Natural Language Processing

Chapter 5 Meaning Representation

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Meaning Representation

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- Meaning Representations
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Introduction
Where we are?

- First, we did words (morphology) and NGram
- Then we looked into Part-of-Speech (POS) and POS Tags
- Then, we looked at Syntax and Parsing
- Now we're moving on to meaning.
- The truth is: Have we ever touch that part yet?
- Where some would say we should have started to begin with at the very beginning.
- However, to understand how to process meaning, first we need to know how to represent meaning, or any logical or scientific method to represent meaning – Meaning Representation.
- Now we look at meaning representations
  – representations that link linguistic forms to knowledge of the world.

What is Meaning?

- Human language is useful and amazing because it allows us to encode/decode:
  - Descriptions of the world
  - What we're thinking
  - What we think about what other people think
- Don't be fooled by how natural and easy it is…
  In particular, you do not ever
  - Utter word strings that match the world
  - Say what you're thinking
  - Say what you think about what other people think
- All these issues seems to be natural, they all involve "meaning"

What is Meaning?

- You're simply uttering linear sequences of words such that when other people read/hear and understand them they come to know what you think of the world.
- How can the other party "understand" what you are talking about?
- You MUST inside the brain from "turn" the "meaning of thing what you want to convey" into some "meaningful words and sentences" and speak it out.
- The other party listen to what you said and "reconstruct" the "meaning" of thing you said and try to do the "inference" and give the response.
- So the basic question is: What is Meaning?

What is Meaning?

What is Meaning?

- In linguistics, meaning is the message that we convey by words, phrase and sentences (or utterance) with a certain context.
- It also called lexical meaning or semantic meaning.
- In The Evolution of Language (2010), W. Tecumseh Fitch described semantics (meaning) as the branch of language study that consistently related with philosophy. This is because the study of (semantic) meaning raises a lot of fundamental problems that needed to be solved and explained by philosophers.
- One might asked: Does meaning is just the meaning of word we checked from a dictionary?
    - The answer is Yes and No.
    - Yes in the sense that we can also check for the "meaning" of a single word from a Good dictionary (noted: many dictionary is just Concept/Language Translation instead of meaning explanation). A good dictionary should explain the "meaning" of the word in details such as the meaning of "table" instead of translate to another language or term)
    - No in the sense that most of the time the meaning of sentence (utterance) is not the "addition" of all individual word together. Most of the time a phrasal word has some more specific meaning than the individual word meaning:

[5.1] Off the hook

What is Meaning?

What is Meaning? (continue)

- In fact, (semantic) meaning is the study of the assignment of meanings to minimal meaning-bearing elements and the combination of these to form a more complex and meaningful idea.
- For example, some elementary word groups may be combined in a relationship of content, forming so-called thematic groups and semantic or lexical fields.
- For example, all the means of expressing the concept of “doctor” in a English language constitute the lexical-semantic field “doctor” in two senses – A medical doctor or a person with PhD title.
- How do we know which one is correct? Or what is the “true” meaning inside the sentence (utterance).
- Because of the trained patterns of response, people listen more respectfully to someone who has “Doctor” after his name than to that of someone who hasn’t.
- In other words, once the meaning of the word (word group) is “decrypted”, a “pattern of reactions”, then, is the sum of the ways we act in response to events, to words, and to symbols.
- The truth is: Words and word meanings are one of the most important information cues used in speaking and understanding, as well as in reading. Indeed, a person’s life experience and cultural experience are most relevant to the development of linguistic “meaning making” in any language, which is very important in the communication process.

Meaning Representations

In this chapter:

- We’re going to take the same basic approach to meaning that we took to syntax and morphology
- We’re going to create representations of linguistic inputs that capture the meanings of those inputs.
- In most cases, they’re simultaneously descriptions of the meanings of utterances and of some potential state of affairs in some world.
- What could this meant is the representations of linguistic inputs that capture the meanings of those inputs.
- But unlike parse trees and the like, these representations aren’t primarily descriptions of the structure of the input
- But rather is a kind of representation of how human understand (mean) anything (object, event, action, etc) and to make “sense” of it in our living environment – The meaning of everything!

