FOL and KR

Representing Knowledge in FOL

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Objectives

Objective

Apply first-order logic to representing knowledge

Establishing the Vocabulary

- **Start from a textual description or diagram:**
  - A juvenile disease affects only children or teenagers
  - Children and teenagers are not adults
  - Juvenile arthritis is a kind of arthritis and a juvenile disease
  - Arthritis affects some adults
- **Identify the important types of objects (unary FOL predicates):**
  - juvenile disease, child, teenager, adult, . . .
- **Identify the important types of relationships (n-ary FOL predicates)**
  - affects, . . .
- **Identify the important functions (none in this particular case)**

Example FOL Sentences

- A juvenile disease affects only children or teenagers
  - $\forall x \forall y (JuvDisease(x) \land Affects(x,y) \rightarrow Child(y) \lor Teenager(y))$
- Children and teenagers are not adults
  - $\forall x (Child(x) \lor Teenager(x) \rightarrow \neg Adult(x))$
- Juvenile arthritis is a kind of arthritis and a juvenile disease
  - $\forall x (JuvArthritis(x) \rightarrow Arthritis(x) \land JuvDisease(x))$
- Arthritis affects some adults
  - $\exists x \exists y (Arthritis(x) \land Affects(x,y) \land Adult(y))$

Does Juvenile Disease Affect Adults?

In propositional logic:

$$JuvDisease \rightarrow AffectsChild \lor AffectsTeenager$$
$$Child \lor Teenager \rightarrow \neg Adult$$

Does not entail $\underbrace{JuvDisease}_{t} \rightarrow \neg \underbrace{AffectsAdult}_{t}$

In first-order logic:

$$\forall x \forall y (JuvDisease(x) \land Affects(x, y) \rightarrow Child(y) \lor Teenager(y))$$
$$\forall x (Child(x) \lor Teenager(x) \rightarrow \neg Adult(x))$$

entails

$$\forall x \forall y (JuvDisease(x) \land Affects(x, y) \rightarrow \neg Adult(y))$$

Basic Facts

- Now that we have the basic vocabulary, we can acquire the data

Child(JohnSmith) JuvenileArthritis(JRA) ¬Affects(JRA, MaryJones)	John Smith is a child JRA is a juvenile arthritis Mary Jones not affected by JRA

- Usually data consists of (possibly negated) atoms

- But data can also reflect more complex information:

Child(JohnSmith) v Child(MaryJones)	Either John or Mary is a child

Terminological Axioms

Sentences describing the general meaning of predicate and function symbols (independently of the concrete data)

Sub-type statements

- $\forall x(JuvArthritis(x) \rightarrow Arthritis(x))$

Full definitions

- $\forall x(JuvArthritis(x) \leftrightarrow Arthritis(x) \land JuvDisease(x))$

Disjointment statements:

- $\forall x\ (Child(x) \rightarrow \neg Adult(x))$

Terminological Axioms, cont'd

Covering statements:

- $\forall x(Person(x) \rightarrow Adult(x) \vee Child(x) \vee Teenager(x))$

Type restrictions:

- $\forall x\, \forall y(Affects(x, y) \rightarrow Arthritis(x) \wedge Person(y))$

Other general statements:

- $\forall x\, \forall y\, (JuvDisease(x) \wedge Affects(x, y) \rightarrow Child(y) \vee Teenager(y))$

Data vs. Terminological Knowledge

- **The Data describes specific objects**
  - Sentences without variables or quantifiers (usually atoms)
- **Terminological axioms describe general properties of the application domain, independently of the data**
  - Universally quantified sentences with no constants
- **This separation is not theoretically "clean" in FOL:**
  - $\forall y(Affects(JRA, y) \rightarrow Child(y) \vee Teenager(y))$
  - $\forall x(Cont(x) \rightarrow (x = Eur) \vee (x = Asia) \vee (x = Amer) \vee (x = Afr) \vee (x = Aus) \vee (x = Antart))$
- **Set of Terminological Axioms often called an Ontology**
- **Ontology + Data often called a Knowledge Base**

The Role of Reasoning

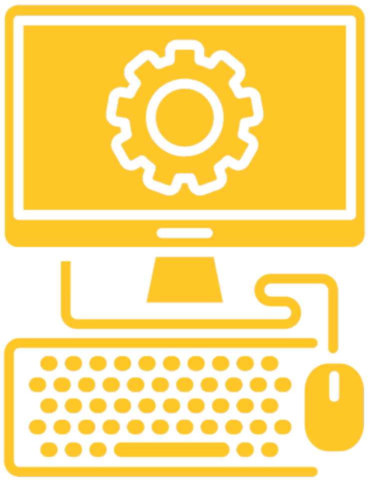
Why are reasoning problems (satisfiability, entailment) useful?

- Detect errors
  - ⇒ Knowledge base becomes unsatisfiable
  - ⇒ We get an unintuitive (and “wrong”) entailment
  - ⇒ We don’t get an intuitive (and “right”) entailment
- Discover new knowledge
  - ⇒ Things we weren’t aware we knew
- Richer query answers ⇒ Retrieve more (relevant) data

The Role of Reasoning

Without reasoning, knowledge engineering becomes unfeasible

- Knowledge bases grow very large (1,000s of sentences)
- Errors are difficult to detect manually
- Query answers do not take knowledge into account



Expressivity vs. Complexity

- **THEOREM: FOL satisfiability is an undecidable problem: there is no procedure that given any set of first order sentences S:**
  - Always terminates
  - Returns true if and only if S is satisfiable
- **So should we just give up (reasoning is intractable)?**
  - MAYBE!
- **Highly optimized FOL theorem provers are effective in practice**
- **But still can’t cope with realistic KR problems**

Limitations of FOL

FOL is powerful, but still can’t capture

- Transitive closure (Ancestor is the transitive closure of Parent)
- Defaults and exceptions (Birds fly by default; Penguins are an exception)
- Probabilistic knowledge (Children suffer from JRA with probability x)
- Vague knowledge (Ian is Tall) ...

We will return to some of these issues later in the course

Wrap-Up