

Scalable authoritative reasoning: a logical reconstruction

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COST WG1 annual meeting
Cyprus, Dec 15, 2009

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- 1 Introduction
- 2 Syntax
- 3 Confidence values
- 4 Semantics
- 5 Conclusions
- 6 The End

Motivations

- Processing billions of triples, distributed over the web
- Even polynomial inference procedures are slow
- An interesting strategy: **incomplete reasoning**
 - LarKC
 - [Hogan, Hart & Polleres, Int. J. Semantic Web Inf. Syst., 2009]

Motivations

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Principled incompleteness

- Normal form for equality (sameAs)
 - use a representative member c for each equivalence class C
 - produce only triples d sameAs c for $d \in C$
- Ontology hijacking (authoritativeness)
 - non-conservative extensions of ontology by other organizations
 - non-authoritative, hence untrusted
 - ignore them
- Blacklisted knowledge
 - ill-formed, e.g. empty key attributes or incomplete URIs
 - many equalities erroneously inferred
 - ignore blacklisted knowledge
- Inconsistencies are not exploded

Principled incompleteness II

In summary, three main ideas

- 1 Partial materialization; completing inference from it is cheap
- 2 Ignore unreliable or ill-formed knowledge
- 3 Paraconsistent semantics

Here we focus on points 2 and 3

Contributions

- A logical model of reasoning with untrusted knowledge
 - extensible to further notions of trusted/reliable knowledge
 - e.g. based on provenance, page ranks, etc.
- Alternative notion of completeness
 - guarantees on the results of reasoning (coverage)
 - guidelines for implementations
 - a basis for interoperability
 - through shared meaning of less-than-perfect knowledge bases
- Without reinventing the wheel

Rule syntax

- As a first step, standard syntax
 - We want to process the rules adopted *today*
- This presentation does not bother with XML details
- Standard rules:

$$A \leftarrow B_1, \dots, B_n \quad (n \geq 0)$$

- and constraints (or *denials*)

$$\leftarrow B_1, \dots, B_n \quad (n > 0)$$

- where A, B_1, \dots, B_n are logical atoms.
- However, we shall adopt a nonclassical semantics

Confidence values

- Each fact (and each conclusion) is associated to a *confidence value*
- Confidence values are **structured** to capture difference facets
 - authoritativeness
 - blacklisted conclusions
 - reputation
 - ...
- Example: $\langle \textit{blacklisted}, \textit{authoritative}, 0.8 \rangle$

Confidence ordering

- Confidence values are **ordered** by their strength
- Example:

$\langle \textit{blacklisted}, \textit{authoritative}, 0.8 \rangle \preceq \langle \textit{correct}, \textit{non_authoritative}, 0.9 \rangle$

$\langle \textit{correct}, \textit{non_authoritative}, 0.9 \rangle \preceq \langle \textit{correct}, \textit{authoritative}, 0.7 \rangle$

Formalizing confidence values

Definition (Domain of confidence values, CV)

CV is the Cartesian product $D_1 \times \dots \times D_z$ of z total orders (D_i, \leq_i) with finite l.u.b. \max_i and finite g.l.b. \min_i ($i = 1, \dots, z$).

CV is totally ordered by \preceq that is the lexicographic ordering of CV based on \leq_i ($1 \leq i \leq z$).

Intuitions

Basic idea

Deriving A with confidence level v means:

there is a proof of A whose components all have a confidence value $\geq v$.

Example

A can be labelled $\langle \textit{non_blacklisted}, \textit{authoritative}, 0.3 \rangle$ only if some of its proofs adopts only

- non-blacklisted and authoritative rules and facts
- with confidence value ≥ 0.3 .

- **Q**: shall we invent a new semantics for rules?
- **A**: not completely...

Annotated programs [Kifer & Subrahmanian, JLP, 1992]

Definition (Syntax)

Rules are expressions

$$A:f(v_1, \dots, v_n) \leftarrow B_1:v_1 \& \dots \& B_n:v_n$$

where

- A, B_1, \dots, B_n are atoms
- v_1, \dots, v_n are constants or variables ranging over confidence values
- $f : CV^n \rightarrow CV$

Annotated programs [Kifer & Subrahmanian, JLP, 1992]

Definition (Semantics, specialized to total orderings)

