Methods in AI Research

Fragments and Subsymbolic vs symbolic AI

Lecture 13

Tuesday, 17 October 2019

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Four lectures on logic and reasoning in AI:

Lecture 12. Knowledge-based reasoning

Lecture 13. Fragments and Subsymbolic vs symbolic AI

Lecture 14. Nonmonotonic reasoning

Lecture 15. Common sense reasoning

1. *Last Tuesday*
2. *Fragments of FOL*
3. *Description Logic*
4. *Symbolic versus Subsymbolic AI*

1. Last Tuesday

Ex. Let the language contain a binary predicate S, constant (0-ary function) c, and a unary function f. $M = (D, I)$, where

- $D = \mathbb{N} = \{0, 1, 2, \dots\}$ *and* $I(c) = 0$
- $I(S) = \{(m, n) \mid m < n\}$ *($I(S)$ is the smaller-than relation)*
- $I(f)(n) = 2n$.

- $M \models \neg S(c, f(c))$
- $M \models \forall x(x \neq c \to S(x, f(x)))$
- $M \not\models \exists x S(x, f(f(c)))$
- $M \not\models \forall x \forall y(S(x, y) \to S(y, x))$
- $M \models \forall x(f(x) = x \to x = c)$.

Dfn. *A sentence is a formula without free variables.*

A sentence φ follows from a set of sentences Γ (written $\Gamma \vDash \varphi$) if φ is valid in all models in which all formulas in Γ are valid.

For finite sets $\Gamma = \{\varphi_1, \ldots, \varphi_n\}$ we write $\varphi_1, \ldots, \varphi_n \vDash \varphi$ for $\Gamma \vDash \varphi$.

Ex. *For any formulas φ and ψ:*

- $\varphi \vDash \varphi$
- $\varphi \vDash \varphi \vee \psi$
- $\forall x \varphi(x) \vDash \neg \exists y \neg \varphi(y)$

Ex. *There are formulas φ and ψ such that*

- $\varphi \nvDash \neg \varphi$
- $\varphi \vee \psi \nvDash \varphi \wedge \psi$
- $\exists x \varphi(x) \nvDash \exists x \neg \varphi(x)$

Ex. Let the language contain a binary predicate $R(x, y)$ and a unary function f.

- $\forall x \forall y(R(x, y) \rightarrow R(y, x)) \not\models \forall z R(z, z)$
- $\forall x \exists y R(x, y) \not\models \forall z R(z, z)$
- $\forall x R(x, f(x)) \wedge \forall y(y \neq f(y)) \not\models \forall z R(z, z)$
- $\forall x \forall y(R(x, y) \leftrightarrow y = f(x)) \wedge \forall y(y \neq f(y)) \models \forall z \neg R(z, z)$.

Why not express a KB in predicate logic as a set of formulas Γ and reason using the valid inferences of predicate logic: deduce φ for those formulas φ such that $\Gamma \vDash \varphi$?

Because ...

Thm. *(Alan Turing 1936–1937)*
There exists no Turing Machine (algorithm) that decides for any finite set of formulas Γ and any formula φ whether $\Gamma \vDash \varphi$.

David Hilbert's Entscheidungsproblem (decision problem) 1900
Find an algoritm that decides whether $\Gamma \vDash \varphi$.

Alonzo Church and Alan Turing proved that there exists no such algorithm.

Why not express a KB in predicate logic as a set of formulas Γ and reason using the valid inferences of predicate logic: deduce φ for those formulas φ such that $\Gamma \models \varphi$?

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FOL is undecidable.

Dfn. A logic is decidable if there is an algorithm that for any formula φ decides whether it is valid in the logic or not.

FOL is undecidable. What to do?

Consider decidable fragments of FOL.

2. *Fragments of FOL*

Consider decidable fragments of FOL, i.e. sets of first-order formulas for which there exists an algorithm that decides whether an arbitrary formula belongs to the set or not.

