Ontology Dynamics
Belief Change
Nonmonotonic Reasoning

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Logic-Based Ontology Dynamics

Ontologies

- Logic-based representations have been enormously beneficial
  - Particularly description logics
- The main advantages
  - A clear formal semantics
  - Efficient reasoners

Ontology Dynamics

- A growing need for coping with changing ontologies
- Current approaches are somewhat ad hoc
- Put Ontology Dynamics on a solid formal footing

Purpose of this talk

What I will attempt to do

- Focus on some aspects of Ontology Dynamics
- Broad overviews
- Look at existing links
- Some thoughts on challenges

What I will **not** attempt to do

- Give a comprehensive survey of Belief Change
- Give a comprehensive survey of Nonmonotonic Reasoning
- Attempt to describe all links between these areas

Outline

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1. Logic-Based Ontologies

2. Ontology Dynamics

3. Belief Change
   - Belief Change and Ontology Dynamics

4. Nonmonotonic Reasoning
   - Nonmonotonic Reasoning and Belief Set Revision
   - Nonmonotonic Reasoning and Ontologies

5. Conclusion

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Description Logics

An Overview

- (Decidable) fragments of first-order logic
- Concepts: classes of individuals
- Roles: binary relations between individuals
- Define a terminology: TBox
- Provide assertions: ABox

Standard Reasoning Services

- Instance checking
- Concept subsumption and equivalence
- Concept satisfiability and knowledge base inconsistency

The Description Logic $\mathcal{ALC}$

Concept construction

- Complex concepts formed using various constructors
- Negation: $\neg C$; Conjunction: $C \sqcap D$; Disjunction: $C \sqcup D$
- TBox statements
  - Subsumption: $C \sqsubseteq D$ where C and D are concepts
- ABox statements
  - $C(a)$ where C is a concept and a is an individual name

Examples

- Person $\sqsubseteq$ Animal $\sqcap$ Biped
- Man $\doteq$ Person $\sqcap$ $\neg$ Woman
- $\neg$Parent(Sam)

Description Logics and the Semantic Web

OWL 2 (Web Ontology Language)

- A W3C recommendation
- Based on the description logic $\mathcal{SROIQ}$

OWL 2 Profiles

- EL for dealing with large TBoxes
  - Based on the $\mathcal{EL}$ family of description logics
- QL for dealing with large ABoxes
  - Based on the DL-Lite family of description logics
- RL for exploiting rule-based technologies within OWL 2
  - Based on Description Logic Programs

Outline

Ontology Dynamics

Ontology Construction

- Debugging and repair; Explanation

Ontology Update

- Updates due to a dynamic world; Web services

Defeasibility in Ontologies

- Not related to ontology dynamics?

Ontology Versioning

- Maintaining different versions of the same ontology

Outline

What is Belief Change?

Informally

- An agent has beliefs about the world it inhabits
- It receives new information
- It adjusts its beliefs accordingly
- It does so in a rational fashion

Formally

- Beliefs are represented as a set of sentences
- The new input is a single sentence
- Adjustment: an operator on belief sets and sentences
- The result is a set of sentences

Rationality Criteria

Basic Criteria

- Categorial Matching
- Logical Consistency
- Logical Closure?

Extended Criteria

- Minimal Change
- Preference: Retain more important beliefs if necessary

Types of Belief Change

Static Environment

- Revision: Consistent incorporation of new information
- Contraction: Removal of specified information
- Merging: Dealing with inconsistency

Dynamic Environment

- Update: Consistent incorporation of new information
- Erasure: Removal of specified information

Static Belief Change

Assumptions

- A logic with a Tarskian consequence relation
  - In practice (frequently), a finitely generated propositional logic
- The set of beliefs K is consistent
- Focus is on contraction
- Revision can be obtained by first contracting and then adding

Belief bases or belief sets?

