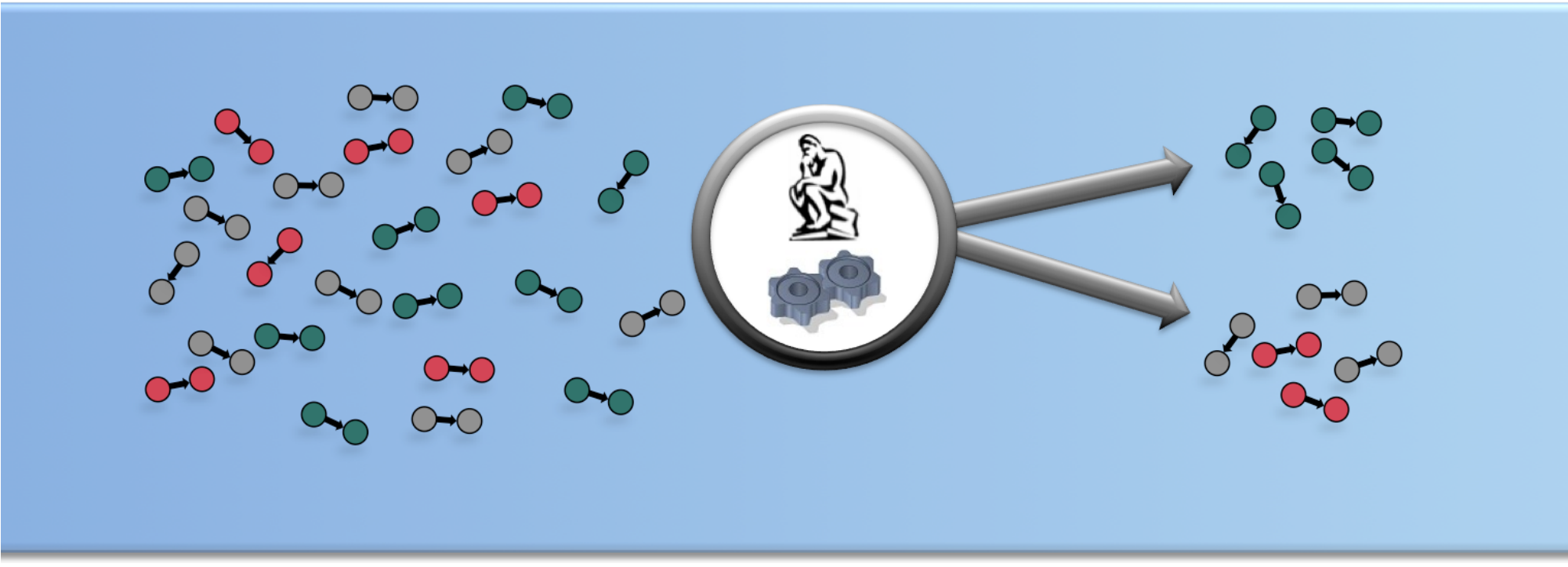
ulm university universität ulm

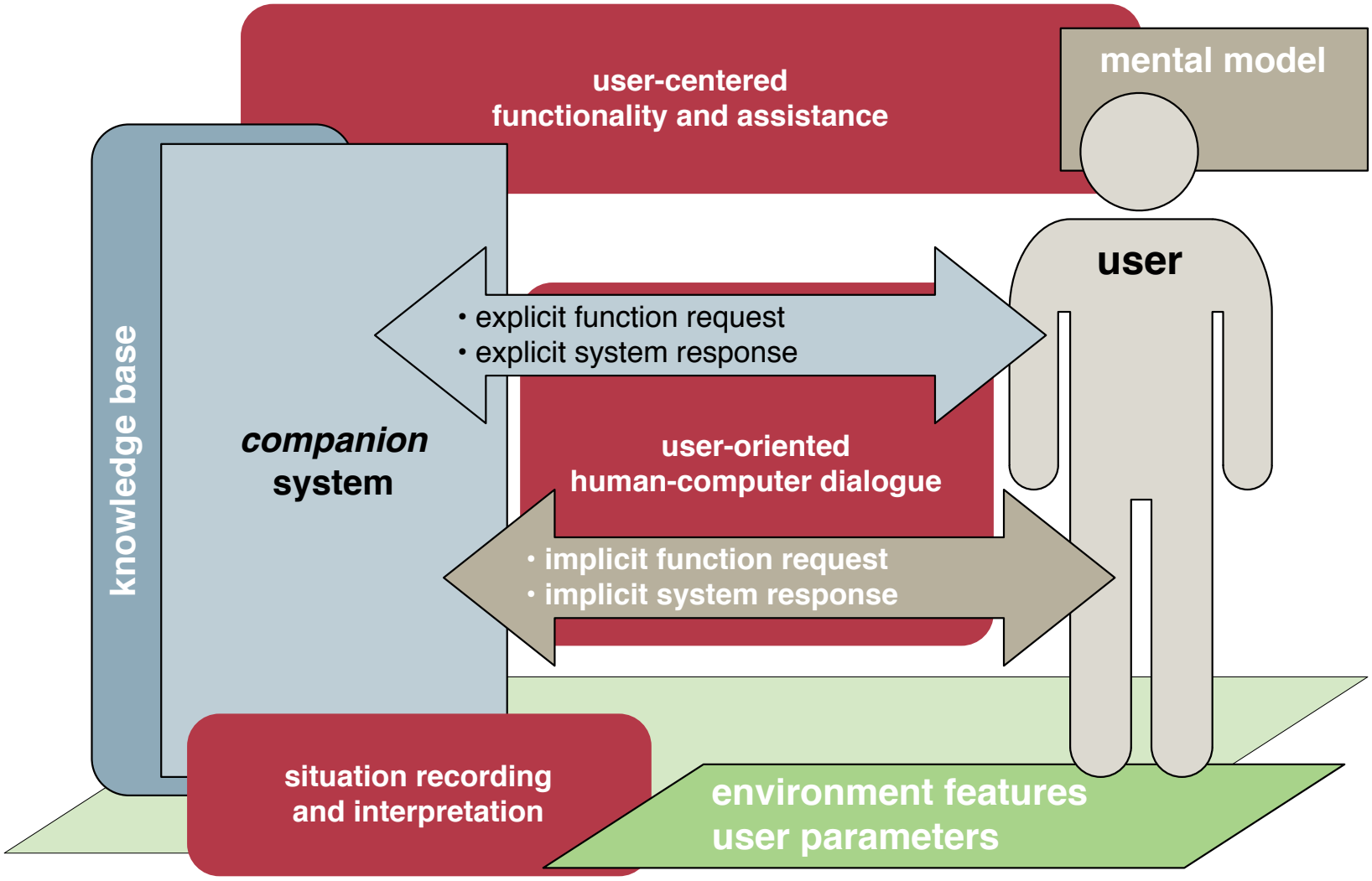


Interactive Reasoning-Based Ontology Revision

SFB/TRR 62 Kolloquium

B. Glimm, N. Nikitina, S. Rudolph
Institute of Artificial Intelligence | 14.11.2011

Ontology Revision in the Context of Companion Systems



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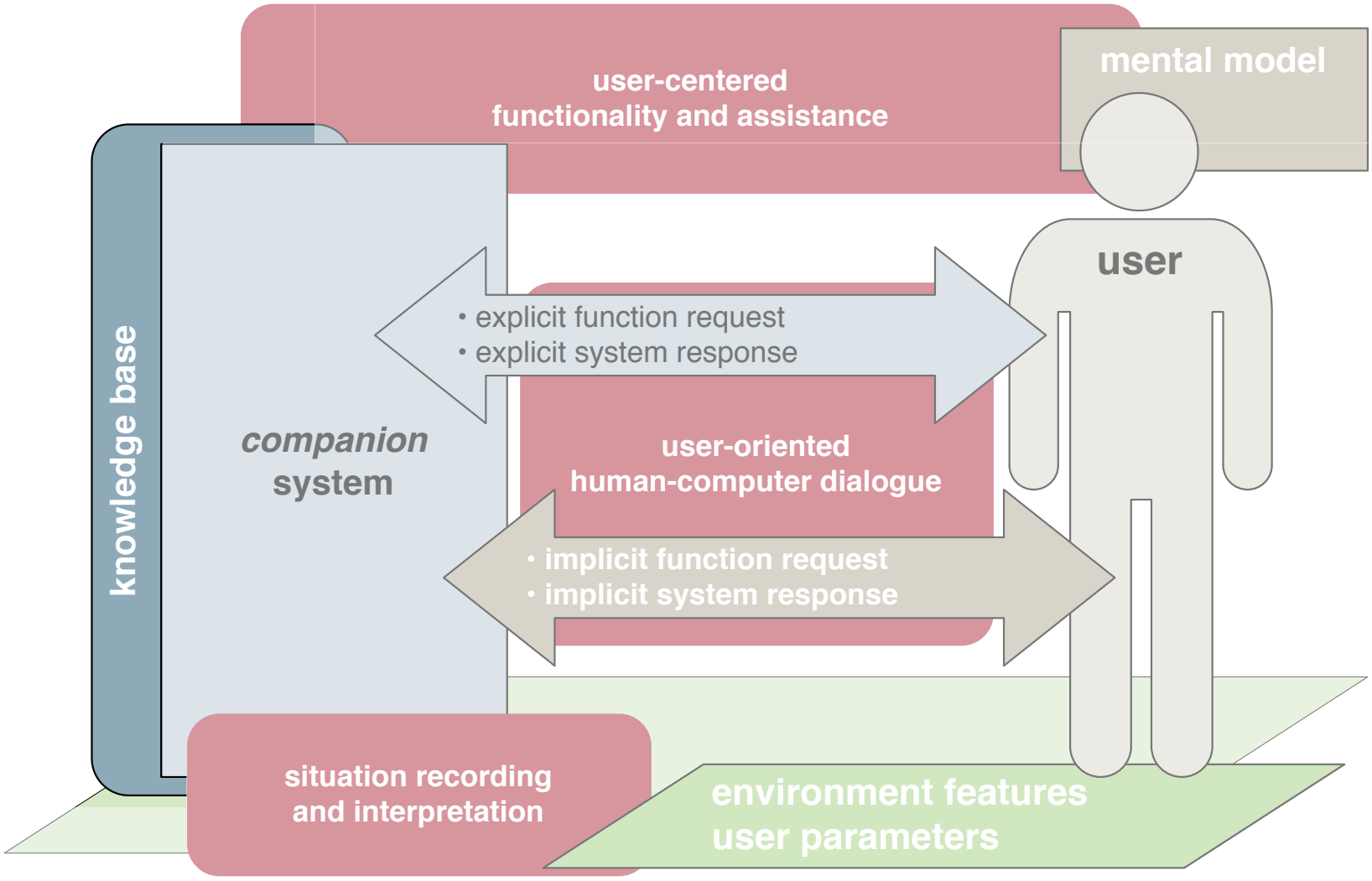

