Generic Schema Matching, Ten Years Later

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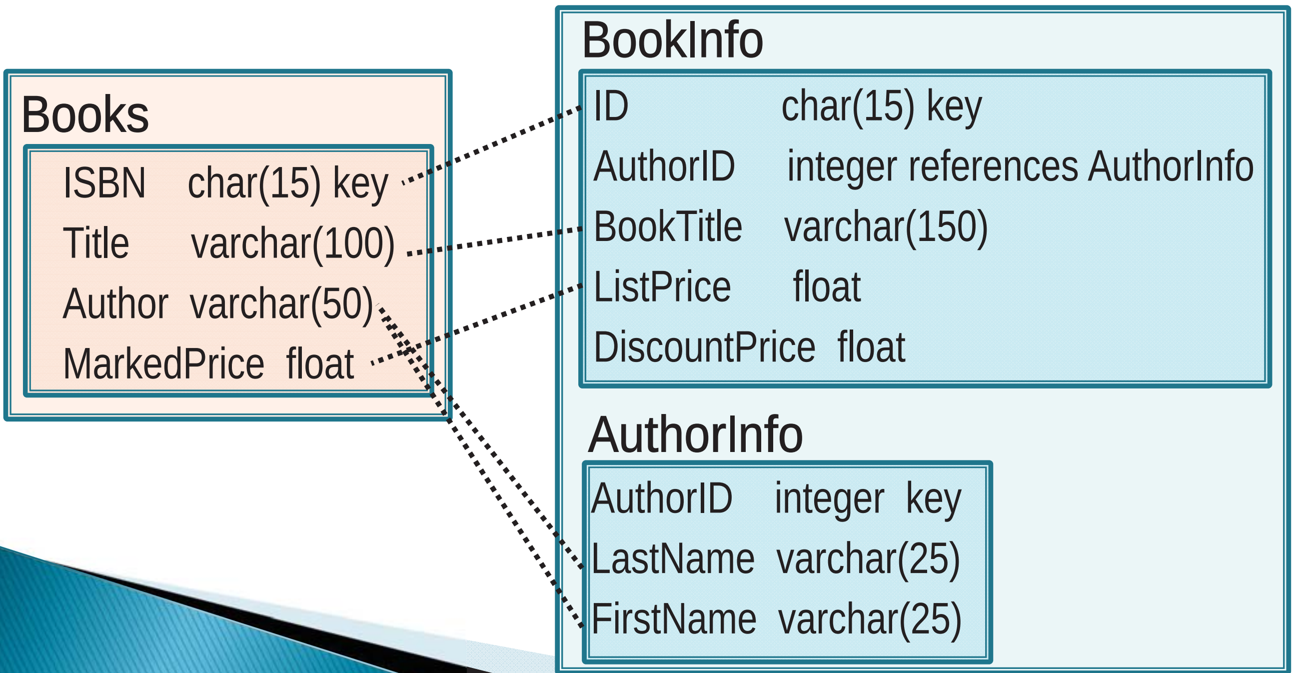
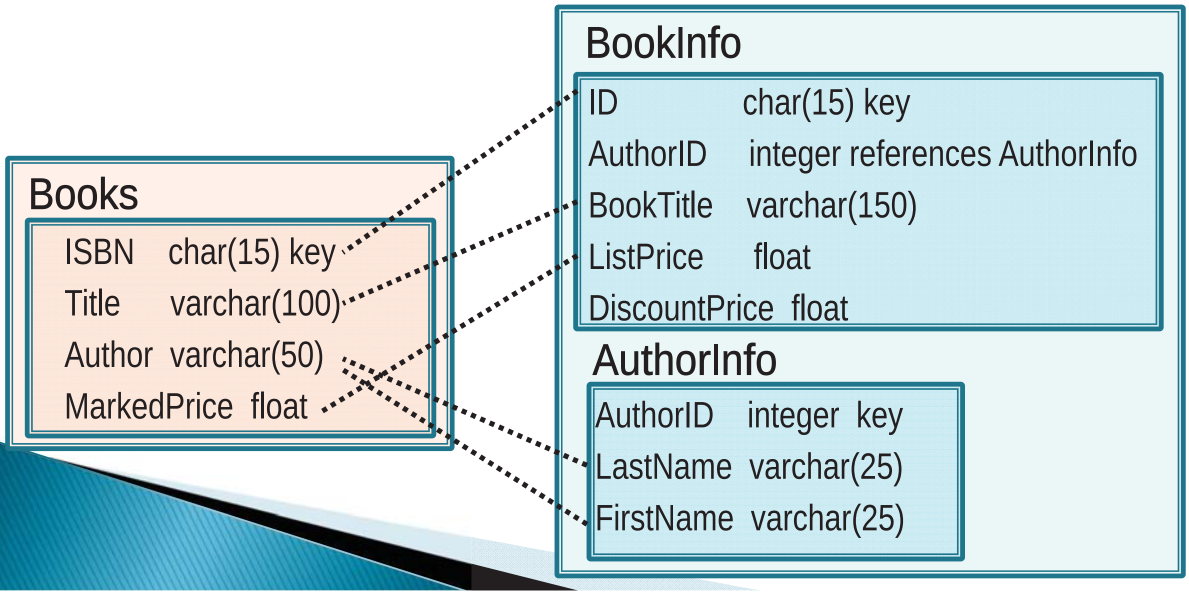
The Schema Matching Problem

