# Tutorial on Schema and Ontology Matching


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# Goals of the tutorial

- Illustrate the role of schema/ontology matching
- Provide an overview of the basic matching techniques
- Demonstrate the use of basic matching techniques in state of the art systems
- Motivate the future research

# Outline

- **Matching problem**
- Classification of schema-based matching techniques
- Basic techniques
- Matching process
- Review of the matching systems
- Conclusions

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# Motivations

**Match operator**

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

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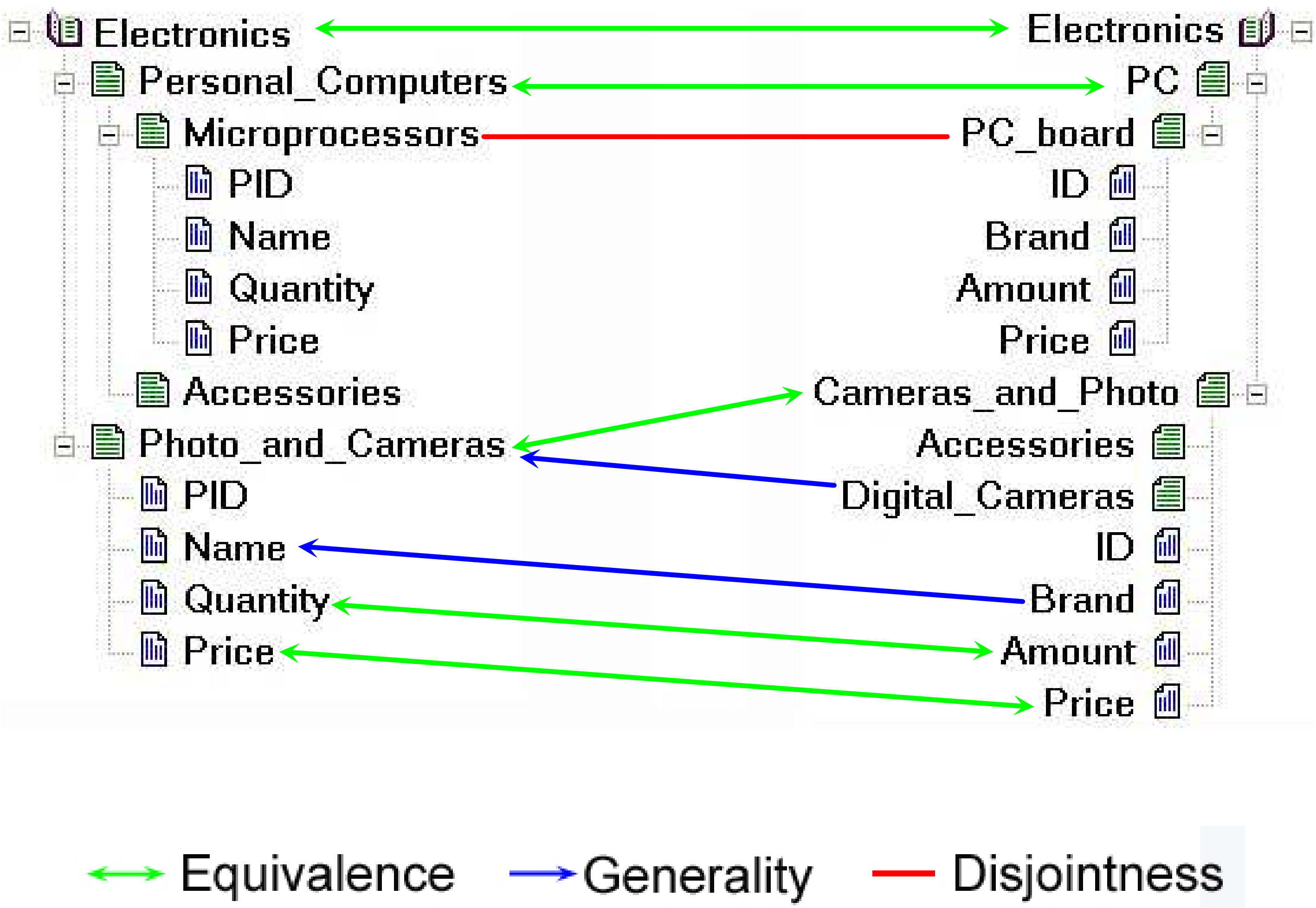
# Motivations

## Two XML schemas

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# Motivations

## Two relational schemas

STAFF

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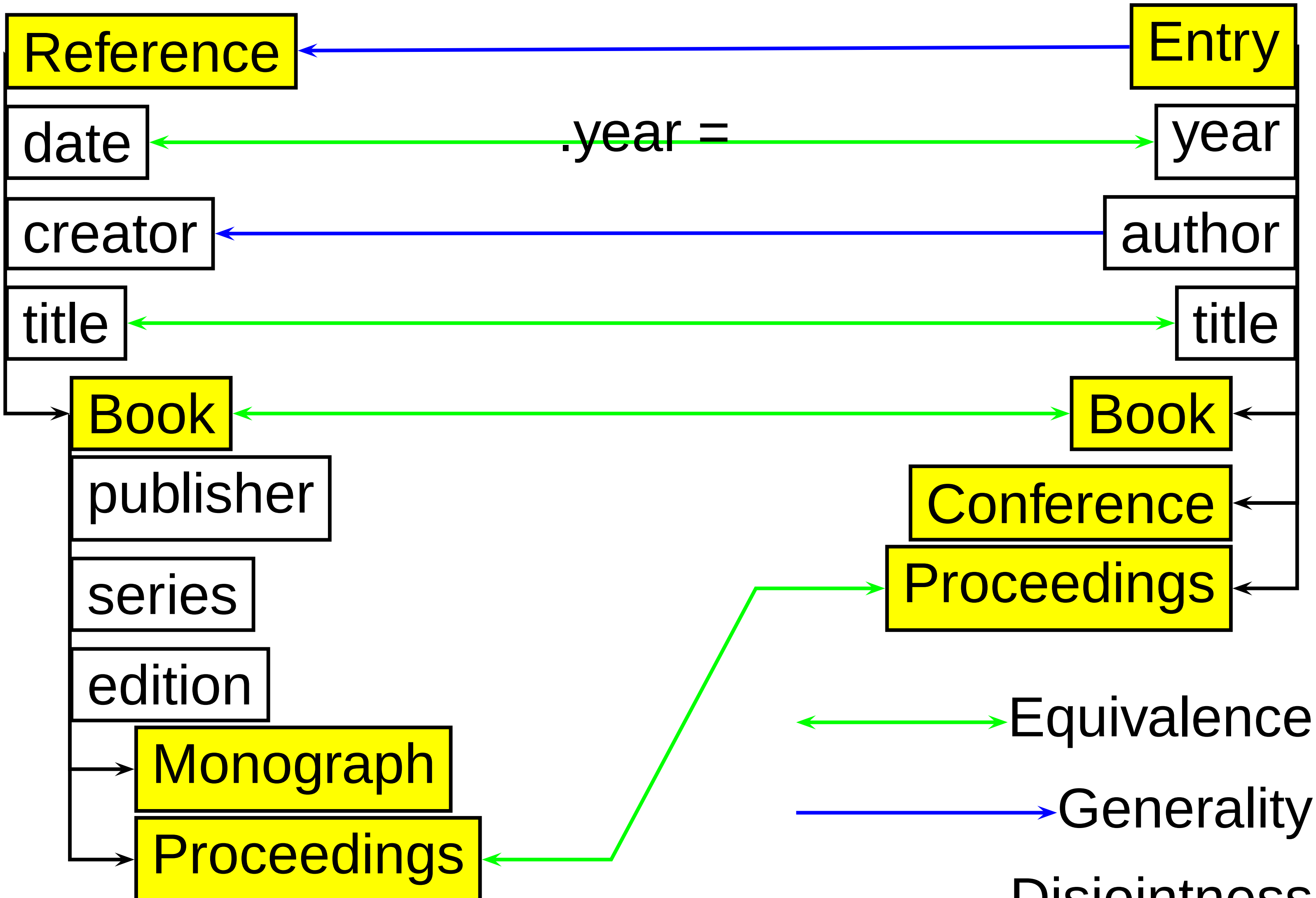
Equivalence Generality Disjointness

# Motivations

**Two ontologies**



# Schema matching vs. Ontology matching

**Differences:**

- Schemas often do not provide explicit semantics for their data
  - Relational schemas provide no generalization
- Ontologies are logical systems that constrain the meaning
  - Ontology definitions as a set of logical axioms

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# Schema matching vs. Ontology matching

**Commonalities:**

- Schemas and ontologies provide a vocabulary of terms that describes a domain of interest
- Schemas and ontologies constrain the meaning of terms used in the vocabulary

Techniques developed for both problems are of a mutual benefit

# Statement of the problem

## Scope

- Reducing heterogeneity can be performed in 2 steps
  - **Determine the alignment** (*matching*)
  - Process the alignment (merging, transforming, etc.)
- When do we match?
  - Design time
  - **Run time**

# Statement of the problem

**Mapping element $M$ is a 5-uple:** $\langle id, e, e', R, n \rangle$

- $id$ is a unique identifier of the given mapping element
- $e$ and $e'$ are entities (e.g., XML elements, classes)
- $R$ is a relation (e.g., *equivalence* (=); *more general* ($\sqsupseteq$); *disjointness* ($\perp$))
- $n$ is a confidence measure in some mathematical structure (typically in the [0,1] range)

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# Statement of the problem

**Alignment ($A$)**

- is a set of mapping elements
- depending on the two schema/ontologies
- with some multiplicity: 1-1, 1-*, etc.
- and some other properties (complete)

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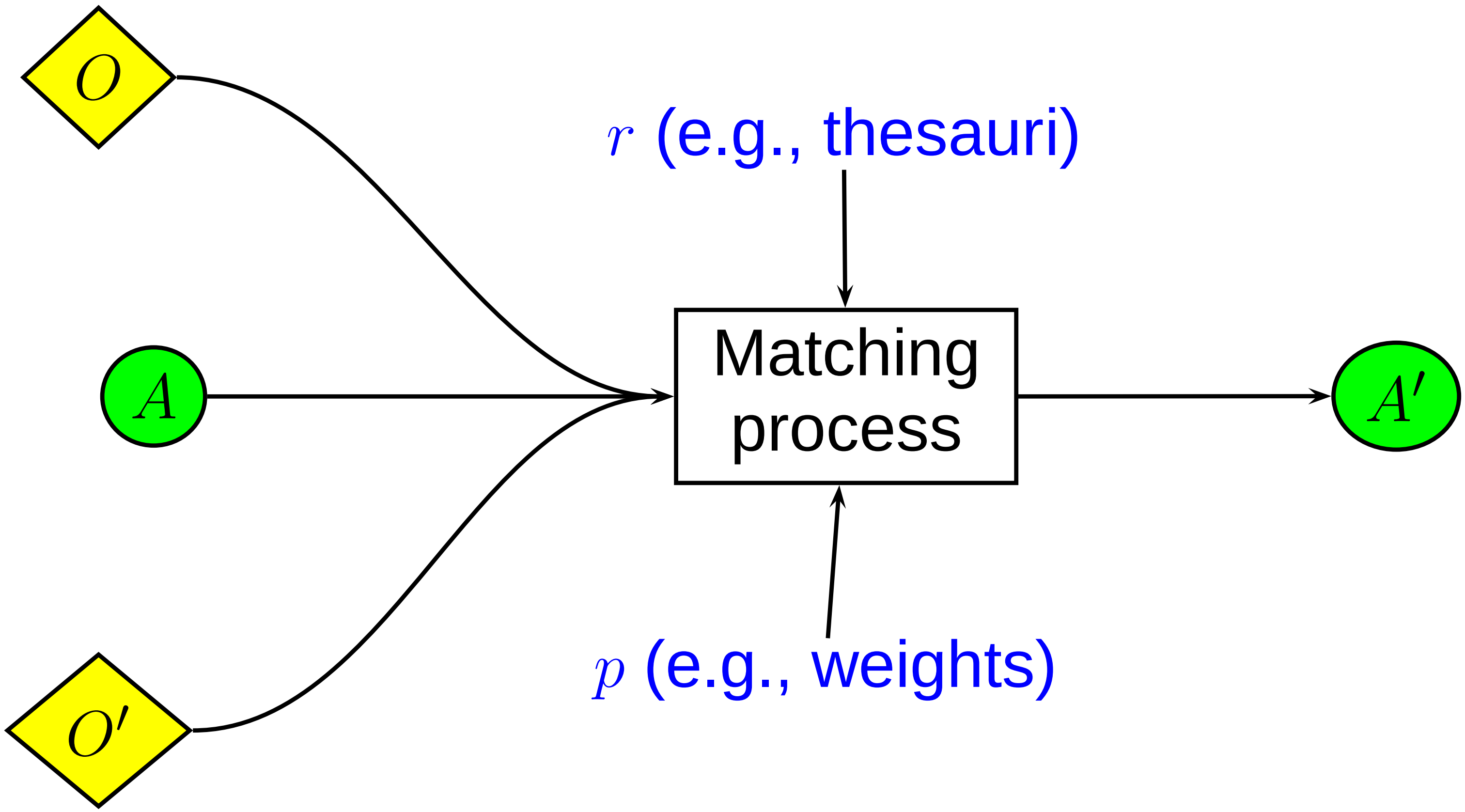
# Statement of the problem

