UNIVERSITÀ DEGLI STUDI DI TRENTO

SCHEMA-BASED SEMANTIC MATCHING

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joint work on “semantic matching” with
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1st European Semantic Technology Conference (ESTC’07), Semantic Web Technology Showcase

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knowledgeweb

Outline

- Part I: The matching problem
- Part II: State of the art in ontology matching
- Part III: Schema-based semantic matching
- Part IV: Evaluation (technology showcase)
- Part V: Conclusions

Outline

- Part I: The matching problem
  - Problem statement
  - Applications
- Part II: State of the art in ontology matching
- Part III: Schema-based semantic matching
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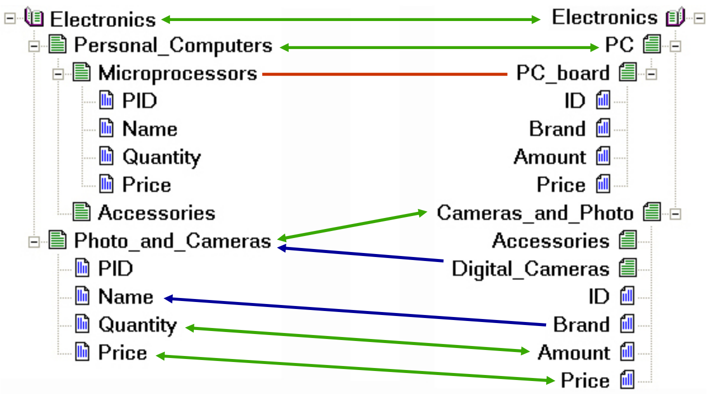
Matching operation

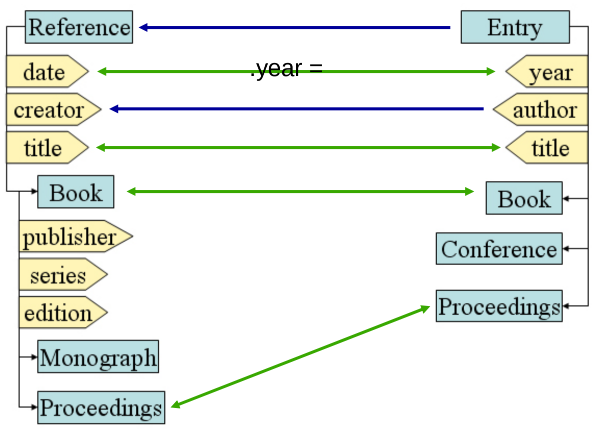
Matching operation takes as input ontologies, each consisting of a set of discrete entities (e.g., tables, XML elements, classes, properties) and determines as output the relationships (e.g., equivalence, subsumption) holding between these entities

Example: two XML schemas



Equivalence   Generality   Disjointness

Example: two ontologies



Equivalence   Generality   Disjointness

Statement of the problem

Scope

- Reducing heterogeneity can be performed in two steps:
  - Match, thereby determine the alignment
  - Process the alignment (merge, transform, translate...)

Statement of the problem

Correspondence is a 5-tuple *<id, e1, e2, R, n>*

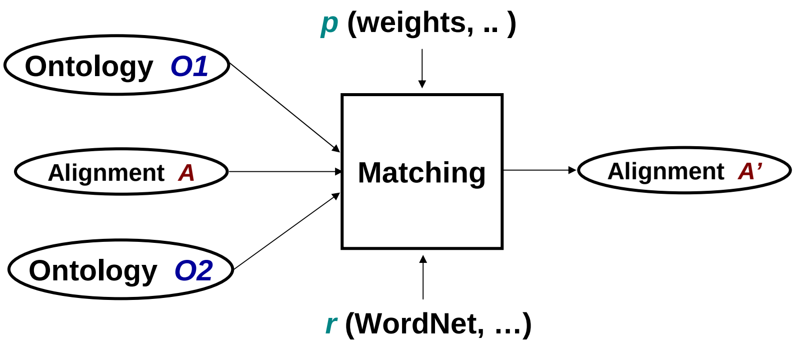
- *id* is a unique identifier of the given correspondence
- *e1* and *e2* are entities (XML elements, classes,...)
- *R* is a relation (equivalence, more general, disjointness,...)
- *n* is a confidence measure, typically in the [0,1] range

Alignment (A) is a set of correspondences

- with some cardinality: 1-1, 1-n, ...
- some other properties (complete)