Ontology Revision in the Context of Companion Systems

Companion systems need some background knowledge

- ⇝ Ontologies
  - Ontology revision helps to ensure the quality of an ontology
  - Revision support for building up the knowledge base through reuse or automated learning methods

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Companion systems need some user specific knowledge

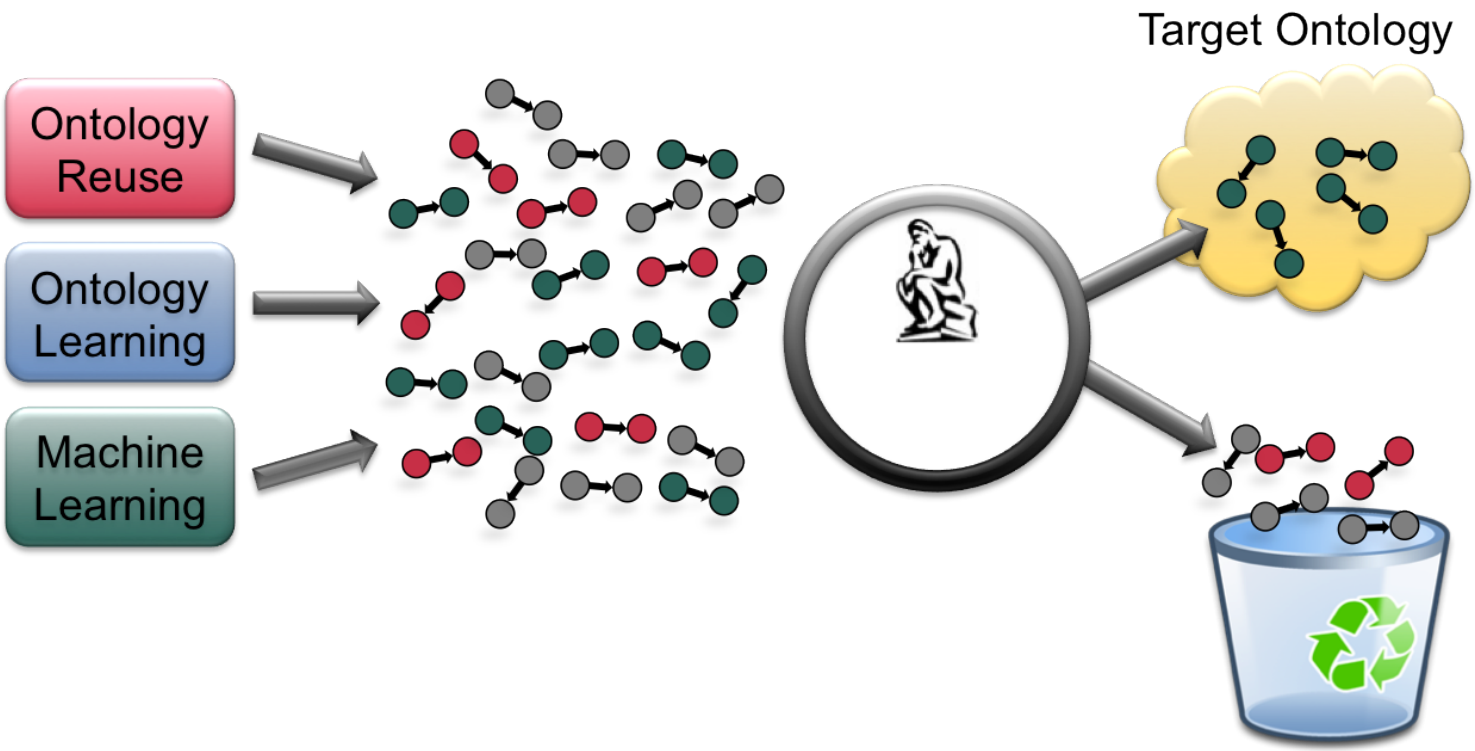
- More dynamic and uncertain knowledge
- ⇝ Reasoning over dynamically changing and uncertain knowledge

Outline

- Motivation
- Ontology and Reasoning Basics
- Semi-automatic Ontology Revision by Example
- Ontology Revision Terminology
- Axiom Ranking
- Decision Spaces
- Empirical Evaluation & Dynamic Ranking Strategies
- Summary & Outlook

Motivation

- Noisy domain statements produced by knowledge acquisition and integration methods
- Manual revision of the acquired information is required to ensure high quality



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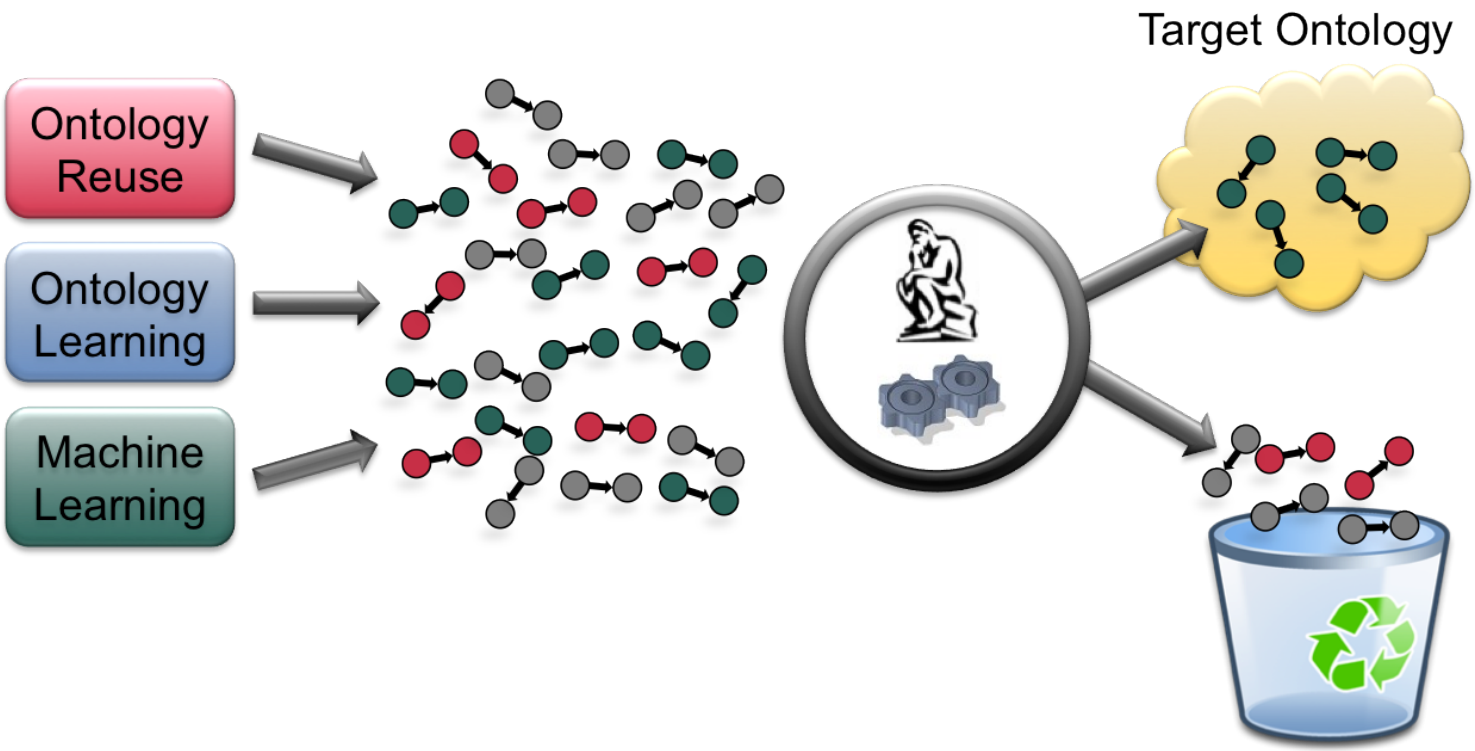