Meaning Representations

- What are the basic linguistic concepts we want to capture? Or What are the basic meaning representation types?
  1. Categories/entities (e.g. Microsoft, Tesla, Egypt, Greece, car, apple, desk)
  2. Events (e.g. walking to class, eating lunch, seeing a movie)
  3. Time (e.g. 9:30am, next week, 2015)
  4. Aspect
     - Stative [5.2] Jane knows how to run
     - Activity [5.3] Jane is running.
     - Accomplishment [5.4] Jane booked the room.
     - Achievement [5.5] Jane found the book.
  5. Beliefs, Desires, Intentions
     [5.6] I think what you are saying is totally correct.
     [5.7] Jane wants to know why she fails in the test.
     [5.8] I believe everything happened must have a reason.
- How? What is most important? This means lots of different things to lots of different philosophers.
- We're not going to go there. For us (in NLP) it means
  - Representations that permit or facilitate semantic processing

Semantic Processing

- Ok, so what does that mean?
- What we take as a meaning representation is a representation that serves the core practical purposes of a program (system) that performs semantic processing.
- Representations that
  - Permit us to reason about their truth (relationship to some world)

    [5.9] Is Jack inside the classroom?
  - Permit us to answer questions based on their content

    [5.10] Who got the highest grade in the test?
  - Permit us to perform inference (answer questions and determine the truth of things we don't actually know)

    [5.11] If Jack is inside the classroom, and Mary is now sitting next to him, then Mary is also inside the classroom.

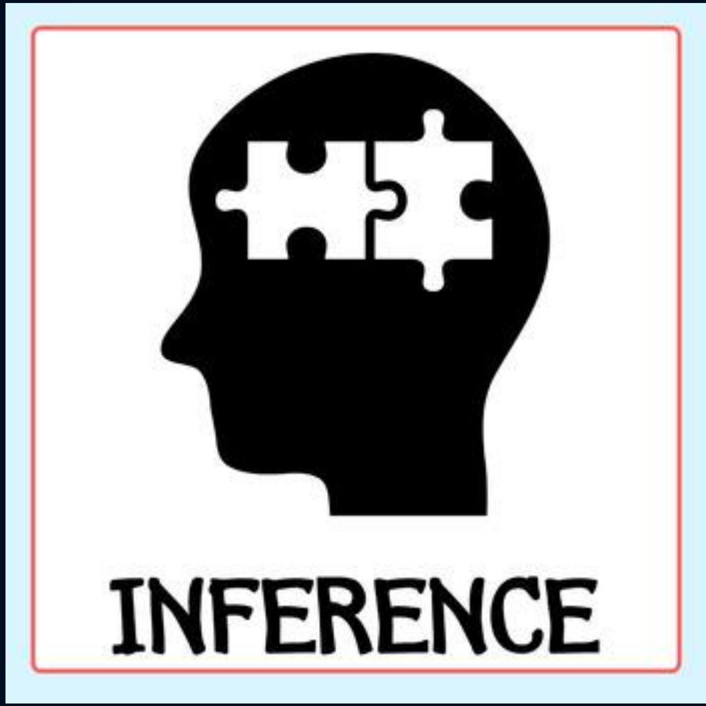

Fig. 5.1 Inferencing in Semantic Processing

Semantic Processing

- Touchstone application is always question answering Chatbot
  - Can I answer questions involving the meaning of some text or discourse?
  - What kind of representations do I need to mechanize that process?
  - Live example from the AI Tutor chatbot:

    [5.12] What is the meaning of NLP?

    [5.13] How does ngram model work?

    [5.14] Is Turing Test still exist?

    [5.15] Why we need to study self-awareness in AI?

    [5.16] Should I study AI?

Sample Meaning Representations

[5.17] Jack drives a Mercedes.