Statement of the problem

Matching process

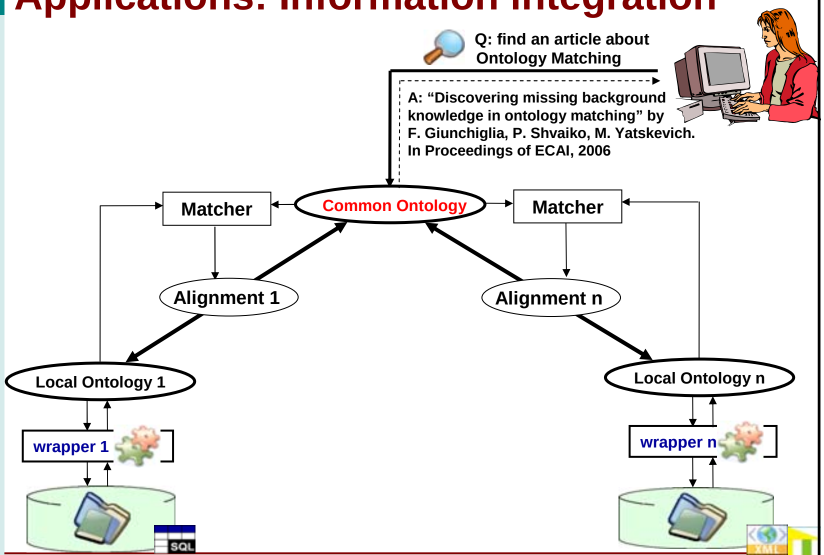


Applications

Traditional
- Ontology evolution
- Schema integration
- Catalog integration
- Data integration

Emergent
- P2P information sharing
- Web service composition
- Agent communication
- Query answering on the web

Applications: Information integration



Applications: summary

Application	instances	run time	automatic	correct	complete	operation
Ontology evolution	√			√	√	transformation
Schema integration	√			√	√	merging
Catalog integration	√			√	√	data translation
Data integration	√			√	√	query answering
P2P information sharing		√				query answering
Web service composition		√	√	√		data mediation
Multi-agent communication		√	√	√	√	data translation
Query answering	√	√		√		query reformulation

Outline

- Part I: The matching problem
- Part II: State of the art in ontology matching
  - Classification of matching techniques
  - Overview of matching systems
- Part III: Schema-based semantic matching
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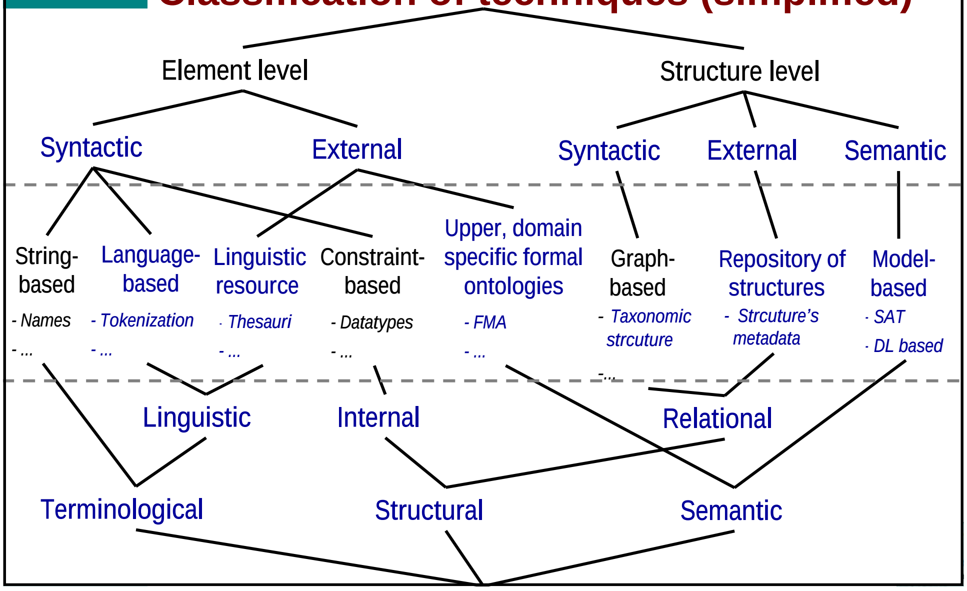
Classification of basic techniques

Three layers

- The upper layer
  - Granularity of match
  - Interpretation of the input information
- The middle layer represents classes of elementary (basic) matching techniques
- The lower layer is based on the kind of input which is used by elementary matching techniques

Classification of techniques (simplified)



Basic techniques

String-based

- **Edit distance**
  - **It takes as input two strings and calculates the number of *insertions*, *deletions*, and *substitutions* of characters required to transform one string into another, normalized by *max(length(string1), length(string2))***
  - **EditDistance(NKN,Nikon) = 0.4**

Basic techniques (cont'd)

Linguistic resources: WordNet

It computes relations between ontology entities by using (lexical) relationships of WordNet

- $A \subseteq B$ if A is a **hyponym** or **meronym** of B
  - Brand $\subseteq$ Name
- $A \supseteq B$ if A is a **hypernym** or **holonym** of B
  - Europe $\supseteq$ Greece
- $A = B$ if they are **synonyms**
  - Quantity = Amount
- $A \perp B$ if they are **antonyms** or **siblings in part of** hierarchy
  - Microprocessors $\perp$ PC Board

