



Structural Summarization of Semantic Graphs

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Structural Summarization of Semantic Graphs

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ESWC Conference, June 5, 2018

Outline

- 1 **Motivation:** **data discovery** in semantic-rich RDF graphs
- 2 **Framework:** **quotient summaries**
 - Smaller graph which represents the original one in some sense
- 3 **Proposal:** use **property cliques** for summarizing **explicit** and **implicit** data
- 4 Summarization **algorithms**
- 5 Perspectives

Joint work with François Goasdoué (U. Rennes 1 and Inria), Paweł Guzewicz (U. Paris Saclay and Inria), and Šejla Čebirić (U. Paris Saclay and Inria) [ČGM15a, ČGM15b, ČGM17a, GM18, PGA⁺18]

Part I

Motivation: data discovery in RDF graphs

Big Data needs semantics

AI Magazine, Spring 2015



The image displays two side-by-side screenshots of the DATA.GOV website, illustrating the application of semantics in big data search. Both screenshots show the 'DATA CATALOG' section with a search filter set to 'Natural Disaster' and 'Earthquakes' respectively. The search results are organized into a grid of cards, each representing a different dataset. The cards include a title, a brief description, and a 'Show More Dataset Type' link. The datasets are categorized by 'Dataset Type' (e.g., 'FEMA Disaster Declarations Summary', 'Noninsured Crop Disaster Assistance Program', 'Child Nutrition Programs Disaster Response Memo') and 'Type' (e.g., 'earthquake (19)', 'disasters (18)'). The search results are ordered by 'Relevance'.

Left Screenshot: Natural Disaster

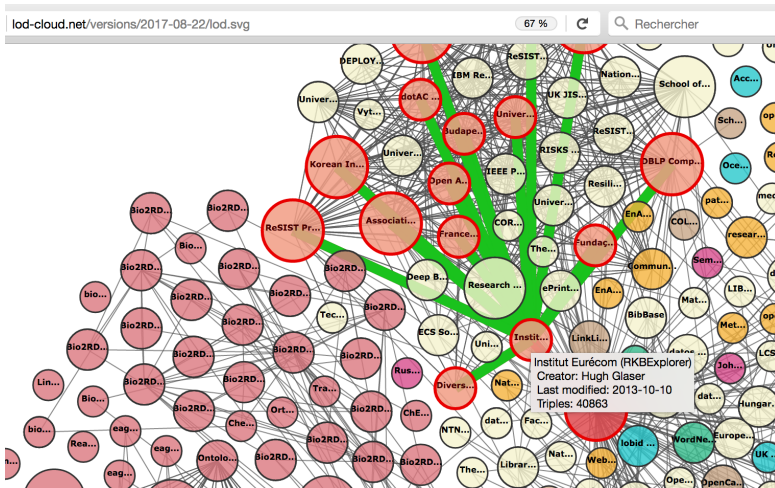
- 93 datasets found for "Natural Disaster"**
- FEMA Disaster Declarations Summary**: Federal Emergency Management Agency (FEMA) Disaster Declarations Summary is a systematic dataset describing all federally declared disasters. This information begins with the first disaster declaration.
- Noninsured Crop Disaster Assistance Program**: Department of Agriculture — USDA's Farm Service Agency's (FSA) Noninsured Crop Disaster Assistance Program (NAP) provides financial assistance to producers of noninsurable crops when they...
- Child Nutrition Programs Disaster Response Memo**: Department of Agriculture — This memo outlines procedures on cooperation of various State agencies, School Food Authorities (SFA) participating in the National School Lunch and School Breakfast...

Right Screenshot: Earthquakes

- 243 datasets found for "Earthquakes"**
- Earthquake Feeds**: U.S. Geological Survey Department of the Interior — Near real-time earthquake information for a variety of time windows in a variety of formats.
- Earthquake Locations**: State of North Dakota — This layer has been compiled from real-time sources depicting the locations of earthquakes that have been confirmed to have occurred within the state of North Dakota.
- Earthquake Damage - General**: National Oceanic and Atmospheric Administration, Department of Commerce — An earthquake is the sudden or breaking of the ground produced by sudden displacement of rock in the Earth's crust. Earthquakes result from crustal stress...

RDF graph discovery

An RDF graph can be large and complex, lack a fixed schema, include many heterogeneous values...



RDF summaries

Simplified views of an RDF graph [ČGK⁺18]

- Most often, a summary is also a **graph**, and/or: **statistics**, **patterns**...
- Summarize: the **data**, the **ontology**, **both**
- Many prior works on graph summarization applied to RDF

RDF summaries

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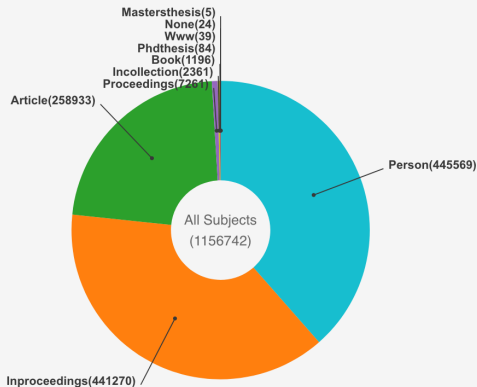
Summary uses:

- ① For **query processing**: give direct access to a group of nodes summarized together, detect empty queries...
- ② For **data discovery**: help identify interesting structure or patterns in the data

RDF graphs are often structurally heterogeneous

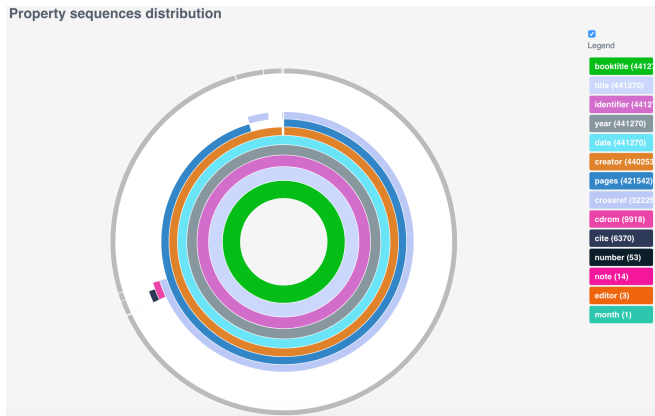
Subject types in DBLP bibliographic data:

Type distribution (Click *All Subjects* or a certain type below for further exploration.)