- First-Order Predicate Calculus (FOPC)
- Semantic Networks
- Conceptual Dependency
- Frame-based representation

Common Meaning Representations

First Order Predicate Calculus (FOPC):

- First-order logic is also known as Predicate logic or First-order predicate logic.
- First-order logic is a powerful language that develops information about the objects in a more easy way and can also express the relationship between those objects.
- We will discuss in detail in next section.
- For the example "John drives a car", the meaning representation in FOPC is:

  $$\exists x, y\ Driving\ (x) \wedge Driver(Speaker, x) \wedge DriveThing(y, x) \wedge CarBrand(Mercedes, y) \quad (5.1)$$

Semantic Net:

- A semantic net (or semantic network) is a knowledge representation technique used for propositional information. It is also called a propositional net.
- Semantic nets convey meaning, in the form of two-dimensional representations of knowledge.
- Mathematically a semantic net can be defined as a labelled directed graph.
- The main idea behind semantic nets is that the meaning of a concept comes from the ways in which it is connected to other concepts. In semantic net, information is represented as a set of nodes connected to each other by set of labelled arcs, which represent relationships among the nodes.
- Fig. 5.2 shows the Semantic Net for the sentence "John drives a Mercedes".

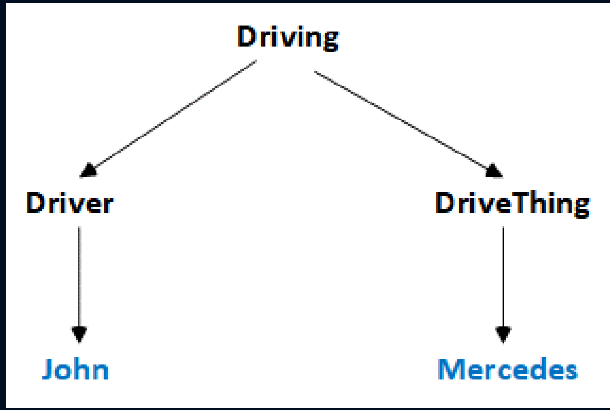

Fig. 5.2 Semantic Net for "John drives a Mercedes"

Common Meaning Representations

Conceptual Dependency Diagram:

- Conceptual dependency (or CD) is a theory of how to represent the meaning of natural language sentences in a way to facilitates for drawing inferences from the sentences.
- It has been argued that the representation (CD) is independent of the language in which the sentences were originally stated
- Schank's (1975) Conceptual Dependency Theory was developed as a part of a natural language comprehension project.
- Using CD method, sentences can be translated into basic concepts expressed as a small set of semantic primitives.
- Conceptual dependency allows these primitives, which signify meanings, to be combined to represent more complex meanings, with the process known as "conceptualisations".
- Fig. 5.3 shows the CD for the utterance "John drives a Mercedes".

Frame-based Representation:

- Frame-based systems are knowledge representation systems that use frames, a notion originally introduced by Marvin Minsky (1975), as their primary means to represent domain knowledge.
- A frame is a structure for representing a CONCEPT such as "a car" or "driving a car."
- Attached to a frame are several kinds of information, for instance, definitional and descriptive information and how to use the frame.
- Based on the original proposal, several knowledge representation systems have been built and the theory of frames has evolved. Important descendants of frame-based representation formalisms are description logics that capture the declarative part of frames using a logic-based semantics.
- Most of these logics are decidable fragments of first order logic and are very closely related to other formalisms such as modal logics and feature logics.
- Fig. 5.4 shows the Frame-based Representation for the utterance "John drives a Mercedes".

- All represent 'linguistic meaning' of "John drives a Mercedes" and state of affairs in some world
- All consist of structures, composed of symbols representing objects and relations among them.

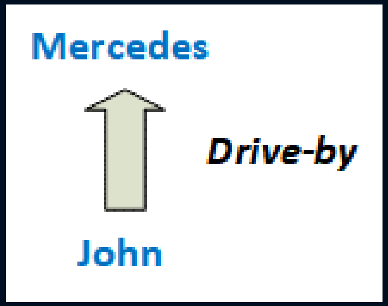

Fig. 5.3 Conceptual Dependency Diagram for "John drives a Mercedes"

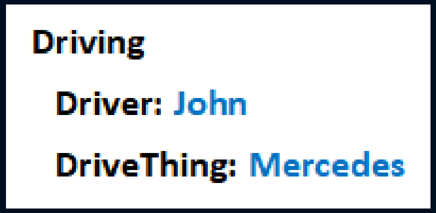

Fig. 5.4 Frame-based Diagram for "John drives a Mercedes'

What requirements must meaning representations fulfill?

