Ontology Integration Using Mappings: Towards Getting the Right Logical Consequences

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ESWC 2009 Crete June 3, 2009

Outline

Our approach in a nutshell

Logic-based Ontology Integration using Mappings

- We present a methodology and tool support
- We evaluate the consequences of integrating ontologies

Tool support — Protégé plugin ContentMap

- Operative for Protégé 4 beta

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Why are Ontologies Integrated?

Some Reasons...

- Ontology reuse in ontology development
- Data integration
- Interoperability between agents

Some Problems...

- How to establish mappings between ontologies
- How to evaluate compatibility between ontologies

Motivating Example

Bibliographic domain . . .

- Ontologies from the 2004 EON Ontology Alignment Contest.
- Describing bibliographic references: INRIA ($\mathcal{O}_{\text{INR}}$), MIT ($\mathcal{O}_{\text{MIT}}$), UMBC ($\mathcal{O}_{\text{UMBC}}$) and AIFB Karlsruhe ($\mathcal{O}_{\text{AIFB}}$).
- $\mathcal{O}_{\text{INR}}$ was used as reference.
- We use the corresponding **gold standard** to evaluate the integration.

Motivating Example: Integrating $\mathcal{O}_{\text{MIT}}$ and $\mathcal{O}_{\text{INR}}$

Some Mappings . . .

- $\mathcal{O}_{\text{INR}} : \text{year} \sqsubseteq \mathcal{O}_{\text{MIT}} : \text{hasYear}$
- $\mathcal{O}_{\text{INR}} : \text{TechnicalReport} \sqsubseteq \mathcal{O}_{\text{MIT}} : \text{Technicalreport}$

Unintended Consequences . . .

- $\text{TechnicalReport} \sqsubseteq \text{Date}$
- $\text{TechnicalReport} \sqsubseteq \exists \text{date.Reference}$

Explanation

- In $\mathcal{O}_{\text{MIT}}$: $\text{TechnicalReport} \sqsubseteq \geqslant \textit{hasYear}\ 1.\textit{Literal}$
- In $\mathcal{O}_{\text{INR}}$: year hasDomain Date

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- $\mathcal{O}_{\text{INR}}$: year $\sqsubseteq$ $\mathcal{O}_{\text{MIT}}$: hasYear
- $\mathcal{O}_{\text{INR}}$: TechnicalReport $\sqsubseteq$ $\mathcal{O}_{\text{MIT}}$: Technicalreport

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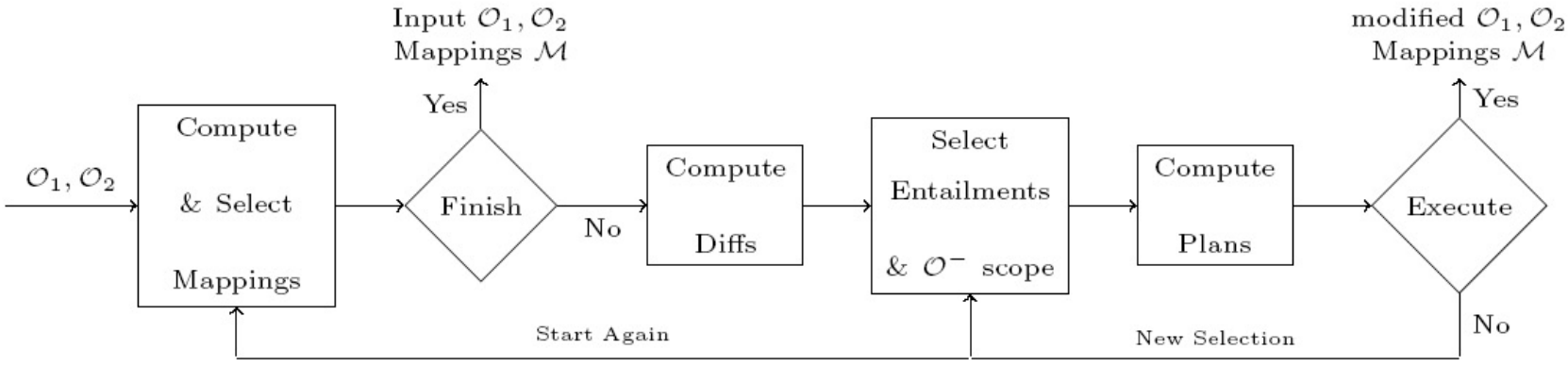
Necessity of a Logic-based Ontology Integration Method