RDF graphs are often structurally heterogeneous

Data properties of DBLP conference articles:



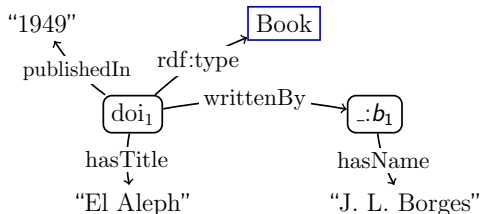
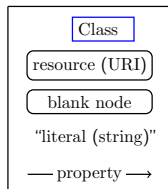
Our goal

Define **structural summaries** which:

- resist to **heterogeneity**
- flexibly take into account **RDF types**
- allow summarizing **implicit triples**
- can be **implemented efficiently**

The Resource Description Framework (RDF)

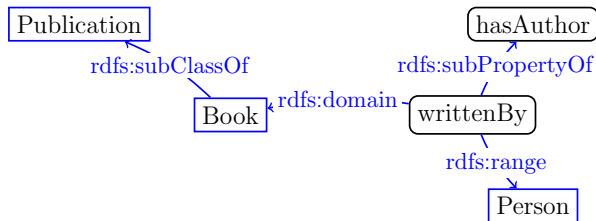
RDF graph: set of triples



RDF Schema

We consider **RDFS** deductive constraints, stating connections between classes and properties

Constraint	Triple	OWA interpretation
Subclass	$c_1 \text{ rdfs:subClassOf } c_2$	$c_1 \subseteq c_2$
Subproperty	$p_1 \text{ rdfs:subPropertyOf } p_2$	$p_1 \subseteq p_2$
Domain typing	$p \text{ rdfs:domain } c$	$\Pi_{\text{domain}}(p) \subseteq c$
Range typing	$p \text{ rdfs:range } c$	$\Pi_{\text{range}}(p) \subseteq c$

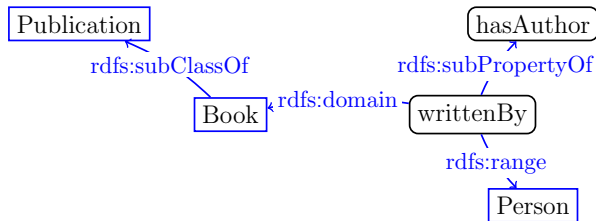


“Any c_1 is also a c_2 ”

RDF Schema

Simple language of deductive constraints between classes and properties

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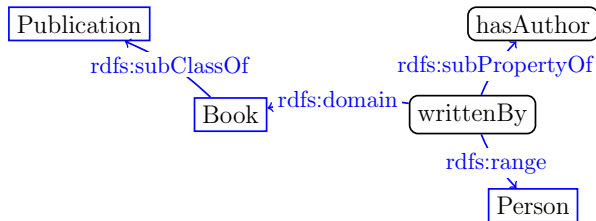


“If two resources are related by p_1 , they are also related by p_2 ”

RDF Schema

Simple language of deductive constraints between classes and properties

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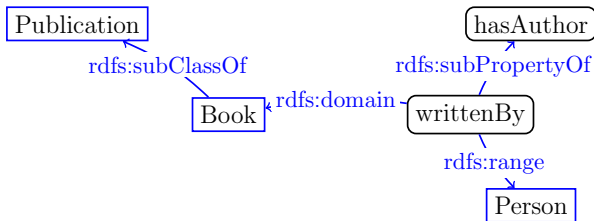


“Anyone having *p* is a *c*”

RDF Schema

Simple language of deductive constraints between classes and properties

Constraint	Triple	OWA interpretation
Subclass	$c_1 \text{ rdfs:subClassOf } c_2$	$c_1 \subseteq c_2$
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Range typing	$p \text{ rdfs:range } c$	$\Pi_{\text{range}}(p) \subseteq c$



“Anyone who is a value of p is a c ”

Open-world assumption and RDF entailment

RDF data model based on the open-world assumption.

Deductive constraints lead to **implicit triples**:
part of the graph even though not explicitly present

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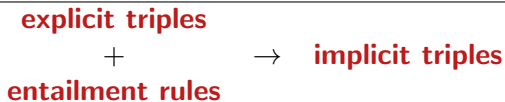
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explicit triples + entailment rules	→	implicit triples
---	---	-------------------------

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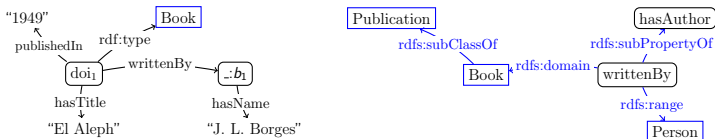
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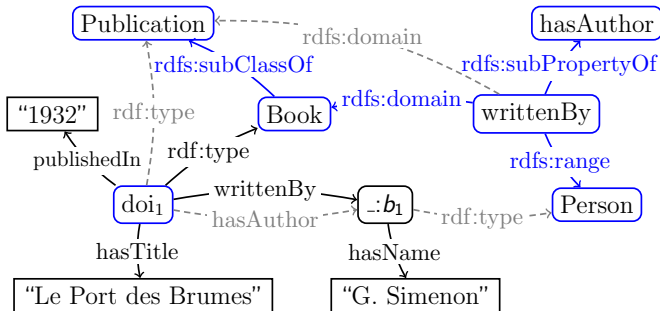
Exhaustive application of entailment leads to **saturation** (**closure**)

The semantics of an RDF graph G is its saturation G^∞

RDF data graph and RDF schema graph:



Saturation of the graph union:



Part III

RDF summarization

RDF summaries

Problem

RDF graph G is large, heterogeneous, partially implicit.
How to compactly represent all its structure?