Ontology Basics

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  - individuals
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- Reasoners implement algorithms to check entailment
- Depending on the expressivity of the ontology language such algorithms can be anything between tractable and super-exponential in worst-case complexity

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- A single evaluation decision can predetermine the decision for several yet unevaluated axioms

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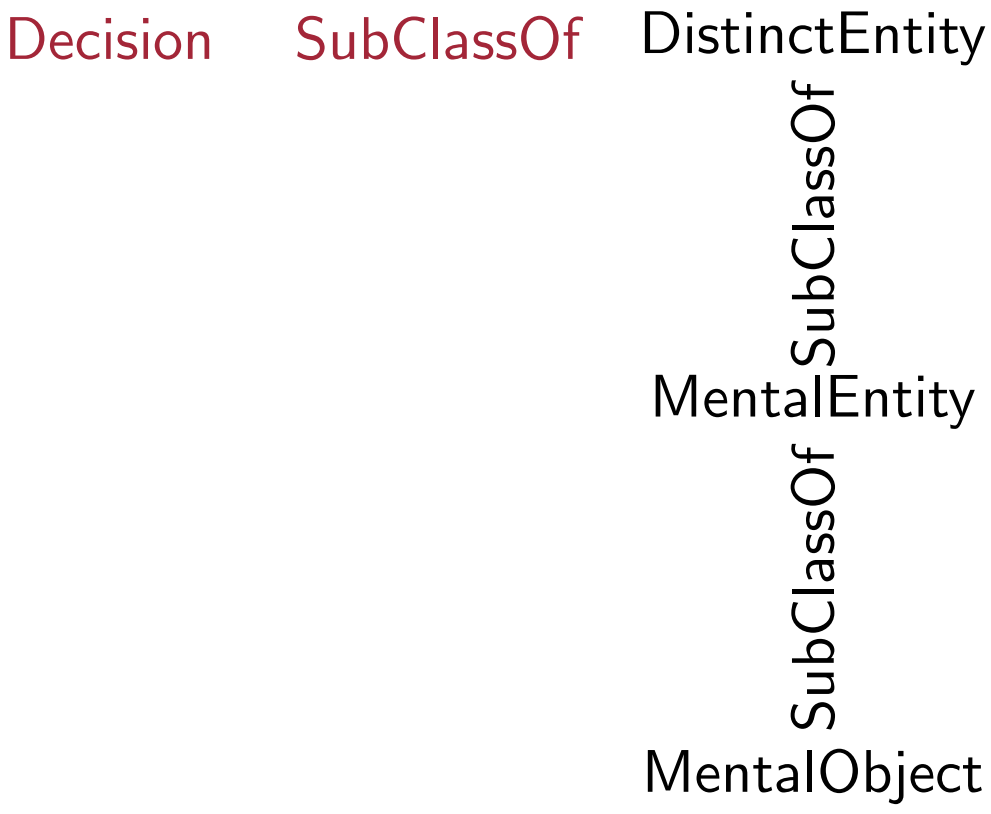

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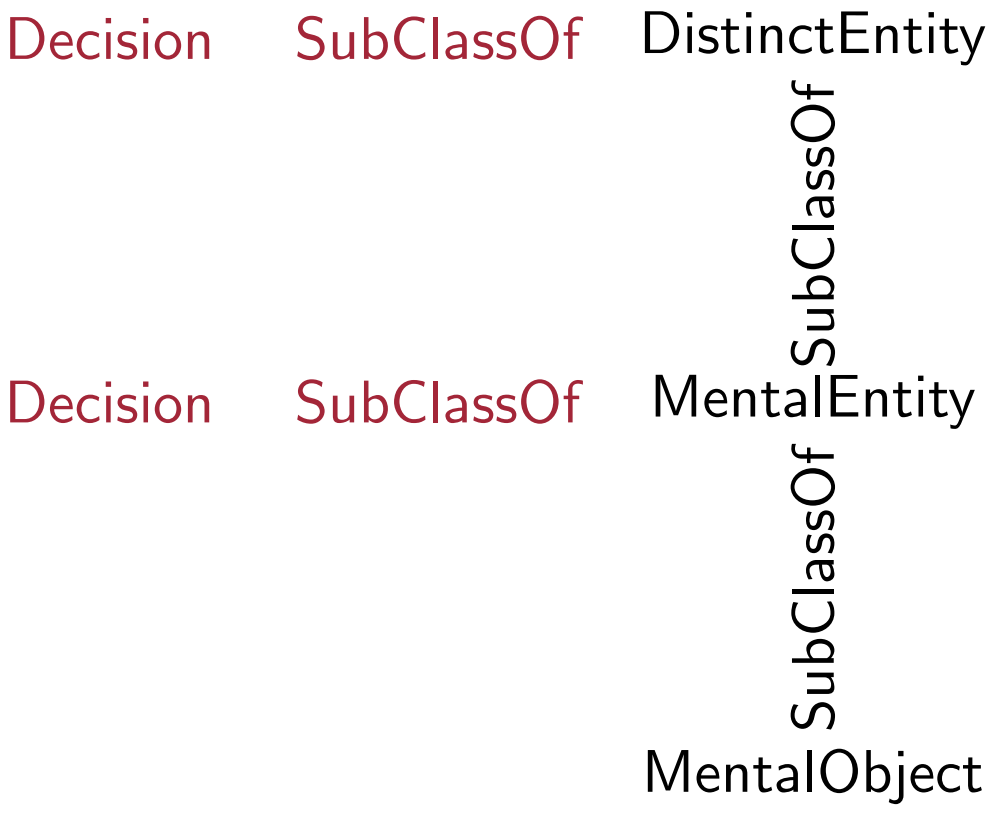

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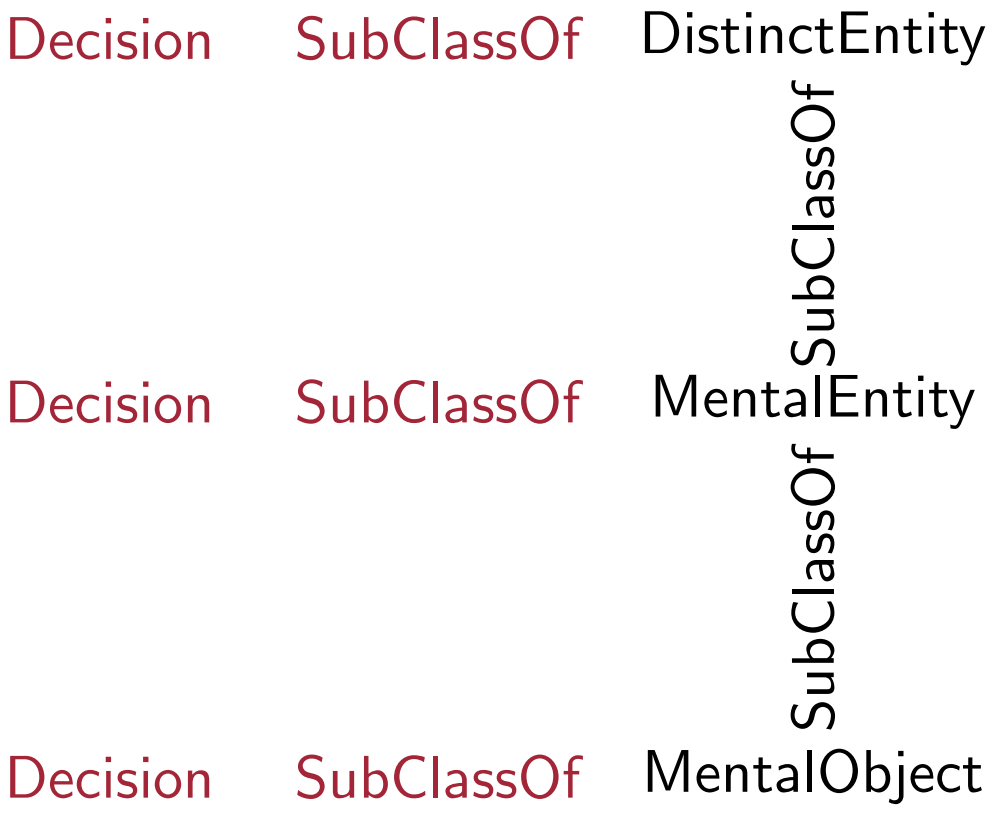

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✓ Decision SubClassOf MentalObject