Steps

- Generate or **reuse mappings** between ontologies
- Select and **filter** erroneous mappings
- **Reasoning** with the ontologies and the mappings
- **Compare entailments** before and after the integration
- Suggest possible ways to **repair errors**

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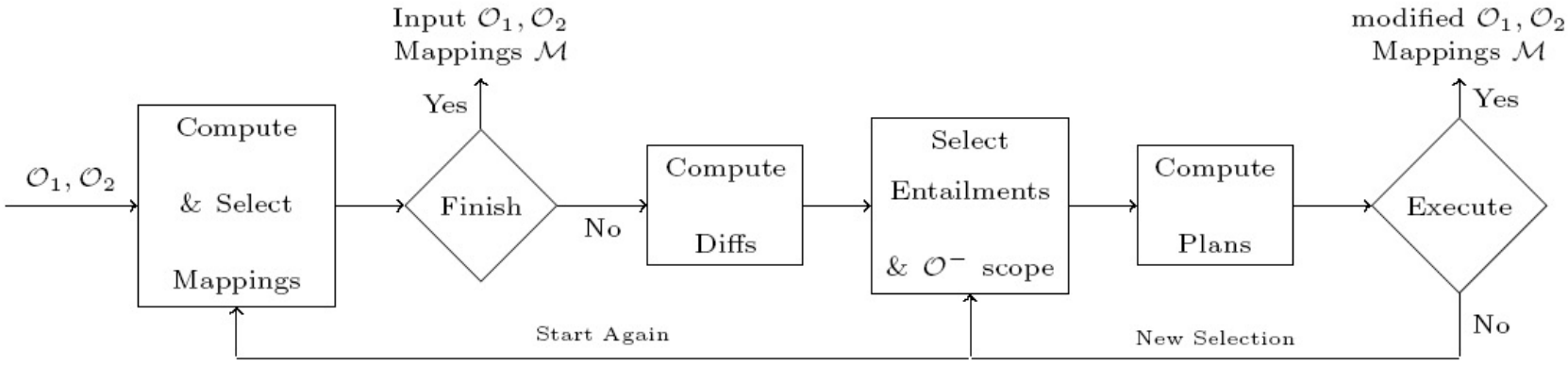