Existing solutions

Partial representation (frequent patterns, statistics etc.)
e.g., [NM11, LYL13]

Potentially not compact e.g., [GW97, CFKP15]
Only for **explicit data**, e.g., [CDT13, ZDYZ14]

A summary of DBLP data

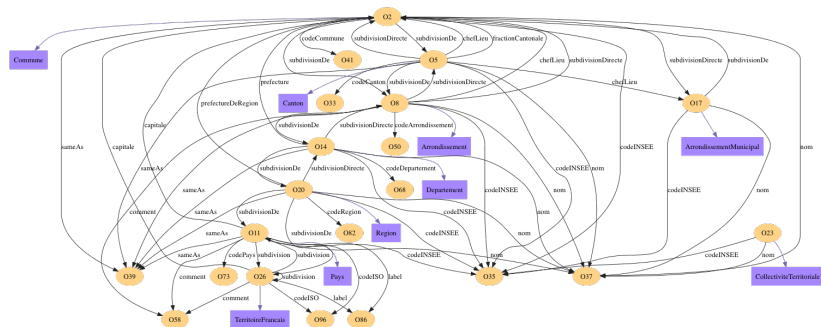
150M triples



A summary of geographic data

French territory division in regions, departments, urban areas, cities, districts etc.

368K triples



Dataset: <http://inec-gis.fr>. Number of triples: 368417
 Nodes: 30 (Typed: 9, Untyped: 21, Property: 0)
 Edges: 69 (Data edges: 69, Schema edges: 0)

Summarization principle: quotient graphs

Let \equiv be an equivalence relation on the nodes of G .

The **quotient G_{\equiv} of a directed graph G by \equiv** is a graph defined as follows:

- G_{\equiv} nodes: one for \equiv equivalence class of V
- G_{\equiv} edges: $n_{\equiv}^1 \xrightarrow{a} n_{\equiv}^2$ iff $\exists n_1 \xrightarrow{a} n_2 \in G$ such that n_1 represented by n_{\equiv}^1 , n_2 represented by n_{\equiv}^2

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Quotients have interesting summary qualities:

- 1 **Property completeness:** All G properties appear in G_{\equiv}
- 2 **Size guarantees:** By definition, G_{\equiv} is at most as large as G (usually much smaller)
- 3 **Structure representativeness:** Given a query q , if its **structure-only** version is empty on G_{\equiv} , then q is empty on G

Common graph quotients: bisimilarity [HHK95]

Two nodes are forward (resp. backward) bisimilar if they have exactly the same incoming (resp. outgoing) paths; \sim_{fw} , \sim_{bw} , \sim_{fb}

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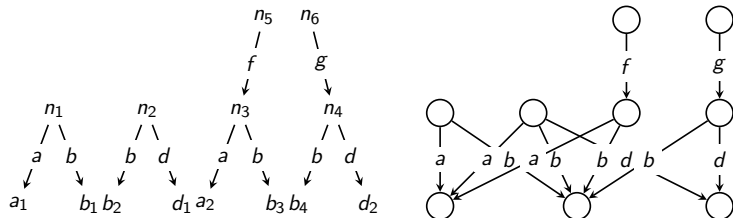
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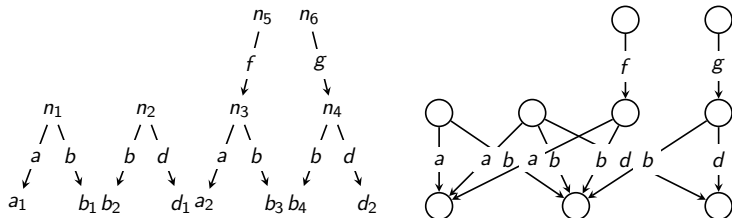
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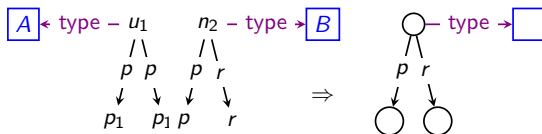
Requirement 1: We need equivalence relationships robust to structural heterogeneity.

What about type and schema triples?

Can we apply quotientization directly to an RDF graph?

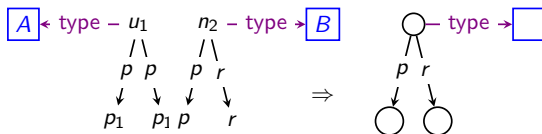
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 Sample graph G and a possible quotient:



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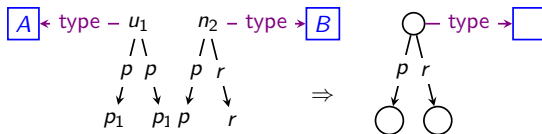


Possible loss of class and property names

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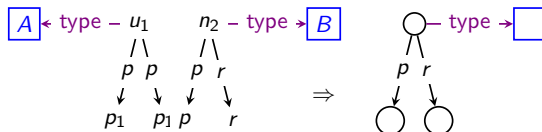
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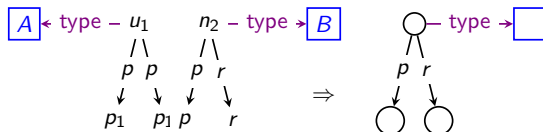
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Sample graph G and a possible quotient thereof:



Possible loss of implicit triples

Requirement 2: Avoid schema loss through quotientization

RDF equivalence relation and RDF summaries

To meet Requirement 2, we define:

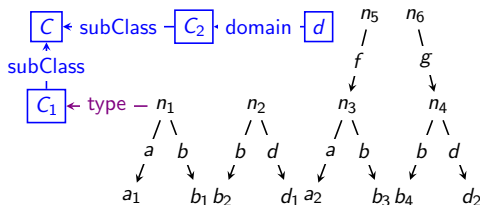
- ❶ **RDF equivalence relation:** an equivalence relation on RDF graph nodes such that any class or property node is only equivalent to itself
- ❷ **RDF summary:** a quotient of a graph G by an RDF equivalence relation such that any class or property node is represented by itself.