Verifiability

- The verifiability theory was based upon the verifiability principle, which states
  "The statement is literally meaningful (it expresses a proposition) if and only if it is either analytic or empirically verifiable".
- In terms of meaning representation, it meant that the system should allow us to compare representations to facts in a Knowledge Base (KB) or the world we know (e.g. world knowledge or common sense).
- For example: [5.18] Does John drive a Mercedes?
- A verifiable meaning representation asserts that we can "prove" the "correctness" of such statement by mean of comparison, match or inferencing operation. In our case, the answer is YES according to the statement [5.17] John drives a Mercedes.

Ambiguity

- Ambiguity, is a word, phrase, or statement which contains more than one meaning.
- Ambiguous words or statements lead to confusion and shape the basis for instances of unintentional misunderstanding or humour.
- For instance, it is ambiguous to say: [5.19] "I rode a white horse in blue pyjamas," because it may lead us to think the horse was wearing blue pyjamas.
- Similarly, same words with different meanings can cause ambiguity, such as in, "John took off his gun by the bank." It is funny if we confuse one meaning of "bank," which is a building, to another meaning, which is "an edge of a river." Context usually resolves any ambiguity in such cases.
- In other words, a good meaning representation system should allow us to represent meanings unambiguously

Vagueness

- Vagueness is standardly defined as the possession of borderline cases.
- For example, 'tall' is vague term because a man who is 1.8 meters in height is neither clearly tall nor clearly non-tall. No amount of conceptual analysis or empirical investigation can settle whether a 1.8 meter man is tall.
- For example: [5.20] "He lives somewhere in the south of US" is also vagueness as what is meant by somewhere south of US.
- Ambiguity and vagueness are two varieties of interpretive uncertainty which are often discussed together, but are distinct both in their essential features and in their significance for semantic theory and the philosophy of language. Ambiguity involves uncertainty about mappings between levels of representation with different structural characteristics, while vagueness involves uncertainty about the actual meanings of particular terms.
- In other words, a good meaning representation system should allow us to represent vagueness

Canonical Form

What is Canonical Form?

- In general, a canonical form means that values of a particular type of resource can be described or represented in multiple ways, and one of those ways is chosen as the favoured canonical form.
- That form is canonized, like books that made it into the bible, and the other forms are not.
- In mathematics, a canonical form of a mathematical object is a standard way of presenting that object as a mathematical expression.
- For example, the canonical form of a positive integer in decimal representation is a finite sequence of digits that does not begin with zero.
- More generally, for a class of objects on which an equivalence relation is defined, a canonical form consists in the choice of a specific object in each class.
- For example, in Discrete Mathematics, a row echelon form and Jordan normal form are canonical forms for matrices.
- In Computer Science, and more specifically in computer algebra, when representing mathematical objects in a computer, there are usually many different ways to represent the same object. In this context, a canonical form is a representation such that every object has a unique representation.
- A classic example of a canonical form in computer science is Paths in a hierarchical file system, where a single file can be referenced in a number of ways.

Canonical Form in Meaning Representation

- In terms of Meaning Representation in NLP, canonical form refers to the phenomena that a single sentences (utterance) can be assigned multiple meanings leads to the related phenomenon of distinct inputs that should be assigned the same meaning representation.
- The truth is: Is it possible? or Is it normal?
- Example:

  [5.21] Peter eats KitKat.

  [5.22] KitKat, Peter likes to eat.

  [5.23] What Peter eats is KitKat?

  [5.24] It's KitKat that Peter eats.

  - One may noted: All these sentences (utterance) have similar meaning. However, they have some minor variation in terms of tone and thematic issues.