Systems: analytical comparison

~50 matching systems exist, …we consider some of them

		SF	Artemis	Cupid	COMA	Prompt	OLA	S-Match
Element-level	Syntactic	string-based, data types, key properties	domain compatibility, language-based	string-based, language-based, data types, key properties	string-based language-based, data types	string-based, domains and ranges	string-based, data types, language-based	string-based, language-based
Element-level	External	-	common thesaurus (CT)	auxiliary dictionary	auxiliary dictionary	-	WordNet	WordNet
Structure-level	Syntactic	iterative fix-point computation	matching of neighbors via CT	tree matching weighted by leaves	DAG (tree) matching with a bias towards leaf or children structures	bounded path matching (arbitrary links, *is-a* links)	iterative fix-point computation, matching of neighbors	-
Structure-level	Semantic	-	-	-	-	-	-	SAT

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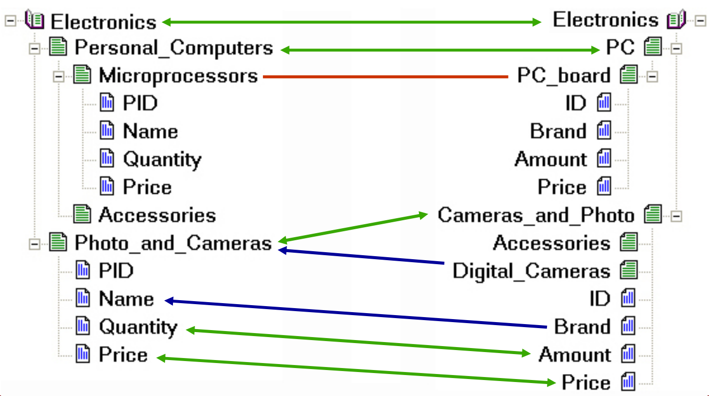
Generic matching

Information sources (classifications, XML schemas, …) can be viewed as **graph-like** structures containing terms and their inter-relationships

Matching takes two graph-like structures and produces **correspondences** between the nodes of the graphs that are supposed to correspond to each other



Semantic matching in a nutshell

Semantic matching: Given two graphs *G1* and *G2*, for any node $n1_i \in G1$, find the strongest semantic relation *R'* holding with node $n2_j \in G2$

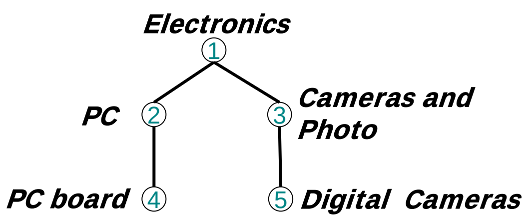
Computed *R's*, listed in the decreasing binding strength order:

- equivalence { = }
- more general/specific { ⊒ , ⊑ }
- disjointness { ⊥ }
- I don't know {idk}

We compute semantic relations by analyzing the ***meaning*** ***(concepts, not labels)*** which is codified in the elements and the structures of ontologies

Technically, labels at nodes written in natural language are translated into propositional logical formulas which explicitly codify the labels' intended meaning. This allows us to codify the matching problem into a propositional validity problem

Concept of a label & concept at a node



Concept of a label is the propositional formula which stands for the set of documents that one would classify under a **label** it encodes

Concept at a node is the propositional formula which represents the set of documents which one would classify under a node, given that it has a certain **label** and that it is in a certain **position** in a tree

Four macro steps

Given two labeled trees T1 and T2, do:

1. For all labels in T1 and T2 compute ***concepts at labels***
2. For all nodes in T1 and T2 compute ***concepts at nodes***
3. For all pairs of labels in T1 and T2 compute **relations between concepts at labels** (background knowledge)
4. For all pairs of nodes in T1 and T2 compute **relations between concepts at nodes**

Steps 1 and 2 constitute the preprocessing phase, and are executed once and each time after the ontology is changed **(OFF- LINE part)**

Steps 3 and 4 constitute the matching phase, and are executed every time two ontologies are to be matched **(ON - LINE part)**

Step 1: compute concepts at labels

The idea

- Translate labels at nodes written in natural language into propositional logical formulas which explicitly codify the labels' intended meaning

Preprocessing

- **Tokenization.** Labels (according to punctuation, spaces, etc.) are parsed into tokens. E.g., Photo and Cameras → <Photo, and, Cameras>
- **Lemmatization.** Tokens are morphologically analyzed in order to find all their possible basic forms. E.g., Cameras → Camera
- **Building atomic concepts.** An oracle (WordNet) is used to extract senses of lemmas. E.g., Camera has 2 senses
- **Building complex concepts.** Prepositions, conjunctions are translated into logical connectives and used to build complex concepts out of the atomic concepts