Consequence: For any RDF equivalence relation \equiv and RDF graph G , the schema of $G_{/\equiv}$ is the schema of G .

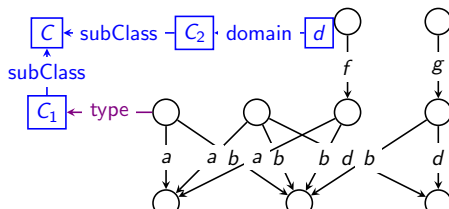
\Rightarrow No schema compression! (to be rediscussed briefly)

Summarization through an RDF equivalence relation

E.g., let \equiv_{1fb} to be the RDF node equivalence obtained from \sim_{1fb} .
Sample graph G:



Its quotient through the RDF node equivalence \equiv_{1fb} :



Recap

We have seen:

- **RDF node equivalence** and **RDF quotients** \Rightarrow structural representativeness, empty query pruning

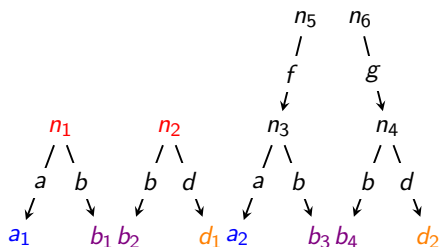
We still need to solve:

- **Requirement 1:** compact (yet preserve structure) even on heterogeneous graphs
- **Requirement 3:** can we summarize implicit triples?

We will address them in this order.

RDF node equivalence based on property cliques

Intuition: n_1, n_2 are “of the same kind”; similarly b_1, b_2, b_3

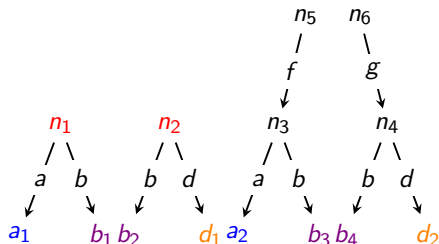


n_3, n_4 may or may not be of the same kind as n_1, n_2 .

RDF node equivalence based on property cliques

Output property cliques: $\{a, b, d\}$; $\{f\}$; $\{g\}$; \emptyset

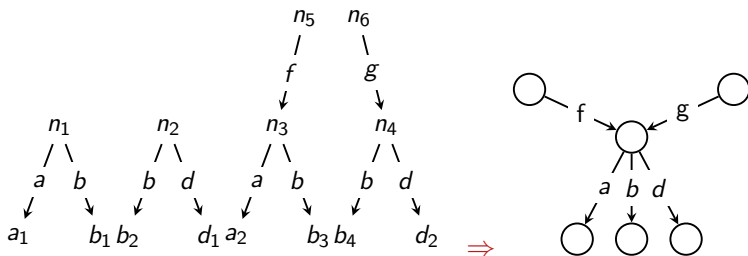
Input property cliques: $\{a\}$; $\{b\}$; $\{d\}$; $\{f\}$; $\{g\}$; \emptyset



Weak clique-based summaries

Two nodes are weakly equivalent (\equiv_w) iff they have **the same input clique** **or** **the same output clique** **or** are weakly equivalent to a third one.

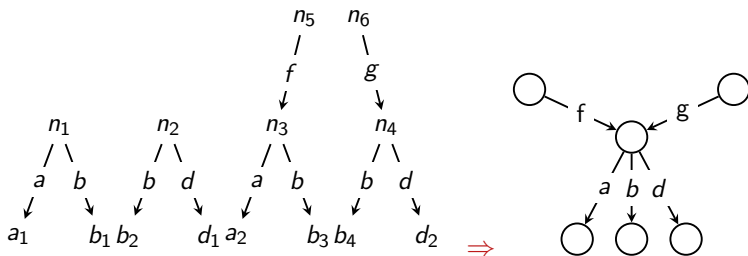
Weak summary G_w of the sample RDF graph G :



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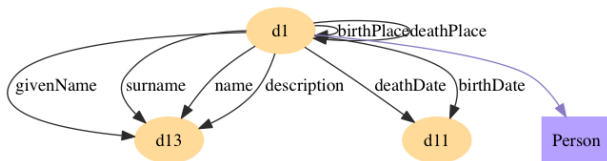


Property: In G_W , each data property appears exactly once \Rightarrow its nodes are “source of p , target of p ” for each p [ČGM15b].

Weak clique-based summaries

Property: G/W nodes are “source of p , target of p ” for each p .

Detecting errors in the data:: why do the birthplace and deathplace loop?



Looking in the data, we find:

```

<http://dbpedia.org/resource/Kunitomo_Ikkansai> <http://www.w3.org/1999/02/22-rdf-syntax-ns#type>
<http://xmlns.com/foaf/0.1/Person> .

```

```

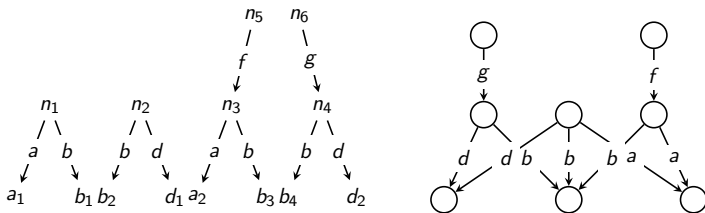
<http://dbpedia.org/resource/Kunitomo_Ikkansai> <http://dbpedia.org/ontology/birthPlace>
<http://dbpedia.org/resource/Kunitomo_Ikkansai> .