Decision SubClassOf MentalEntity

Decision SubClassOf DistinctEntity

SubClassOf

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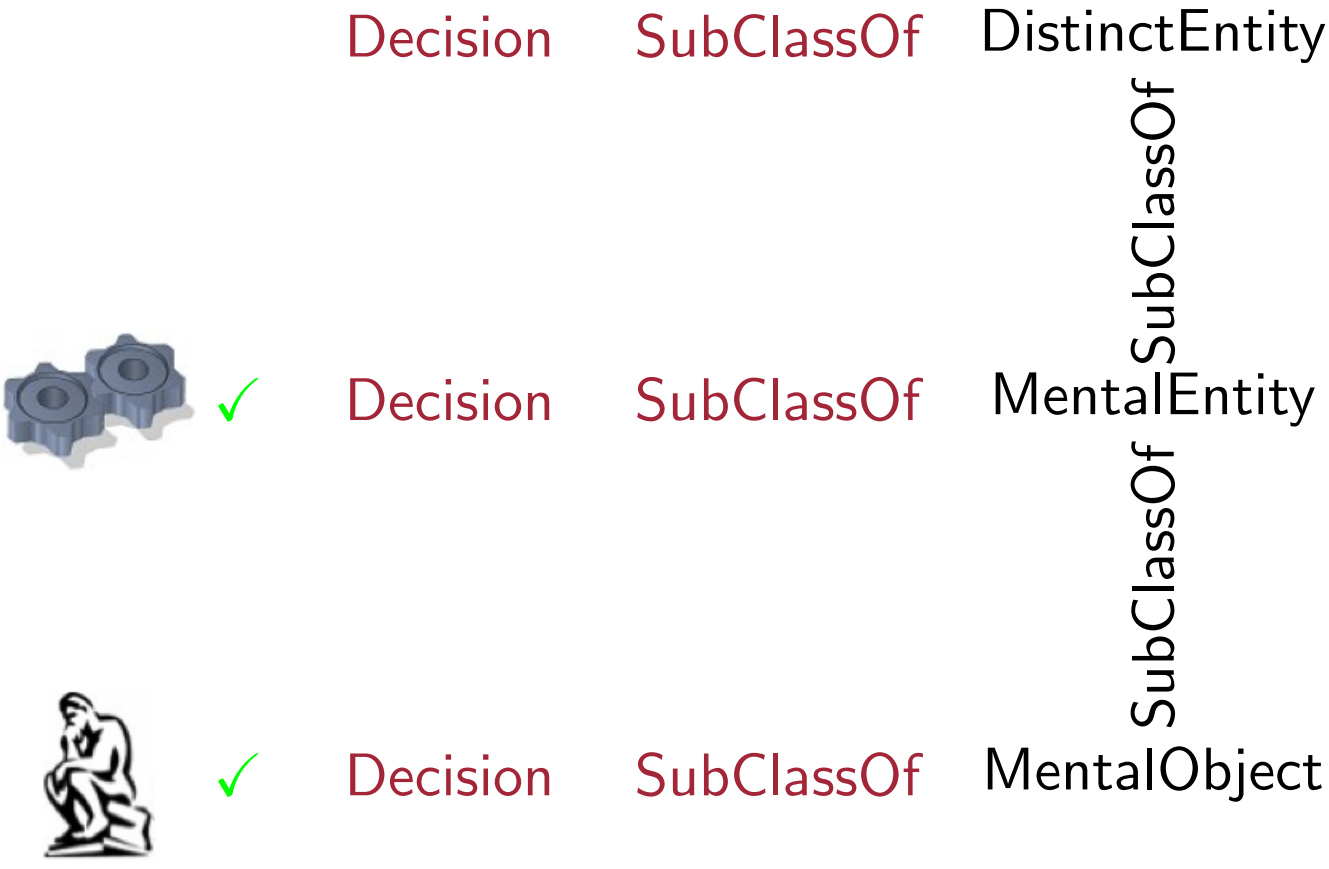

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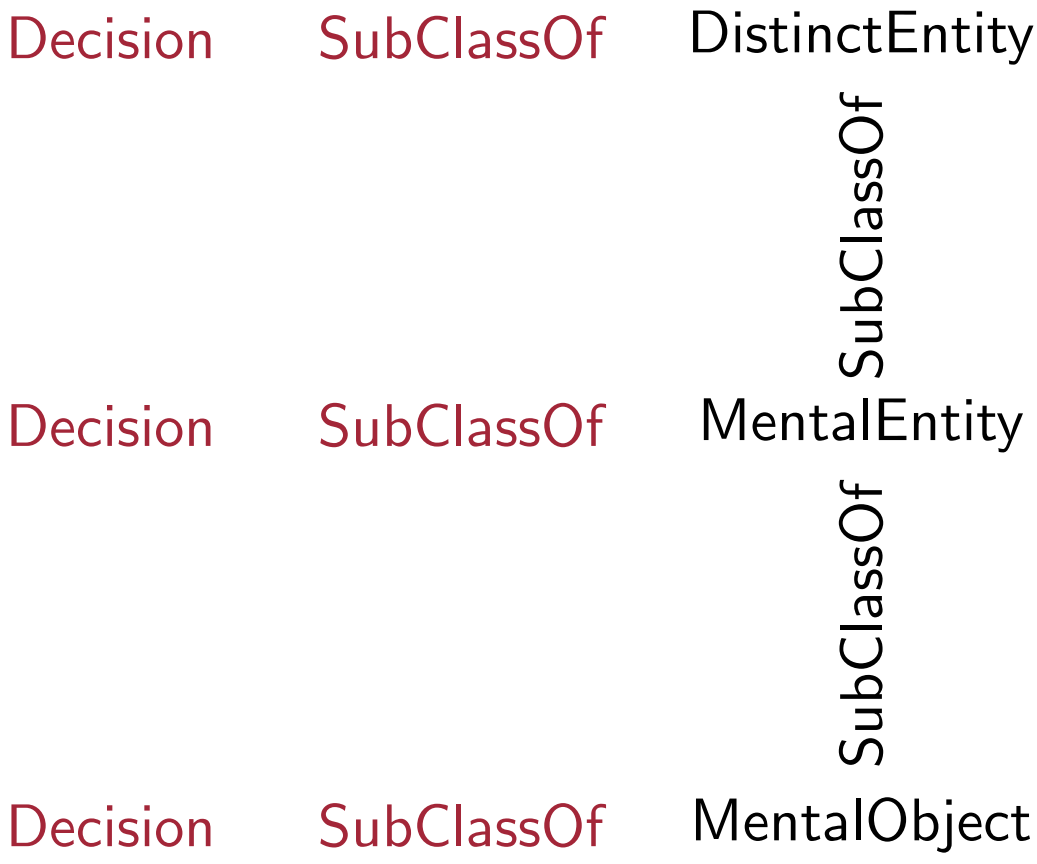

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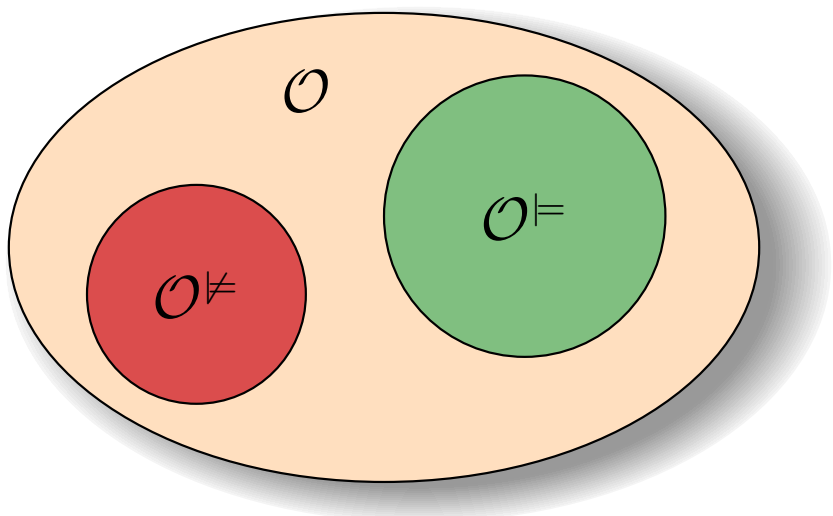
Ontology Revision

Assumption: Deductive closure of the intended consequences must not contain unintended consequences

- A single evaluation decision can predetermine the decision for several yet unevaluated axioms
- Order influences method effectiveness

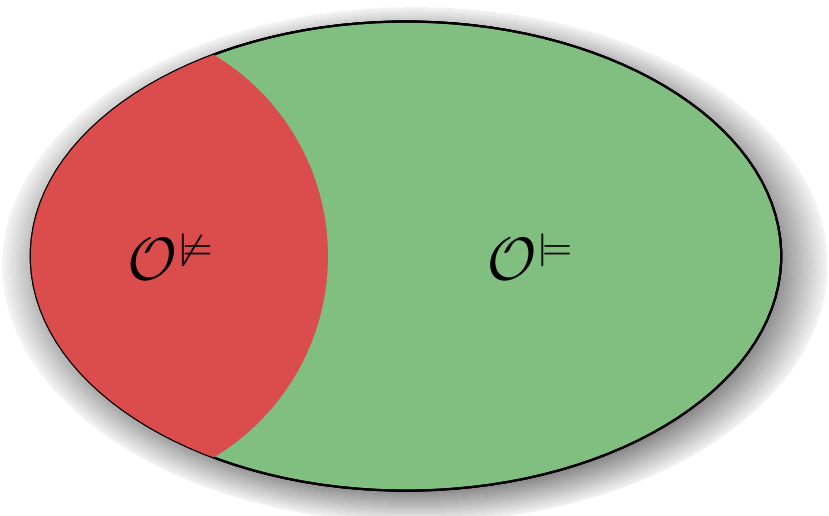
Revision States

- A revision state is defined as a tuple $(\mathcal{O}, \mathcal{O}^{\models}, \mathcal{O}^{\not\models})$ of ontologies with $\mathcal{O}^{\models} \subseteq \mathcal{O}, \emptyset \neq \mathcal{O}^{\not\models} \subseteq \mathcal{O}$, and $\mathcal{O}^{\models} \cap \mathcal{O}^{\not\models} = \emptyset$.
  $\mathcal{O}^{\models}$: the set of desired consequences
  $\mathcal{O}^{\not\models}$: the set of undesired consequences