  E.g., $C_{Cameras\_and\_Photo} = \langle Cameras, \{WN_{Camera}\}\rangle \sqcup \langle Photo, \{WN_{Photo}\}\rangle$

Step 2: compute concepts at nodes

The idea

Extend concepts at labels by capturing the knowledge residing in a structure of a tree in order to define a context in which the given concept at a label occurs

Computation

Concept at a node for some node *n* is computed as a conjunction of concepts at labels located above the given node, including the node itself

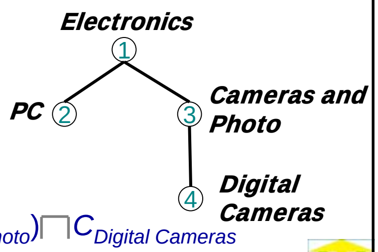
Two types of concepts of nodes

Conjunctive

$C_2 = C_{Electronics} \sqcap C_{PC}$

Disjunctive

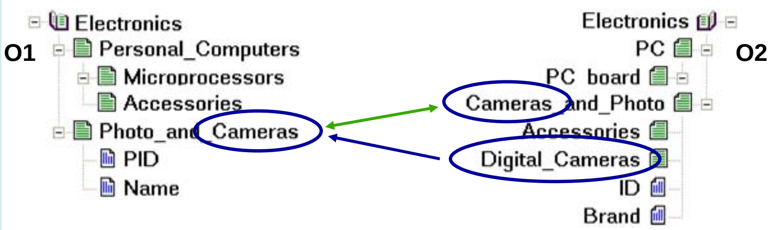
$C_4 = C_{Electronics} \sqcap (C_{Cameras} \sqcup C_{Photo}) \sqcap C_{Digital\ Cameras}$



Step 3: compute relations between (atomic) concepts at labels

The idea

- Exploit a priori knowledge, e.g., lexical, domain knowledge, with the help of element level semantic matchers



cLabsMatrix (result of Step 3)

	$Cameras_2$	$Photo_2$	$Digital\_Cameras_2$
$Photo_1$	*idk*	=	*idk*
$Cameras_1$	=	*idk*	⊒

Step 3:
Element level semantic matchers

Sense-based matchers have two WordNet senses in input and produce semantic relations exploiting (direct) lexical relations of WordNet

String-based matchers have two labels in input and produce semantic relations exploiting string comparison techniques

Matcher name	Execution order	Approximation level	Matcher type	Schema info
WordNet	1	1	Sense-based	WordNet senses
Prefix	2	2	String-based	Labels
Suffix	3	2	String-based	Labels
Edit distance	4	2	String-based	Labels
Ngram	5	2	String-based	Labels

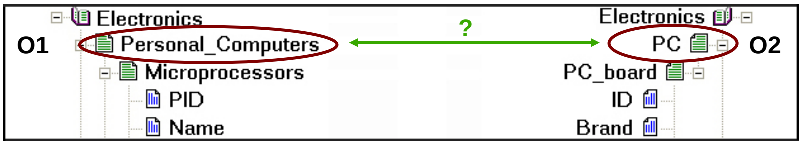
Step 4: compute relations between concepts at nodes

The idea

- Decompose the tree matching problem into the set of node matching problems
- Translate each node matching problem, namely pairs of nodes with possible relations between them, into a propositional formula
- Check the propositional formula for validity

Step 4: Example of a node matching task

Axioms $\rightarrow$ *rel(context$_1$, context$_2$)*



Axioms

$$\underbrace{(Electronics_1 \leftrightarrow Electronics_2) \wedge (Personal\_Computers_1 \leftrightarrow PC_2)}_{Axioms} \rightarrow$$

$$\underbrace{(Electronics_1 \wedge Personal\_Computers_1)}_{context_1} \leftrightarrow \underbrace{(Electronics_2 \wedge PC_2)}_{context_2}$$

Step 4: Efficient semantic matching

Conjunctive concepts at nodes

- Matching formula is Horn
  - Satisfiability can be determined in linear time
  - SAT solver requires quadratic time
- We developed ad hoc linear time reasoning procedure
  - Avoid conversion to propositional formula
  - Reason on the axioms matrix

Disjunctive concepts at nodes

- Matching formula is not in CNF by construction
  - Most SAT solvers require the input formula to be in CNF
  - Conversion to CNF may lead to exponential space explosion
- Exploit structure preserving transformation
  - Size of formula in CNF is linear with respect to original formula

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Motivation: Problem of low recall (incompletness) - I

Facts

- Matching (usually) has two components: element level matching and structure level matching
- Contrarily to many other systems, the semantic matching structure level algorithm is correct and complete
- Still, the quality of results is not very good