```

Strong clique-based summaries

Two nodes are strongly equivalent (\equiv_S) iff they have **the same input clique** **and** **the same output clique**.

Strong summary $G_{/\equiv_S}$ of the same G :



Which role should node types play in summarization?

Having the same type(s) is orthogonal w.r.t. having the same structure.

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Having the same type(s) is orthogonal w.r.t. having the same structure. Two alternatives:

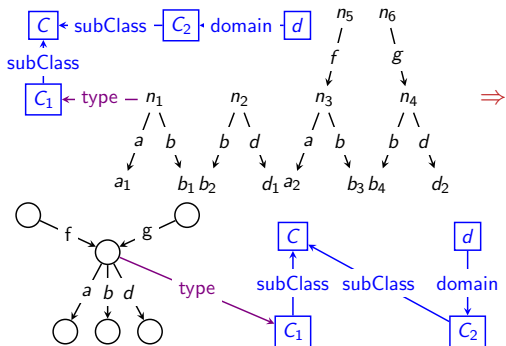
- 1 **Data-then-type:** group nodes first by their data triples, then carry the types from each \equiv group to its representative.

Which role should node types play in summarization?

Having the same type(s) is orthogonal w.r.t. having the same structure. Two alternatives:

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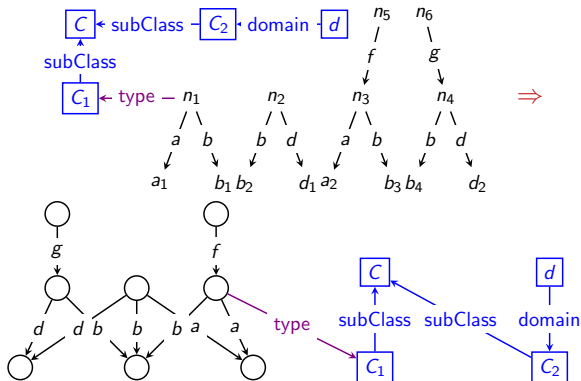
Extended Weak summary:



Adding types after data summarization

- 1 **Data-then-type:** group nodes first by their data triples, then carry the types from each \equiv group to its representative.

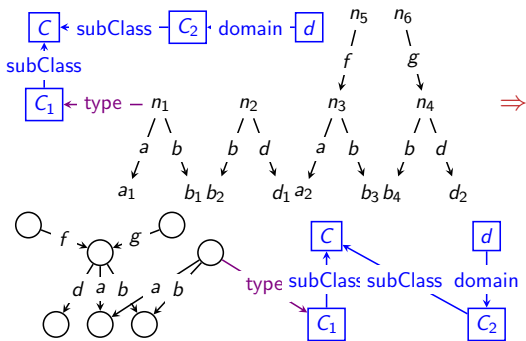
Extended Strong summary:



Giving prominence to types

- Type-then-data:** Group nodes by their type set, and **untyped** nodes by their data properties.

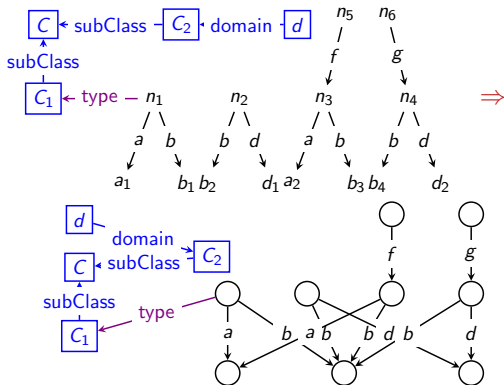
Typed Weak summary $G_{/\equiv TW}$ of the sample graph:



Giving prominence to types

- 1 **Type-then-data:** Group nodes first by their types. Only untyped nodes are grouped by their data properties.

Typed Strong summary $G_{\equiv TS}$ of the sample graph:



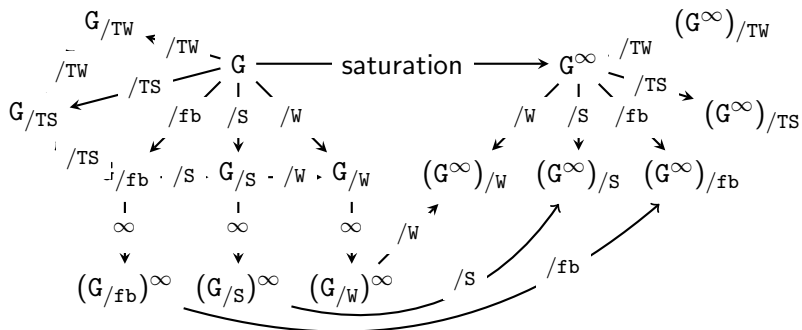
RDF summaries outline

Summary	Weak?	Strong?	Types first?
$G/\equiv W$	✓		
$G/\equiv S$		✓	
$G/\equiv TW$	✓		✓
$G/\equiv TS$		✓	✓

RDF summaries outline

Summary	Weak?	Strong?	FW bisim?	BW bisim?	Types first?
$G \equiv W$	✓				
$G \equiv S$		✓			
$G \equiv TW$	✓				✓
$G \equiv TS$		✓			✓
$G \equiv_{fw}$			✓		
$G \equiv_{bw}$				✓	
$G \equiv_{fb}$			✓	✓	
$G \equiv_{fw,T}$			✓		✓
$G \equiv_{bw,T}$				✓	✓
$G \equiv_{fb,T}$			✓	✓	✓

Relations between RDF summaries [ČGM17b]



Summary size comparison (more in [ČGM17b])

Graph G	$ G $	Summary $G_{/\equiv}$	$ G_{/\equiv} $	cf_{\equiv}
DBLP	150,787,464	$G_{/W}$	71	2,123,767
DBLP	150,787,464	$G_{/S}$	206	731,978
DBLP	150,787,464	$G_{/fw}$	262,695	574
LUBM1M	1,227,868	$G_{/W}$	161	7,579
LUBM1M	1,227,868	$G_{/S}$	207	5,903
LUBM1M	1,227,868	$G_{/fw}$	1982	617
LUBM10M	11,990,183	$G_{/W}$	162	74,013
LUBM10M	11,990,183	$G_{/S}$	206	58,204
LUBM10M	11,990,183	$G_{/fw}$	24,958	480
LUBM10M	11,990,183	$G_{/bw}$	6,162	1,944
LUBM10M	11,990,183	$G_{/fb}$	11,990,076	1

Summarizing G^∞

Recall: With an RDF Schema, the semantics of G is $G^\infty \Rightarrow$
We really need $(G^\infty)_{/\equiv}$!