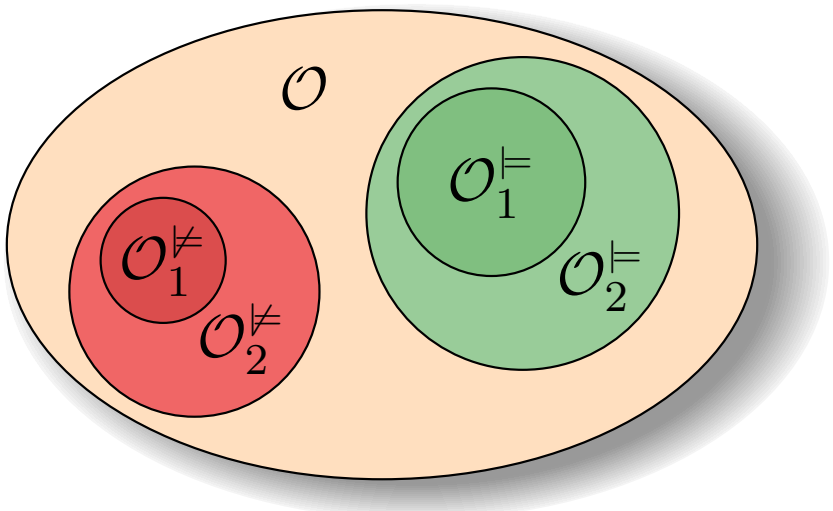
Revision State Completeness

- A revision state is complete, if $\mathcal{O} = \mathcal{O}^{\models} \cup \mathcal{O}^{\not\models}$, and incomplete otherwise.



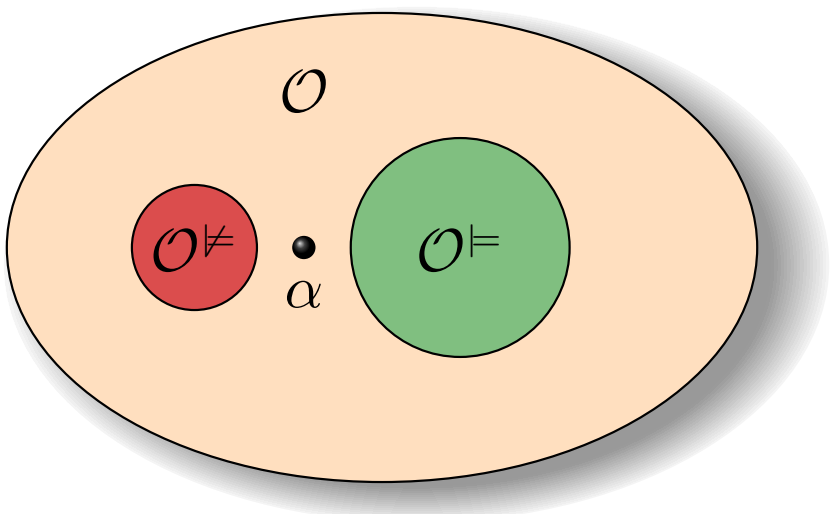
Revision State Refinements

- Given two revision states $(\mathcal{O}, \mathcal{O}_1^{\models}, \mathcal{O}_1^{\not\models})$ and $(\mathcal{O}, \mathcal{O}_2^{\models}, \mathcal{O}_2^{\not\models})$, we call $(\mathcal{O}, \mathcal{O}_2^{\models}, \mathcal{O}_2^{\not\models})$ a refinement of $(\mathcal{O}, \mathcal{O}_1^{\models}, \mathcal{O}_1^{\not\models})$, if $\mathcal{O}_1^{\models} \subseteq \mathcal{O}_2^{\models}$ and $\mathcal{O}_1^{\not\models} \subseteq \mathcal{O}_2^{\not\models}$.



Elementary Refinements of Revision States

- An incomplete revision state $(\mathcal{O}, \mathcal{O}^{\models}, \mathcal{O}^{\not\models})$ can be refined by evaluating a further axiom $\alpha \in \mathcal{O} \setminus (\mathcal{O}^{\models} \cup \mathcal{O}^{\not\models})$, obtaining $(\mathcal{O}, \mathcal{O}^{\models} \cup \{\alpha\}, \mathcal{O}^{\not\models})$ or $(\mathcal{O}, \mathcal{O}^{\models}, \mathcal{O}^{\not\models} \cup \{\alpha\})$.



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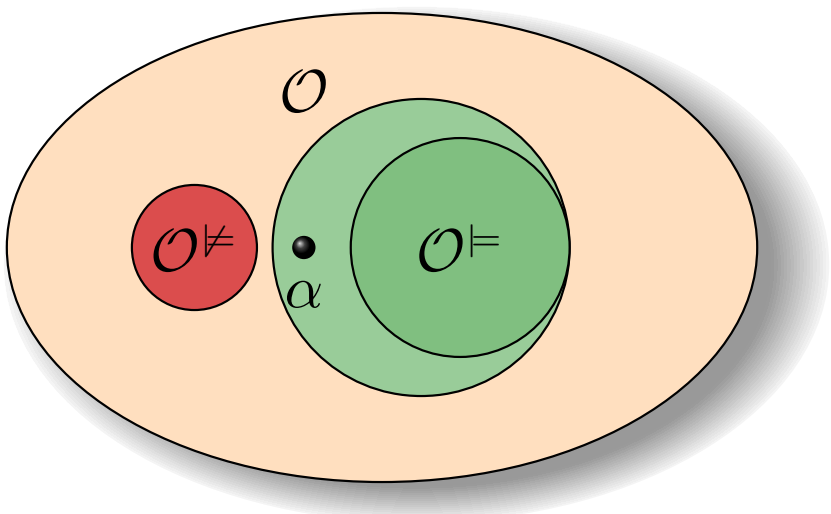

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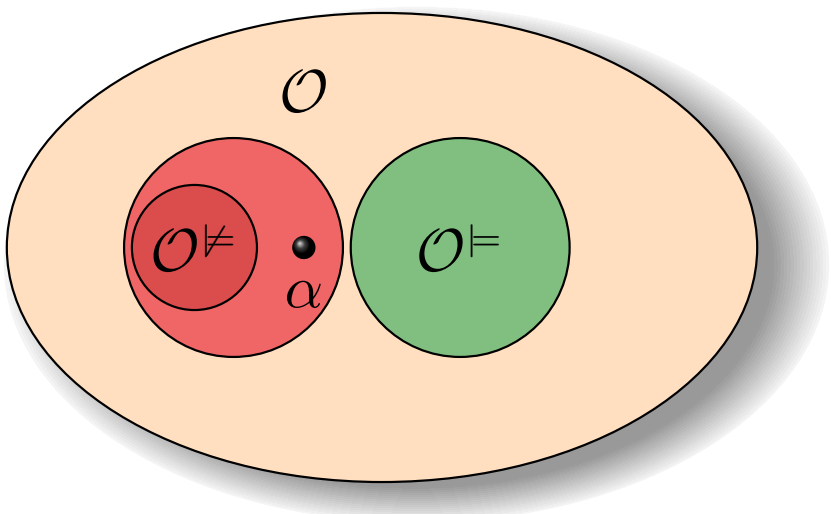

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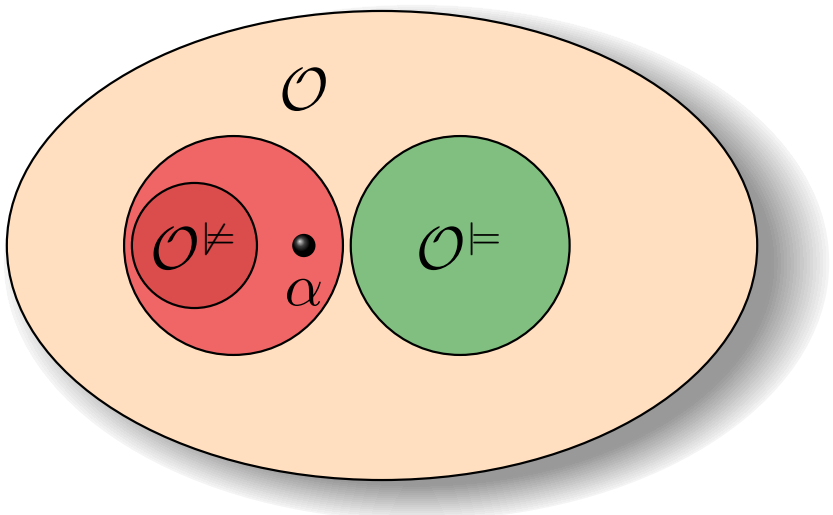
- We call the resulting revision state an elementary refinement of $(\mathcal{O}, \mathcal{O}^{\models}, \mathcal{O}^{\not\models})$.