- For Mean Representation in NLP, the Four different semantic representations of meaning representation: ie. FOPC, Semantic Net, Conceptual Dependency Diagram and Frame-based Representation are good elaboration of how canonical form works.
- In a closer perspective, different variations of canonical form stores all possible meaning representations in Knowledge Base (KB).

Canonical Form: Pros and Cons

Advantages

- Simplifies reasoning tasks
- Compactness of representations: don't need to write inference rules for all different "paraphrases" of the same meaning

Disadvantages

- Complicates task of semantic analysis

Inference

What is Inference?

- In Logic, an inference is a process of deriving logical conclusions from premises known or assumed to be true.
- The term "infer" derives from the Latin term, which means "bring in."
- Inference is theoretically traditionally divided into deduction and induction, with the origin which can be dated back to Ancient Greece from Aristotle (300s BCE).
- Deduction is inference deriving logical conclusions from premises known or assumed to be true, with the laws of valid inference being studied in logic.
- "Deduction" means using the information available to make a guess or draw a conclusion about the facts, famous example MUST be the deductive reasoning by Sherlock Holmes in Sir Conan Doyle detective stories.
- Example of Inference by deductive reasoning:
  [5.25] Jack is a pilot, he must travel a lot.
  [5.26] Jane's hair is totally wet, it might be raining outside.
  [5.27] Mary has been very busy at work, she may not be able to come for the gathering this evening.
- Induction is inference from particular evidence to a universal conclusion.
- Induction begins with facts, and we draw conclusions based on the facts that we have.
- One important fact is that: Our conclusions may be correct; or they may be wrong.
- Induction is very different from deduction which is starting with the general statement or claim, and then giving a specific example, while Induction starts with the specifics and then draws the general conclusion based on the specific facts.
- Example of Inference with inductive reasoning:
  [5.29] The sun raises in the morning everyday in the past 30 years. The sun raises everyday (in human history).
  [5.30] The first two kids I met at my new school were nice to me. The students at this school are really nice.
  [5.31] Our teacher is letting us to pick a piece of object out of a box. The first four students got a candy. The box must be full of candy.
- In general, an inference is said to be valid if it's based upon sound evidence and the conclusion follows logically from the premises.

Example of Inferencing with FOPC

- Draw valid conclusions based on the meaning representation of inputs and its store of background knowledge.
  [5.32] Does Peter eat KitKat?
  - Thing(KitKat) (5.2)
  - Eat(Peter , x) ^ Thing(x) (5.3)
  - Given the above 2 FOPC statements which are all TRUE. We can infer the saying [5.32] as Yes by using "Inductive" or "Deductive" reasoning?

Fillmore’s Theory of Universal Cases

What is Fillmore’s Theory of Universal Cases?

- In linguistic analysis, Case Grammar is a linguistic system focuses on the link between the valence, or number of subjects, objects, etc., of a verb and the grammatical context it requires.
- This Case Grammar System was created by the American linguist Charles J. Fillmore in the context of Transformational Grammar in his famous work "The Case for Case" in semantic analysis published in 1968, also known as Fillmore’s Theory of Universal Cases.
- Fillmore believed that there are only a small number of semantic roles that an NP in a sentence may play with respect to the verb.
- This theory analyzes the surface syntactic structure of sentences by studying the combination of the so-called deep cases of semantic roles such as Agent, Object, Benefactor, Location or Instrument etc, which are required by a specific verb.
- For instance, the verb "pay" in English requires an Agent (A) and Object (O), and a Beneficiary (B).
  Example: [5.33] Mary (A) pays money (O) to the shop (B).
- According to Fillmore’s Case Theory, each verb selects a certain number of deep cases which form its case frame.
- Thus, a case frame describes important aspects of semantic valency of verbs, adjectives and nouns.
- Case frames are subject to certain constraints, such as that a deep case can occur only once per sentence.
- In reality, some of the cases are mandatory and others are optional. Mandatory cases cannot be deleted, otherwise it will be resulted in producing ungrammatical sentences.
  For example: [5.34] "This form is used to provide you" make no sense without the additional role that explain provide you "to" or "with" what matter or notion.
  Like this: [5.35] This form is used to provide you with the necessary information .
- The relationships between nouns and their containing structures is one of both syntactic and semantic value. The syntactic positional relationships between forms in sentences varies cross-linguistically and allows grammarians to observe semantic values in these nouns by examining their syntactic values. Using these semantic values gives the base for considering case role in a specific language
- In Fillmore’s Theory, a major task of semantic analysis is to provide an appropriate mapping between the syntactic constituents of a parsed clause and the semantic roles (cases) associated with the verb.
- The term case role is most widely used for purely semantic relations, including theta roles and thematic roles, that can be independent of the morpho-syntax.
- In which:
  - Theta Role (θ-role) refers to a formal device for representing syntactic argument structure—the number and type of noun phrases—required syntactically by a particular verb.
    For example, the verb give requires three arguments in [5.36] Jack gives the toy to Michael. Whereas: Jack is assigned the external theta role of agent/source, the toy is assigned the theme role, and to Michael is assigned the goal role.
  - Thematic Role, also known as semantic role refers to the various roles that a noun phrase NP may play with respect to the action or state described by a governing verb, commonly the sentence's main verb.
    For example: [5.37] "Jack gets a prize", Jack is the doer of the getting, so he is an agent; the prize is the object being got, so it is a patient.