In theorie

Focus on decidable fragments of FOL:

- *the quantifier free fragment;*
- *the fragment without functions and only 1-ary predicates;*

$\vdots$

In AI practice

Focus on logics that correspond to a decidable fragment of FOL:

- *modal logics;*
- *epistemic logics;*
- *agent logics;*
- *description logics;*

$\vdots$

Tension:

expressive power (what can be represented)
versus
effciency (good computational properties)

Extremes:

FOL (strong expressive power, bad computational properties)
versus
propositional logic (weak expressive power, good computational properties, decidable)

Description Logics as a well-known example between these extremes. They correspond to a fragment of FOL, although they are formulated in a different language.

3. Description Logic

(An Introduction to Description Logic – 2017)
(Baader & Horrocks & Lutz & Sattler)

Description Logics (DLs) are a family of knowledge representation languages that can be used to represent knowledge of an application domain in a structured and well-understood way.

Many applications, for exmaple
Ontology languages (OWL),

DLs introduced in the 1980s.

Knowledge Representation before DLs:

Frames, semantic networks, . . .

Important: DLs are variants of the multi-modal logic K.

Main notion: Concept descriptions, i.e., expressions that are built from atomic concepts (unary predicates) and atomic roles (binary predicates) using the concept and role constructors provided by the particular DL.

Notation: atomic concepts uppercase; atomic roles lowercase.

Ex. The concept a student that has a sloppy roommate and only happy friends:

$$Student \sqcap \exists roommate.Sloppy \sqcap \forall friends.Happy$$

Translation into FOL:

$$Student(x) \wedge \exists y(roommate(x,y) \wedge Sloppy(y)) \wedge \forall z(friends(x,z) \rightarrow Happy(z))$$

Dfn. The language of the weak Description Logic FL^w: Concepts are defined via the following rule

$$C, D \rightarrow A \mid \neg C \mid C \sqcap D \mid C \sqcup D \mid \forall r.C$$

C, D are concept names, r a role name.

In terms of FOL: $\wedge = \sqcap$, $\vee = \sqcup$, C, D range over unary predicates, r ranges over binary predicates.

$$\forall r.C \text{ in FOL: } \forall y(r(x,y) \rightarrow C(y))$$
$$\exists r.C \text{ in FOL: } \exists y(r(x,y) \wedge C(y))$$

An interpretation/model for FL^w is defined as for FOL under the above translation.

New concepts can be defined in terms of previously given ones:

$$Man \equiv Person \sqcap Male \quad Mother \equiv \neg Male \sqcap \exists child.Person$$

Ex. Language has atomic concepts $C_1, C_2, \ldots, C_7$ and a role r.

Model $M = (\mathcal{D}, \mathcal{I})$ has domain $\mathcal{D} = \{R_1, R_2, \ldots, R_7\}$ consisting of seven restaurants, and $\mathcal{I}(r)(x, y)$ holds when x, y are in the same street.

$$C(x) \equiv \forall r.\neg R_2$$

$\mathcal{I}(C)$ is the concept consisting of all restaurants in $\mathcal{D}$ that are not in the same street as R_2.

In FOL:

$$\varphi(x) = \forall y(r(x, y) \to \neg R_2(y))$$

$M, \mu \vDash \varphi(x)$ iff $\mu(x)$ is not in the same street as R_2.

FL^w equals FL^- in Chapter 16 (16.1.1) without [EXISTS 1 r] and

$$[ALL\ r\ d] = \forall r.D \quad [AND\ d_1 \ldots d_n] = D_1 \sqcap D_2 \sqcap \cdots \sqcap D_n.$$

At exam:
Please use the standard notation, which is the one on the slides.

The main purpose of reasoning in DLs is to explicate knowledge that is contained only implicitly in a given concept description.

Key ingredient: Subsumption

Concept D subsumes C in model $M = (\mathcal{D}, \mathcal{I})$ if $\mathcal{I}(C) \subseteq \mathcal{I}(D)$ holds in M.

$C \sqsubseteq D$ denotes that D subsumes C.