## Matching process

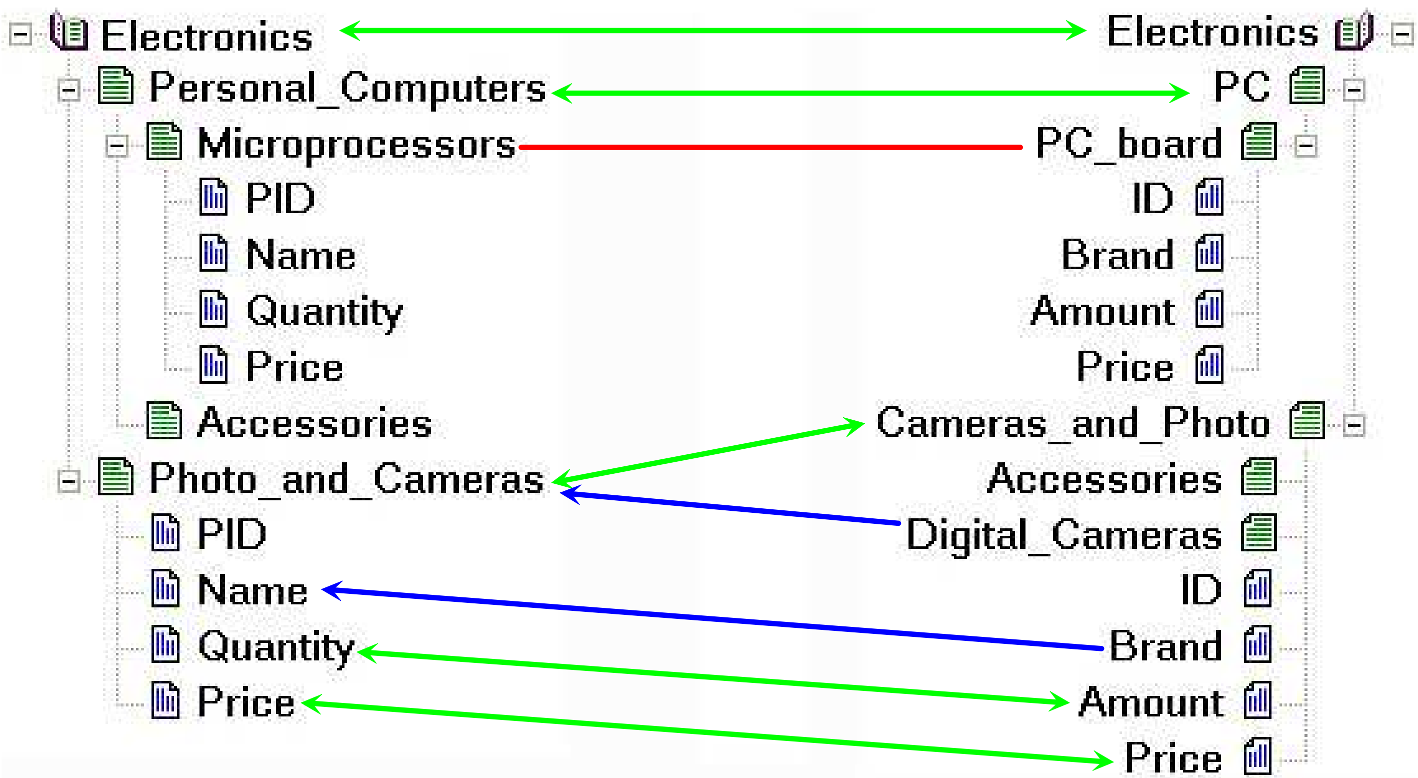


# Application domains

- **Traditional**
  - Schema integration
  - Data warehouses
  - Mediator generation
- **Emergent**
  - P2P databases
  - Agent communication
  - Web services integration

# Application domains

## Schema integration: catalog matching



# Application domains

## Schema integration: catalog matching

- In order for a private company to participate in the marketplace (e.g., eBay), it has to determine correspondences between entries of its catalogs and entries of a common catalog of a marketplace
- Once the correspondences between two schemas have been determined, the next step is to generate query expressions that automatically translate data instances of these catalogs under an integrated catalog
- Having aligned the catalogs, users of a marketplace have a unified access to the products which are on sale

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# Application domains

## P2P databases

- Peers are autonomous
  - They appear and disappear on the network
  - They use different terminology
- Matching (on-the-fly)
  - Determine the relationships between peer schemas
  - Use these relationships for query answering
  - An assumption that all peers rely on one global schema, as in data integration, can not be made, because the global schema might need to be updated any time the system evolves

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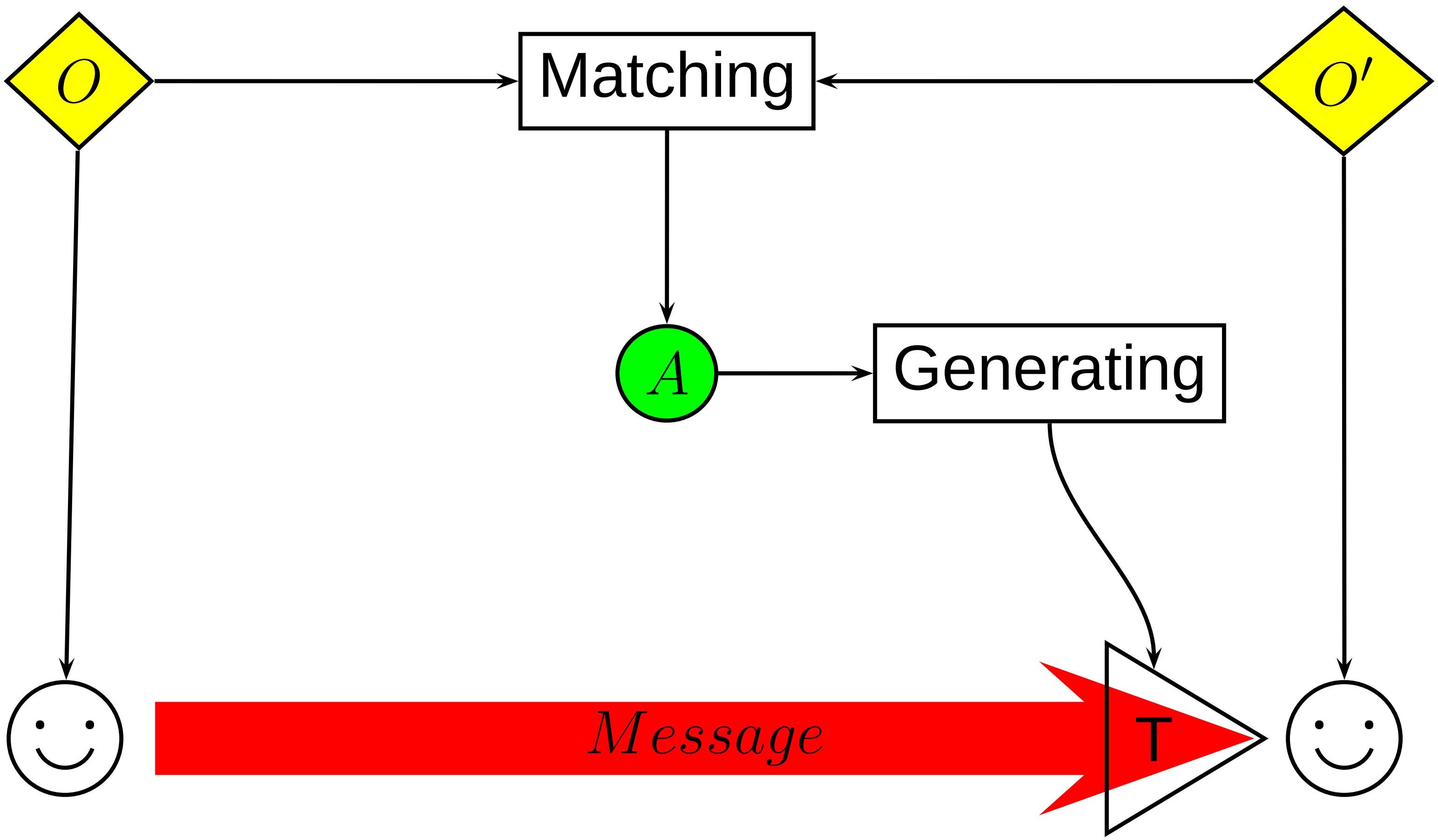
# Application domains