Revision Closure

- The revision closure $\mathrm{clos}(\mathcal{O}, \mathcal{O}^{\models}, \mathcal{O}^{\not\models})$ of $(\mathcal{O}, \mathcal{O}^{\models}, \mathcal{O}^{\not\models})$ is $(\mathcal{O}, \mathcal{O}_c^{\models}, \mathcal{O}_c^{\not\models})$ with
  - $\mathcal{O}_c^{\models} := \{\alpha \in \mathcal{O} \mid \mathcal{O}^{\models} \models \alpha\}$ and
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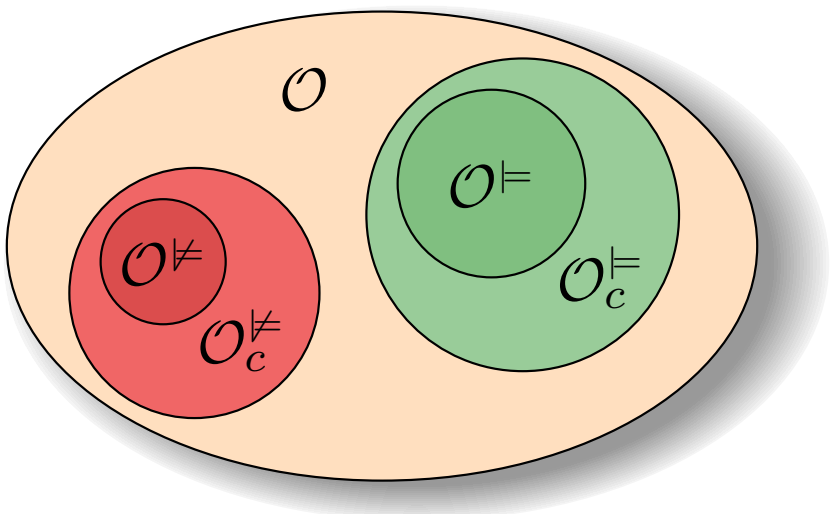

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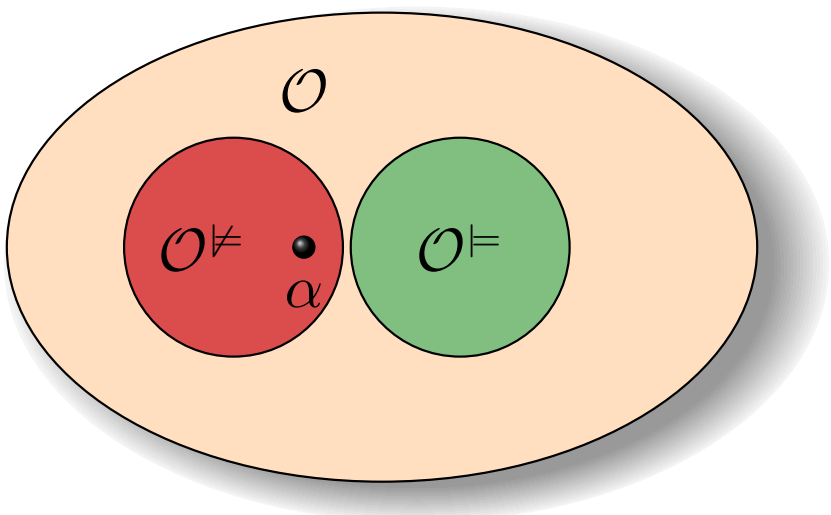

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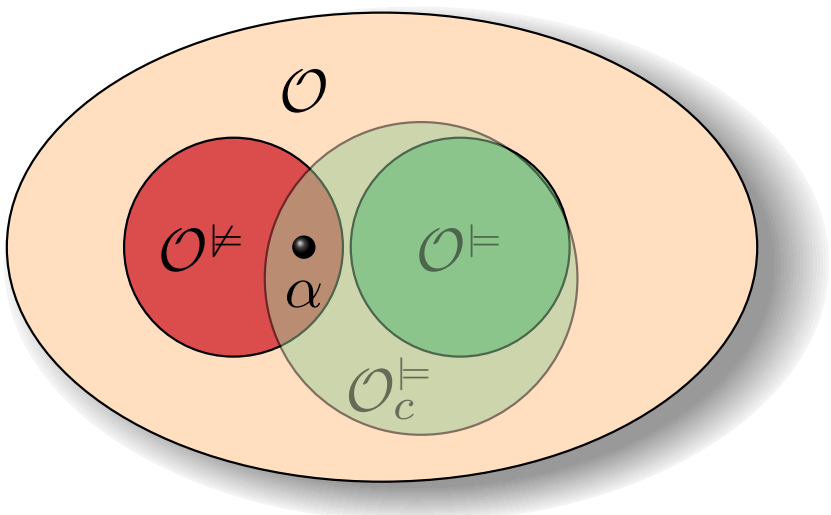

Revision States

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Goals:

- Obtain complete and consistent revision state
- Reduce number of manual decisions
- Reduce the time for automatic decisions

Properties of the Revision Closure

For $(\mathcal{O}, \mathcal{O}^{\models}, \mathcal{O}^{\not\models})$ a consistent revision state:

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$\rightsquigarrow$ Revision closures reduce the manual effort of revision and ensure the consistency of revision states

Axiom Impact

- The evaluation order has an impact on the degree of atomatization

$(\mathcal{O}, \mathcal{O}^{\models}, \mathcal{O}^{\not\models})$: a consistent revision state with $\alpha \in \mathcal{O}$

$?(\mathcal{O}, \mathcal{O}^{\models}, \mathcal{O}^{\not\models})$: $|\mathcal{O} \setminus (\mathcal{O}^{\models} \cup \mathcal{O}^{\not\models})|$

- Approval impact: Number of automatically evaluated axioms in case α is approved:
  $\text{impact}^{+}(\alpha) = ?(\mathcal{O}, \mathcal{O}^{\models}, \mathcal{O}^{\not\models}) - ?(\text{clos}(\mathcal{O}, \mathcal{O}^{\models} \cup \{\alpha\}, \mathcal{O}^{\not\models}))$,

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Axiom Impact

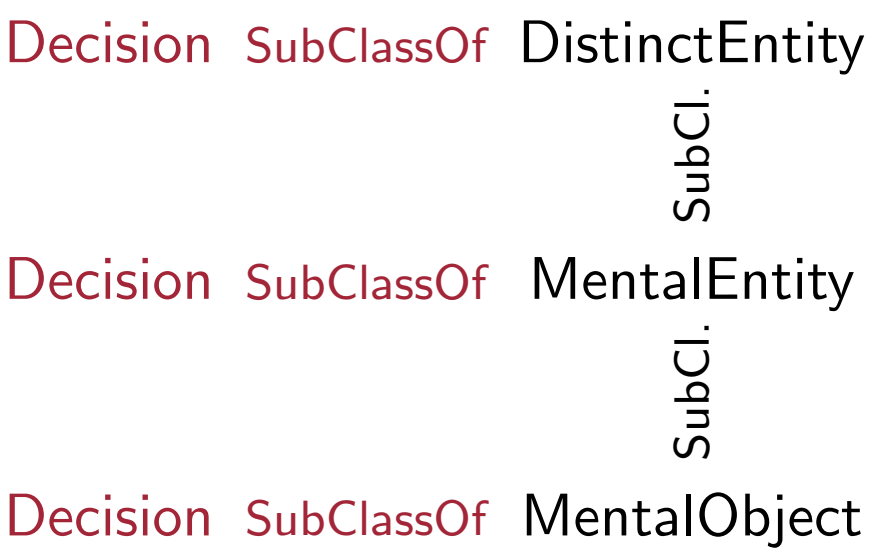
- The evaluation order has an impact on the degree of atomatization

$(\mathcal{O}, \mathcal{O}^{\models}, \mathcal{O}^{\not\models})$: a consistent revision state with $\alpha \in \mathcal{O}$

$?(\mathcal{O}, \mathcal{O}^{\models}, \mathcal{O}^{\not\models})$: $|\mathcal{O} \setminus (\mathcal{O}^{\models} \cup \mathcal{O}^{\not\models})|$

- Approval impact: Number of automatically evaluated axioms in case α is approved:
  $\mathsf{impact}^{+}(\alpha) = ?(\mathcal{O}, \mathcal{O}^{\models}, \mathcal{O}^{\not\models}) - ?(\mathrm{clos}(\mathcal{O}, \mathcal{O}^{\models} \cup \{\alpha\}, \mathcal{O}^{\not\models}))$,
- Decline impact: number of automatically evaluated axioms in case α is declined:
  $\mathsf{impact}^{-}(\alpha) = ?(\mathcal{O}, \mathcal{O}^{\models}, \mathcal{O}^{\not\models}) - ?(\mathrm{clos}(\mathcal{O}, \mathcal{O}^{\models}, \mathcal{O}^{\not\models} \cup \{\alpha\}))$,
- Guaranteed impact:
  $\mathsf{guaranteed}(\alpha) = \min(\mathsf{impact}^{+}(\alpha), \mathsf{impact}^{-}(\alpha))$.

Impact Computation



impact^+	impact^-	guaranteed
0	2	0
1	1	1
2	0	0

Decision Spaces: Saving Computational Effort

- Computing the closure and impact measures requires entailment checking:
  - $\alpha E \beta$ iff $\mathcal{O}^{\models} \cup \{\alpha\} \models \beta$
  - $\alpha C \beta$ iff $\mathcal{O}^{\models} \cup \{\alpha, \beta\} \models \gamma$ for some $\gamma \in \mathcal{O}^{\not\models}$

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Decision spaces exploit the following properties of E and C:

P1 $(\mathcal{O}^?, E)$ is a quasi-order (i.e., reflexive and transitive),

P2 C is symmetric,

P3 $\alpha E \beta$ and $\beta C \gamma$ imply $\alpha C \gamma$ for all $\alpha, \beta, \gamma \in \mathcal{O}^?$, and

P4 if $\alpha E \beta$ then $\alpha C \beta$ does not hold.