- The problem of generating correspondences between elements of two schemas



Basic Inputs to Matching Techniques

- Element names
- Schema structure
- Constraints: data type, keys, nullability



Other Inputs to Basic Matching

- Synonyms
  - Code = Id = Num = No
  - Zip = Postal [code]
  - Node = Server
- Acronyms
  - PO = Purchase Order
  - UOM = Unit of Measure
  - SS# = Social Security Number
- Data instances
  - Elements match if they have similar instances or value distributions

Many Apps Need Correspondences

- Data translation
- Data integration
- ER design tools
- Schema evolution
- Object-to-relational mapping
- XML message translation
- Data warehouse loading (ETL)

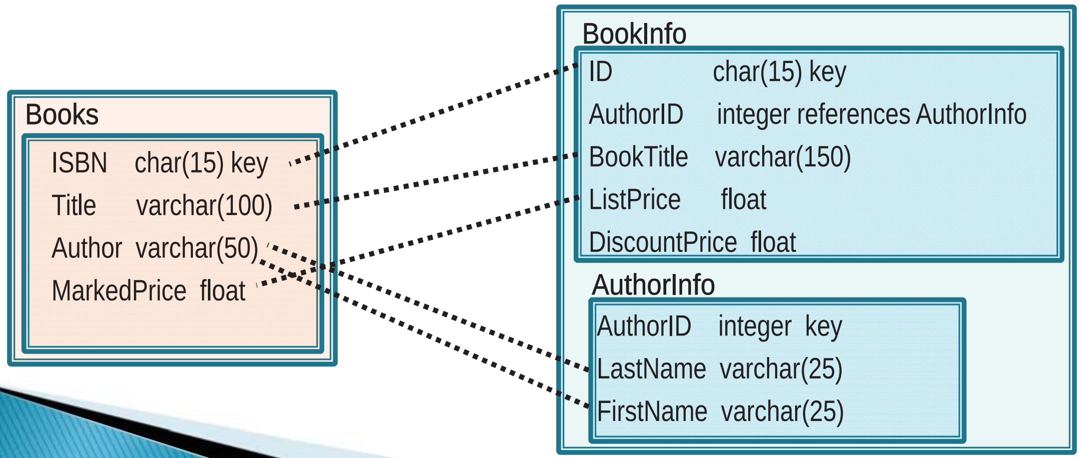
Semantics of Correspondences

- A correspondence is just a relationship, with no semantics
- Correspondences can be directly useful
  - Schema merging, impact analysis, …
- Or they can be semantically enriched
  - Clio project [Miller et al., VLDB 2000]
  - Translate correspondences into constraints on instances
  - Then translate constraints into an executable mapping

Example

$$\pi_{\text{ISBN,Title,MarkedPrice}}(\text{Books}) = \pi_{\text{ID,BookTitle,ListPrice}}(\text{BookInfo})$$

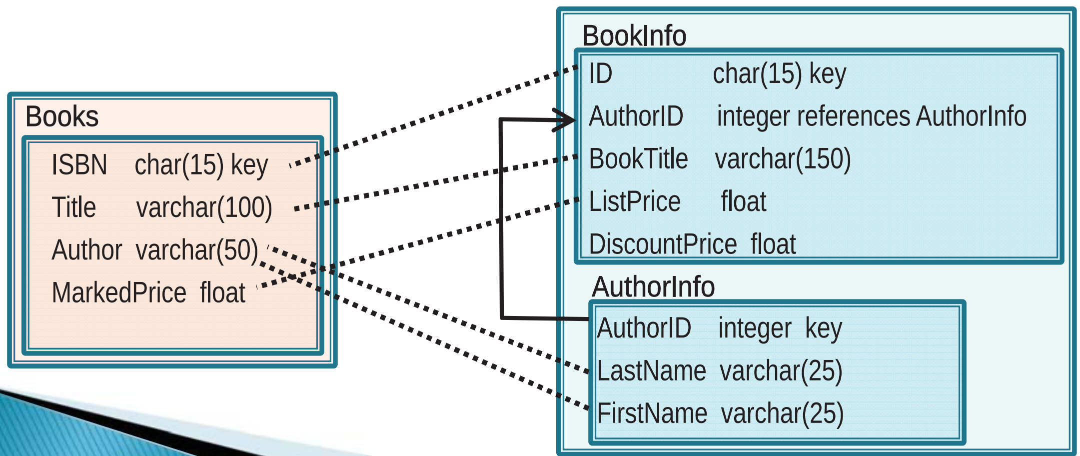
$$\pi_{\text{Author}}(\text{Books}) = \pi_{\text{FirstName+LastName}}(\text{AuthorInfo})$$



Example (continued)

Books

$$= \pi_{\text{ID, BookTitle, FirstName+LastName, ListPrice}}(\text{BookInfo} \bowtie \text{AuthorInfo})$$



History

- 1994–98, I worked on Microsoft Repository
  - [Bernstein et al, "The Microsoft Repository," VLDB 1997]
- I talked to many tool developers
  - They were all working with models of software artifacts and mappings between them
- This led me to propose Model Management
  - Bulk operators to manipulate models & mappings
  - Match, Merge, Diff, Compose, Invert, ModelGen, …
  - [Bernstein, Halevy, Pottinger, SIGMOD Record '00]

Model Management Scenarios

- They're all multi-step
  - The first step usually generates a mapping: S–map–T
  - Then merge(S,T), diff(S,T), compose(S′–map–S, S–map–T)
- So the Match operator was the place to start.
  - Survey the literature
  - Develop new match algorithms
- We found existing work on schema matching was embedded in other multi-step solutions

Schema Matching is an Independent Problem

- It was one of our contributions
- There are now hundreds of papers on the topic
- The problem can't be solved perfectly because
  - It depends on the available information
  - It depends on the required accuracy
  - It depends on the application and usage scenario
- So it's no wonder our paper is highly cited!