## Agent communication

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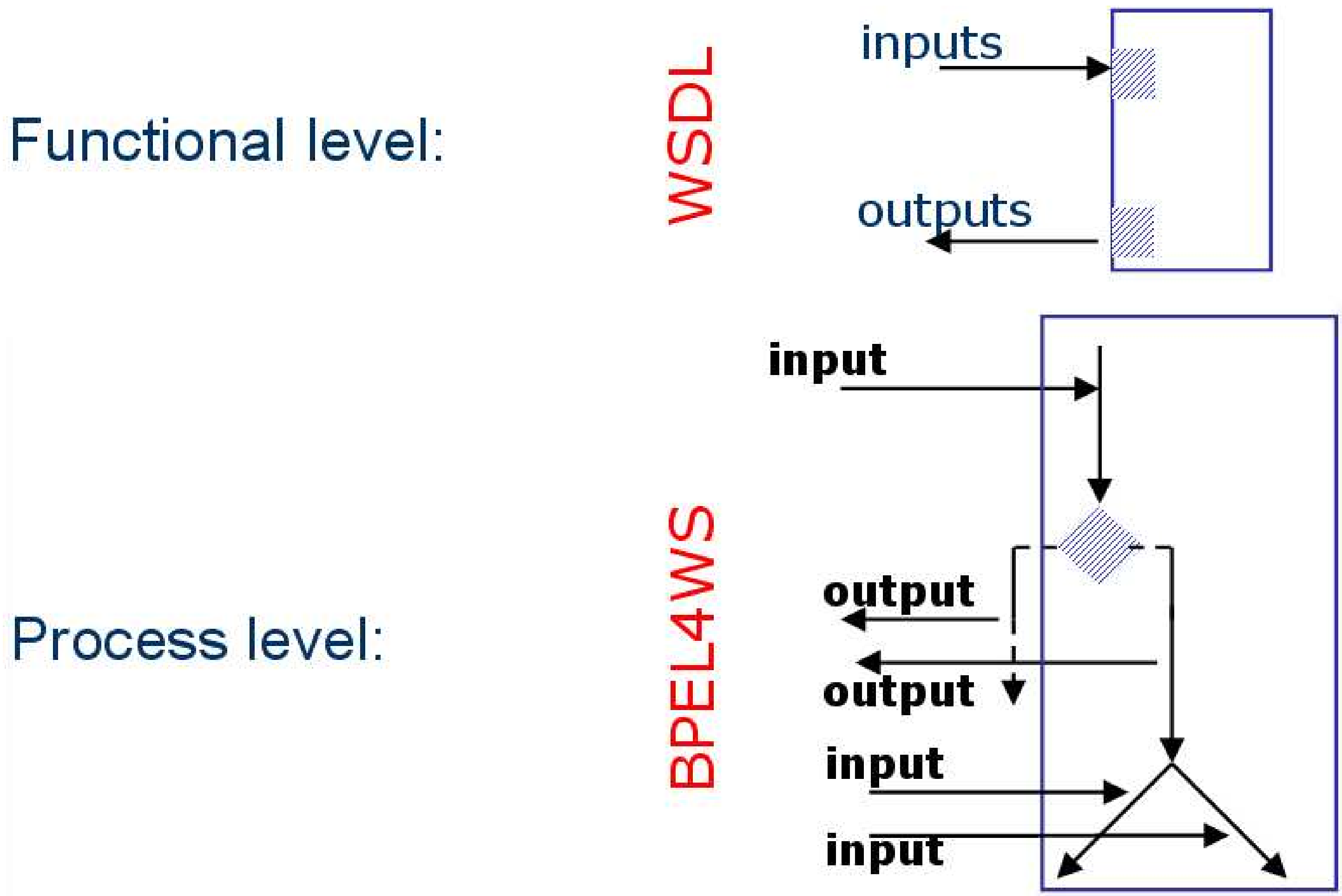
# Application domains

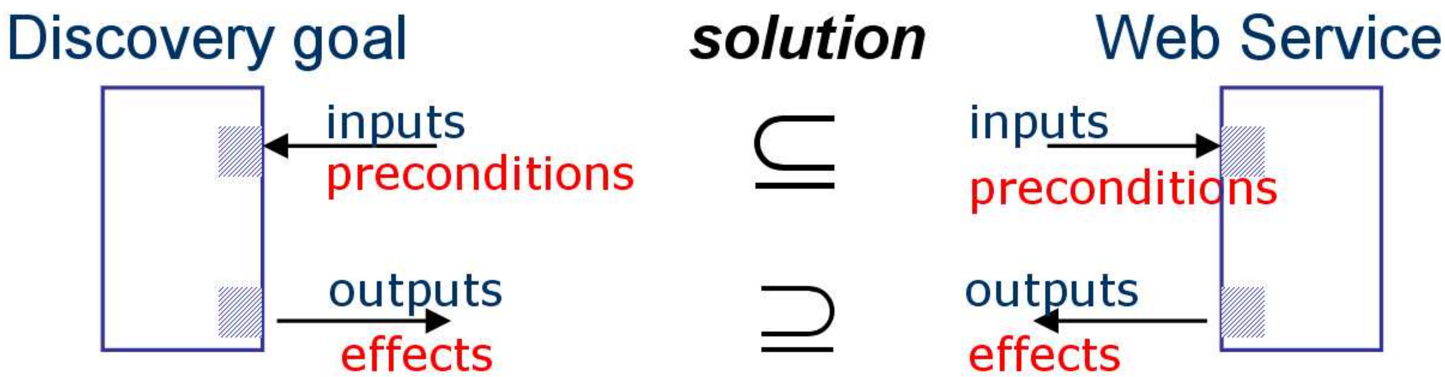
## Web services integration



# Application domains

## Web services integration

- Matching




- Executing the alignment
  - Generate a mediator able to transform the output of the first service in order to be input to the second one

# Outline

- Matching problem
- **Classification of schema-based matching techniques**
- Basic techniques
- Matching process
- Review of the matching systems
- Conclusions

# Matching dimensions

- Input dimensions
  - Underlying data models (e.g., XML, OWL)
  - **Schema-level** vs. Instance-level
- Process dimensions
  - Approximate vs. Exact
  - Interpretation of the input
- Output dimensions
  - Cardinality (e.g., 1:1, 1:m)
  - Equivalence vs. Diverse relations (e.g., subsumption)
  - Graded vs. Absolute confidence

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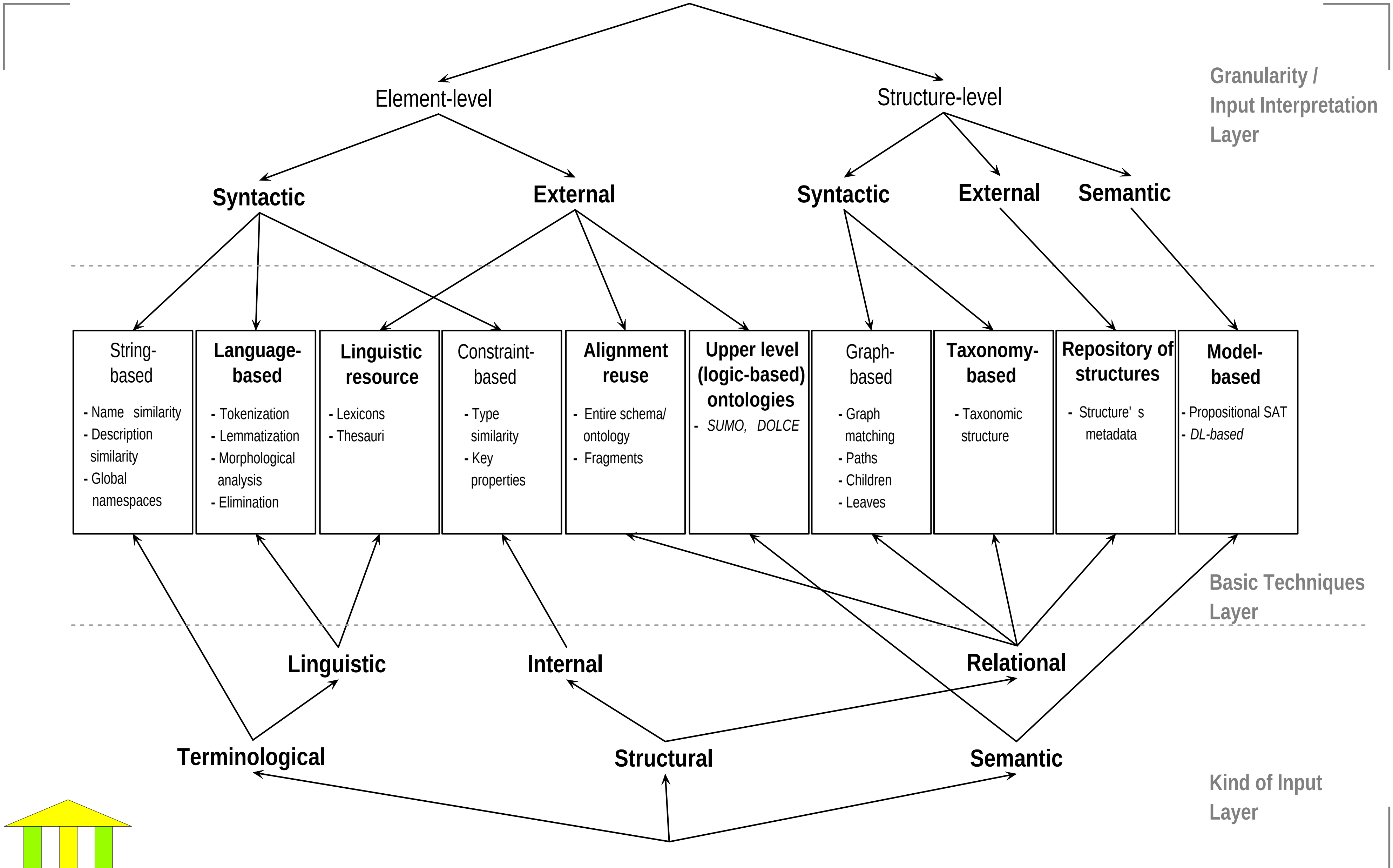
# Classification of schema-based techniques

**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 schema-based techniques



# Outline

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# Basic techniques

. . . techniques from the following systems have been taken into consideration:

- Anchor-PROMPT
- Artemis
- COMA, COMA++
- Cupid
- NOM, QOM, FOAM
- OLA
- SF, Rondo
- CtxMatch, S-Match

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# Element-level techniques

**String-based** (e.g., COMA, SF, S-Match, OLA)

- Prefix
  - It takes as input two strings and checks whether the first string starts with the second one
  - net = network; but also hot = hotel
- Suffix
  - It takes as input two strings and checks whether the first string ends with the second one
  - phone = telephone; but also word = sword

# Element-level techniques

**String-based** (e.g., S-Match, OLA, Anchor-Prompt)

- 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

# Element-level techniques

**String-based** (e.g., COMA, S-Match)

- N-gram
  - It takes as input two strings and calculates the number of the same n-grams (i.e., sequences of $n$ characters) between them
  - $trigram(3)$ for the string nikon are nik, iko, kon

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# Element-level techniques

**Language-based** (e.g., COMA, Cupid, S-Match, OLA)

- Tokenization
  - Names are parsed into tokens by recognizing punctuation, cases
  - Hands-Free_Kits $\longrightarrow \langle$ hands, free, kits $\rangle$
- Lemmatization
  - Tokens are morphologically analyzed in order to find all their possible basic forms
  - Kits $\longrightarrow$ Kit

# Element-level techniques

**Language-based** (e.g., Cupid, S-Match)

- Elimination
  - Tokens that are articles, prepositions, conjunctions, and so on, are marked to be discarded
  - a, the, by, type of

# Element-level techniques

**Constraint-based** (e.g., OLA, COMA)

- Datatype comparison
  - $integer < real$
  - $date \in [1/4/2005\ 30/6/2005] < date[year = 2005]$
  - $\{a, c, g, t\}[1 - 10] < \{a, c, g, u, t\}+$
- Multiplicity comparison
  - $[1\ 1] < [0\ 10]$

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# Element-level techniques

**Linguistic resources** (e.g., Artemis, S-Match, OLA)

- Sense-based: WordNet
  - Relations between schema/ontology entities can be computed in terms of lexical relationships

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# Element-level techniques

**Linguistic resources** (e.g., Artemis, S-Match)

- Sense-based: WordNet
  - $A \sqsubseteq B$ if $A$ is a hyponym or meronym of $B$
    - Brand $\sqsubseteq$ Name
  - $A \sqsupseteq B$ if $A$ is a hypernym or holonym of $B$
    - Europe $\sqsupseteq$ Greece
  - $A = B$ if they are synonyms
    - Quantity $=$ Amount
  - $A \perp B$ if they are antonyms or the siblings in the part of hierarchy
    - Microprocessors $\perp$ PC_Board

