Sistemas Baseados em Conhecimento
Aula 25

Renata Wassermann

renata@ime.usp.br

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Belief Change — An example (Gärdenfors & Rott 1995)

- Beliefs

  The bird caught in the trap is a swan
  The bird caught in the trap comes from Sweden
  Sweden is part of Europe
  All European swans are white

- Consequences

  The bird caught in the trap is white

- New information

  The bird caught in the trap is black

Which sentence(s) would you give up?

Motivation

Problem arises in several areas:

Databases: New entry inconsistent with database.

Robotics: Sensor information inconsistent with plans.

Diagnosis: Device behavior inconsistent with device description.

...

- Problem is not trivial:
  - Choice involved.
  - Indirect consequences of revision.
  - Representation issues.

Motivation

- Study the dynamics of ontologies, specially “OWL-like” DL ontologies.
- AGM Belief Revision deals with the problem of adding/removing information in a consistent way.
- AGM is most commonly applied to propositional classical logic and cannot be directly used with DLs.
- How can we adapt AGM so that it can deal with interesting DLs?

In this talk

- Brief introduction to AGM Belief Revision
- Show reasons why AGM fails to apply to DLs.
- Adapt Contraction (easy).
- Adapt Revision (less easy).
- Belief bases
- Ontology debugging via base revision.

Outline of the Talk

1. Motivation
2. The AGM paradigm
3. AGM and DLs
4. Belief Base Change
5. Ontology Debugging

AGM Belief Revision

Alchourrón, **G**ärdenfors, and **M**akinson (1985)
Belief sets $K = Cn(K)$.
Three operations defined to deal with knowledge base dynamics:

- **Expansion** - adding knowledge (possibly inconsistent)

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Three operations defined to deal with knowledge base dynamics:

- **Expansion** - adding knowledge (possibly inconsistent)
- **Contraction** - removing knowledge
- **Revision** - adding knowledge consistently

Revision usually defined in terms of contraction:
$K * \alpha = (K - \neg\alpha) + \alpha$

AGM Theory

For contraction and revision:

- **Rationality Postulates**

AGM Theory

For contraction and revision:

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- **Construction**

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- **Representation Theorem** (postulates $\Leftrightarrow$ construction)

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AGM Assumptions: Tarskian, Compact, Deduction Theorem, Supraclassical.

AGM contraction

(**K-1**) $K-\alpha$ is a belief set (*closure*)

(**K-2**) $K-\alpha \subseteq K$ (*inclusion*)

(**K-3**) If $\alpha \notin K$, then $K-\alpha = K$ (*vacuity*)

(**K-4**) If not $\vdash \alpha$, then $\alpha \notin K-\alpha$ (*success*)

(**K-5**) If $\alpha \in K$, then $K \subseteq (K-\alpha) + \alpha$ (*recovery*)

(**K-6**) If $\vdash \alpha \leftrightarrow \beta$, then $K-\alpha = K-\beta$ (*equivalence*)

Partial Meet Contraction – 1

Remainders: $K \perp \alpha$ is the set of maximal subsets of K that do not imply α.

Selection Function: γ selects "the best" elements of $K \perp \alpha$

Partial Meet Contraction – 2

Example: Let $K = Cn(p \wedge q)$

- $K \perp p = \{Cn(p \leftrightarrow q), Cn(q)\}$
- $K \perp p \wedge q = \{Cn(p), Cn(q), Cn(p \leftrightarrow q)\}$
- $K \perp p \rightarrow q = \{Cn(p), Cn(q)\}$

We may have:

- $\gamma(K \perp p) = \{Cn(p \leftrightarrow q)\}$
- $\gamma(K \perp p \wedge q) = \{Cn(p), Cn(q)\}$
- $\gamma(K \perp p \rightarrow q) = \{Cn(p), Cn(q)\}$

Partial Meet Contraction – 3

Definition: $K - \alpha = \bigcap \gamma(K \perp \alpha)$

Theorem (AGM): An operation $-$ on K is a partial meet contraction if and only if it satisfies postulates (**K-1**)-(**K-6**).

Safe Contraction – 1

Kernel: $K \perp\!\!\!\perp \alpha$ is the set of minimal subsets of K that imply α.

Incision Function: σ selects the minimal elements of each $K \perp\!\!\!\perp \alpha$

Safe Contraction – 2

Definition: $K - \alpha = K \setminus \sigma(K \perp\!\!\!\perp \alpha)$

Theorem (AM85): An operation $-$ on K is a safe contraction if and only if it satisfies postulates (**K-1**)-(**K-6**).