Pruning the Space of Unknown Elements of E and C

R0		$\rightarrow E(x,x)$	reflexivity of E
R1	$E(x,y) \wedge E(y,z)$	$\rightarrow E(x,z)$	transitivity of E
R2	$E(x,y) \wedge C(y,z)$	$\rightarrow C(x,z)$	(P3)
R3	$C(x,y)$	$\rightarrow C(y,x)$	symmetry of C
R4	$E(x,y)$	$\rightarrow \overline{C}(x,y)$	disjointness of E and C
R5	$\overline{C}(x,y)$	$\rightarrow \overline{C}(y,x)$	symmetry of C
R6	$E(x,y) \wedge \overline{C}(x,z)$	$\rightarrow \overline{C}(y,z)$	(P3)
R7	$C(x,y)$	$\rightarrow \overline{E}(x,y)$	disjointness of E and C
R8	$\overline{C}(x,y) \wedge C(y,z)$	$\rightarrow \overline{E}(x,z)$	(P3)
R9	$E(x,y) \wedge \overline{E}(x,z)$	$\rightarrow \overline{E}(y,z)$	transitivity of E

$\overline{E}$: complement of E

$\overline{C}$: complement of C

Computing E and C

- Rules have an acyclic structure

$\rightsquigarrow$ E, C, $\overline{C}$, and $\overline{E}$ can be saturated one after another

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Condensed rule set:

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\begin{array}{lcl}
E & \leftarrow & E^* \\
C & \leftarrow & E \circ (C \cup C^-) \circ E^- \\
\overline{C} & \leftarrow & E^- \circ (\overline{C} \cup Id \cup \overline{C}^-) \circ E \\
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- Algorithm now initializes the relations and applies the rules
- Executes an entailment check to clarify a missing case
- Closes the relations under the rule set

Complexity of Computing E and C

Assuming that entailment checking is a constant time operation:

Lemma

Let $(\mathcal{O}, \mathcal{O}^{\models}, \mathcal{O}^{\not\models})$ with $n = |\mathcal{O}|$ be a revision state. Computing E and C can be done in time $O(n^5)$ and space $O(n^2)$.

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- Entailment checking usually outweighs the other operations
- For the Web Ontology Language OWL entailment checking is N2ExpTime-complete
- Lower complexities for fragments of OWL

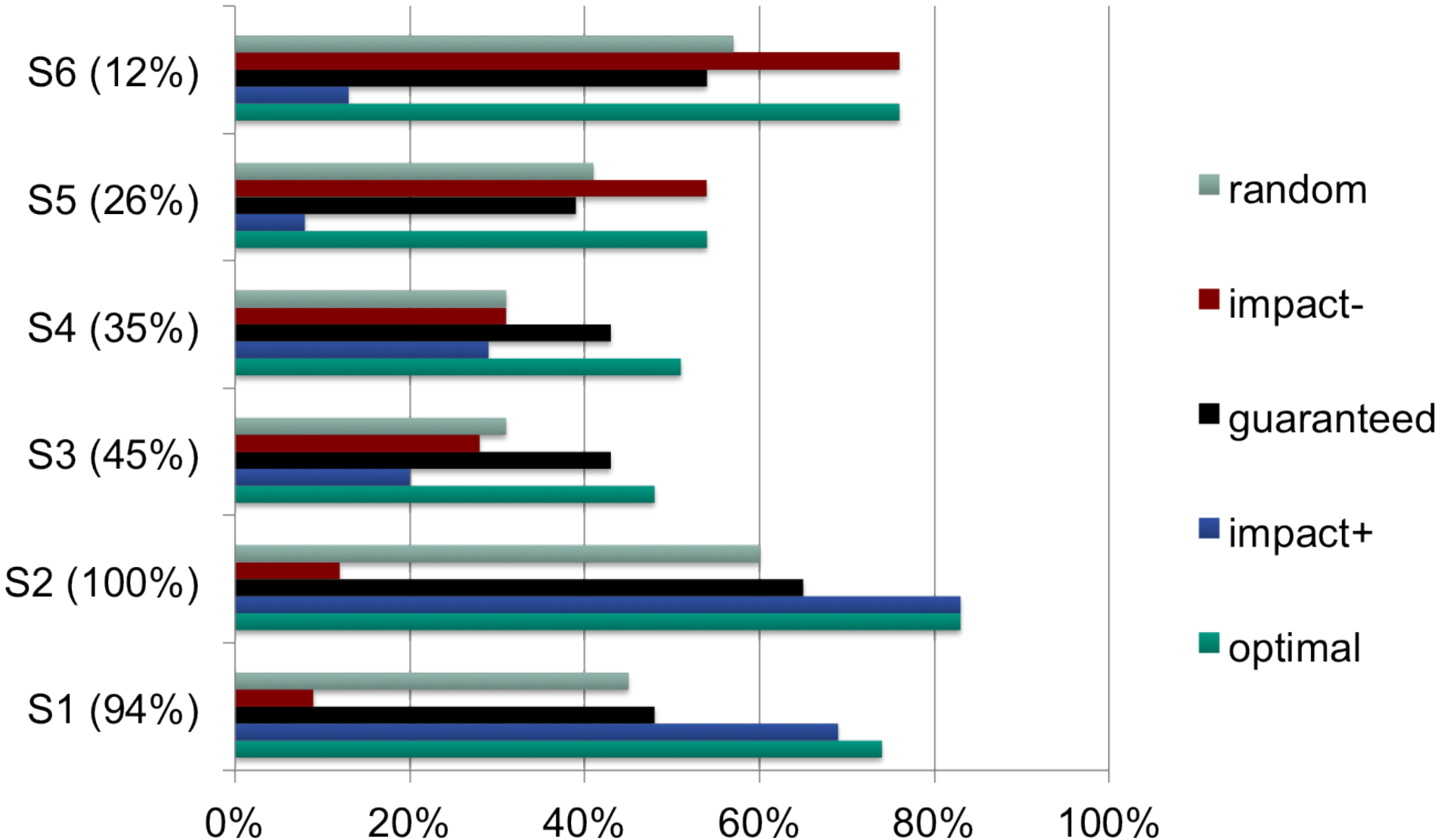
Advantages of Decision Spaces

- Revision closures can be read off the E and C relations
- Axiom impact can be read off the E and C relations
- Updating a decision space after an axiom approval or decline can be done incrementally

Ontology Revision Use Case

- Empirical evaluation based on data from the NanOn project
- NanOn goals: semi-automatic ontology generation for nano technology
- Ontology captures substances, structures, and procedures used in the domain of nano technology
- Scientific documents are automatically analyzed for the occurrence of NanOn classes and properties by the means of lexical patterns
- Documents are annotated with these terms to facilitate topic-specific information retrieval
- Revision is needed to ensure the quality

Evaluation Results: Reduction of Manual Effort



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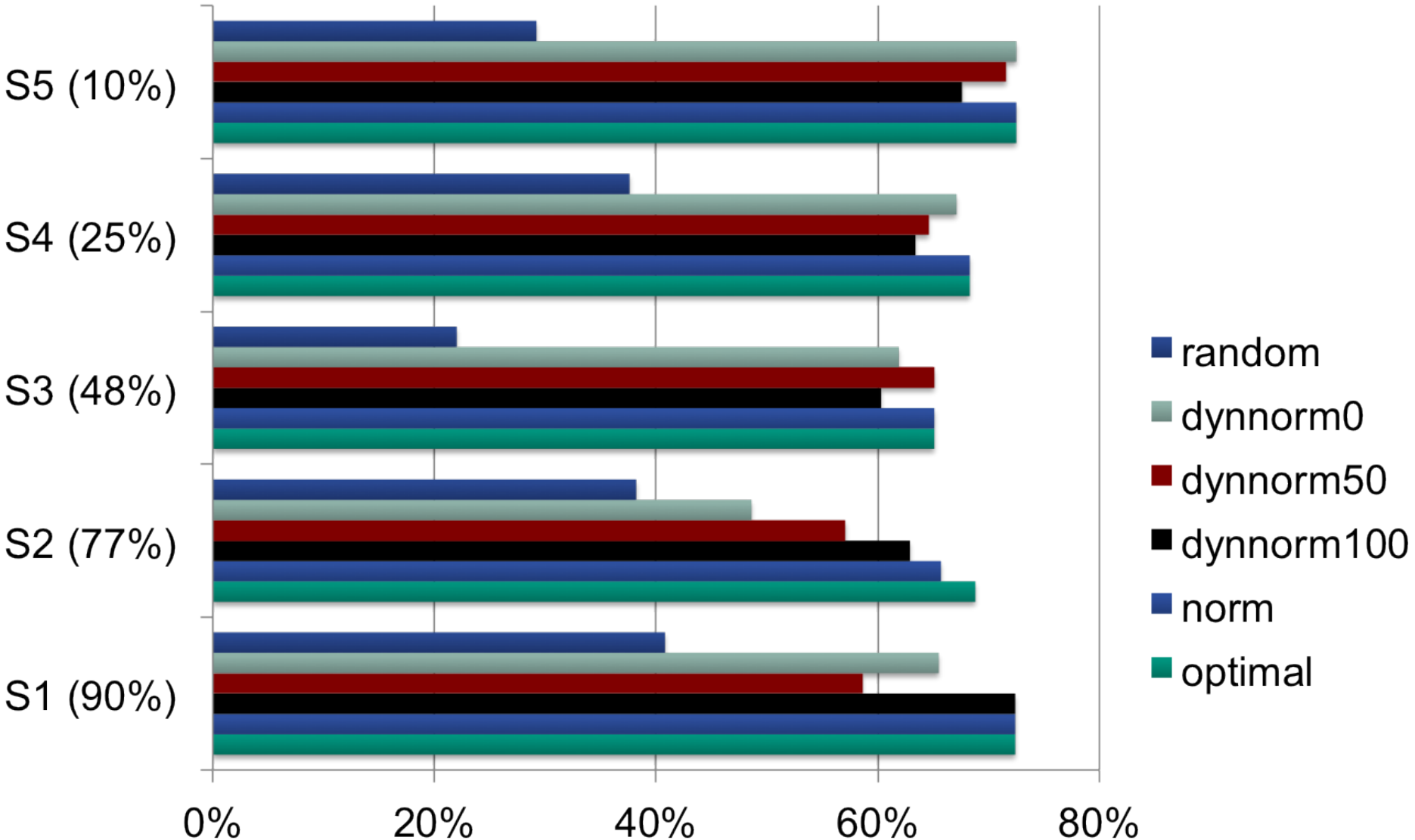
Evaluation Results with Learned Parametrized Ranking