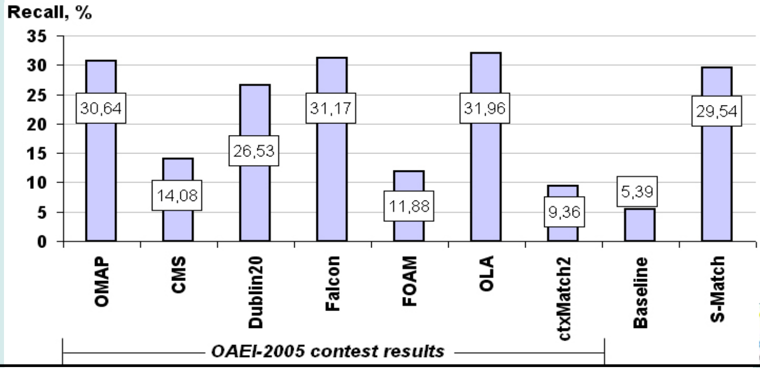
Why? ... the problem of lack of knowledge

Motivation:
Problem of low recall (incompleteness) - II

Preliminary (analytical) evaluation

Matching tasks	#nodes	max depth	#labels per tree
Google vs Looksmart	706/1081	11/16	1048/1715
Google vs Yahoo	561/665	11/11	722/945
Yahoo vs Looksmart	74/140	8/10	101/222

Dataset
[P. Avesani et al., ISWC'05]



On increasing the recall: an overview

Multiple strategies

- Strengthen element level matchers
- Reuse of previous match results from the same domain of interest
  - PO = Purchase Order
- Use general knowledge sources (unlikely to help)
  - WWW
- Use, if available (!), domain specific sources of knowledge
  - UMLS, FMA

Iterative semantic matching (ISM)

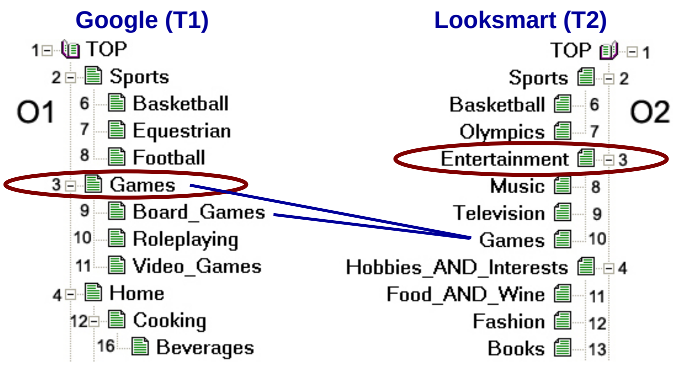
The idea

Repeat ***Step 3*** and ***Step 4*** of the matching algorithm for some **critical** (hard) matching tasks

ISM macro steps

- Discover ***critical points*** in the matching process
- Generate candidate ***missing axiom(s)***
- Re-run SAT solver on a critical task taking into account the new axiom(s)
- If SAT returns **false**, save the newly discovered axiom(s) for future reuse

ISM: Discovering critical points - example



cLabsMatrix (result of Step 3)

	TOP_1	$Games_1$	$Board\_Games_1$
TOP_2	=	*idk*	*idk*
$Entertainment_2$	*idk*	~~*idk*~~	*idk*
$Games_2$	*idk*	=	⊒

cNodesMatrix (result of Step 4)

	$C1_1$	$C1_2$	$C1_3$	$C1_4$	$C1_9$	$C1_{10}$	$C1_{11}$
$C2_1$	=	⊒	⊒	⊒	⊒	⊒	⊒
$C2_3$	⊑	*idk*	~~*idk*~~	*idk*	*idk*	*idk*	*idk*

ISM:
Generating candidate axioms

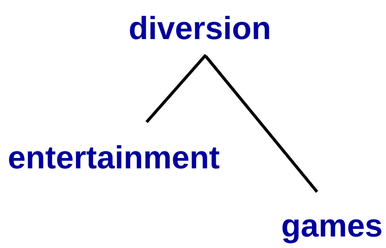
- ***Sense-based* matchers** have two WordNet senses in input and produce semantic relations exploiting structural properties of WordNet hierarchies
  - Hierarchy Distance (HD)
- ***Gloss-based* matchers** have two WordNet senses as input and produce relations exploiting gloss comparison techniques
  - WordNet Gloss (WNG)
  - Extended WordNet Gloss (EWNG)
  - Gloss Comparison (GC)

ISM: generating candidate axioms
Hierarchy Distance

Hierarchy distance returns the equivalence relation if the distance between two input senses in WordNet hierarchy is less than a given threshold value (e.g., 3) and *idk* otherwise

There is no direct relation between *games* and *entertainment* in WordNet

Distance between these concepts is 2 (1 more general link and 1 less general). Thus, we can conclude that *games* and *entertainment* are close in their meaning and return the equivalence relation