Applying to DL

- AGM cannot be applied to every logic. In particular it can not be applied to SHIF and SHOIN. [Flouris 2006]
- Solution: substitute recovery by relevance

  (relevance) If $\beta \in K \setminus K - \alpha$, then there is K' s. t. $K - \alpha \subseteq K' \subseteq K$ and $\alpha \notin Cn(K')$, but $\alpha \in Cn(K' \cup \{\beta\})$.

- Good property: AGM assumptions + 5 postulates $\Rightarrow$ recovery and relevance are equivalent.

Results - contraction

Representation Theorem [RW06]

If the underlying logic is tarskian and compact, partial meet contraction is equivalent to the AGM postulates with relevance instead of recovery.

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Can we do the same for revision???

AGM Revision

(closure) $K * \alpha = Cn(K * \alpha)$

(success) $\alpha \in K * a$

(inclusion) $K * \alpha \subseteq K + \alpha$

(vacuity) If $K + \alpha$ is consistent then $K * \alpha = K + \alpha$

(consistency) If α is consistent then $K * \alpha$ is consistent.

(extensionality) If $Cn(\alpha) = Cn(\beta)$ then $K * \alpha = K * \beta$

Applying to DL

- Problem: no negation $\Rightarrow$ no Levi identity.
- Solution: Direct constructions.

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Definition

$X \in K \downarrow \alpha$ iff X maximal subset of K such that $X \cup \{\alpha\}$ is consistent.

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Definition (Revision without negation)

$$K *_\gamma \alpha = \bigcap \gamma(K \downarrow \alpha) + \alpha$$

where γ selects at least one element of $K \downarrow \alpha$.

Properties

1. Inconsistent explosion: Whenever K is inconsistent, then for all formulas α, $\alpha \in Cn(K)$
2. Distributivity: For all sets of formulas X, Y and W, $Cn(X \cup (Cn(Y) \cap Cn(W))) = Cn(X \cup Y) \cap Cn(X \cup W)$

Properties

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Representation Theorem [RW09]

If the logic is monotonic and compact and satisfies Inconsistent explosion and Distributivity, then * is a revision without negation iff it satisfies closure, success, inclusion, consistency, relevance and uniformity.

(uniformity) If for all $K' \subseteq K$, $K' \cup \{\alpha\}$ is inconsistent iff $K' \cup \{\beta\}$ is inconsistent then $K \cap K * \alpha = K \cap K * \beta$

Which Logics Satisfy Distributivity?

- Classical logic does.
- But what about DLs?
  - $\mathcal{ALC}$ does not.
  - $\mathcal{ALC}$ with empty $\mathcal{A}$Box does.
  - not many more...

New characterisation

Representation Theorem [RW14]

If the logic is monotonic and compact and satisfies Inconsistent explosion ~~and Distributivity~~, then * is a revision without negation iff it satisfies closure, success, *strong* inclusion, consistency, relevance and uniformity.

(strong inclusion) $K * \alpha \subseteq (K \cap K * \alpha) + \alpha$

In classical logics this postulate is equivalent to inclusion.

Bases

Problems with the use of logically closed belief sets:

- Infinite sets.
- Inconsistency leads to trivialization.
- No distinction between explicit and implicit beliefs.

Reasons for Using Belief Sets

- Syntax independence
  - what matters is the content, not the form.
- Knowledge level in AI
  - coexists with other levels of description.
- Logical elegance.

Belief Bases (à la Hansson)

- Belief base B finite set of formulas.
- Expansion: $B + \alpha = B \cup \{\alpha\}$.
- Epistemic attitudes:
  - $\alpha \in Cn(B)$: α (implicitly) believed.
  - $\alpha \in B$: α explicitly believed.
  - $\alpha \in Cn(B) \setminus B$: α merely derived.

Example (Hansson)

- α: Paris is the capital of France.
- β: There is milk in the fridge.
- $\alpha, \beta \in B \Rightarrow \alpha \leftrightarrow \beta \in Cn(B)$

When we revise by $\neg\beta$, we must choose between giving up α and $\alpha \leftrightarrow \beta$.
*In the belief base approach, $\alpha \leftrightarrow \beta$ is automatically chosen and α remains in the revised base (**"Disbelief Propagation"**).*

More advantages of the use of bases

Expressivity $B_1 = \{\alpha, \beta\}$, $B_2 = \{\alpha, \alpha \leftrightarrow \beta\}$.
$Cn(B_1) = Cn(B_2)$
$B_1 * \neg\alpha = \{\neg\alpha, \beta\}$
$B_2 * \neg\alpha = \{\neg\alpha, \alpha \leftrightarrow \beta\}$
$\beta \in Cn(B_1 * \neg\alpha)$, but $\beta \notin Cn(B_2 * \neg\alpha)$.

