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

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
Outline

1. Logic-Based Ontologies
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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 $\models$ 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 $SROIQ$

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
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
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. $\{p, p \rightarrow q\}$
- 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:
  \[ Cn(p \rightarrow q, (\neg p \land q) \rightarrow r), Cn(q \rightarrow r, (p \land r) \rightarrow q) \]
- 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 $\alpha$: take the union of all minimal $\alpha$-worlds
- Represents the models of the updated beliefs $K'$
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Ontology Debugging

- Identify causes of unwanted consequences
- \( T = \{ A \sqsubseteq B \cap C, C \sqsubseteq \neg B, B \sqsubseteq \neg C \} \)
- Unwanted axiom \( \alpha: A \sqsubseteq \bot \)
- Based on obtaining justifications for a sentence \( \alpha \):
  - A minimal subset of \( T \) which entailed \( \alpha \)
- Justifications: \( \{ A \sqsubseteq B \cap C, C \sqsubseteq \neg B \}, \{ A \sqsubseteq B \cap C, B \sqsubseteq \neg C \} \)
- Justifications are special cases of kernels
Ontology Repair

- Maximal subsets of $\mathcal{T}$ not entailing $\alpha$
- $\mathcal{T} = \{A \sqsubseteq B \cap C, C \sqsubseteq \neg B, B \sqsubseteq \neg C\}$
- Repairs: $\{A \sqsubseteq B \cap C\}$, $\{C \sqsubseteq \neg B, B \sqsubseteq \neg C\}$
- 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?
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Nonmonotonic Reasoning

The basics

- Based on a classical monotonic logic:
  - Monotonicity: If $K \vDash \alpha$, $K \subseteq K'$ then $K \vDash \alpha$
- Replace $\vDash$ with a nonmonotonic consequence relation $\models \sim$
  - 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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An abstract view of Belief Revision

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

An abstract view of Nonmonotonic Reasoning

- A nonmonotonic consequence relation $\models$
- $\alpha \models \beta$ means “given $\alpha$, it usually follows that $\beta$”
Nonmonotonic Reasoning and Belief Set Revision

Nonmonotonic Reasoning as Belief Revision

\[ K = \{ \beta \mid T \models \sim \beta \}; \quad K * \alpha = \{ \beta \mid \alpha \models \sim \beta \} \]

Belief Revision as Nonmonotonic Reasoning

\[ \alpha \models \sim \beta \iff \beta \in K * \alpha \]
Another perspective on Nonmonotonic Reasoning

Enrich the language with a nonmonotonic operator $\sim$

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

Conditional knowledge base

- $KB = \{\alpha_1 \sim \beta_1, \alpha_2 \sim \beta_2, \ldots\}$
- $\neg \alpha \sim \bot$ is equivalent to $\alpha$
- $KB \models_C (\alpha \sim \beta)$?
- $\models_C$ is a monotonic consequence relation
- The nonmonotonicity is in the enriched language
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
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 $\alpha \models \beta$ to conditional subsumption $\sqsubseteq$
- TBox may contain statements of the form $A \sqsubseteq B$
- Conditional TBox $CT = \{ A_1 \sqsubseteq B_1, A_2 \sqsubseteq B_2, \ldots \}$
- $\mathcal{T} \cup CT \models_C \alpha$?

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
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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