

### **Scalable Authoritative OWL Reasoner**



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National University of Ireland, Galway Ollscoil na hÉireann, Gaillimh



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SAOR - Scalable Authoritative OWL Reasoning

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- Apply a subset of OWL reasoning to the billion triple challenge dataset
- Forward-chaining rule based approach, e.g.[ter Horst, 2005]
- Reduced output statements for the SWSE use case...
  - □ Must be *scalable*, must be *reasonable*
- incomplete w.r.t. OWL BY DESIGN!
  - □ SCALABLE: Tailored ruleset
    - file-scan processing
    - avoid joins
  - □ AUTHORITATIVE: Avoid Non-Authoritative inference
    - ("hijacking", "non-standard vocabulary use")







## **Scalable** Reasoning



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### **Scan 1:**

Scan all data (1.1b statements), separate T-Box statements, load T-Box statements (8.5m) into memory, perform authoritative analysis.

### **Scan 2:**

Scan all data and join all statements with in-memory T-Box .

□ Only works for inference rules with 0-1 A-Box patterns

- $\Box$  No T-Box expansion by inference
- → Needs "tailored" ruleset



### **Rules Applied:** Tailored version of [ter Horst, 2005]

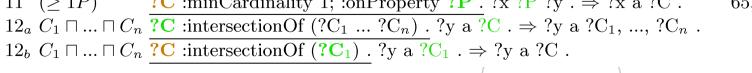


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# DL Syntax	Rule	# Inferred					
$\mathcal{G}0: NO A-BOX PATTERNS IN ANTECEDENT$							
$00 \ \{o_io_n\}$	<b>?C</b> :oneOf $(?o_1 \dots ?o_n) \rightarrow ?o_1 \dots ?o_n a ?C$ .	35,161					
G1 : ONE A-BOX PATTERN IN ANTECEDENT							
$01  C \sqsubseteq D$	<u><b>?C</b></u> rdfs:subClassOf ?D . ?s a ?C . $\Rightarrow$ ?s a ?D .	$1,\!124,\!758,\!631$					
$\frac{02_a}{02_a} C \equiv D$	<b>?C</b> :equivalentClass ?D . ?s a ?C . $\Rightarrow$ ?s a ?D .	$8,\!137,\!162$					
$02_b C \equiv D$	$\overrightarrow{C}$ :equivalentClass $\overrightarrow{D}$ . ?s a ?D . $\Rightarrow$ ?s a ?C .	$90,\!372$					
$03  P \sqsubseteq Q$	<b>?P</b> rdfs:subPropertyOf ?Q . ?s ?P ?o . $\Rightarrow$ ?s ?Q ?o .	$156,\!462,\!399$					
$\begin{array}{c} 04_a \\ 04_b \end{array} P \equiv Q$	<b>?P</b> :equivalentProperty ?Q . ?s ?P ?o . $\Rightarrow$ ?s ?Q ?o .	$5,\!667,\!464$					
$04_b$ $T \equiv Q$	$\overline{\text{P}:\text{equivalentProperty } \mathbf{?Q}}$ . ?s ?Q ?o . $\Rightarrow$ ?s ?P ?o .	$6,\!642$					
$\frac{05_a}{05} P \equiv P_0^-$	<b>?P</b> :inverseOf ?Q . ?s ?P ?o . $\Rightarrow$ ?o ?Q ?s .	$230,\!945,\!040$					
$05_b$ $I \equiv I_0$	$\overrightarrow{P}$ :inverseOf $\overrightarrow{Q}$ . ?s ?Q ?o . $\Rightarrow$ ?o ?P ?s .	$230,\!941,\!648$					
$06  \top \sqsubseteq \forall P^C$	<u><b>?P</b> rdfs:domain ?C</u> . ?s ?P ?o . $\Rightarrow$ ?s a ?C .	$588,\!530,\!865$					
07 $\top \sqsubseteq \forall P.C$	<b>?P</b> rdfs:range ?C . ?s ?P ?o . $\Rightarrow$ ?o a ?C .	$528,\!995,\!909$					
$08  P \equiv P^-$	<b>?P</b> a :SymmetricProperty . ?s ?P ?o . $\Rightarrow$ ?o ?P ?s .	$560,\!460$					
$\frac{09_a}{09_b} \exists P.x$	<b>?C</b> :hasValue ?x; :onProperty <b>?P</b> . ?y ?P ?x . $\Rightarrow$ ?y a ?C .	$98,\!601$					
	<b>?C</b> :hasValue ?x; :onProperty ?P . ?y a ?C . $\Rightarrow$ ?y ?P ?x .	104,780					
10 $C_1 \sqcup \ldots \sqcup C_n$	$\mathbf{C}: \text{unionOf} \left( (C_1 \dots C_i \dots C_n) : \mathbf{X} \neq C_i \ . \Rightarrow \mathbf{X} \neq \mathbf{X} \right)$	$81,\!736,\!234$					
11 $(\geq 1P)$	<b>?C</b> :minCardinality 1; :onProperty <b>?P</b> . ?x ?P ?y . $\Rightarrow$ ?x a ?C .	$65,\!283,\!322$					
$12_a C_1 \sqcap \ldots \sqcap C_n$	<b>?C</b> :intersectionOf (?C <sub>1</sub> ?C <sub>n</sub> ) . ?y a ?C . $\Rightarrow$ ?y a ?C <sub>1</sub> ,, ?C <sub>n</sub>	. 115,383					