- Base change: Syntax matters $\{p, q\}$ vs. $\{p, p \to q\}$
- Belief set: Syntax independence

Base Contraction : $B = \{p \rightarrow q, q \rightarrow r\}$ entails $p \rightarrow r$

Partial meet contraction

- Find the $(p \rightarrow r)$-remainder sets:
  Maximal subsets of B not entailing $p \rightarrow r$: $\{p \rightarrow q\}, \{q \rightarrow r\}$
- Choose some of these and take their intersection:
  $\{p \rightarrow q\}, \{q \rightarrow r\}, \emptyset$
- Maxichoice: choose exactly one; Full Meet: choose all

Kernel meet contraction

- Find the $(p \rightarrow r)$-kernels:
  Minimal subsets of B entailing $p \rightarrow r$: $\{p \rightarrow q, q \rightarrow r\}$
- Choose an incision (at least one sentence from each kernel) and remove from B: $\{p \rightarrow q\}, \{q \rightarrow r\}, \{p \rightarrow q, q \rightarrow r\}$

Theory Contraction : $Cn(B) = \{p \rightarrow q, q \rightarrow r, p \rightarrow r, \ldots\}$

Partial meet contraction

- Find the $(p \rightarrow r)$-remainder sets:
  $Cn(p \rightarrow q, (\neg p \wedge q) \rightarrow r), Cn(q \rightarrow r, (p \wedge r) \rightarrow q)$
- Choose some and take their intersection (always a theory)
- Maxichoice and Full Meet as before

Kernel meet contraction

- Find the $(p \rightarrow r)$-kernels, choose an incision (at least one sentence from each) and remove from $Cn(B)$
- More kernels: $\{p \rightarrow q, q \rightarrow r\}$, $\{p \rightarrow r\}$, $\ldots$
- Not necessarily a theory, so close under Cn

Link between partial meet and kernel contraction

Base contraction

- Partial meet contraction is strictly weaker than kernel contraction

Belief set contraction

- Partial meet contraction coincides with kernel contraction

Dynamic Belief Change

Assumptions

- Change has taken place because the world has changed
  - In practice (usually), a finitely generated propositional logic
- The set of beliefs K is consistent
- Focus is on belief update

Construction methods for belief update

- Model update operators
- A partial order over worlds for every model of K
- Update with α: take the union of all minimal α-worlds
- Represents the models of the updated beliefs K'

Outline

Belief Change and Ontology Dynamics

Ontology Debugging

- Identify causes of unwanted consequences
- $\mathcal{T} = \{A \sqsubseteq B \sqcap C, C \sqsubseteq \neg B, B \sqsubseteq \neg C\}$
- Unwanted axiom α: $A \sqsubseteq \bot$
- Based on obtaining **justifications** for a sentence α:
  - A minimal subset of $\mathcal{T}$ which entailed α
- Justifications: $\{A \sqsubseteq B \sqcap C, C \sqsubseteq \neg B\}$, $\{A \sqsubseteq B \sqcap C, B \sqsubseteq \neg C\}$
- Justifications are special cases of kernels

Belief Change and Ontology Dynamics

Ontology Repair

- Maximal subsets of $\mathcal{T}$ not entailing α
- $\mathcal{T} = \{A \sqsubseteq B \sqcap C, C \sqsubseteq \neg B, B \sqsubseteq \neg C\}$
- Repairs: $\{A \sqsubseteq B \sqcap C\}$, $\{C \sqsubseteq \neg B, B \sqsubseteq \neg C\}$
- Special cases of partial meet base contraction
- Also obtained from justifications
    - Frequently using the **hitting set algorithm** (Reiter, 1987)
- Special cases of kernel base contraction

Challenges

Syntax independence?

- Results are syntax dependent
- Approaches to syntax independence
  - Laconic and precise justifications (Horridge et al., 2008)
  - Work on **belief set** contraction
    - (Delgrande, 2008, Booth et al. 2009)

Unique solutions?

- Current approaches provide multiple solutions
- Methods for providing a unique solution
- Belief set contraction and preferences

Challenges

"Lifting" belief change to description logics

- Propositional belief change has certain properties
- Description logics have more **structure**
- Belief change for DLs need to take this into account

Example

- $B \sqsubseteq F$
- $B(T), \neg F(T), B(C)$
- $F(C)$?
- Replace $B \sqsubseteq F$ with "$B \sqsubseteq F$ except for T"?

Ontology Update

"Lifting" to description logics

- Distinguish between TBox and Abox updates
- Virtually no work on TBox updates
- Some work on Abox updates (Baader et al., 2005)

Results and Challenges

- Computing updates is expensive
- Results not always expressible in the same description logic
  - Move to a more expressive description logic?
  - Approximate results?
  - Constraints on the structure of updates?

