Web Data Integration

Introduction and Course Outline
Hallo

- Prof. Dr. Christian Bizer
- Professor for Information Systems V
- Research Interests:
  - Web-based Systems
  - Linked Data Technologies
  - Data and Web Mining
  - Identity Resolution
  - Data Quality Assessment and Fusion
- Room: B6, 26 - B1.15
- Consultation: Wednesday 13:30-14:30
- eMail: chris@informatik.uni-mannheim.de
Hallo

- **Dr. Heiko Paulheim**
- Postdoctoral Researcher
- **Research Interests**
  - Semantic Web, Linked Open Data, and their Applications
  - Machine Learning and Data Mining on Linked Data
  - Ontology Matching
  - Data Quality and Data Cleaning
- Room: B6, 26, C 1.08
- eMail: heiko@informatik.uni-mannheim.de
- Will supervise the student projects.
– **Dr. Volha Bryl**
– Postdoctoral Researcher
– Research Interests
  • Linked Data
  • Data Quality and Data Cleaning
  • Identity Resolution
  • Natural Language Processing
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– eMail: volha@informatik.uni-mannheim.de

– Will supervise the student projects.
1. What is Data Integration?
2. Application Areas
3. Types of Heterogeneity
4. The Data Integration Process
5. Data Integration Architectures
6. Course Outline and Organization
1. What is Data Integration?

- Databases are great: They let us manage huge amounts of data.
  1. Assuming you’ve put it all into a single schema.
  2. Assuming the database doesn’t contain duplicate records.
  3. Assuming that there are no data conflicts.

- In reality, applications often need to work with data from multiple independently created data sources.
  1. Different sources use different data models.
  2. Different sources use different schemata.
  3. Different sources describe the same real-world entity.
  4. Different sources provide conflicting data about a single entity.
  5. Different sources provide different limited query interfaces to their data.
What is Data Integration?

Data integration is the process of consolidating data from a set of heterogeneous data sources into a single uniform data set.

- The integrated data set should:
  1. Correctly and completely represent the content of all data sources.
  2. Use a single data model and a single schema.
  3. Only contain a single representation of every real-world entity.
  4. Not contain any conflicting data about single entities.

- To achieve this data integration needs to resolve different types of heterogeneity that exist between data sources.
Overview: Data Integration

Application

Integrated Data

Oracle, DB2...
CSV File
Web Service
App.
Web pages
Integrated Data
2. Application Areas

1. Business
2. Science
3. Government
4. the Web
5. .... pretty much every application area
Application Area: Business

Enterprise Databases

- CRM
- ERP
- Business Intelligence
- Company Mergers
- ...

Legacy Databases

Services and Applications

Oracle estimate: 50% of all IT $$$ are spent here!
Hundreds of biomedical data sources available; growing rapidly!
Application Area: The Web
The Unofficial Harry Potter Cookbook: From Cauldron Cakes to Knickerbocker Glory--More Than 150 Magical Recipes for Muggles and Wizards [Book]

$3 online

By Dinah Bucholz  Adams Media  2010  Hardcover  256 pages  ISBN 1440303257

Bangers and mash with Harry, Ron, and Hermione in the Hogwarts dining hall: A proper cuppa tea and rock cakes in Hagrid's hut; Cauldron cakes and pumpkin juice on the Hogwarts Express. With this cookbook, dining a la Hogwarts is as easy as Barmbric Pie! With more than 150 easy-to-make ... more »

### Online stores

<table>
<thead>
<tr>
<th>Sellers</th>
<th>Seller Rating</th>
<th>Details</th>
<th>Base Price</th>
<th>Total Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>MovieMars.com</td>
<td>★★★★★ (42)</td>
<td>Free shipping</td>
<td>$20.92</td>
<td></td>
</tr>
<tr>
<td>ValoreBooks.com</td>
<td>No rating</td>
<td>No tax</td>
<td>$3.24 $3.95 shipping</td>
<td>$7.19</td>
</tr>
</tbody>
</table>

Set your location

Free shipping  Refurbished / used
The President and Vice-President are elected every four years. They must be at least 35 years of age, they must be native-born citizens of the United States, and they must have been residents of the U.S. for at least 14 years. (Also, a person cannot be elected to a third term as President.)