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# Good "excuses" to avoid G2 rules



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### The obvious:

□ G2 rules would need joins, i.e. to trigger restart of file-scan

### The interesting one:

- Take for instance IFP rule: **?P** a :InverseFunctionalProperty . ?x ?P ?o . ?y ?P ?o .  $\Rightarrow$  ?x :sameAs ?y  $\Box \forall \leq 1P^{-}$ Maybe not such a good idea on real Web data 000 SWSE. Semantic Web Search Engine C
  C
  (C) (X) (http://swse.deri.org/list?keyword=+++08445a31a78661b5c746feff39a9db6e4ed ) - (C C Google Q Home ? KEYWORD 08445a31a78661b5c746feff39a... ⊠ Results 1 - 10 of 195 next genid1http3A2F2Fluka Erweiterte Suche 08445a31a78661b5c746feff39a9db6e4e2cc5cf Suche Person Einstellungen Suche: 
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  - More experiments including G2, G3 rules in [Hogan, Harth, Polleres, ASWC2008]

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Document D authoritative for concept C iff:

- $\Box$  C not identified by URI
  - OR

 $\hfill\square$  De-referenced URI of  ${\bf C}$  coincides with or redirects to  ${\bf D}$ 

- $\Box$  FOAF spec authoritative for foaf:Person  $\checkmark$
- □ MY spec not authoritative for foaf:Person ¥
- Only allow extension in authoritative documents
   my:Person rdfs:subClassOf foaf:Person . (MY spec)
- BUT: Reduce obscure memberships

□ foaf:Person rdfs:subClassOf my:Person . (MY spec) 🗴

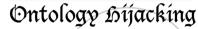
- Similarly for other T-Box statements.
- In-memory T-Box stores authoritative values for rule execution