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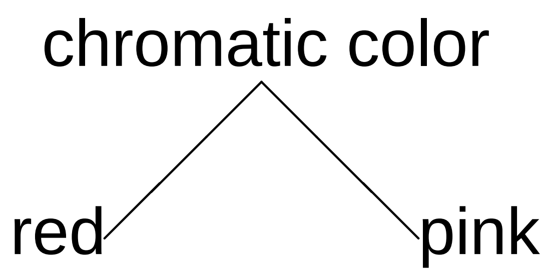
# Element-level techniques

**Linguistic resources** (e.g., S-Match)

- Sense-based: WordNet hierarchy distance
  - These return the equivalence relation if the distance between two input senses in the WordNet hierarchy is less than a given threshold
  - red = pink

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# Element-level techniques

**Linguistic resources** (e.g., S-Match)

- Gloss-based: WordNet gloss comparison
  - The number of the same words occurring in both input glosses increases the similarity value. The equivalence relation is returned if the resulting similarity value exceeds a given threshold
  - Maltese dog is a breed of toy dogs having a long straight silky white coat
    Afghan hound is a tall graceful breed of hound with a long silky coat

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# Element-level techniques

**Linguistic resources** (e.g., Cupid, COMA)

- Specific thesauri
  - These usually store specific domain knowledge
  - PO = Purchase Order
    uom = UnitOfMeasure
    line = item

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# Element-level techniques

**Alignment reuse** (e.g., COMA, COMA++, OLA)

- Entire schemas
- Schema fragments
- ... we need to match schema/ontology $o'$ and $o''$, given the alignments between $o$ and $o'$, and between $o$ and $o''$ from the external resource, storing previous match operations results

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# Structure-level techniques

**Taxonomy-based** (Anchor-Prompt, NOM, QOM)

. . . schemas/ontologies are viewed as graph-like structures containing terms and their inter-relationships

- Bounded path matching
  - These take two paths with links between classes defined by the hierarchical relations, compare terms and their positions along these paths, and identify similar terms
- Super(sub)-concepts rules
  - If super-concepts are the same, the actual concepts are similar to each other

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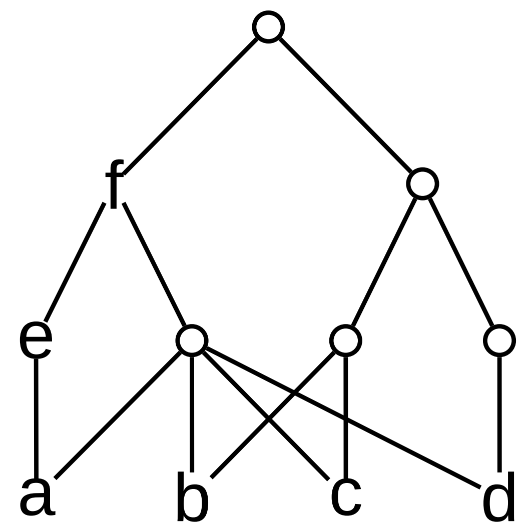
# Structure-level techniques

## Taxonomy-based

- Upward cotopic distance
  Measures the ratio of common superclasses.

$$\delta(c,c') = 1 - \frac{|UC(c,H) \cap UC(c',H)|}{|UC(c,H) \cup UC(c',H)|}$$

where $UC(c,H) = \{c' \in H; c \leq c'\}$ is the set of superclasses of $c$.




$\delta(a,a) = 1 - 1 = 0$

$\delta(a,e) = 1 - 3/5 = .4$

$\delta(a,f) = 1 - 2/5 = .6$

$\delta(d,a) = 1 - 3/8 \approx .625$

$\delta(b,c) = 1 - 5/7 \approx .286$

$\delta(c,d) = 1 - 4/8 = .5$

$\delta(a,b) = 1 - 3/8 \approx .625$

# Structure-level techniques

**Graph-based** (e.g., Cupid, COMA)

- Children
  - Two non-leaf schema elements are structurally similar if their immediate children sets are highly similar
- Leaves
  - Two non-leaf schema elements are structurally similar if their leaf sets are highly similar, even if their immediate children are not

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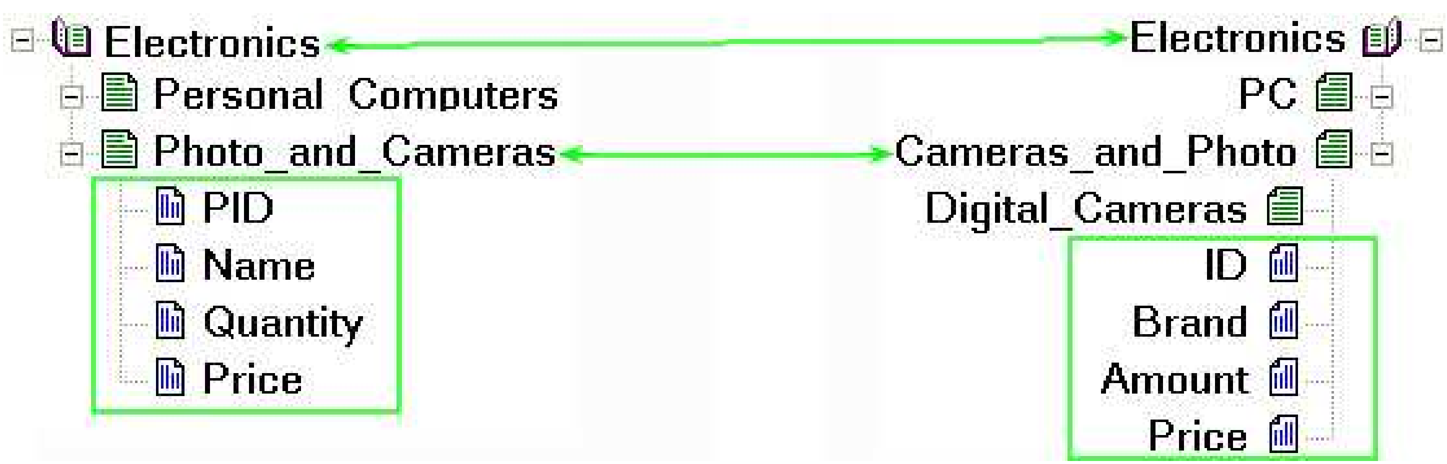
# Structure-level techniques

**Graph-based** (e.g., Cupid, COMA)

- Leaves



# Structure-level techniques

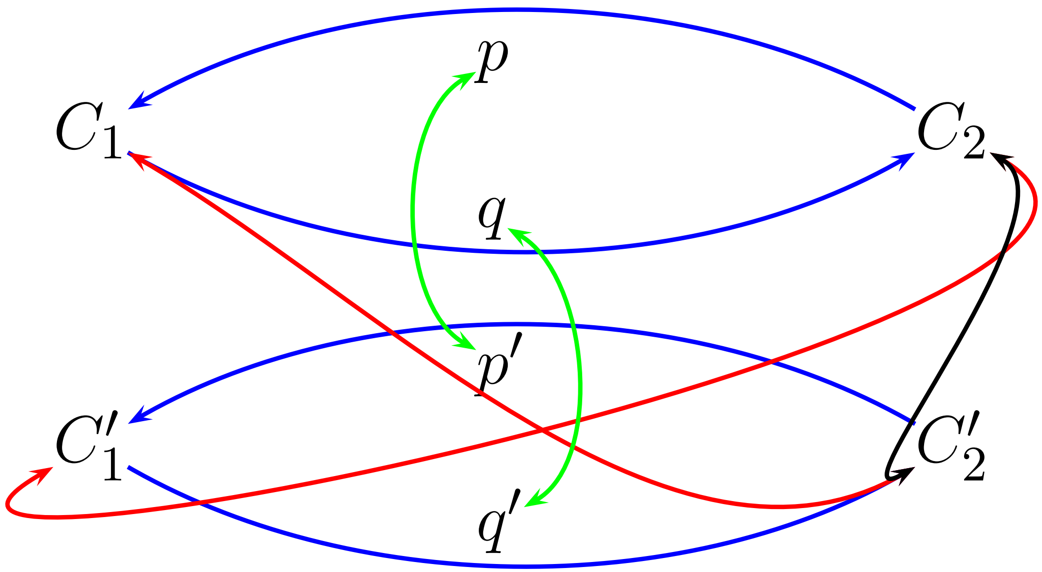
**Graph-based** (e.g., SF, OLA)

- Iterative fix point computation
  - If two nodes from two schemas/ontologies are similar, their neighbors might also be somehow similar

# Structure-level techniques

**Graph-based** (e.g., SF, OLA)

- Iterative fix point computation




| | $C_1$ | $p$ | $C_2$ | $q$ |
|---|---|---|---|---|
| $C'_1$ | .4 | | .6 | |
| $p'$ | | .8 | | .2 |
| $C'_2$ | .5 | | .6 | |
| $q'$ | | .4 | | .5 |

$$\sigma_C(c,c') = .6.\frac{1}{max(|A(c)|,|A(c')|)}.\sum_{\langle a,a'\rangle \in match(A(c),A(c'))} \sigma_A(a,a') + .4.\sigma(N(c),N(c'))$$

$$\sigma_A(a,a') = .6.\sigma_C(domain(a),domain(a')) + .4.\sigma(N(a),N(a'))$$

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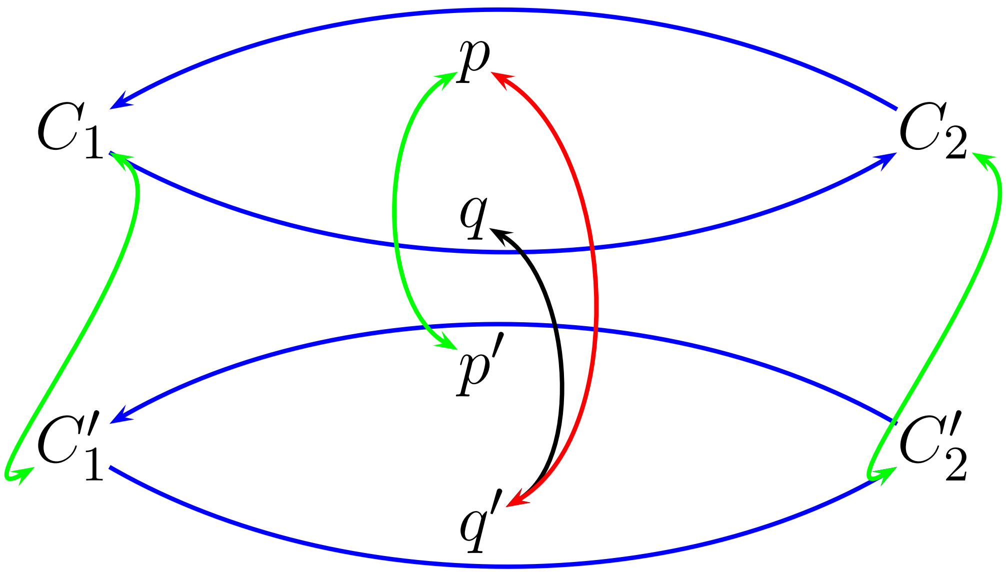
# Structure-level techniques