<table>
<thead>
<tr>
<th>President</th>
<th>Party</th>
<th>Term as President</th>
<th>Vice-President</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. George Washington (1732-1799)</td>
<td>None, Federalist</td>
<td>1789-1797</td>
<td>John Adams</td>
</tr>
<tr>
<td>2. John Adams (1735-1826)</td>
<td>Federalist</td>
<td>1797-1801</td>
<td>Thomas Jefferson</td>
</tr>
<tr>
<td>3. Thomas Jefferson (1743-1826)</td>
<td>Democratic-Republican</td>
<td>1801-1809</td>
<td>Aaron Burr, George Clinton</td>
</tr>
<tr>
<td>4. James Madison (1751-1836)</td>
<td>Democratic-Republican</td>
<td>1809-1817</td>
<td>George Clinton, Elbridge Gerry</td>
</tr>
<tr>
<td>5. James Monroe (1758-1831)</td>
<td>Democratic-Republican</td>
<td>1817-1825</td>
<td>Daniel Tompkins</td>
</tr>
<tr>
<td>7. Andrew Jackson (1767-1845)</td>
<td>Democratic-Republican</td>
<td>1829-1837</td>
<td>Andrew Jackson</td>
</tr>
<tr>
<td>8. Martin van Buren (1782-1862)</td>
<td>Democratic-Republican</td>
<td>1837-1841</td>
<td>Martin Van Buren</td>
</tr>
<tr>
<td>10. John Tyler (1790-1862)</td>
<td>Democratic-Republican</td>
<td>1841-1841</td>
<td>John Tyler</td>
</tr>
<tr>
<td>14. Franklin Pierce (1804-1869)</td>
<td>Democrat</td>
<td>1853-1857</td>
<td>William King</td>
</tr>
</tbody>
</table>

There are hundreds of millions of high-quality tables on the Web and in Wikipedia.
The Deep Web accessible via HTML Forms

Yahoo! Hot Jobs

USAJOBS: "Working for America"

Search for Jobs Across the Web

Keyword(s):
City & State or Zip:
(e.g. Job title, company, occupation)
Include surrounding cities

Job Category:

Search

Find a job

Enter keywords
Select an employer:
All

Select a job type:
All

SEARCH

Location Search

Select all
US
AK
AK-Aleutian Islands
AK-Anchorage

Job Category Search

---------- SELECT ALL ----------
Accounting, Budget and Finance
Biological Sciences
Business, Industry, and Procurement
Copyright, Patent, and Trademark

Salary Range:
Pay Grade (GS):
More and more Websites

- semantically markup the content of their HTML pages
- publish structured data in addition to HTML pages

Microformats

RDFa

Linked Data

Microdata

Web APIs
3. Types of Heterogeneity

We distinguish five types of heterogeneity:

1. Technical Heterogeneity
2. Syntactical Heterogeneity
3. Data Model Heterogeneity
4. Structural Heterogeneity
5. Semantic Heterogeneity

The main goal of data integration is to bridge all these types of heterogeneity.

- Data source autonomy is the main reason for heterogeneity:
  - Data sources independently decide on what to store and how to store it
  - Design autonomy, interface autonomy, legal autonomy
Technical heterogeneity comprises all differences in the means to access data, not the data itself.

<table>
<thead>
<tr>
<th>Level</th>
<th>Possibilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communication Protocol</td>
<td>HTTP, ODBC/JDBC, SOAP</td>
</tr>
<tr>
<td>Exchange Format</td>
<td>XML, RDF, JSON, CSV, HTML, binary data</td>
</tr>
<tr>
<td>Query Language</td>
<td>Full query language: SQL, SPARQL</td>
</tr>
<tr>
<td></td>
<td>Canned queries: Web Services, Web Forms</td>
</tr>
<tr>
<td></td>
<td>Download of complete data set dumps</td>
</tr>
<tr>
<td>Additional Restrictions</td>
<td>Number of queries</td>
</tr>
<tr>
<td></td>
<td>Cost per query / data set</td>
</tr>
<tr>
<td></td>
<td>Access rights</td>
</tr>
</tbody>
</table>
Syntactical heterogeneity comprises all differences in the encoding of values.