### **Rules Applied**



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	$\mathcal{G}0$ : NO A-BOX PATTERNS IN ANTECEDENT	
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	$\bigcirc$ $\mathcal{G}_1: ONE A\text{-}BOX PATTERN IN ANTECEDENT$	
$01  C \sqsubseteq D$	<u>C dfs:subClassOf ?D</u> . ?s a ?C $\rightarrow$ ?s a ?D.	$1,\!124,\!758,\!631$
$\frac{02_a}{02_b} C \equiv D$	equivalentClass ?D . ?s a ?C . $\Rightarrow$ ?s a ?D .	$8,\!137,\!162$
	$\overline{\text{?C:equivalentClass ?D}}$ ?s a ?D . $\Rightarrow$ ?s a ?C .	$90,\!372$
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$\begin{array}{c} 04_a\\ 04_b \end{array} P \equiv Q \end{array}$	<b>?P</b> :equivalentProperty ?Q. ?s ?P ?o. $\Rightarrow$ ?s ?Q ?o.	$5,\!667,\!464$
	$\overline{\text{P}:\text{equivalentProperty } \mathbf{?Q}}$ . ?s ?Q ?o . $\Rightarrow$ ?s ?P ?o .	$6,\!642$
$05_{a} - D^{-}$	<b>?P</b> :inverseOf ?Q . ?s ?P ?o . $\Rightarrow$ ?o ?Q ?s .	$230,\!945,\!040$
$\frac{5_a}{5_b} P \equiv P_0^-$	$\overline{\text{P}:\text{inverseOf } ?\mathbf{Q}}$ . ?s ?Q ?o . $\Rightarrow$ ?o ?P ?s .	$230,\!941,\!648$
$6  \top \sqsubseteq \forall P^C$	<u><b>?P</b> rdfs:domain ?C</u> . ?s ?P ?o . $\Rightarrow$ ?s a ?C .	$588,\!530,\!865$
7 $\top \sqsubseteq \forall P.C$	<b>?P</b> rdfs:range ?C . ?s ?P ?o . $\Rightarrow$ ?o a ?C .	$528,\!995,\!909$
8 $P \equiv P^-$	<b>?P</b> a :SymmetricProperty . ?s ?P ?o . $\Rightarrow$ ?o ?P ?s .	$560,\!460$
$\overset{9_a}{\supset} \exists P.x$	<b>?C</b> :hasValue ?x; :onProperty <b>?P</b> . ?y ?P ?x . $\Rightarrow$ ?y a ?C .	$98,\!601$
$09_b \exists P.x$	<b>?C</b> :hasValue ?x; :onProperty ?P . ?y a ?C . $\Rightarrow$ ?y ?P ?x .	$104,\!780$
$0  C_1 \sqcup \ldots \sqcup C_n$	$\overrightarrow{\mathbf{C}} : \text{unionOf} \left( ?C_1 ?C_i ?C_n \right) . ?x \text{ a } ?C_i \Rightarrow ?x \text{ a } ?C .$	$81,\!736,\!234$
$1  (\geq 1P)$	<b>?C</b> :minCardinality 1; :onProperty <b>?P</b> . ?x ?P ?y . $\Rightarrow$ ?x a ?C .	$65,\!283,\!322$
$2_a C_1 \sqcap \dots \sqcap C_n$	$\overrightarrow{\mathbf{C}} : intersectionOf(?C_1 \dots ?C_n) \cdot ?y a ?C \rightarrow ?y a ?C_1, \dots, ?C_n$	. 115,383
$2_b C_1 \sqcap \ldots \sqcap C_r$	$\mathbf{C}$ : intersectionOf $(\mathbf{C}_1)$ . ?y a $\mathbf{C}_1$ . $\Rightarrow$ ?y a $\mathbf{C}$ .	42

The 17 rules applied including statements considered to be <u>T-Box</u>, elements which must be **authoritatively** spoken for (including for bnode OWL abstract syntax), and output count