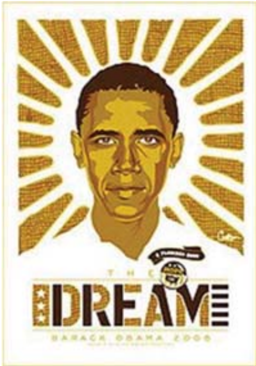
Outline

✓ Problem definition

✓ History – what led us to the problem

- Summary of our 2001 paper (Jayant Madhavan)
- Approaches since 2001 & Future trends

  (Erhard Rahm)



boo.com

Startups.com

pets.com because pets can't drive

GeoCities HOME PAGES & BEYOND

Goals and Contributions

- Our original goals
  - Introduce schema matching as an independent problem and independent component
  - Provide a credible candidate algorithm and implementation as a basis for future work
  - Generic: independent of data model and target application
- Our contributions
  - Taxonomy of schema matching algorithms
  - Schema-based hybrid matching algorithm
  - Evaluation that compared multiple approaches

Cupid overview

Schema-based hybrid matching algorithm

- Combines multiple approaches that use only schema (no instances)

Input: Two schema graphs

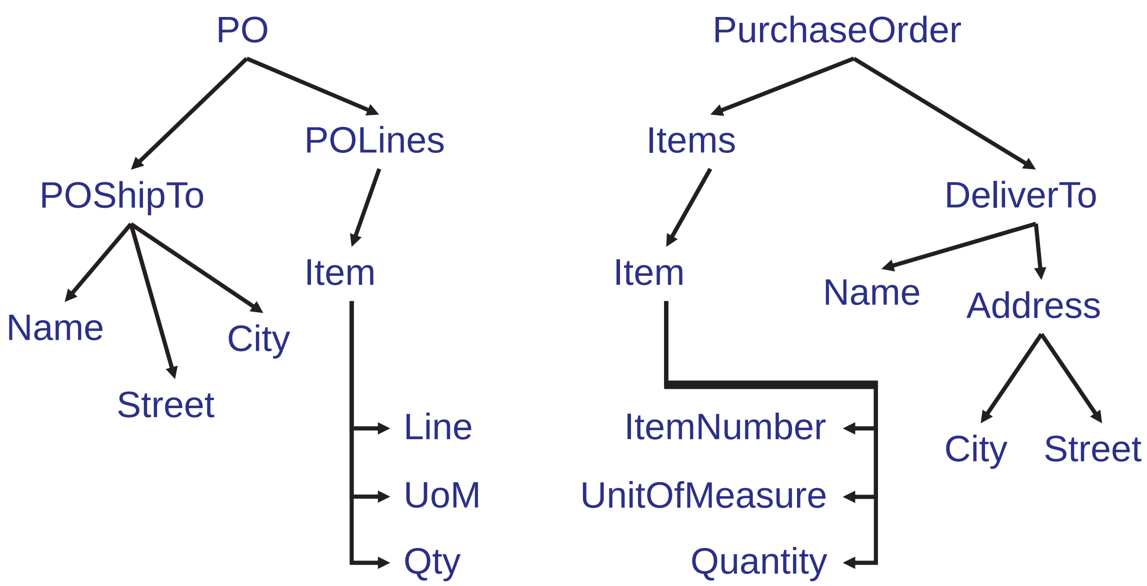
Output: Similarity matrix and candidate mapping

- Linguistic matching: compare elements based on names
- Structure matching: compare elements based on relationships