<table>
<thead>
<tr>
<th>Level</th>
<th>Possibilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number format</td>
<td>Little endian versus big endian</td>
</tr>
<tr>
<td>Character format</td>
<td>ASCII versus Unicode</td>
</tr>
<tr>
<td>Delimiter format</td>
<td>Tab-delimited versus Comma-separated values</td>
</tr>
</tbody>
</table>

Syntactical heterogeneity does not comprise

- Synonymous values
  - 1GB versus 1000MB ➔ Semantic heterogeneity
- Structural differences
  - First name: Chris, last name: Bizer versus name: Chris Bizer ➔ Structural heterogeneity
Data model heterogeneity comprises differences in the data model that is used to represent data.

Data Models:
1. Relational data model
2. XML data model
3. Object-oriented data model
4. RDF graph data model
Structural heterogeneity comprises differences in the way different schemata represent the same part of reality.

1. Alternative Modeling
   - Relation vs. Attribute
   - Attribut vs. Value
   - Relation vs. Value

2. Normalized vs. Denormalized

3. Nested vs. Foreign Key Relationship
Example: Alternative Modelling

Man( Id, Firstname, Surname)
Woman( Id, Firstname, Surname)

Relation vs. Attribute

Relation vs. Value

Person( Id, Firstname, Surname, Male, Female)

Attribute vs. Value

Person( Id, Firstname, Surname, Sex)
Semantic heterogeneity comprises differences concerning the meaning of data and schema elements.

1. Naming Conflicts
   - Synonyms, Homonyms, slightly deviating concepts

2. Object Identity / Duplicates
   - Which “Franz Müller” does a record describe?
   - Multiple data sources as well as multiple records within one data source describe the same real-world entity.

3. Data Conflicts
   - Conflicting data about the same real-world entity in different data sources as well as within different records in the same data source.
The intension of a name is the abstract concept the name refers to.

The extension of a name is the set of real-world objects that are instances of the concept.
Synonyms

Different words having the same meaning (intension).

1. Synonymous schema element names:

   DB1:
   Employee(Id, FirstName, Name, Male, Female)

   DB2:
   Person(Id, FirstName, Surname, Sex)

2. Synonymous attribute values:
   - Different value coding schemas: Manager vs. 2
   - Different spellings / abbreviations: Kantstr. vs. Kantstrasse vs. Kant Str.
   - Different units of measurement: 1 GB vs. 1000 MB
Homonyms

Same words having the **different meanings** (intensions).

- Reason: Different people (in different situations) associate different meanings with the same word.

- Examples:

  **DB1:**
  
  Employee( Id, Name, Salary, m, f, Title)

  **DB2:**
  
  Person( Id, Name, Salary, Sex, Titel)

  - USD
  - Secretary, Engineer, Manager, etc.
  - Euro
  - Mr., Mrs., Dr., Prof. Dr., ...
Business question: How many employees has IBM?

- Definition of Employee:
  - Temporary employees?
  - Students writing master theses?
  - External consultants?
  - Positions in organization chart or currently employed people?
- Definition of IBM
  - Which global region? Which business unit?
  - Include companies that are owned by IBM?
- Which point in time?
- How to count people that work part-time?
Problem: The same real-world entity is often represented
- within multiple data sources.
- by multiple records within the same data base.

- Relevant for: Product data, customer data, scientific data, …
- Business question: How much hardware did we sell to the University of Mannheim?
- Problem: CRM database likely contains multiple records referring to the university itself as well as the different faculties/professors.
- Reasons for duplicates in the same data base:
  - Different people entered data without identity checks
  - Same entity observed several times
  - No consistent global IDs in input data (ISBN, IBAN, URL, EAN, …)
Data Conflicts

Problem: Two duplicate records contain different values for the same attribute.

<table>
<thead>
<tr>
<th>ID</th>
<th>Author</th>
<th>Title</th>
<th>Price</th>
<th>Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>0766607194</td>
<td>H. Melville</td>
<td>Moby Dick</td>
<td>$43.98</td>
<td>442 pages</td>
</tr>
<tr>
<td>0766607194</td>
<td>Herman Melville</td>
<td>Moby Dick</td>
<td>$35.99</td>
<td>44 pages</td>
</tr>
</tbody>
</table>

Reasons for data conflicts

1. Errors: Typos and other errors when data is entered.
2. Out-dated data: One source/record is older than the other one.
3. Disagreement: Different sources actually disagree on the correct value / the truth.
4. The Data Integration Process

- Data Collection
- Schema Mapping
- Data Translation
- Identity Resolution
- Data Quality Assessment
- Data Fusion
4.1 Data Collection

Goal: Resolve technical and data model heterogeneity so that data from all sources can be accessed / gathered and represented in the same data model.