**Graph-based** (e.g., SF, OLA)

- Iterative fix point computation




| | $C_1$ | $p$ | $C_2$ | $q$ |
|---|---|---|---|---|
| $C'_1$ | .64 | | .36 | |
| $p'$ | | .68 | | .38 |
| $C'_2$ | .32 | | .54 | |
| $q'$ | | .52 | | .44 |

$$\sigma_C(c,c') = .6.\frac{1}{max(|A(c)|,|A(c')|)}.\sum_{\langle a,a'\rangle \in match(A(c),A(c')} \sigma_A(a,a') + .4.\sigma(N(c),N(c'))$$

$$\sigma_A(a,a') = .6.\sigma_C(domain(a),domain(a')) + .4.\sigma(N(a),N(a'))$$

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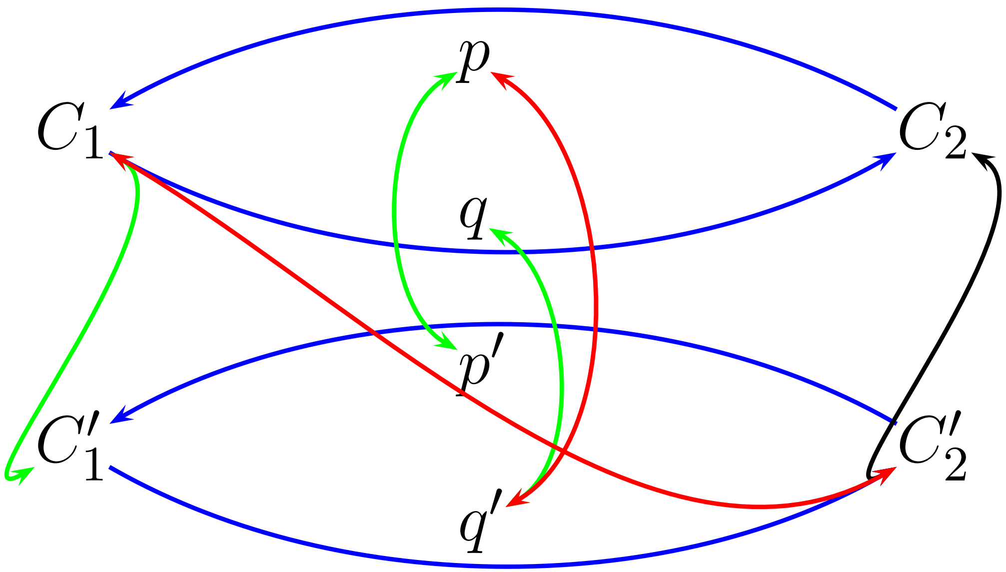
# Structure-level techniques

**Graph-based** (e.g., SF, OLA)

- Iterative fix point computation




| | $C_1$ | $p$ | $C_2$ | $q$ |
|---|---|---|---|---|
| $C'_1$ | .57 | | .47 | |
| $p'$ | | .64 | | .27 |
| $C'_2$ | .51 | | .5 | |
| $q'$ | | .38 | | .58 |

$$\sigma_C(c,c') = .6.\frac{1}{max(|A(c)|,|A(c')|)}.\sum_{\langle a,a'\rangle \in match(A(c),A(c'))} \sigma_A(a,a') + .4.\sigma(N(c),N(c'))$$

$$\sigma_A(a,a') = .6.\sigma_C(domain(a), domain(a')) + .4.\sigma(N(a),N(a'))$$

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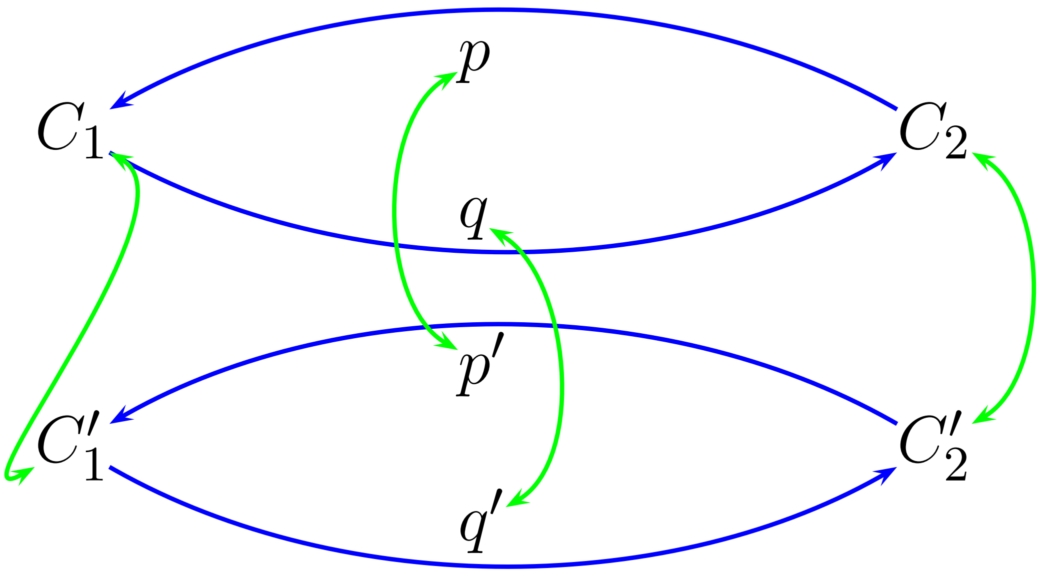
# Structure-level techniques

**Graph-based** (e.g., SF, OLA)

- Iterative fix point computation




| | $C_1$ | $p$ | $C_2$ | $q$ |
|---|---|---|---|---|
| $C'_1$ | .54 | | .4 | |
| $p'$ | | .62 | | .39 |
| $C'_2$ | .43 | | .59 | |
| $q'$ | | .44 | | .54 |

$$\sigma_C(c,c') = .6.\frac{1}{max(|A(c)|,|A(c')|)}.\sum_{\langle a,a'\rangle \in match(A(c),A(c'))} \sigma_A(a,a') + .4.\sigma(N(c),N(c'))$$

$$\sigma_A(a,a') = .6.\sigma_C(domain(a),domain(a')) + .4.\sigma(N(a),N(a'))$$

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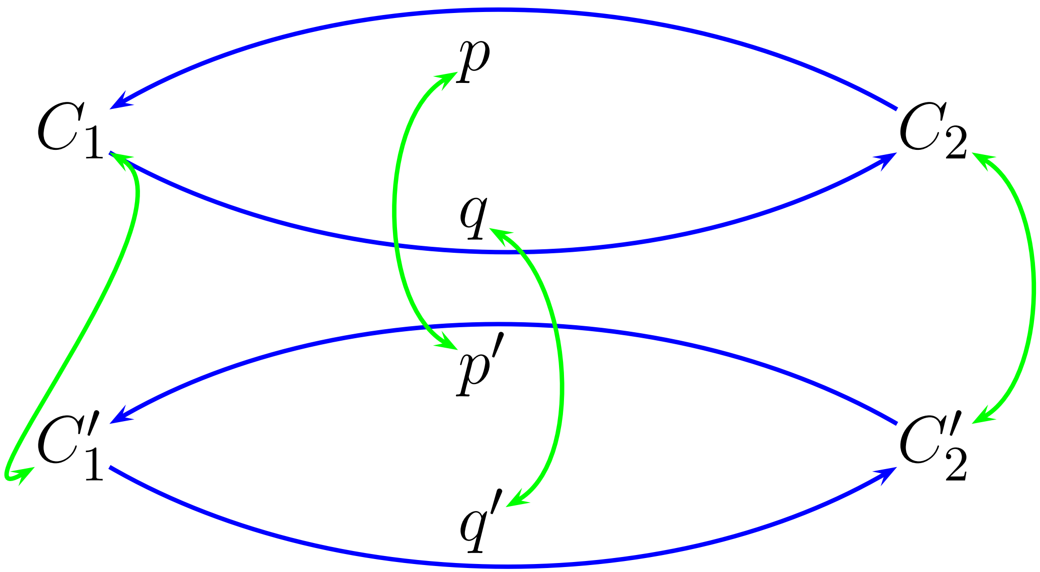
# Structure-level techniques

**Graph-based** (e.g., SF, OLA)

- Iterative fix point computation




| | $C_1$ | $p$ | $C_2$ | $q$ |
|---|---|---|---|---|
| $C'_1$ | .53 | | .47 | |
| $p'$ | | .67 | | .34 |
| $C'_2$ | .46 | | .56 | |
| $q'$ | | .4 | | .52 |

Threshold reached: no $.1$ variation

$$\sigma_C(c,c') = .6.\frac{1}{max(|A(c)|,|A(c')|)}.\sum_{\langle a,a'\rangle \in match(A(c),A(c'))} \sigma_A(a,a') + .4.\sigma(N(c),N(c'))$$

$$\sigma_A(a,a') = .6.\sigma_C(domain(a),domain(a')) + .4.\sigma(N(a),N(a'))$$

# Structure-level techniques

**Model-based** (e.g., CtxMatch, S-Match)

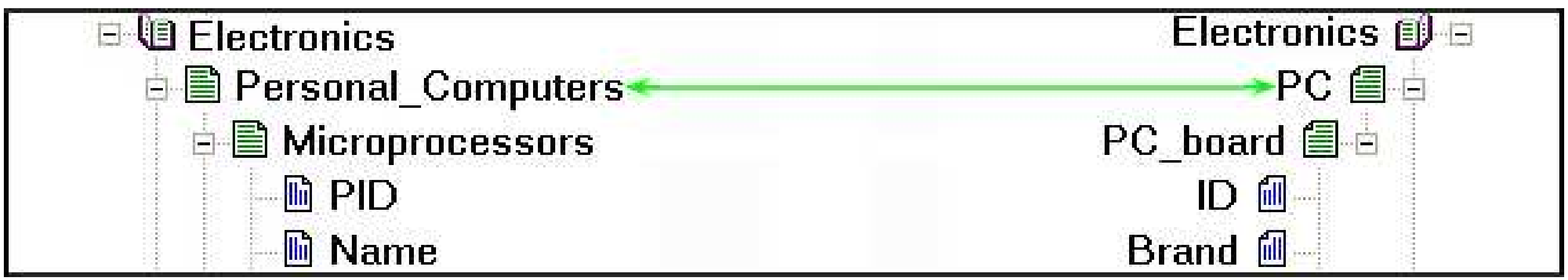
- Propositional satisfiability (SAT)
  - Decompose the graph (tree) matching problem into the set of node matching problems
  - Translate each node matching problem, namely pairs of nodes with possible relations between them, into a propositional formula
  - Check the propositional formula for validity

# Structure-level techniques

**Model-based** (e.g., CtxMatch, S-Match)

- Propositional satisfiability (SAT)

$$Axioms \rightarrow rel(context_1, context_2)$$




$$\overbrace{(Electronics_1 \leftrightarrow Electronics_2) \wedge (Personal\_Computers_1 \leftrightarrow PC_2)}^{Axioms} \longrightarrow$$

$$\overbrace{(Electronics_1 \wedge Personal\_Computers_1)}^{context_1} \longleftrightarrow \overbrace{(Electronics_2 \wedge PC_2)}^{context_2}$$