Major Cases Include

- Agent – doer of the action, entails intentionality
- Experiencer – doer when no intentionality
- Theme – thing being acted upon or undergoing change
- Instrument – tool used to do the action
- Beneficiary – person/thing for whom the event is performed
- To/At/From Loc/Poss/Time – location or possession or time representations

Some Sentences and their cases

[5.38] John opened the door with a key.

[5.39] The door was opened by John.

[5.40] The door was opened with a key.

[5.41] A key opened the door.

[5.42] The door opened.

[5.43] John gave Mary the book.

[5.44] John gave the book to Mary.

Let's identify the cases in these sentences – notice any syntactic regularities in the case assignment.

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- Instrument – tool used to do the action
- To-Poss – the one that possesses sth.

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Intuition – syntactic choices are largely a reflection of underlying semantic relationships.

Semantic Analysis

- A major task of semantic analysis is to provide an appropriate mapping between the syntactic constituents of a parsed clause and the semantic roles associated with the verb.
- We will discuss in detail in the next Chapter.

Complications in Case Roles

1. Ability of syntactic constituents to indicate several different semantic roles
   - E.g., Subject position: agent versus instrument versus theme

     [5.45] John broke the window.

     [5.45] The rock broke the window.

     [5.45] The window broke.
2. Large number of choices available for syntactic expression of any particular syntactic role
   - E.g., agent and theme in different configurations

     [5.46] John broke the window.

     [5.47] It was the window that John broke.

     [5.48] The window was broken by John.

Complications in Case Roles

3. Prepositional ambiguities – it is the case that a particular preposition does not always introduce the same role
   - E.g., proposition "by" may indicate either agent or instrument

   [5.49] The door was opened by John.

   [5.50] The door was opened by a key.

4. Optionality of a given role in a sentence

   [5.51] John opened the door with a key.

   [5.52] The door was opened by John.

   [5.53] The door was opened with a key.

   [5.54] A key opened the door.

   [5.55] The door opened.

How bad is it?

- It seems that semantic roles are playing "musical chairs" with the syntactic constituents.
- That is, they seem to "sit down" in any old syntactic constituent and one or more of them seem to be left out at times!
- Actually, it isn't as bad as it may seem!
- There is a great deal of regularity – consider the following set of rules.
- But also, it is the beauty of human language.

Some Possible Rules in Case Roles

If ∃ Agent it becomes Subject

Else If ∃ Instrument it becomes Subject

Else If ∃ Theme it becomes Subject

Agent preposition is BY

Instrument preposition is BY if no agent, else WITH

Some Rules:

- Some verbs may have exceptions
- No case can appear twice in the same clause
- Only NP's of same case can be conjoined
- Each syntactic constituent can fill only 1 case

What's missing???

If ∃ Agent it becomes Subject

Else If ∃ Instrument it becomes Subject

Else If ∃ Theme it becomes Subject

How do I know whether or not an agent exists? How about an instrument?