$$Wsim = w * Lsim + (1 – w) * Ssim$$

- Not the first to propose either linguistic or structure matching

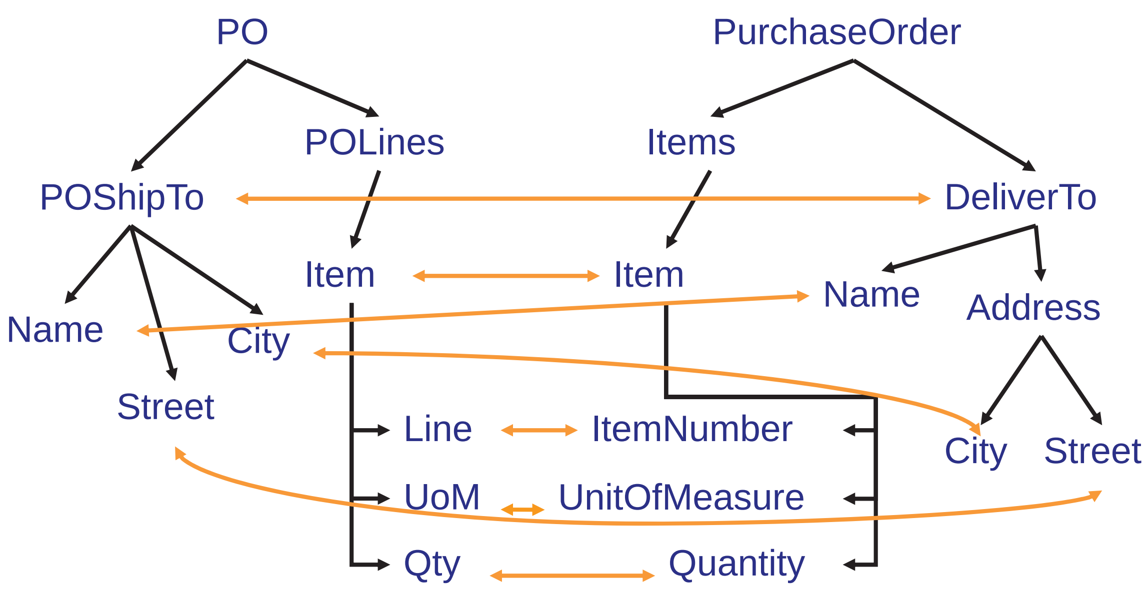
Example from VLDB’01



Linguistic Matching

- Tokenization of names
  - PurchaseOrder → purchase + order
- Expansion of acronyms
  - UOM → unit + of + measure
- Clustering based on keywords and data-types
  - Street, City, POAddress → Address
- Linguistic similarity
  - Pair-wise comparison of elements that belong to the same cluster
  - Token similarity = f(string matching, synonymy score)
  - Token set similarity = average (best matching token similarity)
- Thesaurus: acronymns, synonyms, stop words and categories

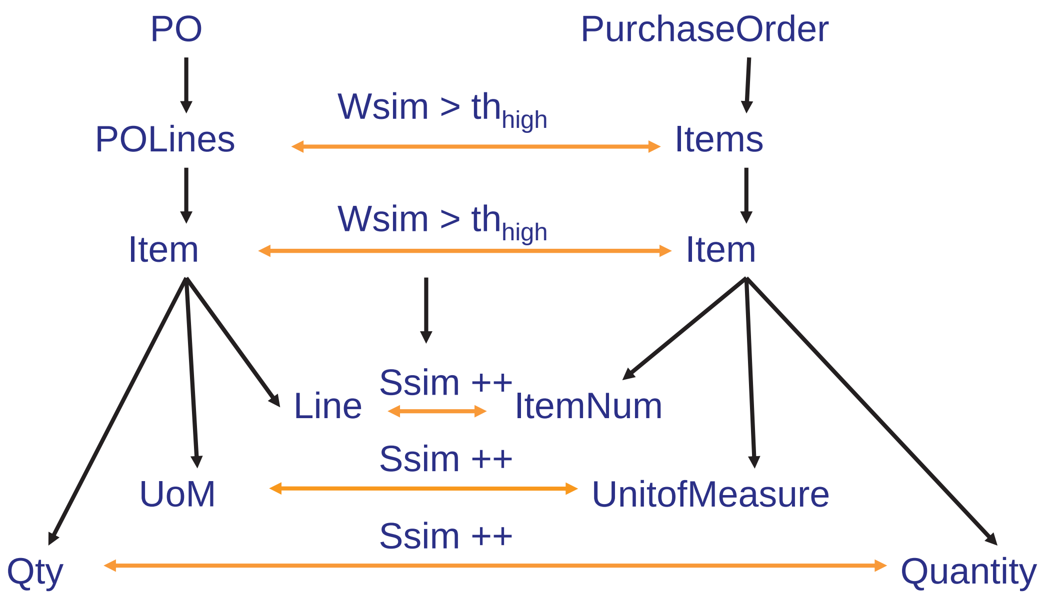
Structure Matching



Tree Match Algorithm

- Atomic elements (leaves) are similar
  - Linguistically and data-type similar
  - Their contexts, i.e., ancestors, are similar
- Compound elements (non-leaves) are similar if
  - Linguistically similar
  - Elements in their context, i.e., subtrees rooted at the elements, are similar
- Mutually dependent formulation
  - Leaves determine internal node similarity
  - Similarity of internal nodes leads to increase in leaf similarity
- Bottom-up traversal of trees

Tree Match: Mutually Reinforcing Similarity



Extensions for shared types, referential integrity, views, etc.

Evaluation

- Cupid compared with MOMIS/ARTEMIS @ Modena/Milano, DIKE @Calabria
- Canonical tasks and real world examples

Technical conclusions

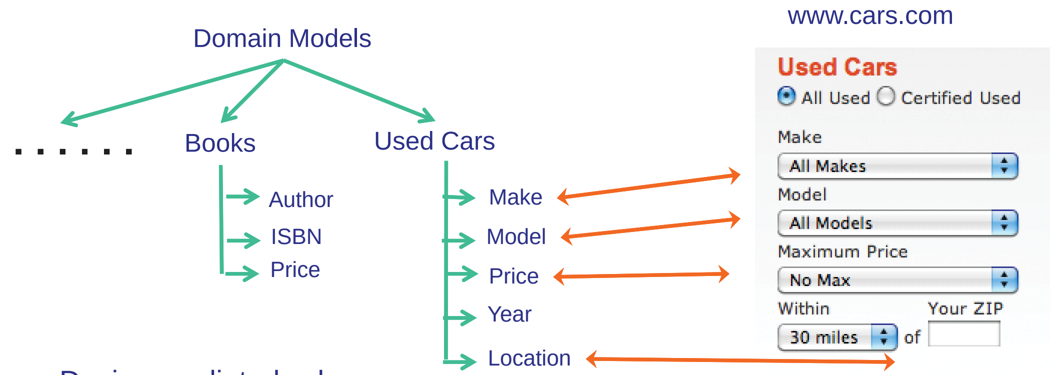
- Linguistic matching with attention to detail does help
- Structure matching can identify non-linguistic matches
- Structure matching can disambiguate between seemingly identical structures in different contexts
- Ability to match across relational schemas, XML variants, possibly others

What we learned?