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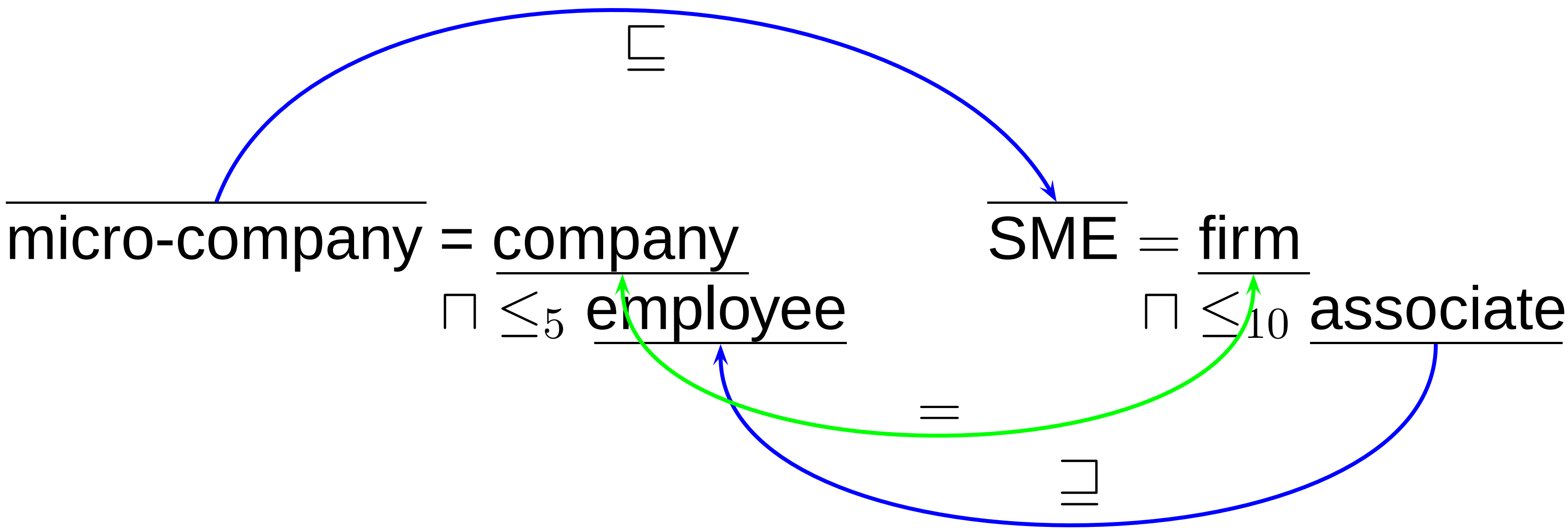
# Structure-level techniques

## Model-based

- Description Logics (DL)-based




$$\frac{\text{company} = \text{firm} \;;\; \text{associate} \sqsubseteq \text{employee}}{\text{micro-company} \sqsubseteq \text{SME}}$$

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- Matching problem
- Classification of schema-based matching techniques
- Basic techniques
- **Matching process**
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- Conclusions

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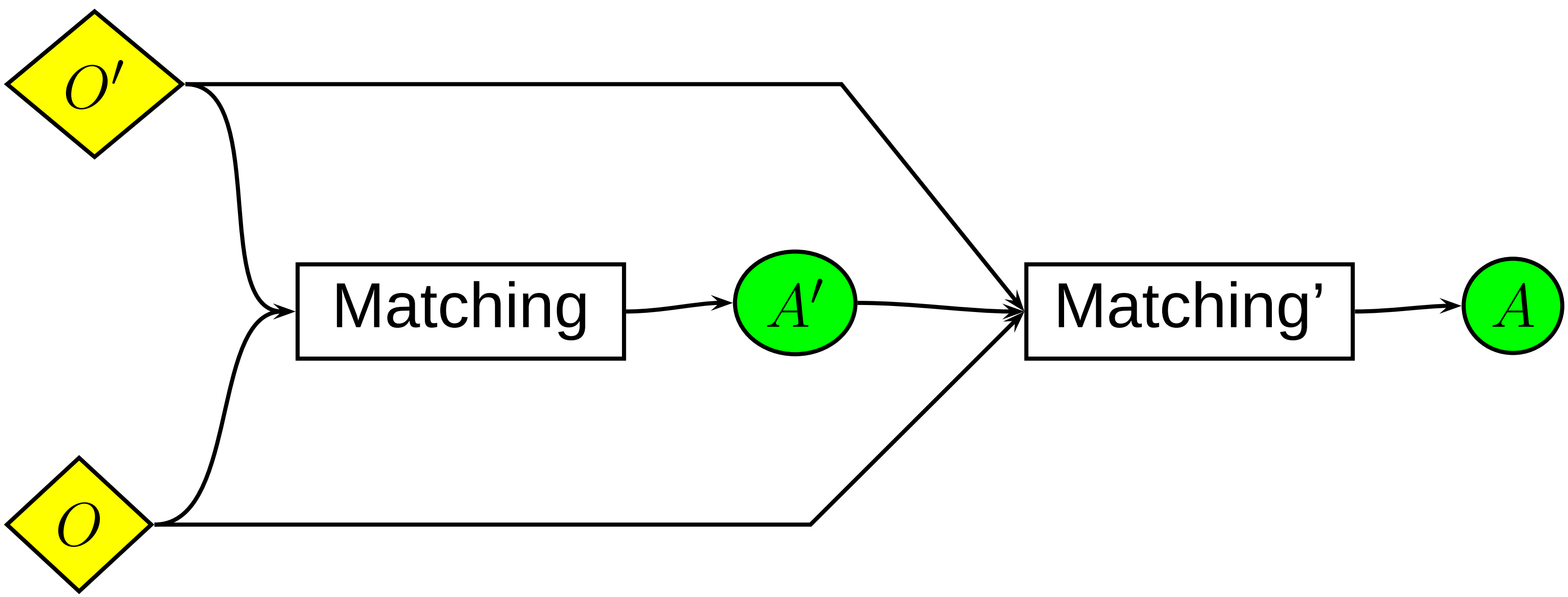
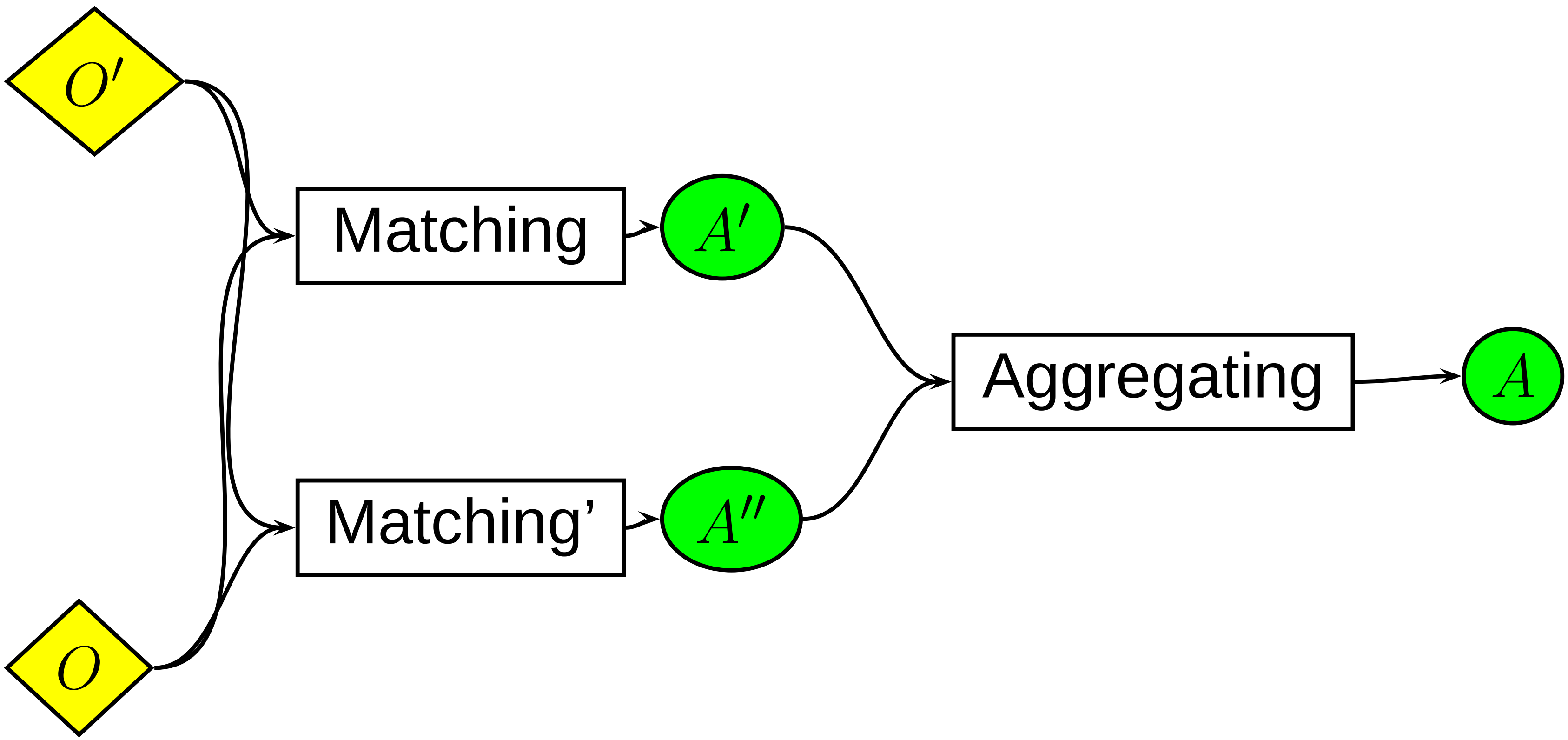
# Matching process

**Architectural perspective:** Sequential (hybrid) (e.g., Cupid, Artemis)



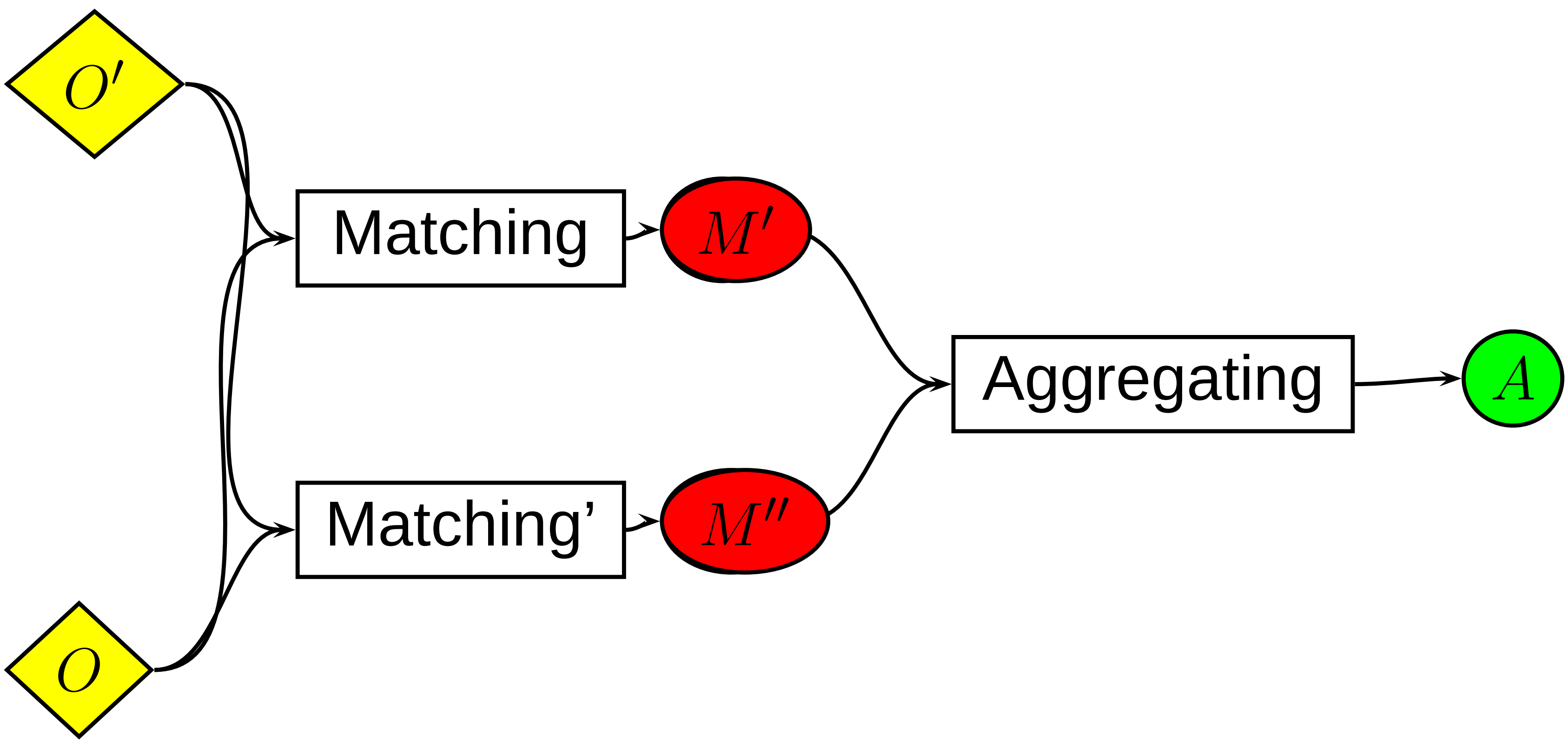
# Matching process

**Architectural perspective:** Parallel (composite) (e.g., COMA, QOM)



# Matching process

**Architectural perspective:** Parallel (composite) (e.g., COMA, QOM)




Aggregation (e.g., Min, Max, Weighted, Average)

