |
*    | *      | *        |

Generalization (1,1,2)

2-anonymity

Suppression
## Background: k-Anonymity

### Original dataset

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### Background knowledge, e.g. voter list

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<td>81925</td>
<td>Bob</td>
</tr>
<tr>
<td>70</td>
<td>male</td>
<td>81931</td>
<td>Charlie</td>
</tr>
</tbody>
</table>

### 2-anonymous dataset

<table>
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<tr>
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<th>Gender</th>
<th>Zip code</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 50</td>
<td>*</td>
<td>816**</td>
</tr>
<tr>
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<td>*</td>
<td>816**</td>
</tr>
<tr>
<td>&lt; 50</td>
<td>*</td>
<td>819**</td>
</tr>
<tr>
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??
Challenge: Tool support

• **Situation**: anonymization of structured data is frequently recommended (laws, regulations, guidelines) but in practice it is only used rarely

• **Main reasons**
  • Lack of understanding of opportunities and limitations
  • Lack of ready-to-use tools

• **Non-trivial**: implementing useful tools is challenging

• **Usefulness has many dimensions**
  • Ability to balance data utility with privacy requirements
  • Support a broad spectrum of privacy methods, transformation techniques and methods for measuring and analyzing data utility
  • Performance and scalability
  • Intuitive visualization and parameterization of all process steps
  • Provide methods to end-users as well as programmers
  • In an integrated and harmonized manner
  • Openness
Challenge: Related software

- **sdcMicro**
  - Cross-platform open source software implemented in “R”
  - Collection of a set of methods, not an integrated application
  - Different types of recoding models and risk models
  - Minimalistic graphical user interface

- **μArgus**
  - Closed source software for MS Windows
  - Methods comparable to sdcMicro but more comprehensive user interface
  - Development has ceased

- **PARAT**
  - Commercial tool for MS Windows
  - Powerful graphical interface
  - Methods implemented overlap with methods implemented in ARX
  - Centered around a risk-based approach

- **More comprehensive list:** [http://arx.deidentifier.org/related-software/](http://arx.deidentifier.org/related-software/)

ARX: Highlights

- **Flexible transformation methods**: generalization and suppression in a parameterizable and utility-driven manner
- **Multiple privacy models**: $k$-anonymity, $\ell$-diversity (three variants), $t$-closeness (two variants) and $\delta$-presence, as well as arbitrary combinations
- **Multiple methods for measuring data utility**: automatically as well as manually
- **Optimality**: classification of the complete solution space
- **Functional generalization rules**: support for continuous and discrete variables
- **Highly scalable**: several million data entries on commodity hardware
- **Comprehensive cross-platform Graphical User Interface**: wizards, visualization of the solution space, analysis of data utility
- **Application Programming Interface**: full-blown Java library
ARX: Anonymization workflow

- Iteratively refine the anonymization process
- Supported by the scalability of our framework
- Three (potentially repeating) steps

1. **Configure**
   - Create and edit rules
   - Define privacy guarantees
   - Parameterize coding model
   - Configure utility measure

2. **Explore**
   - Filter and analyze the solution space
   - Organize transformations

3. **Analyze**
   - Compare and analyze input and output

**Diagram:**
- Import Data
- Configure
- Explore
- Analyze
- Export Data
ARX: Demo
ARX: Facts and credits

- Three years of work by two main developers: Florian Kohlmayer and Fabian Prasser
- With help from multiple students: see credits on our website
- Interdisciplinary cooperation: Chair for IT Security, Chair for Database Systems, Chair for Biomedical Informatics
- Code metrics
  - ARX Core/API: 178 files, 200 classes
    37,332 LOC (16,281 lines of comments)
  - ARX GUI: 174 files, 207 classes
    44,772 LOC (15,062 lines of comments)
  - ARX Tests: 997 JUnit tests
  - Commits: 1,722 commits (since 03/2013)
ARX: Publications

- **Implementation framework:** Proc Int Symp CBMS, 2012 [4]
- **Anonymization algorithm:** Proc Int Conf PASSAT, 2012 [5]

- **Anonymization of distributed data:** J Biomed Inform, 2013 [6]
- **Benchmark for anonymity methods:** Proc Int Symp CBMS, 2014 [7]

Thank you for your attention! Questions?

• Disclaimer
  • Anonymization must be performed by experts
  • Additional safeguards are required (e.g., contractual measures)

• ARX is open source software
  • Contributions are welcome, e.g., feature requests, code reviews, criticism, enhancements, questions

• Future developments: various projects, especially risk models

• Resources
  • Project website: http://arx.deidentifier.org
  • Code repository: https://github.com/arx-deidentifier/arx
  • Get in touch
    • Fabian Prasser (prasser@in.tum.de)
    • Florian Kohlmayer (florian.kohlmayer@tum.de)
References


*Equal contributors