- Schema Matching Taxonomy
  - Provided a framework to describe future solutions and place them in comparison to other work
- Quantitative evaluation
  - Set a precedent for future papers
  - Very thankful to MOMIS/ARTEMIS and DIKE teams
- Making software available helps a lot
  - Possible even when developed in industry
  - We get requests for software even to this day

Follow up Techniques

- Using schema matching results as is: possible when matches only contribute implicitly end-user task
- For example, building a deep-web crawler [Madhavan+, VLDB'08]

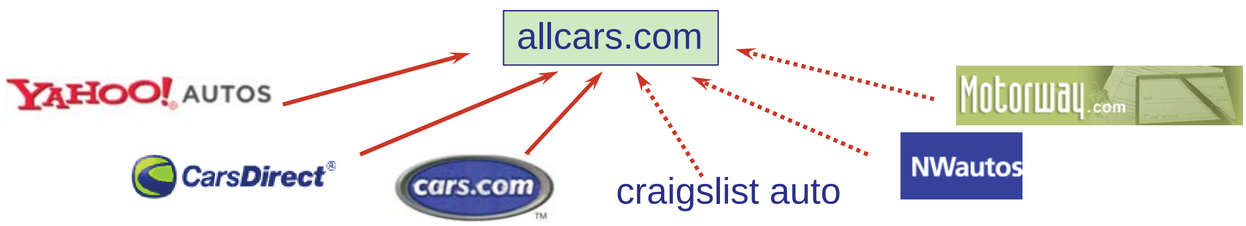


  - Design mediated schema
  - Extract schemas of web forms
  - Match web forms to mediated schemas
  - Generate URLs for interesting subset of form submissions
  - Add generated pages to the corpus of indexed pages

Collective Schema Matching

Schema matching is almost never an isolated task

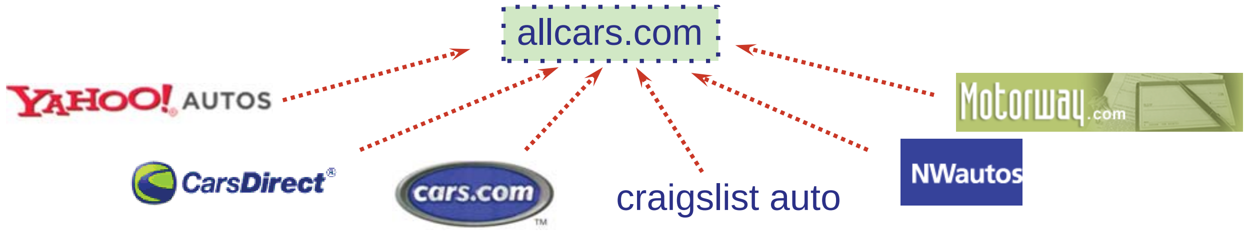
It ought to get easier over time!



- [Doan+, SIGMOD'01]: Learn to match sources to a mediated schema

- [Do+, ICDE'02]: Compose known matches to discover new ones

Collective Schema Matching



- [He+, SIGMOD'03]: Build mediated schema for a domain by clustering elements in multiple schemas

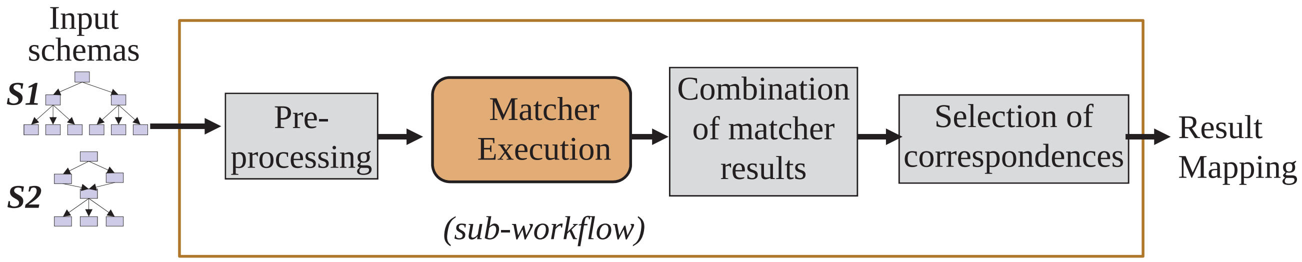
- [Madhavan+, ICDE'05]: Learn to map between new schemas based on other schemas and mappings in the same domain

Progress in many areas

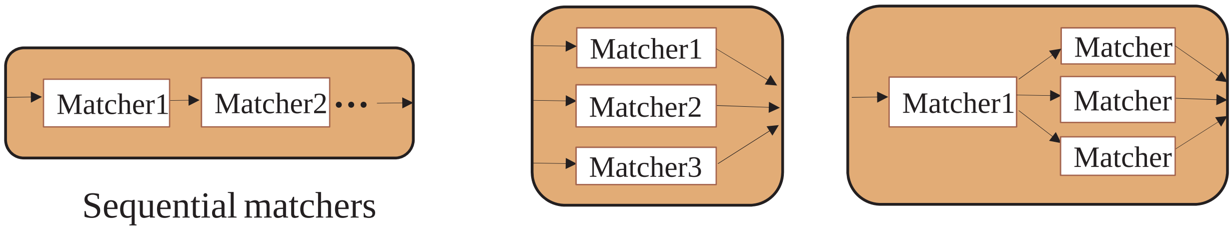
- Match workflows
- New match techniques
- User interaction for Match
- Semantic matching
- Match techniques for large schemas
- Self-tuning match workflows
- Reuse-oriented matching
- Holistic (collective) schema matching
- Numerous match prototypes
- Evaluation of match tools
- Commercial tools

Schema matching is a multi-step process

General workflow (COMA, …)