- 1 Saturate G , then summarize
- 2 Can we avoid saturating G ...

Summarizing G^∞

Recall: With an RDF Schema, the semantics of G is $G^\infty \Rightarrow$
 We really need $(G^\infty)_{/\equiv}$!

- ① Saturate G , then summarize
- ② Can we avoid saturating G ?

Shortcut theorem [ČGM17a]

For the summaries $G_{/\equiv} W$, $G_{/\equiv} S$, $G_{/\equiv} fw$, $G_{/\equiv} bw$, $G_{/\equiv} fb$:

$(G^\infty)_{/\equiv}$ is the same as $((G_{/\equiv})^\infty)_{/\equiv}$

Also: **sufficient condition** for any \equiv to admit the shortcut.

Shortcut path to G^∞

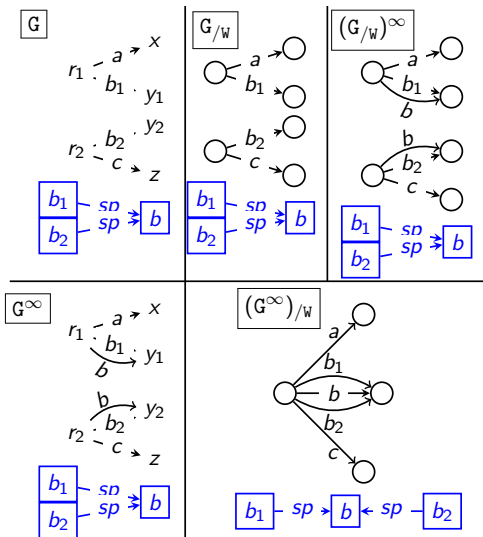
Direct $G \rightarrow \mathbf{sat.} \rightarrow G^\infty \rightarrow \mathbf{summ.} \rightarrow (G^\infty)_\equiv$

Shortcut $G \rightarrow \mathbf{summ.} \rightarrow G_\equiv \rightarrow \mathbf{sat.} \rightarrow (G_\equiv)^\infty \rightarrow \mathbf{summ.} \rightarrow ((G_\equiv)^\infty)_\equiv$

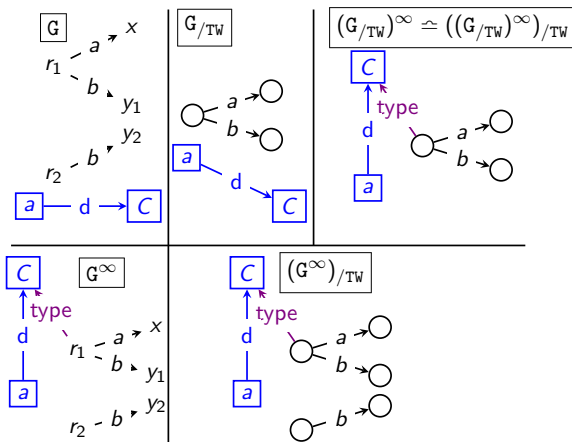
If G_\equiv is much smaller than G , **the shortcut may be faster!**

Up to 20 times in our experiments [ČGM17b]

Shortcut example: $G/\equiv W$



Shortcut counter-example: $G/\equiv \text{TW}$



Summarization algorithms

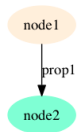
- 1 **Global algorithms:** visit all G , compute \equiv relation, then traverse G again and represent each triple in $G_{/\equiv} W$
- 2 **Incremental algorithms:** visit G , compute \equiv and summary based on knowledge gained so far; **adjust** summary

We devised global and incremental summarization algorithms for $G_{/\equiv} W$, $G_{/\equiv} S$, $G_{/\equiv} TW$, $G_{/\equiv} TS$.

Difficulty of incremental summarization: adjusting \equiv and revisiting summarization decisions

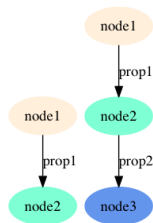
Example: weak incremental summarization (1)

Each color corresponds to a different \equiv_w class



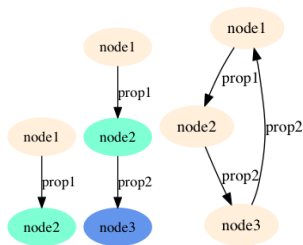
Example: weak incremental summarization (1)

Each color corresponds to a different \equiv_w class



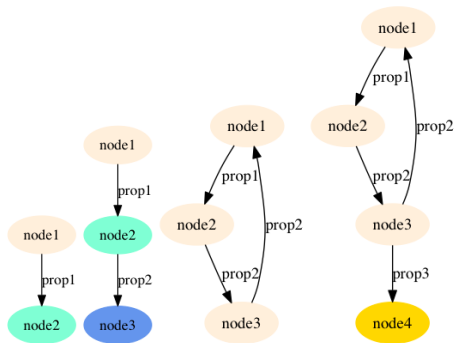
Example: weak incremental summarization (1)