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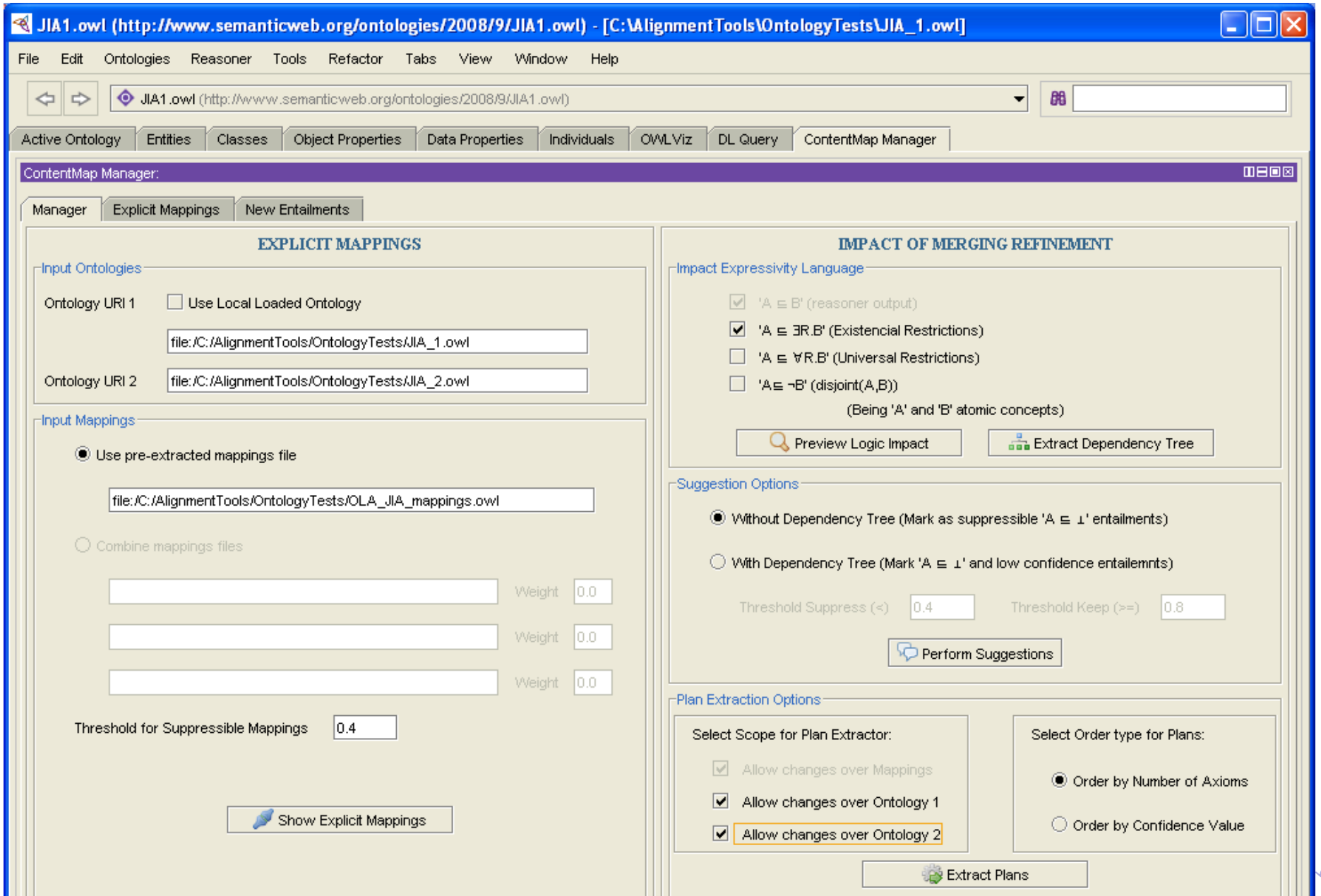
Tool Support: ContentMap Overview



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Computation of the Mappings

Mapping Representation

- Mappings $\langle id, e_1, e_2, n, \rho \rangle$
- are considered as OWL 2 axioms: SubClassOf(e_1 e_2), EquivalentClasses(e_1 e_2), or DisjointClasses(e_1 e_2)
- with ρ of the form ($\sqsubseteq$), ($\equiv$), or ($\bot$)
- and n (the confidence value) added as OWL 2 axiom annotation
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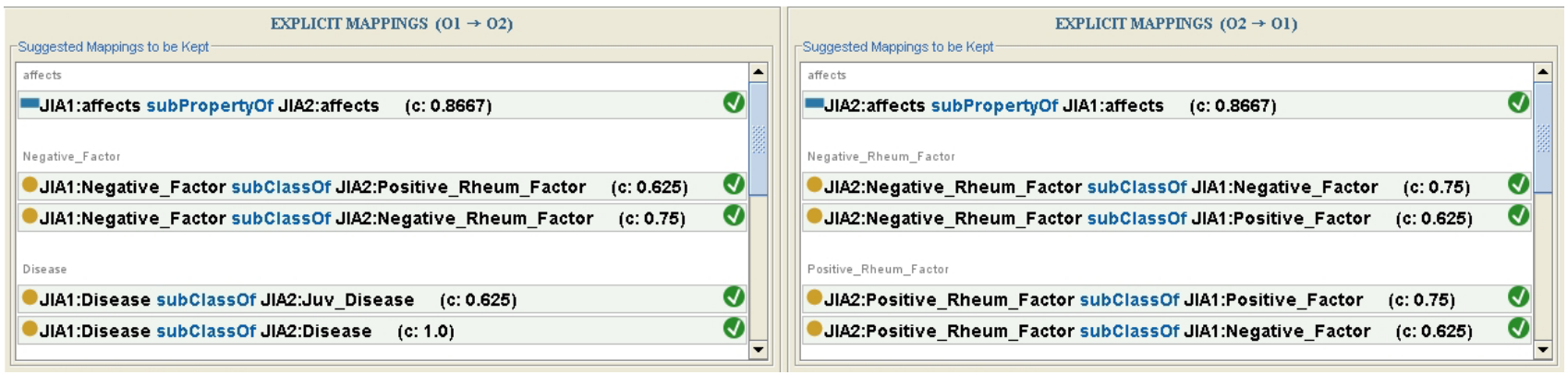
Mappings Selection: ContentMap support