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$B_2 * \neg\alpha = \{\neg\alpha, \alpha \leftrightarrow \beta\}$

$\beta \in Cn(B_1 * \neg\alpha)$, but $\beta \notin Cn(B_2 * \neg\alpha)$.

Inconsistency Tolerance $B_1 = \{p, \neg p, q_1, q_2, q_3\}$

$B_2 = \{p, \neg p, \neg q_1, \neg q_2, \neg q_3\}$

$Cn(B_1) = Cn(B_2)$, but $Cn(B_1 - p) \neq Cn(B_2 - p)$

Partial Meet Base Contraction – Construction

- $B \perp \alpha$: maximal subsets of B that fail to imply α
- γ: function that selects some elements of $B \perp \alpha$
- $B -_\gamma \alpha = \bigcap \gamma(B \perp \alpha)$

Partial Meet Base Contraction – Postulates

- If $\alpha \notin Cn(\emptyset)$, then $\alpha \notin Cn(B - \alpha)$ (success)
- $B - \alpha \subseteq B$ (inclusion)
- If $\beta \in B \setminus (B - \alpha)$, then there is some B' such that $B - \alpha \subseteq B' \subseteq B$, $\alpha \notin Cn(B')$ and $\alpha \in Cn(B' \cup \{\beta\})$ (relevance)
- If for all subsets B' of B, $\alpha \in Cn(B')$ if and only if $\beta \in Cn(B')$, then $B - \alpha = B - \beta$ (uniformity)

Partial Meet Base Contraction – Results

- Representation Theorem.
- Postulates not as intuitive as AGM.
- Recovery does not hold: $B = \{p \wedge q\}$, $(B - p) + p = \{p\}$.

Kernel Contraction – Idea

- Generalization of safe contraction.
- No hierarchy of formulas.
- Selects at least one formula from every minimal set implying α.
- Unlike AGM partial meet/safe contraction, kernel contraction is more general than partial meet.

Kernel Base Contraction – Construction

- $B \perp\!\!\!\perp \alpha$: minimal subsets of B that imply α
- σ: function that selects at least one element of each set in $B \perp\!\!\!\perp \alpha$
- $B -_\sigma \alpha = B \setminus \sigma(B \perp\!\!\!\perp \alpha)$

Kernel Base Contraction – Postulates

- If $\alpha \notin Cn(\emptyset)$, then $\alpha \notin Cn(B - \alpha)$ (success)
- $B - \alpha \subseteq B$ (inclusion)
- If $\beta \in B \setminus B - \alpha$, then there is some $B' \subseteq B$ such that $\alpha \notin Cn(B')$ and $\alpha \in Cn(B' \cup \{\beta\})$ (core-retainment)
- If for all subsets B' of B, $\alpha \in Cn(B')$ if and only if $\beta \in Cn(B')$, then $B - \alpha = B - \beta$ (uniformity)

Contraction - Example

$B = \{p, p \vee q, p \leftrightarrow q\}$

$B \perp\!\!\!\perp (p \wedge q) = \{\{p, p \leftrightarrow q\}, \{p \vee q, p \leftrightarrow q\}\}$
$B \perp (p \wedge q) = \{\{p, p \vee q\}, \{p \leftrightarrow q\}\}$

$B - (p \wedge q) = \{p\}$ can be constructed as kernel but not partial meet contraction.

Motivation

- Ontology Debugging:
  - Explanations;
  - Ontology Repair;
  - *Undesired* Entailment.
- **Idea:** Use belief base revision.

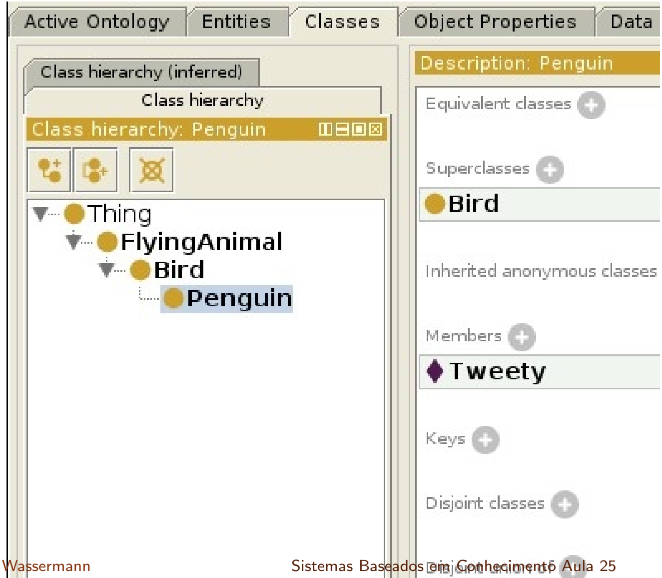
Contraction

- Kernel
  - Minimal subsets keeping the undesired entailment - *Kernel Set*
  - Incision Function:
    - Select elements to be removed.