Outline

Nonmonotonic Reasoning

The basics

- Based on a classical monotonic logic:
  - Monotonicity: If $K \models \alpha$, $K \subseteq K'$ then $K \models \alpha$
- Replace $\models$ with a nonmonotonic consequence relation $|\!\sim$
  - Birds usually fly, Tweety is a bird, but Tweety doesn't fly

Best known approaches to nonmonotonicity

- Default Logic (Reiter, 1980)
- Autoepistemic logic (Moore, 1985)
- Logic programming (Gelfond et al. 1988)
  - Answer set programming

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Nonmonotonic Reasoning and Belief Set Revision

An abstract view of Belief Revision

- K is a belief set (closed under logical consequence)
- $K * \alpha$ is the new belief set resulting from a revision by α

An abstract view of Nonmonotonic Reasoning

- A nonmonotonic consequence relation $\mid\sim$
- $\alpha \mid\sim \beta$ means "given α, it usually follows that β"

Nonmonotonic Reasoning and Belief Set Revision

Nonmonotonic Reasoning as Belief Revision

- $K = \{\beta \mid \top \mid\sim \beta\}$; $K * \alpha = \{\beta \mid \alpha \mid\sim \beta\}$

Belief Revision as Nonmonotonic Reasoning

- $\alpha \mid\sim \beta$ iff $\beta \in K * \alpha$

Another perspective on Nonmonotonic Reasoning

Enrich the language with a nonmonotonic operator $\mid\!\sim$

- Typically an underlying propositional logic
  - Sentences α, β, etc.
- $\alpha \mid\!\sim \beta$ is a sentence in the enriched language

Conditional knowledge base

- $KB = \{\alpha_1 \mid\!\sim \beta_1, \alpha_2 \mid\!\sim \beta_2, \ldots\}$
- $\neg\alpha \mid\!\sim \perp$ is equivalent to α
- $KB \models_C (\alpha \mid\!\sim \beta)$?
- $\models_C$ is a monotonic consequence relation
- The nonmonotonicity is in the enriched language

Another perspective on Nonmonotonic Reasoning

Default reasoning (Lehmann 1995)

- Two readings of nonmonotonic reasoning
  - presumptive and stereotypical
- Both are encoded as conditional knowledge bases
- Both can be “compiled” away
  - Computing maximally consistent subsets
- Complexity for both remain the same as the classical case

Outline

Nonmonotonic Reasoning and Ontologies

A need for nonmonotonicity

- "Bacteria **may** cause pneumonia" (Rector et al. 2008)
- "In humans, the heart is usually located on the left-had side of the body" (Rector, 2004; Stevens et al. 2007)

Nonmonotonic extensions to description logics

- Description logic programming (Grosof et al. 2003)
- Adding epistemic operators (Donini et al. 1998)
- Default logic extensions (Baader et al. 1995)

Complexity issues

Nonmonotonic Reasoning and Ontologies

TBoxes as conditional knowledge bases

- Lift $\alpha \mid\!\sim \beta$ to conditional subsumption $\precsim$
- TBox may contain statements of the form $A \precsim B$
- Conditional TBox $\mathcal{CT} = \{A_1 \precsim B_1, A_2 \precsim B_2, \ldots\}$
- $\mathcal{T} \cup \mathcal{CT} \models_C \alpha$?

Lehmann's Default Reasoning?

- Presumptive and Stereotypical reasoning for ontologies
- Will not affect the complexity in many cases

Main challenge

- Are these forms of reasoning appropriate in this context?

Ontology Versioning

Semantic Diff

- A need for maintaining different versions of ontologies
- Tools exist for keeping track of changes
- The methods developed so far are mostly syntactic in nature
- A semantic approach is needed
- Current work (Konev et al., 2008; Franconi et al., 2010)
  - Development of methods for defining "Semantic Diff"
  - Related to Belief Change
  - Refinement of existing reasoning tools necessary

Outline

Conclusion

Summary

- Increasing demand for coping with Ontology Dynamics
  - Largely due to the efficiency of ontology reasoners
- Dramatic increase in tools for Ontology Dynamics
- Many based on existing work

Challenges

- Restriction on languages
- Do not reinvent the wheel
- Appropriate refinement of existing methods
- Complexity issues