Speech and Language Processing

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15 Logical Representations of Sentence Meaning

The meaning of linguistic expressions can be captured in formal structures, which is necessary for any semantic processing.

The process whereby such representations are created and assigned to linguistic units is called semantic parsing or analysis.

All approaches share the basic idea that a meaning representation consists of structures from a representational vocabulary.

15.1 Computational Desiderata for Representations

Verifiability

Verifiability is a system's ability to compare the state of affairs decribed by a representation to the state of affairs in some world as modelled in a knowledge base.

Unambiguous Representations

The meaning representations should represent only one thing. Furthermore, it should be possible to leave some parts of the meaning unspecified (vagueness).

Canonical Form

Distinct inputs that mean the same thing should have the same meaning representation.

Inference and Variables

A system must be able to use inference, or draw valid conclusions based on the meaning representation of inputs and its background knowledge.

Expressiveness

A meaning representation scheme must be expressive enough to handle a wide range of subject matter.

15.2 Model-Theoretic Semantics

A model is a formal construct that stands for the particular state of affairs in the world. Expressions in a meaning representation language can be mapped to elements of the model.

The vocabulary of a meaning representation consists of the non-logical vocabulary (the set of names) and the logical vocabulary (the formal means for composing expressions).

Each element of the non-logical vocabulary must have a denotation in the model. The domain of a model is the set of objects that are being represented.

Properties of objects denote sets (the set of the domain elements that have the property). Relations among objects denote sets of tuples of domain elements. This is called the extensional approach to semantics.

A mapping from the non-logical vocabulary items to their denotation is called an interpretation of the model.

A method for determining the truth of a complex expression from its parts is called truth-conditional semantics.

First-Order Logic

15.3.1 Basic Elements of First-Order Logic

A term is FOL's device to represent objects. It is either a constant (a specific object in the world; capital letter), a variable or a function (equivalent to single-argument predicates) applied to a term.

Predicates are symbols that name relations among a fixed number of objects.

Logical connectives allow us to conjoin formulae to get larger composite representations.

15.3.2 Variables and Quantifiers

Variables can be used to talk about a specific unknown objetct or about all objects in a collection, made possible by quantifiers.

There are two basic quantifiers – "there exists" $\exists$ and "for all" $\forall$.

15.3.3 Lambda Notation

The lambda notation expands the syntax of FOl to include expressions like $\lambda x.P(x)$

The technique of currying enables us to convert a predicate with multiple arguments into a sequence of single-argument predicates.

15.3.4 The Semantics of First-Order Logic

15.3.5 Inference

The most widely implemented inference method provided by FOL is called modus ponens: if $A \implies B$ and A, then B, where A is the antecedent and B the consequent.

In forward chaining systems, modus ponens is used to fire all applicable implication rules until no new facts can be deduced. In backward chaining, modus ponens is run in reverse to prove specific queries (like in Prolog).

Both these approaches are sound, but not complete – there are valid inferences that cannot be found by these methods alone. Resolution is another inference technique which is both sound and complete, but far more computationally expensive.

15.4 Event and State Representations

Predicates in FOL have fixed arity, which is a problem when considering the variable number of arguments a verb can have. To overcome this, we use an event variable to make assertions about events; for example, ∃e Eating(e) ∧ Eater(e, Speaker) ∧ Eaten(e, TurkeySandwich).

These representations are called neo-Davidsonian event representations.

15.4.1 Representing Time

The concern of representing time information lies in th domain of temporal logic. Tense logic is the way that verb tenses convey temporal information.

Combining a temporal ordering relationship with the idea of the current moment yields the past, present and future. We can add temporal variables representing the interval corresponding to the event and its end point and temporal predicates relating this end point to the current moment to express the time at which the event occurs.

The notion of a reference point, distinct from the current time, is needed to represent constructions like the perfect aspect.

15.4.2 Aspect

Event expressions are generally of four types: stative (participant has a state or a property), activity (event undertaken with no particular end point), accomplishment and achievement (events resulting in a state, typically happening in an instant). Accomplishments and achievements are sometimes grouped together under the name "telic eventualities".

15.5 Description Logics

The difficulty in translating other semantic approaches to FOL lies in their procedural definition of semantics. Description logics are an effort to specify the semantics of these structured network representations.

When using Description Logics, the representation of knowledge on categories, individuals and relationships is emphasised. The set of concepts that make up a particular domain is called its terminology, and the part of the knowledge base that contains it is called the TBox. The ABox, on the other hand, contains facts about individuals.

The terminology is usually organised into a hierarchy called an ontology, which captures the inclusion relation among the categories.

For a hierarchical relation, we asset a subsumption relation between concepts. We can also use negation, disjunction and conjunction relations on categories.

Further, in Description Logics, statements about what it means to be a member of a category come in the form of relations between the concepts being described and other concepts, called roles or role-relations. These can be subsumptions or equivalences.

Inference Subsumption as a form of inference is the question of whether an inclusion relation holds between two concepts. Instance checking is whether an individual can be a member of a particular category.

A related task is to derive the implied hierarchy for a terminology, given facts about the categories in it.

The implementation of these tasks varies according to the expressivity of the Description Logic being used.

OWL and the Semantic Web

15.6 Summary

1. A major approach to meaning in CL is making formal meaning representations that capture the content of linguistic expressions.

2. The frameworks that specify the syntax and semantics of these representations are called meaning representation languages.

3. These languages need to be able to support the practical requirements of semantic processing, like determining truth values, unambiguous representations, inference and expressivity.

4. Human languages have the ability to convey meaning through a predicate-argument structure.

5. FOL is a well-understood, computationally tractable meaning representation language.

6. It captures important elements like states and events.

7. Semantic networks and frames can be captured within the FOL framework.

8. Modern Description Logics consist of useful and computationally tractable subsets of full FOL. The Web Ontology Language (OWL), used in the specification of the Semantic Web, is the most promiment use of DLs.