Ontology Mapping Tools

- We reuse mapping generated by ontology matching tools
- For the experiments we used OLA, CIDER and AROMA



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Computation of New Entailments

Reasoning with $\mathcal{M}$, $\mathcal{O}_1$ and $\mathcal{O}_2$

- $\mathcal{M} \subseteq \text{map}(\mathcal{O}_1, \mathcal{O}_2)$ given by a tool
- $\mathcal{U} := \mathcal{O}_1 \cup \mathcal{O}_2 \cup \mathcal{M}$
- New entailments in $\mathcal{U}$ but not in $\mathcal{O}_1$, $\mathcal{O}_2$ or $\mathcal{M}$, regarding their respective signatures.

Computation of New Entailments: *Semantic Difference*

How to extract new entailments in $\mathcal{U}$

- Notion of *deductive difference*
- B. Konev, D. Walther and Frank Wolter: *"The Logical Difference Problem for Description Logic Terminologies"*

Definition (Deductive Difference)

$$\text{diff}_\Sigma(\mathcal{O}, \mathcal{O}') = \{\alpha \mid \alpha \text{ a } \mathcal{DL}\text{-axiom}, \mathcal{O} \not\models \alpha, \mathcal{O}' \models \alpha \text{ and } \text{Sig}(\alpha) \subseteq \Sigma\}$$

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$$\text{mdiff}_{\Sigma_1,\Sigma_2}(\mathcal{O}, \mathcal{O}') = \{\alpha \in \text{diff}_\Sigma(\mathcal{O}, \mathcal{O}') \mid \alpha \ \mathcal{DL}\text{-mapping between } \Sigma_1, \Sigma_2\}$$

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Problems of Semantic Difference...

- No algorithm for expressive DLs, such as $\mathcal{SROIQ}$ (OWL 2) and $\mathcal{SHOIQ}$ (OWL DL)
- Algorithms only for (fragments of) the OWL 2 EL and QL profiles
- The number of entailments in the difference can be huge (even infinite)

Necessity of an approximation

- $\mathrm{diff}^{\approx}_{\Sigma}(\mathcal{O}, \mathcal{O}') \subseteq \mathrm{diff}_{\Sigma}(\mathcal{O}, \mathcal{O}')$
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Approximations in ContentMap

A, B are atomic concepts (including $\top, \bot$) and R, S atomic roles

Approximation 1: reasoner output

- $A \sqsubseteq B$
- $R \sqsubseteq S$

Approximation 2: reasoner output plus . . .

- $A \sqsubseteq \neg B$
- $A \sqsubseteq \exists R.B$
- $A \sqsubseteq \forall R.B$

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Evaluation of Entailments: ContentMap support

Manual Entailment selection

- Once we have
  $\Lambda = \mathsf{diff}^{\approx}_{\Sigma_1}(\mathcal{O}_1, \mathcal{U}) \cup \mathsf{diff}^{\approx}_{\Sigma_2}(\mathcal{O}_2, \mathcal{U}) \cup \mathsf{mdiff}^{\approx}_{\Sigma_1,\Sigma_2}(\mathcal{M}, \mathcal{U})$
- Some entailments may be intended (called $\mathfrak{S}^+$),
- while others may reveal potential errors in $\mathcal{U}$ (called $\mathfrak{S}^-$).