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  - **Evaluation setup**
  - Evaluation results
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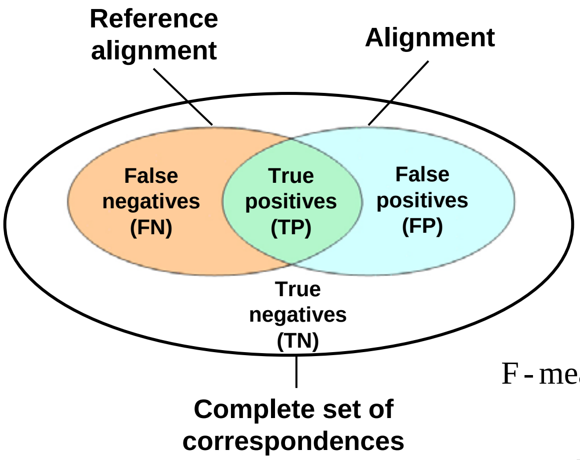
Evaluation (quality) measures



$$\text{Precision} = \frac{|TP|}{|TP| + |FP|}$$

$$\text{Recall} = \frac{|TP|}{|FN| + |TP|}$$

$$\text{F-measure} = 2 \cdot \frac{\text{Precision} \cdot \text{Recall}}{\text{Precision} + \text{Recall}}$$

$$\text{Overall} = \text{Recall} \cdot \left(2 - \frac{1}{\text{Precision}}\right)$$

Test cases

#	Matching task	#nodes	max depth	#labels per tree
1	Images vs Europe	4/5	2/2	6/5
2	Product schemas	13/14	4/4	14/15
3	Yahoo Finance vs Standard	10/16	2/2	22/45
4	Cornell vs Washington	34/39	3/3	62/64
5	CIDX vs Excel	34/39	3/3	56/58
6	Google vs Looksmart	706/1081	11/16	1048/1715
7	Google vs Yahoo	561/665	11/11	722/945
8	Yahoo vs Looksmart	74/140	8/10	101/222
9	Iconclass vs Aria	999/553	9/3	2688/835

Matching systems

Schema-based systems

- S-Match
- Cupid
- COMA
- Similarity Flooding as implemented in Rondo
- OAEI-2005 and OAEI-2006 participants

Systems were used in default configurations

PC: PIV 1,7Ghz; 512Mb. RAM; Win XP

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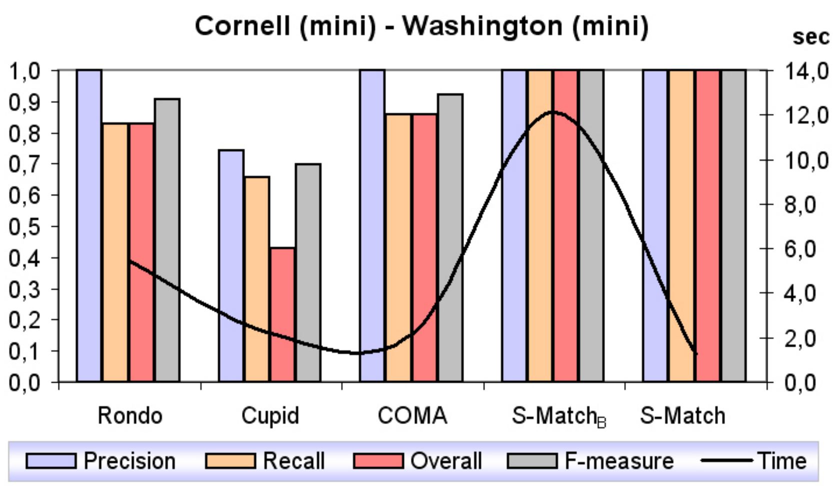
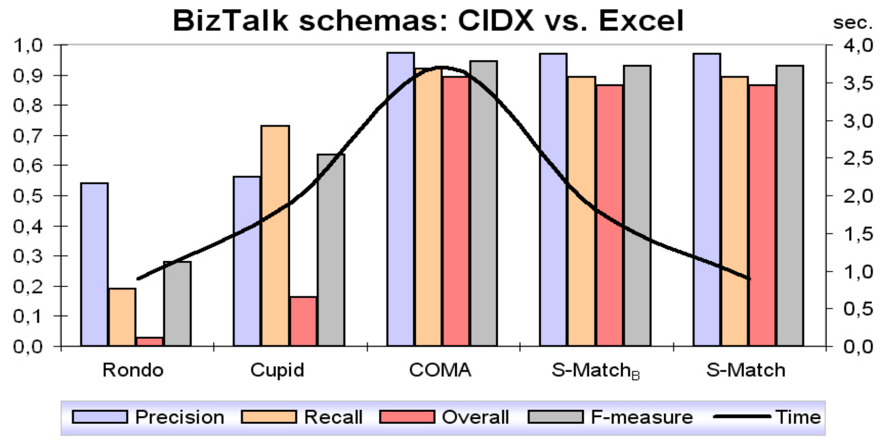
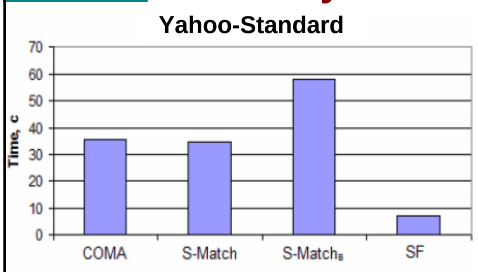
Experimental results, test case #4