Inferences are of the form:

$$\text{if } C_1 \equiv D_1, \ldots, C_n \equiv D_n, \text{ then } C \sqsubseteq D,$$

Meaning that if the left n expressions hold in a model, so does $C \sqsubseteq D$.

Ex.
if $Disease \equiv SymptomX \sqcap SymptomY$, $SymptomX \equiv SymptomY$,

then $SymptomY \sqsubseteq Disease$.

Like many DLs, FL^{w} (and FL^{-} in book) have good computational properties: subsumption between to concepts is not only decidable, it can be decided in time polynomial in the length of the concept expressions.

In Chapter 16 an example is given, description logic FL, for which subsumption is decidable, but deciding it is as hard as deciding whether a given propositional formula is unsatisfiable.

Since it it assumed that there is no polynomial algorithm for the latter, it is assumed that there is no polynomial algorithm that decides subsumption in FL.

Conclusion: For many appliations, DLs have sufficient expressive power and are reasonably efficient.

Tension:

expressive power (what can be represented)
versus
effciency (good computational properties)

Extremes:

FOL (strong expressive power, bad computational properties)
versus
propositional logic (weak expressive power, good computational properties, decidable)

DLs as a well-known example between these extremes.

FOL is normative/absolute.

Not all reasoning is normative, especially not reasoning exhibited by humans. (next two lectures)

Other logic paradigms than FOL:

- *Nonmonotonic logic (next lecture)*
- *Fuzzy logic*
- *Many valued logic*

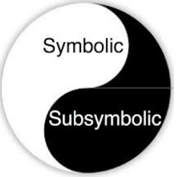
$\vdots$

The issue of tension remains:

expressive power (what can be represented)
versus
effciency (good computational properties)

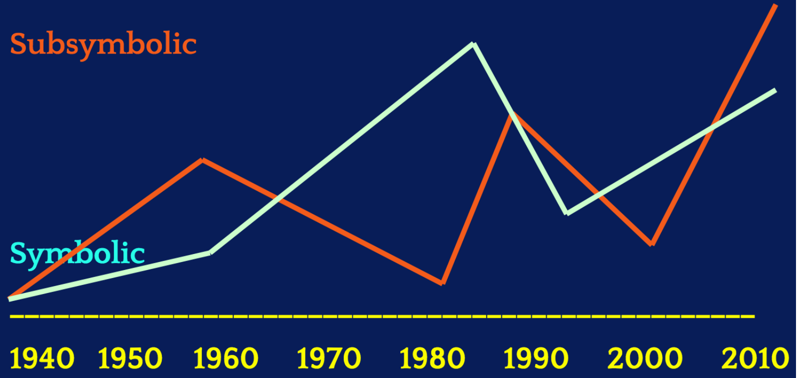
4. Symbolic versus Subsymbolic AI

Symbolic AI: concerned with describing and manipulating our knowledge of the world via explicit symbols.
reasoning, logic, knowledge,. . .



Subsymbolic AI: concerned with obtaining correct responses to input stimuli without looking inside the "black box".
networks, learning, probability,. . .

Timeline



Henry Lieberman • MIT

Recent years have seen a strong increase in interest in combining Machine Learning methods with Knowledge Representation methods.

(A Boxology of Design Patterns for Hybrid Learning and Reasoning Systems – van Harmelen & ten Teije, 2019)

Examples from recent literature:

https://www.theverge.com/2016/10/10/13224930/ai-deep-learning-limitations-drawbacks

https://www.sciencedirect.com/science/article/pii/S2352154618301943

Chatbot-based Tourist Recommendations Using Model-based Reasoning

(Nica, Tazl & Wotowa 2018)

https://www.semanticscholar.org/paper/Chatbot-based-Tourist-Recommendations-Using-Nica-Tazl/a59d177989e33a079348401df726264b731be8ef

The reasoning part: find inconsistencies in user requirements and possible solutions.

Homework:

Exercises 3 & 4 in Section 2.7 of Chapter 2.

Exercise 1 in Section 16.7 of Chapter 16.

File with additional exercises in Blackboard by Sunday, October 20.

Finis