# Matching process

## User-centric perspective

- Alignments as solutions (e.g., Rondo, OLA)
  - These consider the matching problem as an optimization problem and the alignment is a solution to it
- Alignments as theorems (e.g., S-Match)
  - These rely on semantics and require the alignment to satisfy it
- Alignments as likeness clues (e.g., Cupid)
  - These produce only reasonable indications to a user for selecting the alignment

# Matching process

## Selecting the final alignment

- Ranking strategies
  - Thresholds
  - MaxDelta
- Cardinalities
  - 1-1; 1-*; *-*
- Directionality
  - $O \rightarrow O'$; $O' \rightarrow O$ (SmallLarge, LargeSmall)
  - $O \rightarrow O'$ and $O' \rightarrow O$ (Both)

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# Review of the matching systems

**Some state of the art systems**

- Cupid (Microsoft Research, USA)
- FOAM/QOM (University of Karlsruhe, Germany)
- OLA (INRIA Rhône-Alpes/Université de Montréal, France/Canada)
- S-Match (University of Trento, Italy)
- ...

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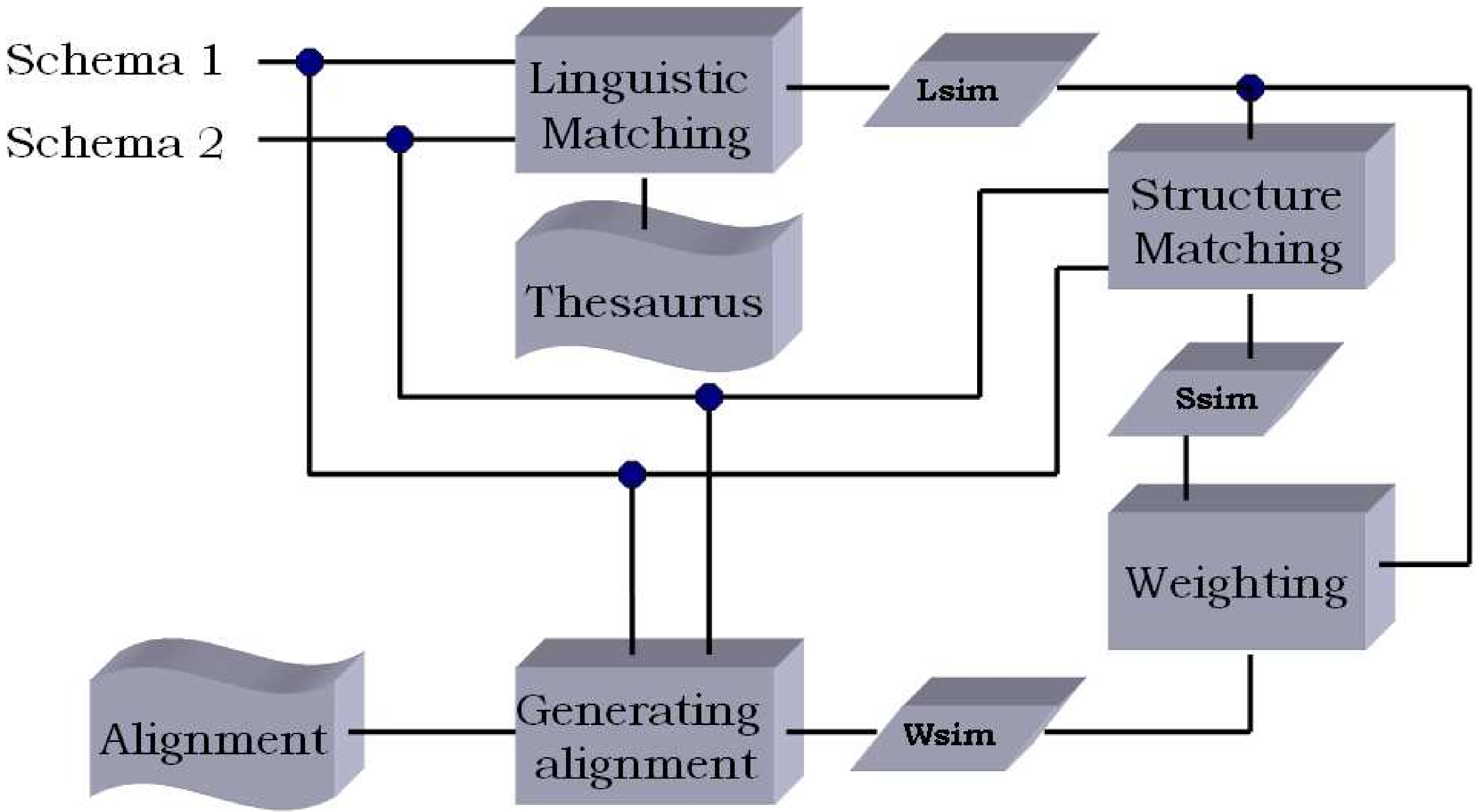
# Review of the matching systems

## Cupid

- Schema-based
- Computes similarity coefficients in the [0,1] range
- Performs linguistic and structure matching
- Sequential system
- Alignments as likeness clues

# Review of the matching systems

## Cupid

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# Review of the matching systems

## OLA

- Schema- and Instance-based
- Computes dissimilarities + extracts alignments (equivalences in the [0,1] range)
- Based on terminological (including linguistic) and structural (internal and relational) distances
- Neither sequential nor parallel
- Alignments as solutions (to an optimization problem)

# Review of the matching systems

## QOM/FOAM

- Schema- and Instance-based
- Computes similarities + extracts alignments (equivalences in the [0,1] range)
- Based on terminological (including linguistic) and structural (internal and relational) distances
- Parallel with elaborated aggregation
- Alignments as likeness clues

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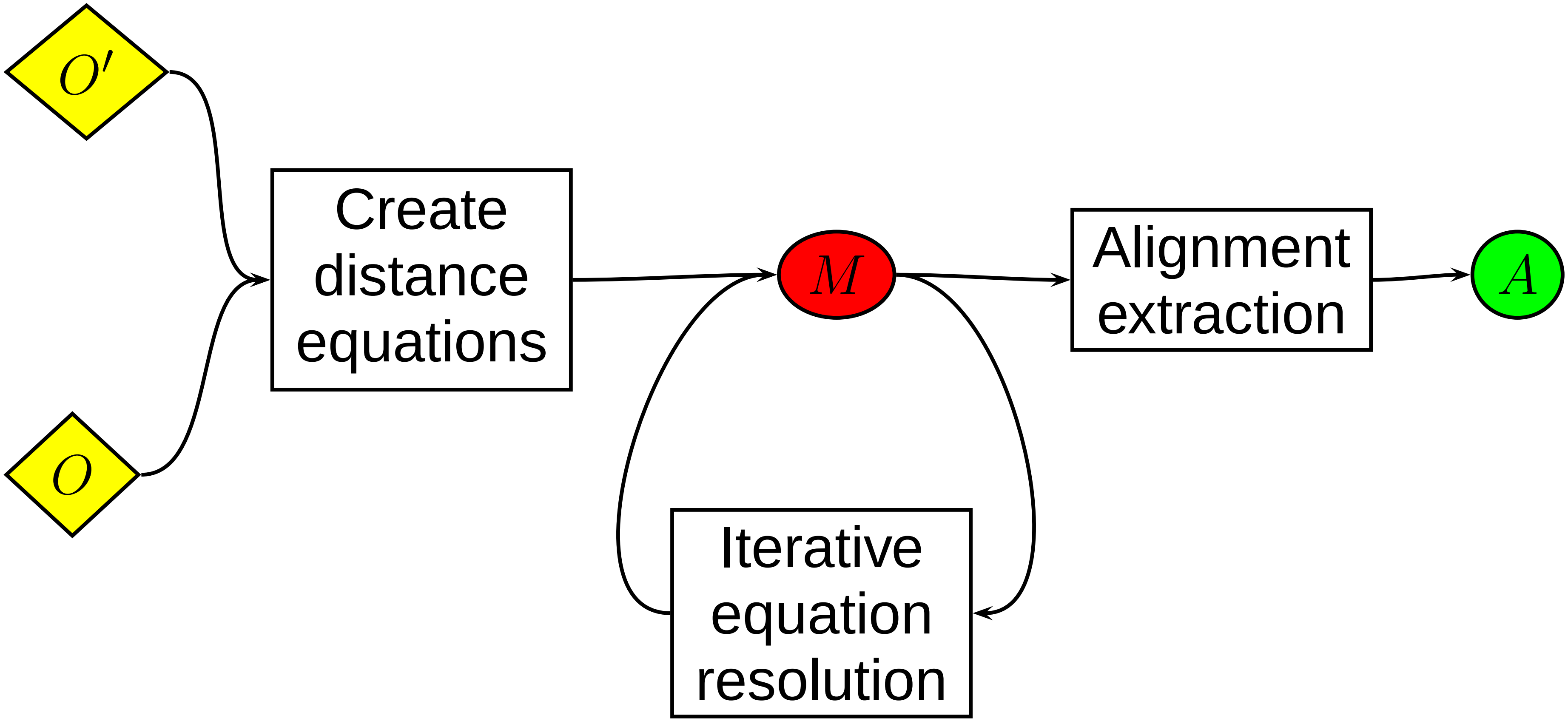
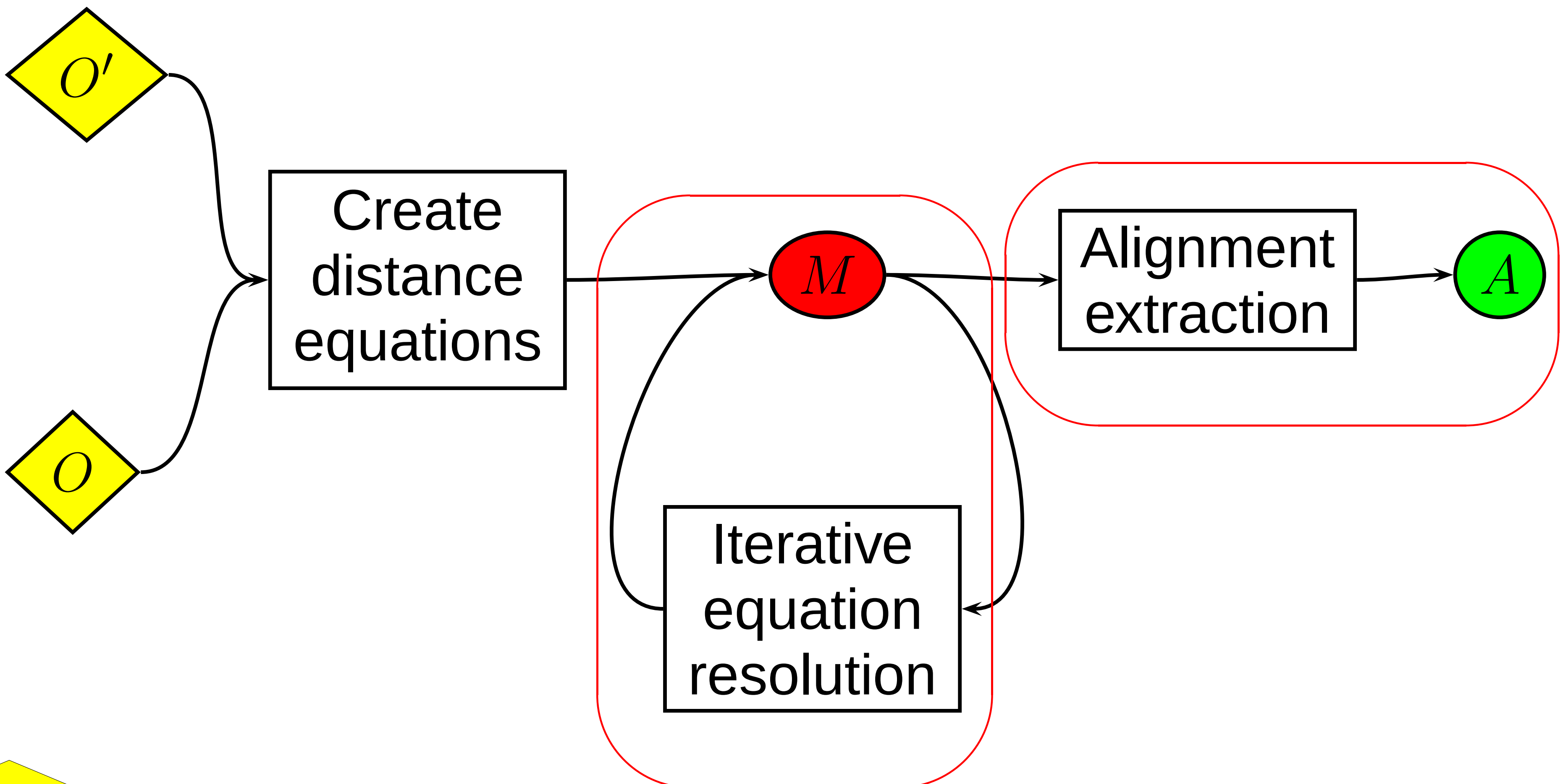
# Review of the matching systems