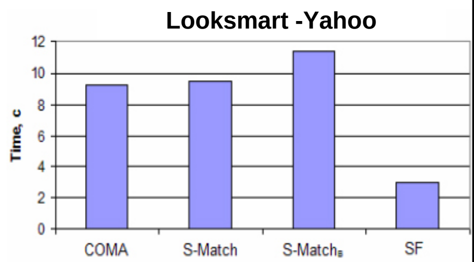


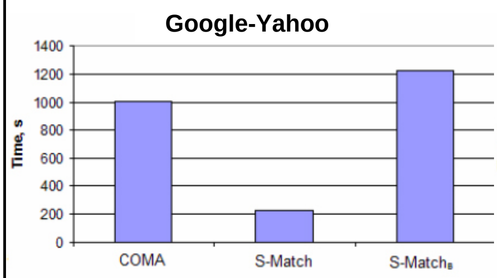
Experimental results, test case #5

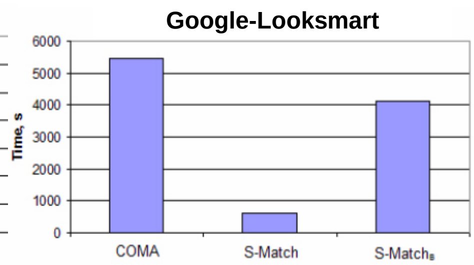


Experimental results, #3,6,7,8: efficiency









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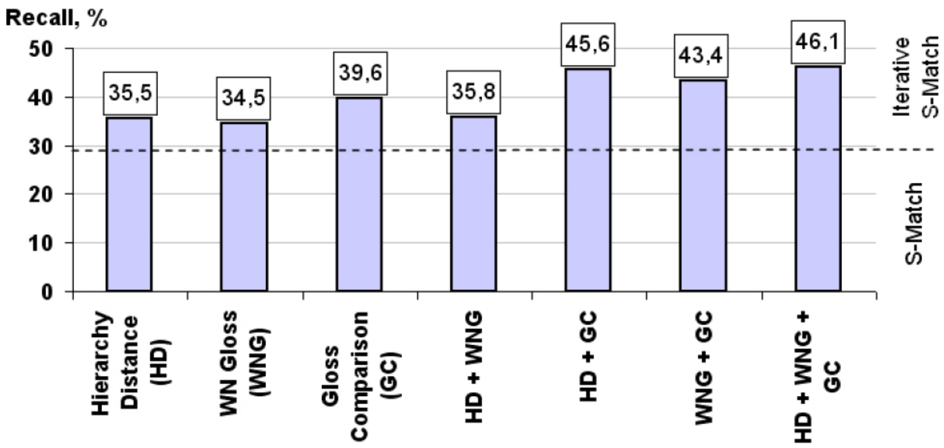
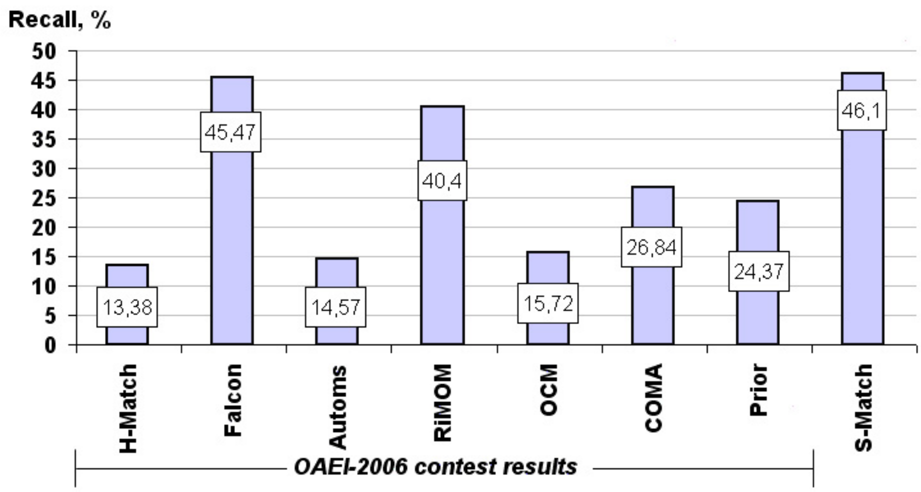
Experimental results, #6,7,8: incompleteness