Each color corresponds to a different \equiv_W class



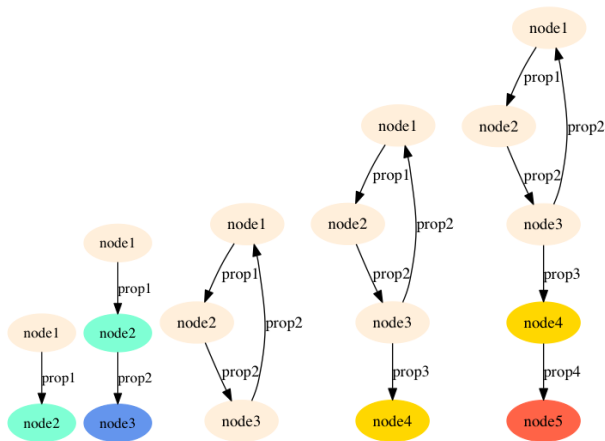
Example: weak incremental summarization (1)

Each color corresponds to a different \equiv_W class



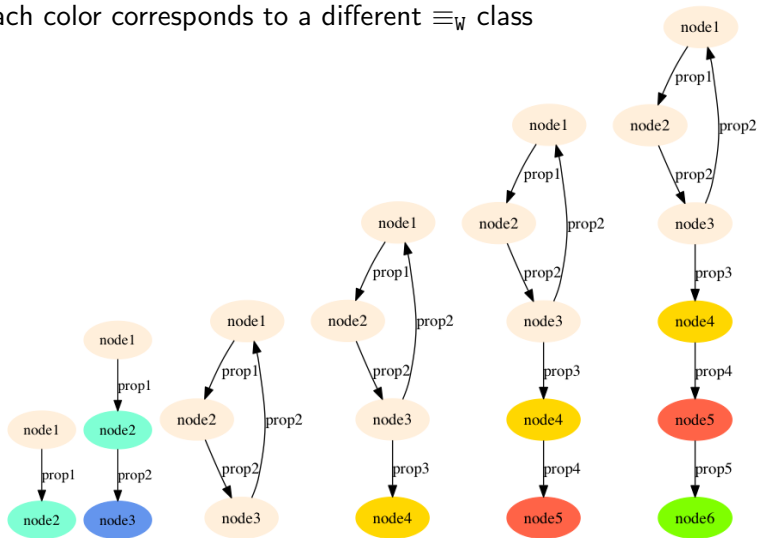
Example: weak incremental summarization (1)

Each color corresponds to a different \equiv_W class



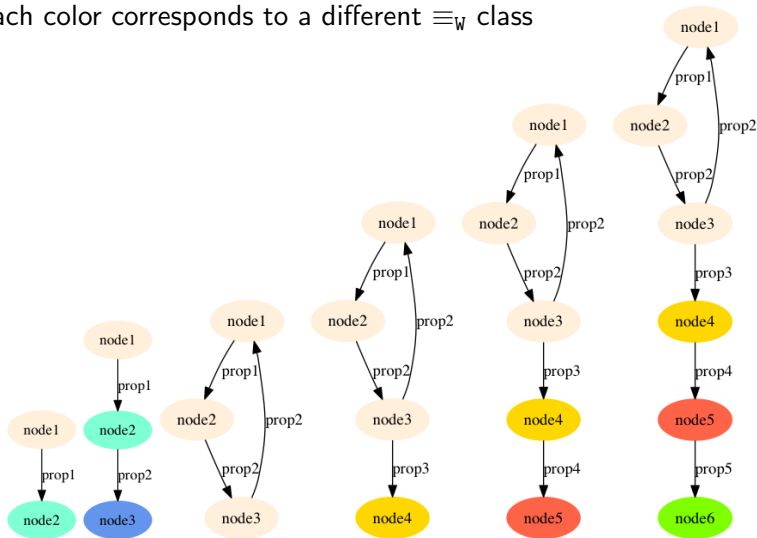
Example: weak incremental summarization (1)

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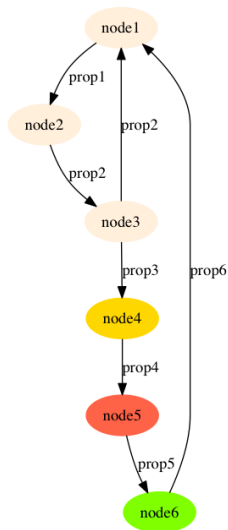


Example: weak incremental summarization (1)

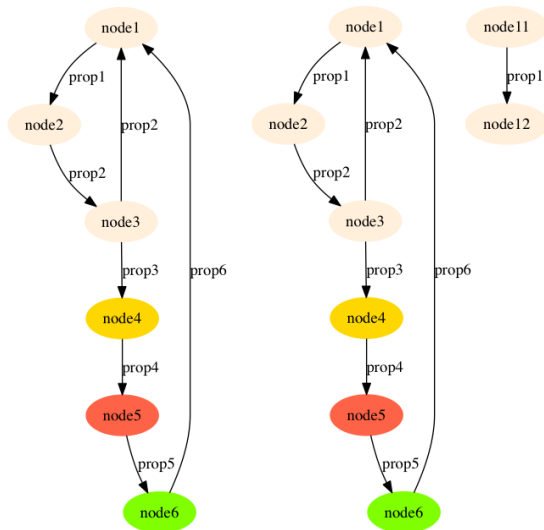
Each color corresponds to a different \equiv_W class



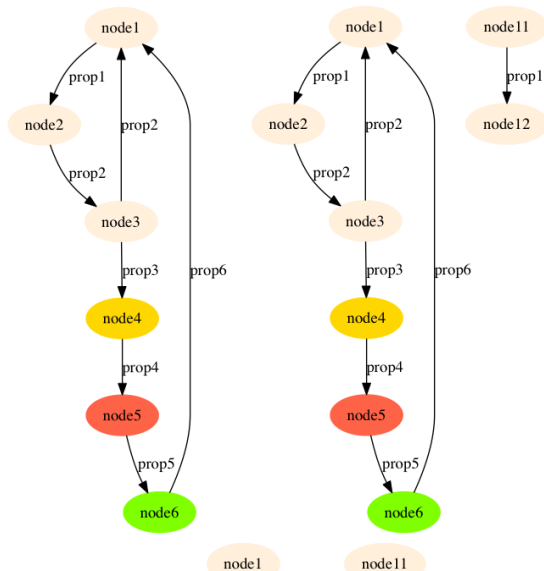
Example: weak incremental summarization (2)