## OLA



# Review of the matching systems

## OLA



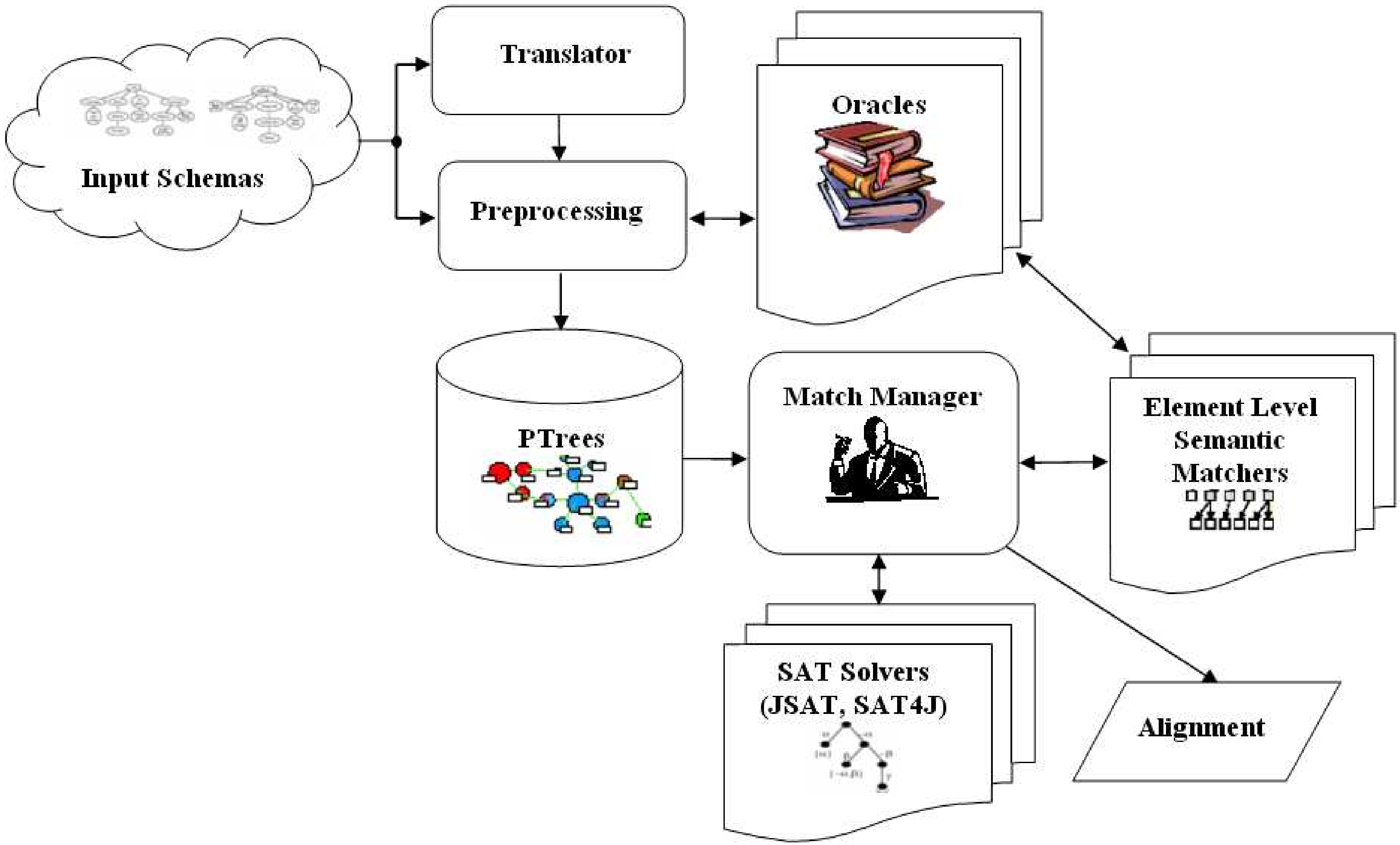
# Review of the matching systems

## S-Match

- Schema-based
- Computes equivalence (=); more general ($\sqsupseteq$); less general ($\sqsubseteq$); disjointness ($\perp$)
- Analyzes the meaning (concepts, not labels) which is codified in the elements and the structures of schemas/ontologies
- Sequential system with a "composition" at the element level
- Alignments as theorems

# Review of the matching systems

## S-Match

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# Review of the matching systems

## Analytical comparison

| | | SF | Artemis | Cupid | COMA | NOM | Anchor-PROMPT | OLA | S-Match |
|---|---|---|---|---|---|---|---|---|---|
| Element-level | Syntactic | string-based (2); data types; key properties | domain compatibility; language-based (1) | string-based (2); language-based (2); data types; key properties | string-based (4); language-based (1); data types | string-based (1); domains and ranges | string-based (1); domains and ranges | string-based (3); data types; language-based (1) | string-based (5); language-based (2) |
| | External | - | common thesaurus (CT): synonyms, broader terms, related terms | auxiliary thesaurus (synonyms, hypernyms, hyponyms, abbreviations ) | auxiliary thesaurus (synonyms, hypernyms, hyponyms, abbreviations ); alignment reuse (2) | application-specific vocabulary | - | WordNet(1) | WordNet: sense-based (2), gloss-based (6) |
| 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 (2); paths | matching of neighbors (2); taxonomic structure (4) | bounded paths matching (arbitrary links); bounded paths matching (processing *is-a* links separately) | Iterative fix-point computation; matching of neighbors; taxonomic structure | - |
| | Semantic | - | - | - | - | - | - | - | propositional SAT (2) |

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# Outline

- Matching problem
- Classification of schema-based matching techniques
- Basic techniques
- Matching process
- Review of the matching systems
- **Conclusions**

# Conclusions

## Summary

- We have discussed the schema/ontology matching problem and its application domains
- We have provided classificatory elements for approaching schema/ontology matching techniques
- We have presented a number of basic matching techniques as well as different strategies for building the matching process
- We have reviewed and compared (analytically) some existing matching systems

# Conclusions

## Uses of classifications

- They provide a common conceptual basis, and hence, can be used for comparing (analytically) different existing schema/ontology matching systems
- They can help in designing a new matching system, or an elementary matcher, taking advantages of state of the art solutions
- They can help in designing systematic benchmarks, e.g., by discarding features one by one from schemas/ontologies, namely, what class of basic techniques deals with what feature

# Conclusions

## Research Challenges

- Industry-strength schema/ontology matching
  - Scalability
- Interactive approaches
- Infrastructures (e.g., Rondo, Chimaera)
  - Representing the alignment
  - Executing the alignment
  - Explaining the alignment

# Conclusions

## Research Challenges

- Matching web services at the process level
- Lightweight ontology matching and emerging semantics
- Automatic partial alignment

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# Conclusions

## Research Challenges

- Evaluation
  - Testbed environment
    - Series of tests, each with a pre-defined problem
    - Real-world case studies
  - More accurate evaluation measures
  - Adequacy task / measure
  - Testing methodology which is able to estimate quality of the alignment between schemas/ontologies with thousands of entities

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Questions?

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Thank You

for your attention and interest!

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## 1 Surveys

Good surveys through the recent years are provided in [18, 24, 36, 40, 44, 47, 49].
Major contributions of the last decades were presented in [2, 26, 27, 43].

## 2 Schema-based matching systems

| **Name** | **Publications** | **Project web-site** |
|---|---|---|
| Artemis | [3, 4, 9] | - |
| COMA, COMA++ | [1, 11, 41] | http://dbs.uni-leipzig.de/Research/coma.html |
| CtxMatch | [7, 8] | - |
| Cupid | [29] | - |
| Naive Ontology Mapping (NOM) | [16] | http://www.aifb.uni-karlsruhe.de/WBS/meh/foam/ |
| OWL Lite Alignment (OLA) | [19, 20] | http://www.iro.umontreal.ca/∼owlola/alignment.html |
| PROMPT | [37–39] | http://protege.stanford.edu/plugins/prompt/prompt.html |
| Quick Ontology Mapping (QOM) | [15] | http://www.aifb.uni-karlsruhe.de/WBS/meh/foam/ |
| Similarity Flooding (SF) | [32, 33] | http://www-db.stanford.edu/ melnik/mm/sfa/ |
| S-Match | [21–23] | http://dit.unitn.it/∼accord/ |

## 3 Infrastructures

| **Name** | **Publications** | **Project web-site** |
|---|---|---|
| Chimaera | [30, 31] | http://www.ksl.stanford.edu/software/chimaera/ |
| OntoMerge | [14] | http://cs-www.cs.yale.edu/homes/dvm/daml/ontology-translation.html |
| Protoplasm | [5] | - |
| Rondo | [32, 34, 35] | http://www-db.stanford.edu/ melnik/mm/rondo/ |

## 4 Further Readings

– **Instance-based Matching**: [10, 13, 25];

– **Languages for the alignment representation**: [6, 42];
– **Executing the Alignment**: [28, 31, 48, 50];
– **Explaining the Alignment**: [10, 45];
– **Evaluation**: [12, 17, 46].

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