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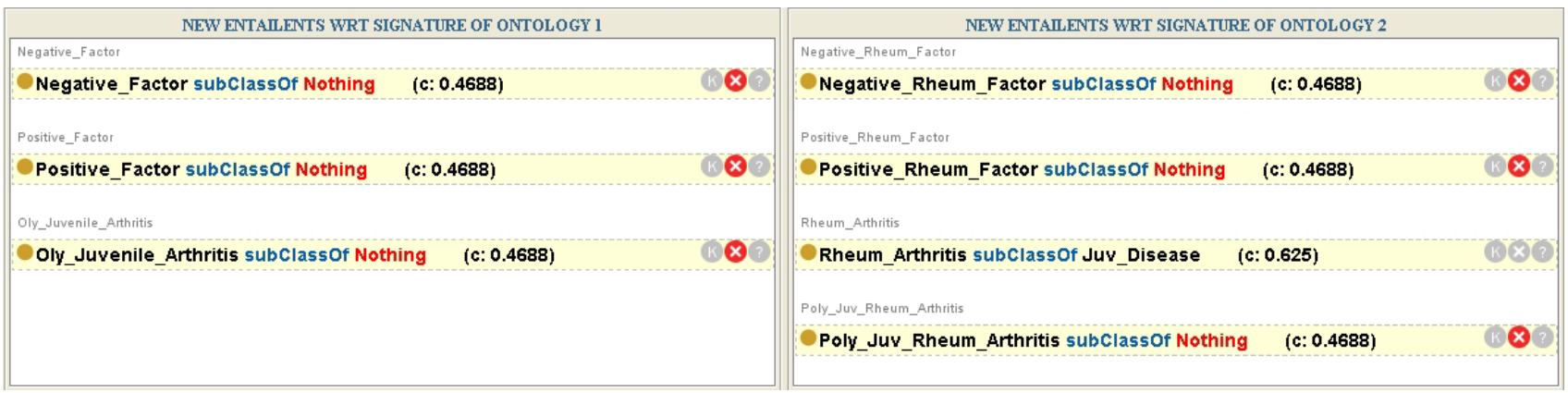

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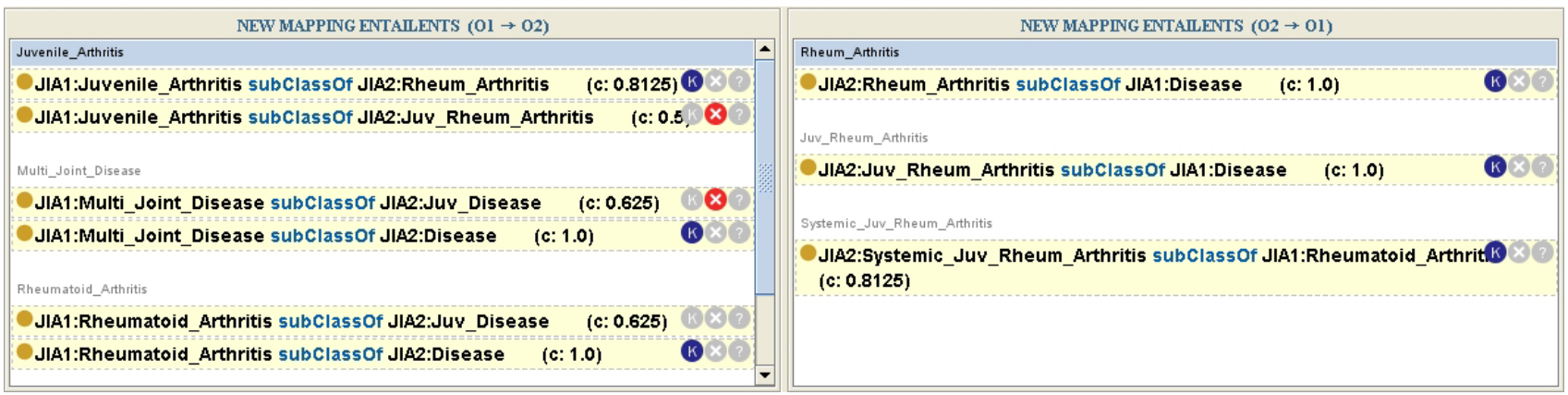

Evaluation of Entailments: ContentMap support

Dependency Relationship $\alpha \rhd \beta$

- Entailments are organized within a dependency tree
- Based on the notion of Justification for an axiom
- $\text{Just}(\alpha, \mathcal{O})$ is the set of all justifications for α in $\mathcal{O}$.