Matcher sub-workflows



Sequential matchers

Parallel (independent) matchers

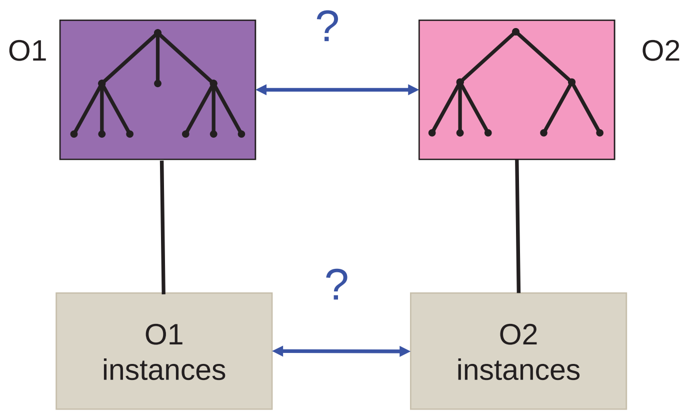
Mixed strategy

New match techniques

- Graph matching
  - e.g., similarity flooding [Melnik et al, ICDE 2002]
- Instance-based ontology matching
  - concepts with similar instances should match
  - consider all instances of a concept as a document and utilize document similarity (e.g., TF/IDF) to find matching concepts
- Usage-based matching
  - utilize query logs for hints about related schema elements (e.g., in join clauses) [Elmeleegy et al., ICDE 2008]
  - Hamster approach for taxonomy matching [Nandi et al, VLDB 2009]

Instance-based ontology matching

- Concepts with most similar instances should match
  - requires shared/similar instances for most concepts
- Mutual treatment of entity resolution (instance matching) and ontology matching
- Promising for link discovery in the Linked Open Web of Data



User interaction for Match

- GUI support to inspect and correct computed correspondences [Falconer et al., ISWC 2007]

- Incremental schema matching [Bernstein et al., VLDB 2006]
  - focused matching on user-selected element / subtree

- Provision of top-k matches per element for selection

  [Gal, J Data Semantics 2006]

- Collaborative schema matching using a wiki-like infrastructure to provide and improve mappings

  [McCann et al., ICDE 2008]

Semantic matching

- Correspondences with semantic relationships
  equality, more general, less general, disjointness
  - ✓e.g. *PortableComputers* $\sqsupseteq$ *Tablets*
  - S-Match [Giunchiglia et al, ESWC 2004]

- Discovery of mapping expressions
  - ✓e.g., *room-price = room-rate * (1 + tax-rate)*
  - iMAP [Dhamankar et al., SIGMOD 2004]

- Conditional correspondences [Bohannon et al., VLDB 2006]
  - ✓e.g., *if productType = "book"*
    then S1.Invoice.Code =S2.ISBN

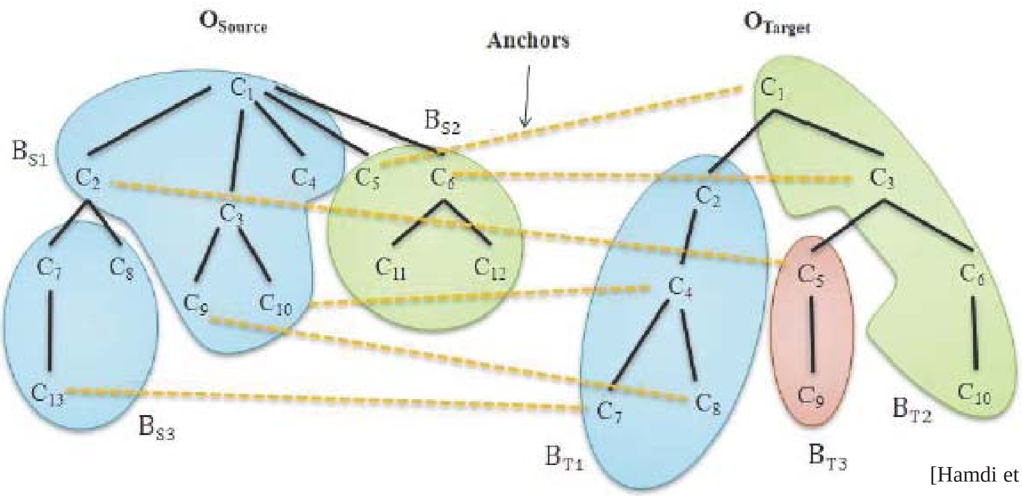
Match techniques for large schemas

- Low-level optimizations
  - Optimized string matching
  - Space-efficient similarity matrices
  - Database-based matching

- Parallel matching
  - Inter-matcher and intra-matcher parallelism

- Partition-based matching (COMA++, Falcon-AO)
  - Reduced search space by matching only similar schema partitions/fragments
  - Light-weight search for similar schema fragments

Partition-based matching in FALCON-AO



[Hamdi et al, 2009]