OAEI-2005

48

Experimental results, #6,7,8: incompleteness (OAEI-2006 comparison)



Preliminary results, test case #9

	Precision, %	Recall, %	F-measure, %
S-Match	44,82	6,45	11,29
Iterative S-Match	47,69	6,6	11,59

Observations

- The dataset is hard and challenging
- Why do we have such a low recall?
  - Gloss-like labels

    Aria: Top>Accessories>Jewelry

    Iconclass: Top>Nature>earth, world as celestial body>rock types; minerals and metals; soil types>rock types>precious and semiprecious stones>precious and semiprecious stones (with NAME)>precious and semiprecious stones: emerald

Outline

- Thesis contributions
- Part I: The matching problem
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Summary

- Ontology matching applications and their requirements
- Overview of the state of the art, including classification of matching techniques and systems
- Semantic matching approach, including algorithms for basic, efficient and iterative semantic matching
- Evaluation of the approach on various data sets with encouraging results

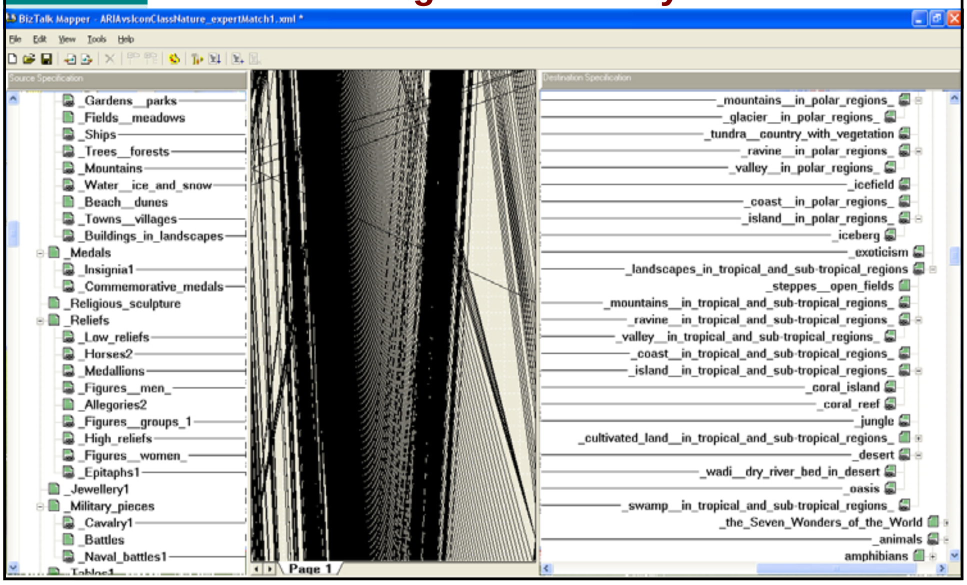
Summary (cont'd)

- Automated reasoning techniques (e.g., SAT) provide good performance for industrial-strength matching tasks
- The issue is not efficiency but rather missing domain knowledge
  - This problem on the industrial size matching tasks is very hard
  - We have investigated it by examples of light weight ontologies, such as Google and Yahoo
  - Partial solution by applying semantic matching iteratively

Future challenges

- Missing background knowledge
- Interactive approaches
- Explanations of matching results
- Social and collaborative ontology matching
- Large-scale evaluation
- Infrastructures
- ...

Future challenges: scalability of visualization



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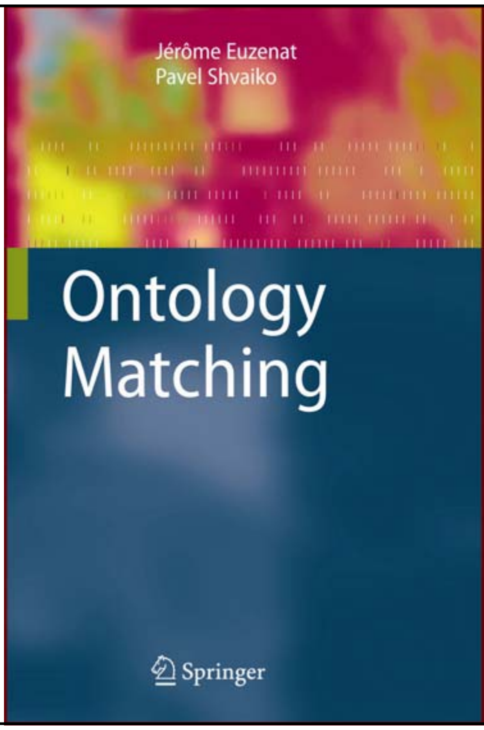
Ontology Matching @ ISWC'07+ASWC'07

http://om2007.OntologyMatching.org

OM-2007

Ontology Alignment Evaluation Initiative OAEI–2007 campaign

http://oaei.OntologyMatching.org/2007



Thank you
for your attention and interest!