Definition (Dependency Relationship)

Let $\mathcal{O} \models \alpha, \beta$. $\alpha \rhd \beta$ iff for each $\mathcal{J}_\beta \in \text{Just}(\beta, \mathcal{O})$, there is $\mathcal{J}_\alpha \in \text{Just}(\alpha, \mathcal{O})$ s.t. $\mathcal{J}_\alpha \subseteq \mathcal{J}_\beta$.

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Dependency Relationship: ContentMap support

DEPENDENCY TREE OF NEW ENTAILEMENTS

Entailments Dependency Tree	Keep	Remove	Confi...	Justificat...
JIA2:Juv_Rheum_Arthritis **equivalentTo** JIA2:Rheum_Arthritis	☑	☐	0.4063	ⓘ
JIA2:Rheum_Arthritis **subClassOf** JIA2:Juv_Disease	☐	☑	0.4063	ⓘ
JIA2:Positive_Rheum_Factor **subClassOf not** JIA1:Positive_Factor	☐	☑	0.625	ⓘ
JIA1:Positive_Factor **subClassOf not** JIA2:Positive_Rheum_Factor	☐	☑	0.625	ⓘ
JIA2:Positive_Rheum_Factor **subClassOf** Nothing	☐	☑	0.4688	ⓘ
JIA2:Poly_Juv_Rheum_Arthritis **subClassOf** Nothing	☐	☑	0.4688	ⓘ
JIA2:Negative_Rheum_Factor **subClassOf not** JIA1:Negative_Factor	☐	☑	0.625	ⓘ
JIA1:Negative_Factor **subClassOf not** JIA2:Negative_Rheum_Factor	☐	☑	0.625	ⓘ
JIA1:Rheumatoid_Arthritis **subClassOf** JIA2:Juv_Disease	☐	☑	0.5	ⓘ
JIA1:Juvenile_Arthritis **subClassOf** JIA2:Juv_Rheum_Arthritis	☑	☐	0.5	ⓘ
JIA2:Positive_Rheum_Factor **subClassOf not** JIA1:Negative_Factor	☑	☐	0.75	ⓘ

Evaluation of Entailments: ContentMap support

Automatic Entailment selection

- Suggestions for $\mathfrak{S}^+$ and $\mathfrak{S}^-$
- **Unsatisfiable concepts** and entailments with **low confidence** will be included in $\mathfrak{S}^-$
- Entailments with **high confidence** will be included in $\mathfrak{S}^+$

Definition (Confidence of an Entailment)

- Confidence of a **mapping**: annotation value
- Confidence of an **axiom** α not annotated with a confidence value: $\mathrm{conf}(\alpha) = 1$
- Confidence of a **Justification**: $\mathrm{conf}(\mathcal{J}) = \prod_{\gamma \in \mathcal{J}} \mathrm{conf}(\gamma)$
- Confidence of an **entailment** β: $\mathrm{conf}(\beta) = \max(\bigcup_{\mathcal{J} \in \mathrm{Just}(\beta, \mathcal{O})} \mathrm{conf}(\mathcal{J}))$

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Repair of Unintended Entailments

Extraction of Plans

- Given $\mathfrak{S}^+$ and $\mathfrak{S}^-$
- A repair plan for $\mathcal{U}$ is a set of axioms $\mathcal{P} \subseteq \mathcal{U}$ such that:
  - $(\mathcal{U} \setminus \mathcal{P}) \models \alpha$ for each $\alpha \in \mathfrak{S}^+$, and
  - $(\mathcal{U} \setminus \mathcal{P}) \not\models \beta$ for each $\beta \in \mathfrak{S}^-$.