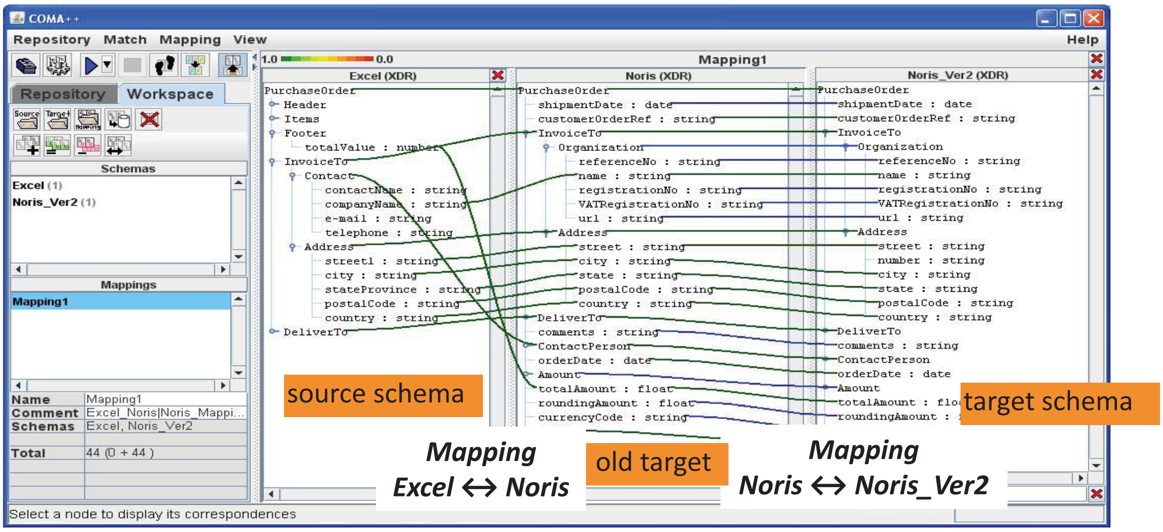
- Initially determine highly similar element pairs called "anchors"
- Only partitions that share at least one anchor are matched

Self-tuning match workflows

- Semi-automatic configuration
  - Selection of promising matchers
  - Ordering of different matchers
  - Combination of match results
  - Selection of correspondences (top-k, threshold, …)
- Initial tuning frameworks: Apfel, eTuner, YAM
- Use of supervised machine learning
  - need previously solved match problems for training
  - difficult to support large schemas
- Heuristic approaches
  - Use linguistic and structural similarity of input schemas to select matchers and their weights (RiMOM)
  - Favor matchers giving higher similarity values in the combination of matcher results (QOM, PRIOR+, OpenII)

Reuse-oriented Matching

- Many similar match tasks → reuse previous matches
  - Schema and mapping repository needed
- Example: reuse match results after schema evolution
  - compose previous match result S—T with mapping T–T’ to solve new match task S—T’



Reuse-oriented Matching (2)

- First proposals for reuse at 3 mapping granularities
  - Reuse complete schema mappings, e.g. after schema evolution
  - Reuse individual element correspondences, e.g. synonyms
  - Reuse mappings between schema fragments
- Fragment-level reuse most sophisticated
  - Populate repository by most relevant fragments and their mappings
  - Analyze schemas to be matched for fragment pairs in the repository
  - Assemble and complement fragment mappings

Holistic (collective) schema matching

- Matching between N schemas, e.g. web forms
  - mostly simple schemas
- Typical use case: creation of a mediated schema

- Holistic matching based on clustering of similar attributes (Wise-Integrator, DCM, HSM, …)
  - utilize high name similarity between schemas
  - similar names within a schema are mismatches

- Probabilistic mediated schemas
  [Das Sarma et al., SIGMOD 2008]
  - Ranking of several clustering alternatives based on probabilistic mappings
  - Fully automatic approach

Research match prototypes

Benchmarking Initiative OAEI*

- Yearly ontology matching contests since 2005
- Up to 17 participating systems per year
- Simple tests (Benchmark) and larger test cases (Anatomy, Directory)
- Improvements for Benchmark and Anatomy, but not for Directory

System	2007	2008	2009	2010
AFlood		√	√	
AgrMaker	√		+	+
AROMA		√	√	
AOAS	+			
ASMOV	√	√	√	√
BLOOMS				+
CODI				√
DSSim	√	√	√	
Ef2Match				+
Falcon AO	√			
GeRMeSMB				√
Kosimap			√	
Lily	√	√	√	
NBJLM				+
Prior+	√			
RiMOM	√	+	√	
SAMBO	+	+		
SOBOM			+	+
TaxoMap	√	√	√	+
X SOM	√			
Avg. F-measure	0.598	0.718	0.764	0.785

[Euzenat et al, OM 2010]

Anatomy test case

- Ontology Alignment Evaluation Initiative, http://oaei.ontologymatching.org

Match Prototype Comparison*

		Cupid	COMA++	Falcon	Rimom	Asmov	Agr.Maker	OII Harmony
year of introduction		2001	2002/2005	2006	2006	2007	2007	2008
Input	*relational*	√	√	-	-	-	-	√
schemas	*XML*	√	√	-	-	-	(√)	√
	ontologies	-	√	√	√	√	√	√
OAEI participation		-	√	√	√	√	√	-
compreh. GUI		-	√	(√)	?	?	√	√
Matchers	*linguistic*	√	√	√	√	√	√	√
	structure	√	√	√	√	√	√	√
	Instance	-	√	-	√	√	√	-
use of ext.dictionaries		√	√	?	√	√	√	√
schema partitioning		-	√	√	-	-	-	-
parallel matching		-	-	-	-	-	-	-
dyn. matcher selection		-	-	-	√	-	-	-
mapping reuse		-	√	-	-	-	-	-