An interpretation \mathcal{I} is a mapping $Atoms \rightarrow CV$

$$\mathcal{I} \models A:v \quad \text{iff} \quad v \preceq \mathcal{I}(A)$$

$$\mathcal{I} \models \neg A:v \quad \text{iff} \quad \neg v \preceq \mathcal{I}(A) \quad (\text{arbitrary operator } \neg : CV \rightarrow CV)$$

$$\mathcal{I} \models F \& G \quad \text{iff} \quad \mathcal{I} \models F \text{ and } \mathcal{I} \models G$$

$$\mathcal{I} \models F \leftarrow G \quad \text{iff} \quad \mathcal{I} \models F \text{ or } \mathcal{I} \not\models G$$

Remark

With this definition, when two sources with different reliability both say “A” there is no inconsistency:

$$A:v \& A:w \text{ entails } A:\max(v, w)$$

(the strongest evidence “wins”)

Annotated programs [Kifer & Subrahmanian, JLP, 1992]

- Under suitable conditions one can define an **immediate consequence operator** R_P which is **monotonic** and **continuous**
 - the study of such preconditions in our particular case is still in progress
- Its least fixpoints is the **least model** of the annotated program
- There exist also **top-down** calculi based on resolution

Application of annotated programs to our framework

The key steps are:

- 1 Implicit annotation of (standard) rules and facts
 - based on the approach of [Hogan et al. 2009]
 - of course, explicit annotations can be used if so desired
- 2 Definition of a suitable negation
- 3 Suitable semantics of denials
 - for paraconsistent contradiction handling

Paraconsistent annotated semantics

Intuitions:

- Each atom A is assigned **two** confidence values
 - associated to A 's **truth** and **falsity**, respectively
 - this allows for independent arguments in favor and against A
 - the closest the two values, the highest the uncertainty about A 's (classical) truth value
- The negation operator (\neg) swaps those two values
 - the confidence in the truth of A is the confidence in the falsity of $\neg A$ and viceversa
- Given a constraint $\leftarrow A, B$, if A has confidence value v then it follows that also $\neg B$ should *at least* have confidence value v
- therefore, if $A:v$ and $B:w$ hold, also $\neg B:v$ and $\neg A:w$ hold
 - $\leftarrow A_1, \dots, A_n$ abbreviates $\neg A_i \leftarrow A_1, \dots, A_{i-1}, A_{i+1}, \dots, A_n$
($1 \leq i \leq n$)

Paraconsistent annotated language

Definition (Syntax, simplified)

Annotated rules are expressions $v:R$ where R is

$$L_0 \leftarrow L_1 \& \dots \& L_n$$

where L_0, L_1, \dots, L_n are literals (A or $\neg A$)

Annotated constraints are annotated rules with empty head

Paraconsistent annotated semantics

Definition (Models and valuation)

An interpretation \mathcal{I} is a mapping $Atoms \rightarrow CV^2$

$$\mathcal{I}(A) = \langle \mathcal{I}^+(A), \mathcal{I}^-(A) \rangle$$

$$\mathcal{I}(\neg A) = \langle \mathcal{I}^-(A), \mathcal{I}^+(A) \rangle$$

If R is $v : L_0 \leftarrow L_1, \dots, L_n$ then

$$I \models R \text{ iff } \min_{\preceq} \{v, I^+(L_1), \dots, I^+(L_n)\} \preceq I^+(L_0)$$

If R is $w : \leftarrow L_1, \dots, L_n$ then

$$I \models C \text{ iff } \min_{\preceq} \{w, I^+(L_1), \dots, I^+(L_{i-1}), I^+(L_{i+1}), \dots, I^+(L_n)\} \preceq I^-(L_i)$$

for $i = 1, \dots, n$

Paraconsistent annotated semantics

Properties relevant to implementation

- Each literal has one confidence value
 - no matter how many proofs it has
 - no storage explosion
- Anytime algorithms are possible
 - store the current value (best proof so far)
 - replace it when a “better” proof is found
- Predefined thresholds can be set
 - literals below threshold can be ignored
 - they can't lead to any consequence above threshold

Conclusions

- A natural generalization of annotated programs nicely addresses
 - inconsistency confinement
 - authoritative reasoning
 - ill-formed knowledgein a uniform way
- Its properties are compatible with scalability needs
 - no storage explosion
 - anytime algorithms
 - thresholds

Further work

- Complete theoretical analysis
- Scalable, parameterizable implementations
- Suitable metalanguage for specifying confidence value domains
- Possibly drop restriction to total orders

QUESTION TIME