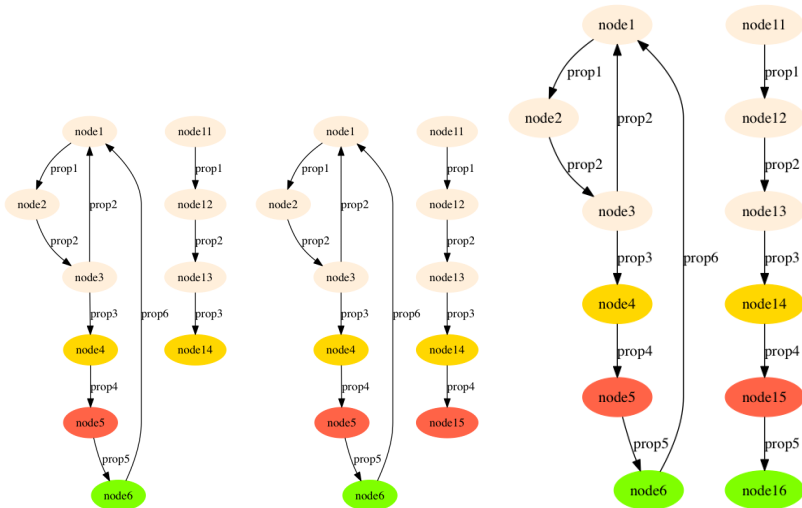
Example: weak incremental summarization (2)



Example: weak incremental summarization (2)

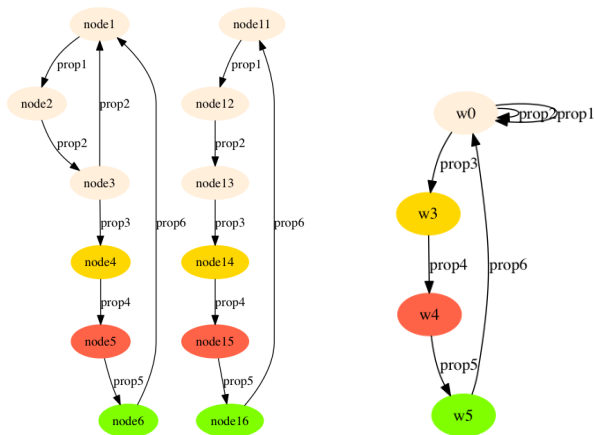


Example: weak incremental summarization (3)



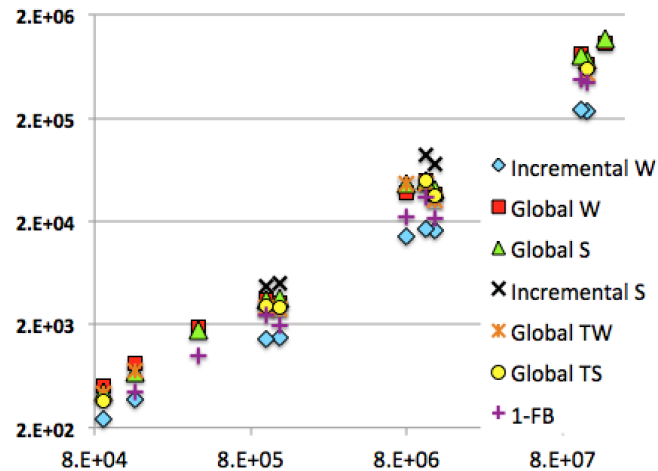
Example: weak incremental summarization (end)

Full graph and its summary:



Algorithm scale-up


10^5 to 1.5×10^8 triples

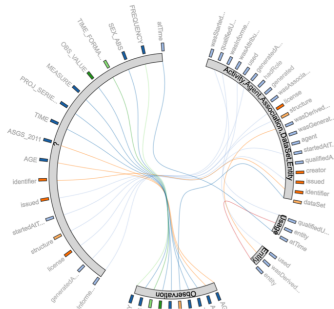
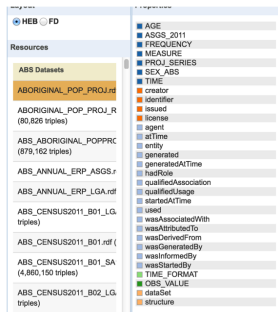


Summary-enabled LOD cloud exploration [PGA⁺18]

Collaboration with ILDA Inria data vizualization team on LODAtlas
<http://lodatlas.lri.fr/>

Use summary to derive visualisation instead of the original graph
 (smaller, faster)

abs-linked-data : Australian Bureau of Statistics (ABS) Linked Data 



Part IV

Conclusion

The need for RDF graph discovery tools

- RDF graphs can be **large and complex**, they lack a prescriptive schema
- Semantic rules lead to **implicit data**
- **Structural quotient summaries** compactly represent graph structure and semantics.
Available online at: (new version soon)

<https://team.inria.fr/cedar/projects/rdfsummary/>

- Type-first summarization variant to cope with large type hierarchies [GM18]
- Integration into LODAtlas platform [PGA⁺18]

Part V

Perspectives

Ongoing and future work

Ongoing:

- ① Experiment with new, parallel summarization algorithms based on Spark
- ② Keyword search in RDF graphs based on quotient summaries

Future:

- ① Controlled inclusion of data value synopsis in the summary
- ② Extension to more expressive ontology languages
- ③ Integration in a larger platform for summary-based data discovery (with Mirjana Mazuran)
- ④ Exploration of interesting aggregate view of RDF graphs (with Yanlei Diao)

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