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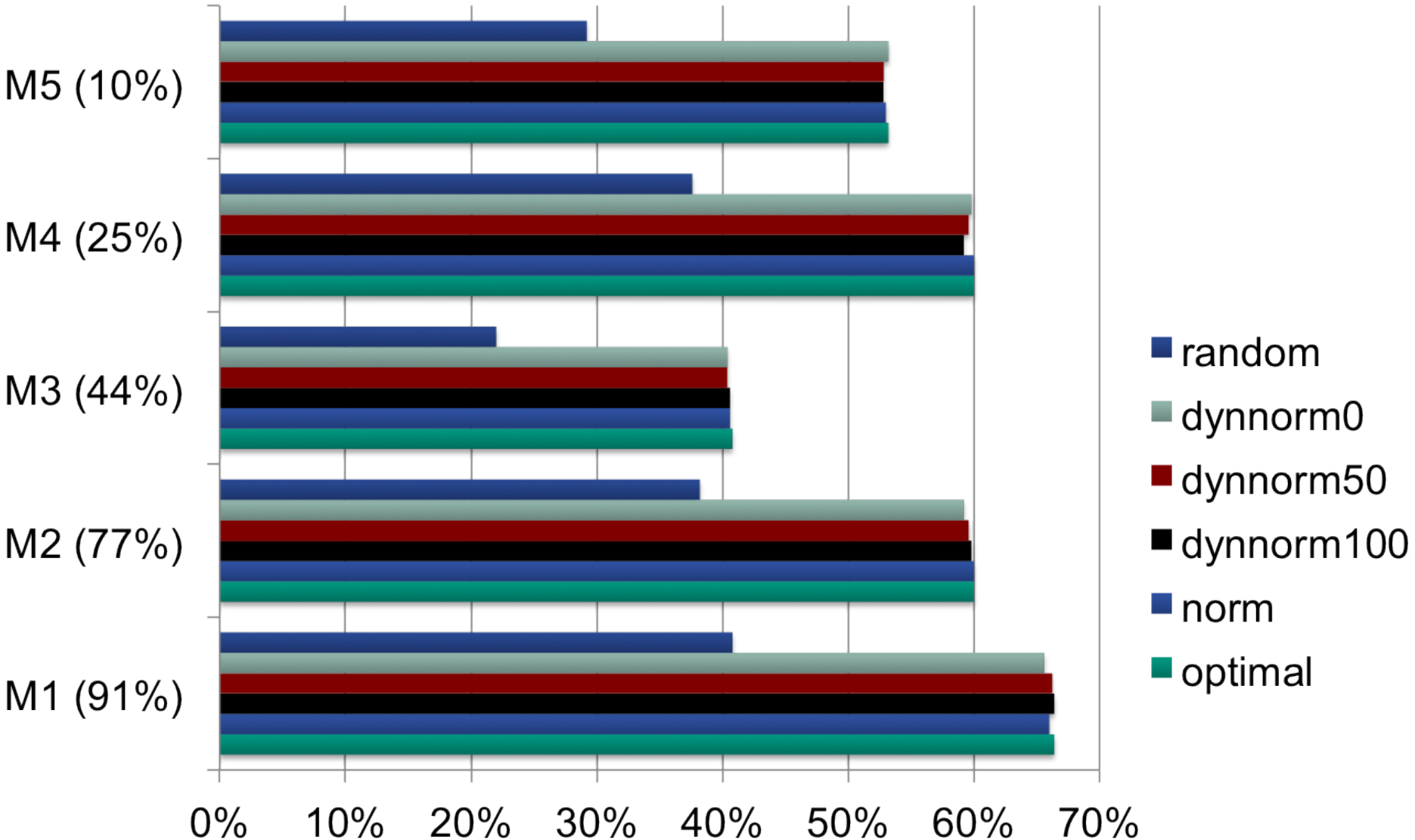

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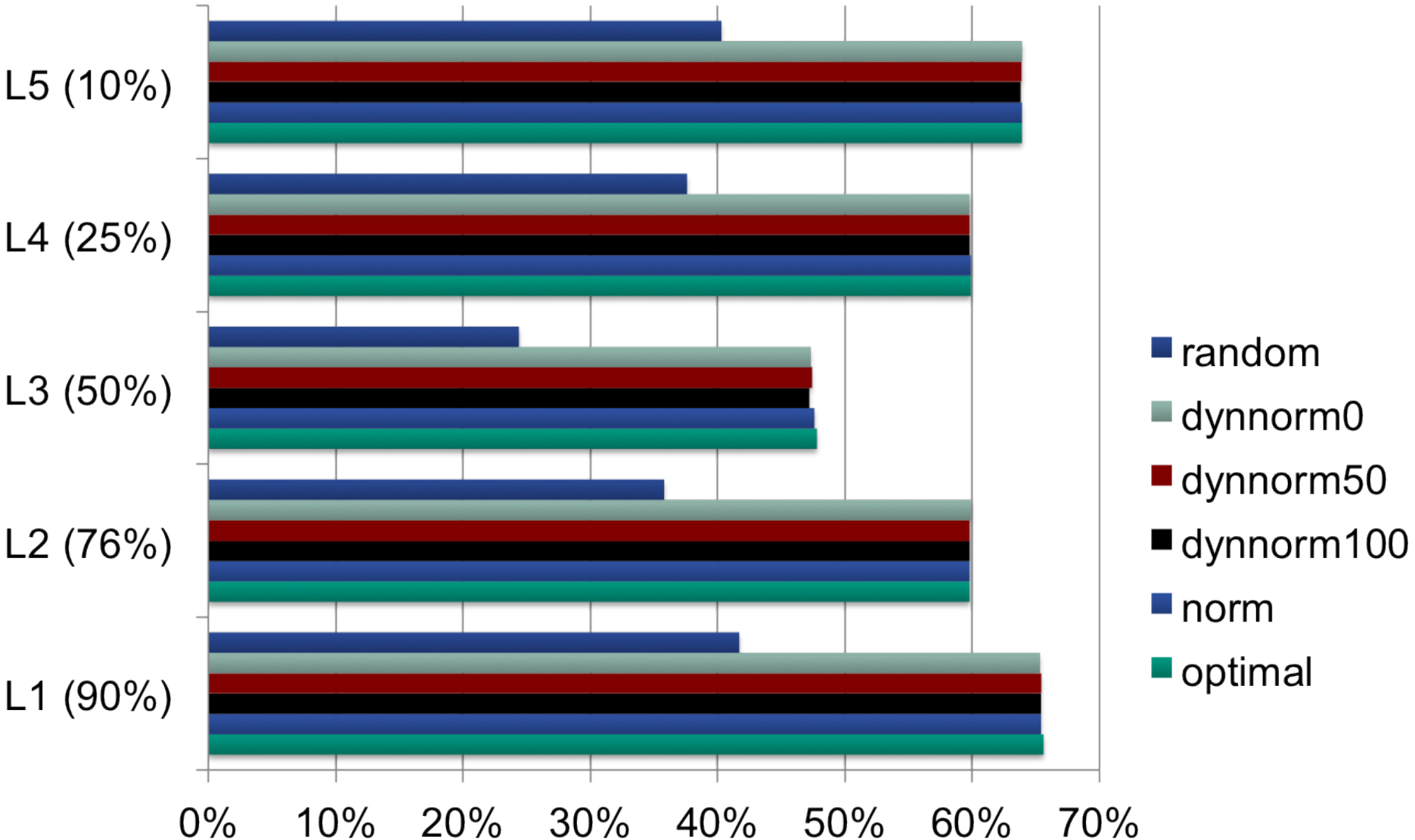

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- Impact function ($\rightsquigarrow$ determines oder) can be parametrized with the validity ratio
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- Decision spaces are efficient for determining the revision closure and axiom impact and saved 75% of reasoning calls in our experiments

Outlook – Ontology Techniques for Companion-Systems

Ontologies as background knowledge for companion systems

- Revision support for building up the ontology (reuse)

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- Can be combined with modularization techniques to extract relevant knowledge

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Companion systems also need user specific knowledge

- Longer-term than current sensor data
- More dynamic knowledge
- For example DS-3:
  - We know that a user is unfamiliar with the exercises
  - Detection that user looks puzzled $\rightsquigarrow$ explain exercises
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- Also includes forgetting of knowledge

$\rightsquigarrow$ Stream reasoning: reasoning with continuously changing knowledge

- Uncertainty has to be taken into account