- Using middleware libraries that provide
  - different communication protocols (HTTP, ODBC, …)
  - readers for different data exchange formats (XML, RDF, JSON, …)
  - for querying remote data sources using different query languages (SQL, SPARQL, …)
  - for crawling remote data sources (HTML pages, Web APIs, Linked Data)
  - for translating data between different data models (XML-2-Relational, …)
4.2 Schema Mapping and Data Translation

Goal: Resolve structural and schema-related semantic heterogeneity by
1. finding correspondences between the elements of the different schemata.
2. translate data to a single target schema based on these correspondences.

**Diagram:**

- **ARTICLE**
  - artPK
  - title
  - pages
- **AUTHOR**
  - artFK
  - name

- **PUBLICATION**
  - pubID
  - title
  - date
  - author

**Correspondences:**

- Source Schema
  - Transformed data
- Transformation Query
- Target Data

Example: Defining Correspondences
4.3 Identity Resolution

Goal: Resolve semantic heterogeneity by identifying all records in all data sources that describe the same real-world entity.

- Other names for the task:
  - Duplicate Detection, Record Linkage, Entity Matching

- Basic Approach:
  1. Compare records using a combination of different similarity metrics
  2. If similarity is above threshold → Consider records to describe the same real-world entity

<table>
<thead>
<tr>
<th>CID1243</th>
<th>Chris Miller</th>
<th>12/20/1982</th>
<th>Bardon Street, Melville</th>
<th>32 sales</th>
</tr>
</thead>
<tbody>
<tr>
<td>34</td>
<td>Christian Miller</td>
<td>2/20/1982</td>
<td>7 Bardon St., Melwille</td>
<td>24 sales</td>
</tr>
<tr>
<td>427859</td>
<td>Chris Miller</td>
<td>12/14/1973</td>
<td>7 Bardon St., Madison</td>
<td>13 sales</td>
</tr>
</tbody>
</table>
Example: Combining different Similarity Metrics
4.4 Data Fusion

Goal: Resolve data conflicts by combining attribute values of duplicate records into a single consolidated description of an entity.

- **Basic Approach:**
  1. Assess the quality of data sources / records / values
     - Quality dimensions: timeliness, reputation of source, ...
  2. Apply a conflict resolution function to choose most promising values or to correct values.
     - Example functions: highest estimated quality, voting, average, ...

<table>
<thead>
<tr>
<th></th>
<th>CID1243</th>
<th>12/20/1982</th>
<th>Bardon Street, Melville</th>
<th>32 sales</th>
</tr>
</thead>
<tbody>
<tr>
<td>DB1</td>
<td>Chris Miller</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>34</td>
<td>2/20/1982</td>
<td>7 Bardon St., Melville</td>
<td>24 sales</td>
</tr>
<tr>
<td>DB2</td>
<td>Christian Miller</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Christian Miller</td>
<td>12/20/1982</td>
<td>7 Bardon Street, Melville</td>
<td>56 sales</td>
</tr>
</tbody>
</table>
5. Data Integration Architectures

1. Materialized Integration
   - Integrate sources by bringing the data into a single physical database (data warehouse).

2. Virtual Integration
   - Leave the data at the sources and access it at query time.

3. Numerous intermediate architectures
### Materialized versus Virtual Integration

<table>
<thead>
<tr>
<th></th>
<th>Materialized Integration</th>
<th>Virtual Integration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data currency</td>
<td>Low (regular updates)</td>
<td>High (always current)</td>
</tr>
<tr>
<td>Storage requirements</td>
<td>High (copy all data locally)</td>
<td>Low (data remains in sources)</td>
</tr>
<tr>
<td>Query processing time</td>
<td>Low (local query processing)</td>
<td>High (slow network traffic)</td>
</tr>
<tr>
<td>System Complexity</td>
<td>Low (like normal DB)</td>
<td>High (planning of distributed queries)</td>
</tr>
<tr>
<td>Query Expressiveness</td>
<td>High (like normal DB)</td>
<td>Low (as sources might be restricted)</td>
</tr>
<tr>
<td>Workload on data source</td>
<td>Can be planned</td>
<td>Hard to plan</td>
</tr>
<tr>
<td>Identity Resolution /</td>
<td>possible</td>
<td>not possible (too slow)</td>
</tr>
<tr>
<td>Data Fusion</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- Rule of thumb: Virtual integration not applicable
  - if 5+ data sources need to be joined.
  - identity resolution and data fusion are important.