Selectional Restrictions – restrict the types of certain roles to be a certain semantic entity

- Agents must be animate
- Instruments are not animate
- Theme? – type may be dependent on the verb itself.

Selectional Restrictions

Selectional Restrictions: constraints on the ***types*** of arguments verbs take

[5.56] ***Someone assassinated the President.***

[5.57] ****The spider assassinated the fly.***

***assassinate:* intentional (political?) killing**

NOTE: dependence on the particular verb being used!

So? What about Case in General?

- You may or may not see particular cases used in semantic analysis.
- In the book, they have NOT used the specific cases.
- But, note, the “roles” they use are derived from the general cases identified in Fillmore’s work – they make them verb-specific.
- Semantic analysis is going to take advantage of the syntactic regularities and selectional restrictions to identify the role being played by each constituent in a sentence!

First Order Predicate Calculus (FOPC) Representational Schemes

- Let's go back to the question – what kind of semantic representation should we derive for a given sentence?
- We're going to make use of First Order Predicate Calculus (FOPC) as our representational framework
  - Not because we think it's perfect
  - All the alternatives turn out to be either too limiting or
  - They turn out to be notational variants
  - Essentially the important parts are the same no matter which variant you choose!

First Order Predicate Calculus (FOPC)

- Allows for…
  - The analysis of truth conditions
    - Allows us to answer yes/no questions
  - Supports the use of variables
    - Allows us to answer questions through the use of variable binding
  - Supports inference
    - Allows us to answer questions that go beyond what we know explicitly
- This choice isn't completely arbitrary or driven by the needs of practical applications
- FOPC reflects the semantics of natural languages because it was designed that way by human beings
- In particular…

Major Elements of FOPC

Major Elements and Components in FOPC

1. Term:
   - Names for objects
   - Three ways of representation:
   - Constants – refers to specific object being described in the sentence. (e.g. John, IBM, Apple, etc)
   - Function – refers to the concepts that often expressed as genitives such as brandname, location, etc. (e.g. Brandname(Mercedes), LocationOf(KFC), etc), which can also be considered as single-argument predicate.
   - Variables – refers to objects that have no particular reference which object is now referred to, just like variable x or y being used in a mathematical equation $x + y = z$. (e.g. a, b, c, x, y, z, etc). Particular powerful and useful in FOPC. Without it, no inferencing and query can be done.
2. Predicates:
   - The notion of a predicate in traditional grammar traces back to Aristotelian logic. A predicate can be considered as a property that a subject has or is characterized by. A predicate is therefore an expression that can be true of something. E.g. He talks, She cries, John plays football.
   - Refer to the relations that hold among some fixed number of objects in a given domain.
   - Predicates are often represented with capital letters like Buy or Play, and combine with object-names to form a proposition.
   - Example: Drive(Mercedes), Drive(Mercedes, John), Drive(Mercedes, x), Drive(Mercedes, John, UIC, Starbucks), Drive(car, x, org, dest), etc.
3. Connectives: which combine propositions together.
   - The most important ones are conjunction (which functions like English and, and is written as & or $\wedge$), disjunction (like English or, written $\vee$), and material implication (possibly like English if/then, written $\supset$ or $\rightarrow$). Negation (English not, written $\neg$ or $\sim$) is also considered a connective, even though it operates on a single proposition.
4. Quantifiers, which allow for generalizations. There are two major types: universal (English all, written $\forall$) and existential (English some, written $\exists$). The term first-order means that this logic only uses quantifiers to generalize over objects, and never over predicates.

Fig. 5.5 shows the Context Free Grammar (CFG) specification of FOPC.

Major Elements of FOPC

```
Formula → AtomicFormula
        | Formula Connective Formula
        | Quantifier Variable; : : : Formula
        | ¬ Formula
        | (Formula)

AtomicFormula → Predicate(Term, ...)

Term → Function(Term, ...)
     | Constant
     | Variable

Connective → ∧ | ∨ →
Quantifier → ∀ | ∃
Constant   → IBM | Tesla | USA | John | A | ...
Variable   → x | y | z | ...
Predicate  → Drive | Buy | Find | ...
Function   → LocationOf | Brandname | ...
```

Fig. 5.5 Context Free Grammar (CFG) specification of FOPC.