Note that conflicting choices in $\mathfrak{S}^+$ and $\mathfrak{S}^-$ may make it impossible to find any plans.

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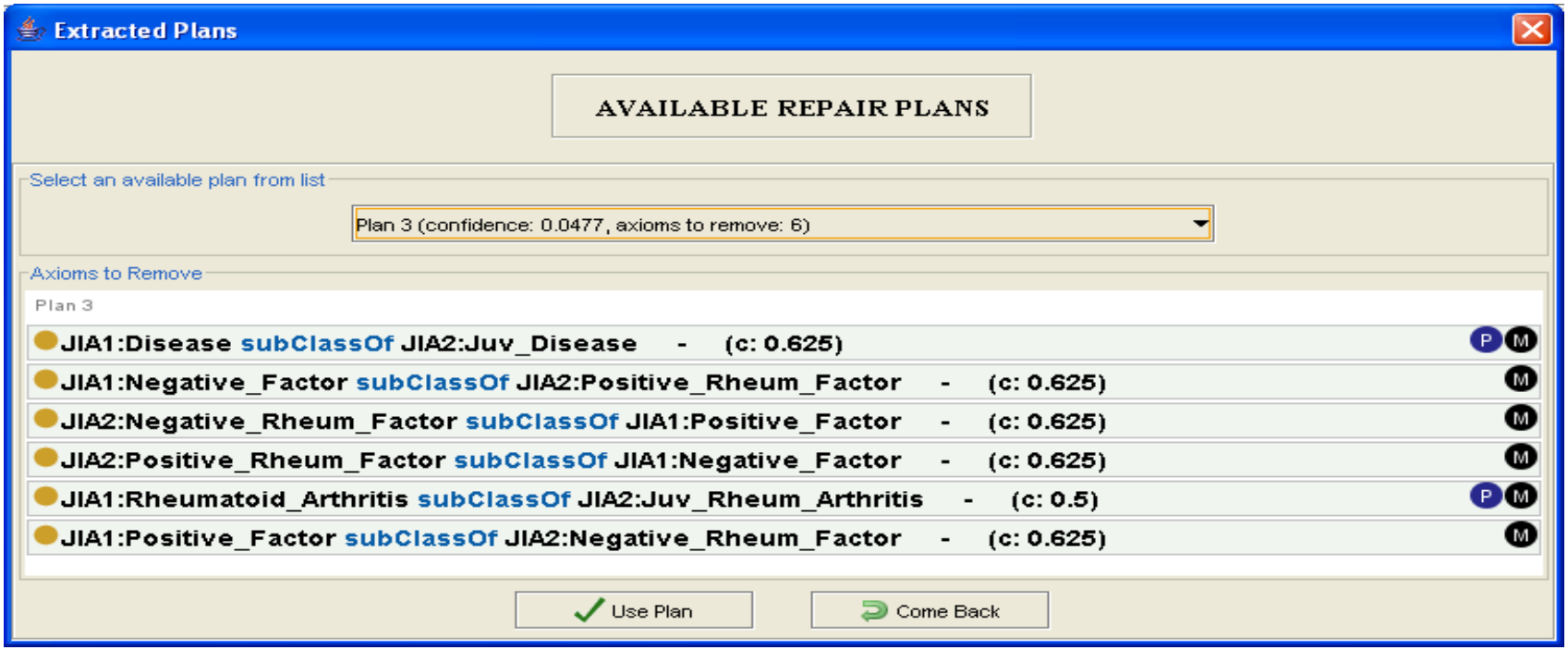
Repair of Unintended Entailments: ContentMap Support

Organization of Candidate Plans

- ContentMap ranks the plans in order of:
  - number of affected axioms, or
  - confidence, $\text{conf}(\mathcal{P}) = \prod_{\alpha \in \mathcal{P}} \text{conf}(\alpha)$.



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Similar approaches

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Our Contribution

- Our approach uses only **OWL 2 semantics**.
- We are not restricted to inconsistencies, but can include **any unintended entailment**.
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- The user is overwhelmed in some cases.

Possible Solution

Modularization and **Divide and Conquer** approach.

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