- The course illustrates data integration technology through the materialized architecture.
Data Integration is AI-Complete.
  • Meaning that completely automated solutions are unlikely.
  • Reasons:
    • System Level: Managing different platforms, distributed query processing
    • Logical reasons: Schema and data heterogeneity
    • Social reasons: Locating relevant data, convincing people to share (data fiefdoms)

Goal 1:
  • Reduce the effort needed to set up an integration application.

Goal 2:
  • Enable the system to perform gracefully with uncertainty (e.g., on the web)
Goal of Data integration: Abstract away the fact that data comes from multiple sources in varying schemata.

The problem occurs everywhere: it’s key to business, science, Web and government.

Goal: reduce the effort involved in integrating.

Architectures range from warehousing to virtual integration.

Regardless of the architecture, bridging heterogeneity is the key issue.
6. Course Outline and Organization
The Lecture

- introduces the principle methods of data integration
- discusses how to evaluate data integration results
- presents practical examples of how the methods are applied

Topics
1. Introduction to Data Integration
2. Structured Data on the Web
3. Web Data Formats
4. Schema Mapping
5. Identity Resolution
6. Data Quality and Data Fusion
The Exercise

- Teams of two students realize a data integration project including
  1. data gathering
  2. schema mapping and data translation
  3. identity resolution
  4. data quality assessment and data fusion
- Teams will use data integration tools and will extend Java projects which implement basic integration methods
- Teams write 12 page report about their project, present project results
- You may choose their own application domain and data sets
  - minimum 4 data sets with a good degree of overlap in attributes and instances
- In addition, we will propose some suitable data sets from the domains of
  - films and actors, products and e-shops, restaurants, geographic information
- Overall grading
  - 50 % written final exam
  - 30 % written project report
  - 20 % presentation of project results
<table>
<thead>
<tr>
<th>Week</th>
<th>Thursday</th>
<th>Friday</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.9.2013</td>
<td>Lecture: Introduction to Web Data Integration</td>
<td>Lecture: Structured Data on the Web</td>
</tr>
<tr>
<td>30.9.2013</td>
<td>Public holiday</td>
<td>Exercise: Feedback about Project Ideas</td>
</tr>
<tr>
<td>7.10.2013</td>
<td>Exercise: Data Translation</td>
<td>Exercise: Data Translation</td>
</tr>
<tr>
<td>28.10.2013</td>
<td>Exercise: Identity Resolution</td>
<td>Public holiday</td>
</tr>
<tr>
<td>4.11.2013</td>
<td>Exercise: Identity Resolution</td>
<td>Lecture: Data Quality and Data Fusion</td>
</tr>
<tr>
<td>11.11.2013</td>
<td>Lecture: Data Quality and Data Fusion</td>
<td>Lecture: Data Quality and Data Fusion</td>
</tr>
<tr>
<td>18.11.2013</td>
<td>Exercise: Data Fusion</td>
<td>Exercise: Data Fusion</td>
</tr>
<tr>
<td>25.11.2013</td>
<td>Exercise: Data Fusion</td>
<td>Exercise: Data Fusion</td>
</tr>
<tr>
<td>2.12.2013</td>
<td>Presentation of project results</td>
<td>Presentation of project results</td>
</tr>
</tbody>
</table>
Course Organization

- **Course Webpage**
  - The lecture slides will be published on this webpage.
  - Project-related material will be provided in ILIAS.

- **Time and Location**
  - Thursday, 13:45 bis 15:15. Building: B6, Room: A 101
  - Friday, 12:00 bis 13:30. Building: B6, Room: A 104
Literature and Credits


2. Ulf Leser, Felix Naumann: Informationsintegration. DBunkt Verlag, 2007. (Several copies in the library, also video lecture by Felix Naumann at http://www.tele-task.de/archive/series/overview/892/)


Credits

The slide set of this lecture builds on slides from:

- Ulf Leser, Felix Naumann
- AnHai Doan, Alon Halevy, Zachary Ives

Lots of thanks to all of you!
1. **Data Translation**
   - Altova MapForce
   - Graphical data mapping and conversion tool

2. **Identity Resolution**
   - We will provide a Java project which implements the basic methods

3. **Data Fusion**
   - We will provide a Java project which implements the basic methods
Questions?