**Rahm, E.: Towards large-scale schema and ontology matching. In: Schema Matching and Mapping, Springer-Verlag, 2011*

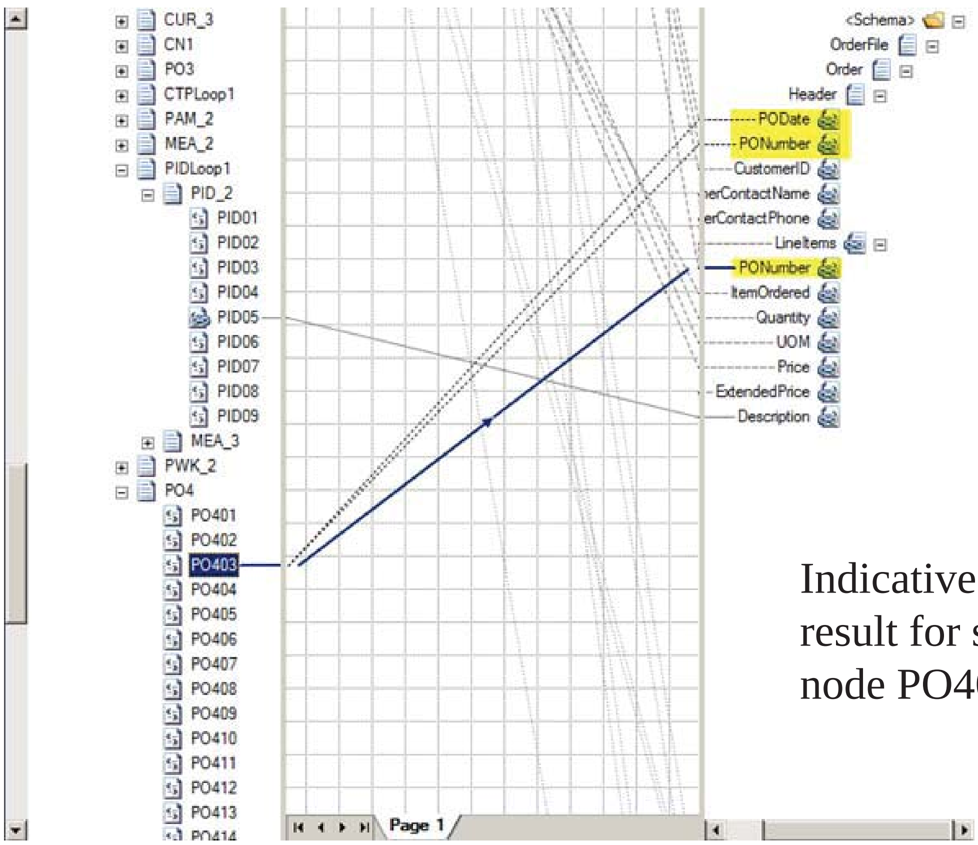
Commercial schema matching tools

- Many GUI-based mapping editors to manually specify correspondences and mappings

- Initial support for automatic matching, in partiular linguistic matching
  - Altova MapForce
  - MS BizTalk Server 2010
  - SAP Netweaver
  - IBM Infosphere

- Many further improvements possible
  - Structural / instance-based matching
  - Advanced techniques for large schemas

BizTalk 2010 Screenshot



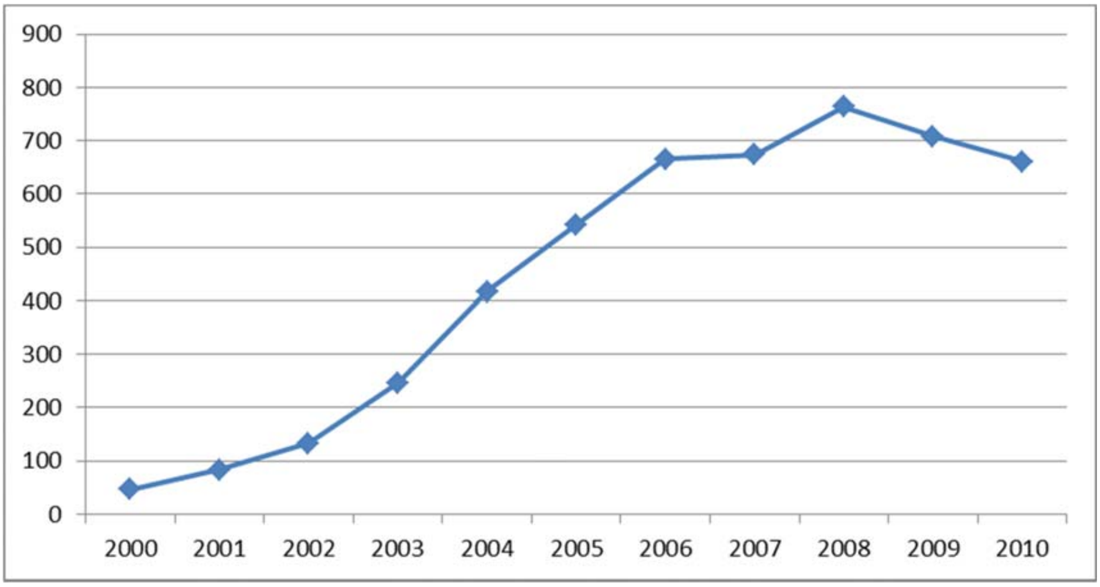
Indicative match result for selected node PO403

Books

Google Scholar: Paper counts

more than 5000 publications for keyword “schema matching” since year 2000

Pubs per year



Remaining research challenges (1)

- Joint treatment of entity resolution and schema matching, e.g. for Linked Data
- More comprehensive mapping reuse
- Self-Tuning
- Improvements for
  - user interaction
  - Large-scale schema matching
  - Semantic matching
  - Holistic/collective schema matching …

Remaining research challenges (2)

- Fully automatic schema matching for web applications
- More match-based approaches for
  - Ontology/schema merging
  - Ontology/schema evolution
  - …