Contraction

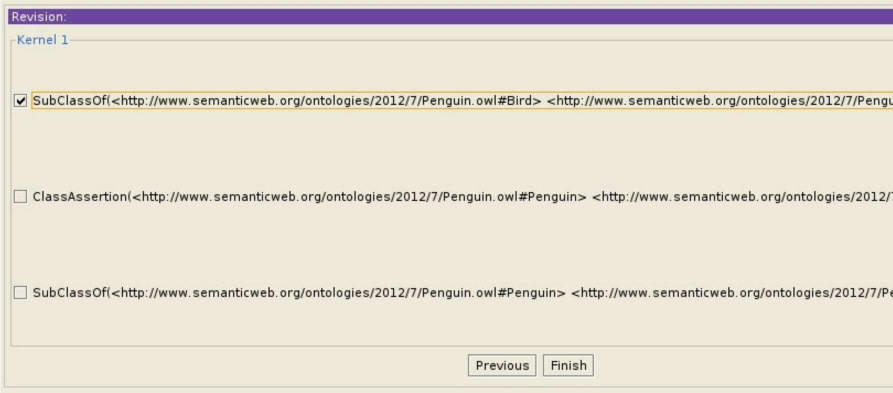
- Kernel
  - Minimal subsets keeping the undesired entailment - *Kernel Set*
  - Incision Function:
    - Select elements to be removed.
- Partial Meet
  - Maximal subsets not keeping the undesired inference - *Remainder Set*
  - Selection Function:
    - Select the best subsets to keep.

Protégé Plugin (2008)

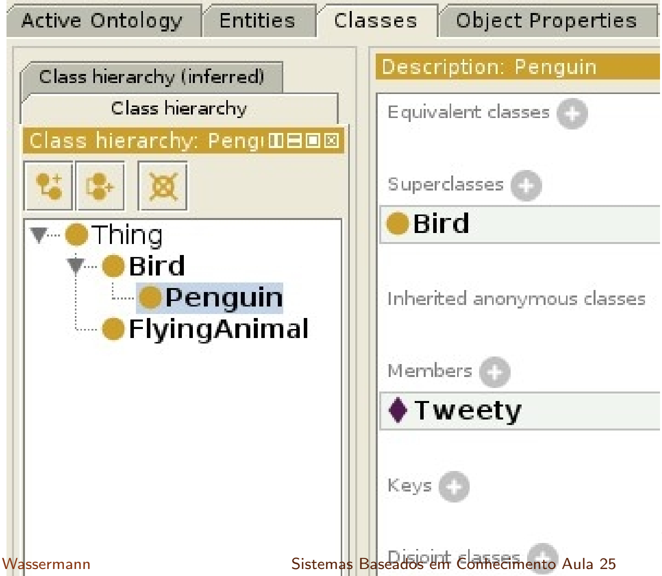


Protégé Plugin – Revision

Protégé Plugin – Kernels



Protégé Plugin – Revised Ontology



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Kernel Set!

Partial Meet vs. Kernel

- One remainder is enough *(maxichoice)*.
- Whole kernel needs to be computed.
- Is one of the contraction operations *"easier"* than the other?

Black-Box Algorithm

(Resina, Ribeiro, Wassermann, 2014)

```
Black-box-remainder(𝒪, φ):
 #Shrink first
 removed_elements← 𝒪
 remainder_element← ∅
 #Now Expand
 for each α ∈ removed_elements do
   if(remainder_element ∪ {α} ⊭ φ) then
     remainder_element ←
                 remainder_element ∪ {α}
 return remainder_element
```

Experiments - Evaluation

- Metrics:
  - Number of reasoner calls;
  - Overall execution time.
- Kernel: Horridge's OWLExplanation plugin

Experiments

Generated Data

- Large Kernel/Small Remainder VS Small Kernel/Large Remainder

Experiments

Generated Data

- Large Kernel/Small Remainder VS Small Kernel/Large Remainder
- For Large Kernel:
  - Building a single Remainder costs less than building a single Kernel set.
  - Remainder algorithm optimizations were effective.

Experiments

Real Data I

- BioPortal:
  - 51 ontologies;
  - 3812 non trivial entailments;
  - Several expressivity levels.

Experiments

Real Data II

- In 44% of the cases, less reasoner calls to build an element of the Remainder set;
- In 6,4% of the cases, the kernel algorithm could not terminate within the allocated time

Experiments

Real Data III

- Less time to build the kernel set.
  - Better usage of the OWLAPI
- Optimizations on the algorithm to build remainder elements have proved to be effective, except for 3 entailments of the *imgt-ontology* ontology