### Authoritative Resoning covers rdfs: owl: vocabulary misuse



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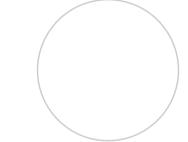
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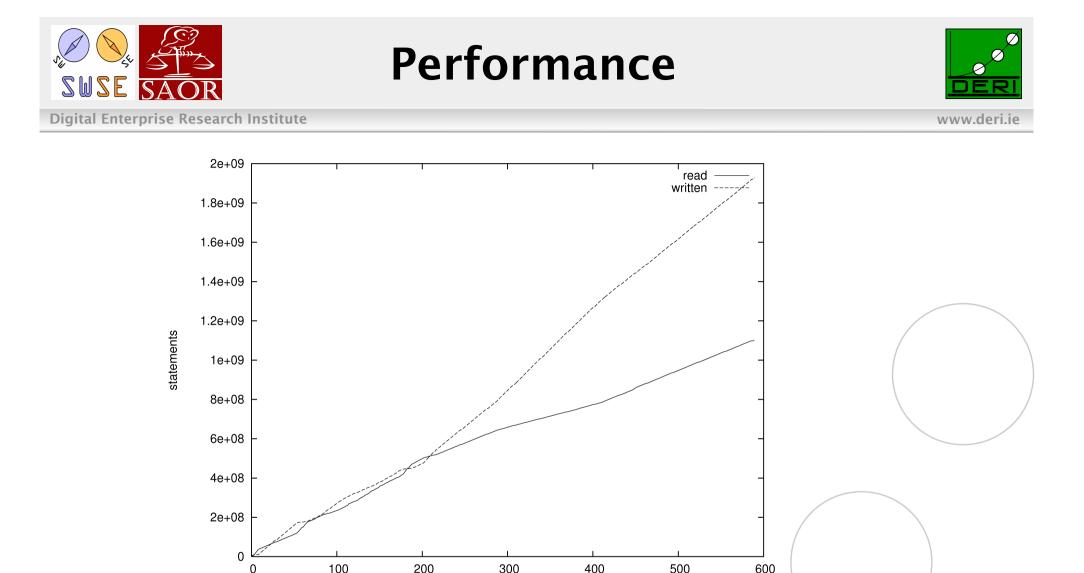
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  - etricProperty.



- Naïve rules application would infer O(n<sup>3</sup>) triples
- By use of authoritative reasoning SAOR/SWSE doesn't stumble over these S







Graph showing SAOR's rate of input/output statements per minute for reasoning on 1.1b statements: reduced input rate correlates with increased output rate and vice-versa

minutes elapsed

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# Results



#### SCAN 1: 6.47 hrs

□ In-mem T-Box creation, authoritative analysis:

SCAN 2: 9.82 hrs

 $\Box$  Scan reasoning – join A-Box with in-mem authoritative T-Box:

#### 1.925b new statements inferred in 16.29 hrs

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1.1b + 1.9b inferred = **3 billion** triples in SWSE

#### On our agenda:

- □ More valuable insights on our experiences from Web data
- □ G2 and G3 rules?
- Detailed comparison to OWL RL





## Search result example:

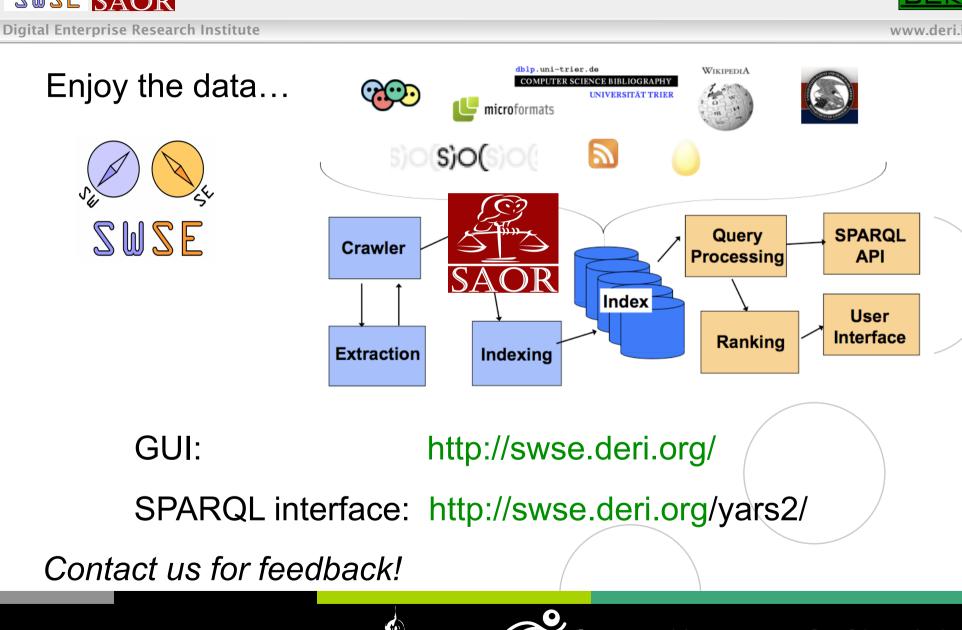
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