Meaning Structure of Language

- The semantics of human languages…
  - Display a basic predicate-argument structure
  - Make use of variables (e.g., indefinites)
  - Make use of quantifiers (e.g., every, some)
  - Use a partially compositional semantics (sort of)

Predicate-Argument Structure

- Events, actions and relationships can be captured with representations that consist of predicates and arguments.
- Languages display a division of labor where some words and constituents function as predicates and some as arguments.
- E.g., predicates represent the verb, and the arguments (in the right order) represent the cases of the verb.

Predicate-Argument Structure

- Predicates
  - Primarily Verbs, VPs, PPs, adjectives, Sentences
  - Sometimes Nouns and NPs

  [5.58] Helen cries.

  [5.59] Helen speaks to Mary.

  [5.60] Helen speaks loudly.

  [5.61] Helen speaks loudly in the classroom.
- Arguments
  - Primarily Nouns, Nominals, NPs
  - But also everything else; as we'll see it depends on the context

  [5.62] John go to the bank.

  [5.63] He go to the bank.

Example

[5.64] John gave a book to Mary

Giving(John, Mary, Book) (5.4)

- More precisely (In terms of Fillmore' s Case Role Theory)
  - Gave conveys a three-argument predicate
  - The first argument is the giver (agent)
  - The second is the recipient (to-poss), which is conveyed by the NP in the PP
  - The third argument is the thing given (theme), conveyed by the direct object
- Of course, we can also have something like this as FOPC to describe the same sentence:

Giving(John, Book, Mary) (5.4)

Gave(John, Book, Mary) (5.5)

More Examples

What about situation of missing/additional cases?

[5.65] John gave Mary a book for Susan.

Giving(John, Mary, Book, Susan) (5.6)

[5.66] John gave Mary a book for Susan on Wednesday.

Giving(John, Mary, Book, Susan, Wednesday) (5.7)

[5.67] John gave Mary a book for Susan on Wednesday in class.

Giving(John, Mary, Book, Susan, Wednesday, InClass) (5.8)

Problem:

Remember each of these predicates would be different because of the different number of arguments! Except for the suggestive names of predicates and arguments, there is nothing that indicates the obvious logical relations among them.

Meaning Representation Problems

- Assumes that the predicate representing the meaning of a verb has the same number of arguments as are present in the verb's syntactic categorization frame.

This makes it hard to

- Determine the correct number of roles for any given event
- Represent facts about the roles associated with the event
- Ensure that all and only the correct inferences can be derived from the representation of an event

Better

- Turns out this representation isn't quite as useful as it could be.
  - Giving(John, Mary, Book) (5.9)
- Better would be one where the "roles" or "cases" are separated out. E.g., consider:

$$\exists x, y\ Giving(x) \wedge Giver(John, x) \wedge Given(y, x) \wedge Givee(Mary, x) \wedge Isa(y, Book) \quad (5.10)$$

- Note: essentially Giver=Agent, Given=Theme, Givee=To-Poss

Predicates

- The notion of a predicate just got more complicated...
- In this example, think of the verb/VP providing a template like the following

$$\exists w, x, y, z Giving(x) \wedge Giver(w, x) \wedge Given(y, x) \wedge Givee(z, x) \quad (5.11)$$

- The semantics of the NPs and the PPs in the sentence plug into the slots provided in the template (we'll worry about how in a bit!)

Advantages

- Can have variable number of arguments associated with an event: events have many roles and fillers can be glued on as appear in the input.
- Specifies categories (e.g., book) so that we can make assertions about categories themselves as well as their instances. E.g., Isa(MobyDick, Novel), AKO(Novel, Book).
- Reifies events so that they can be quantified and related to other events and objects via sets of defined relations.
- Can see logical connections between closely related examples without the need for meaning postulates.

Inference using FOPC

Inference using FOPC

- One of the most powerful function of FOPC is to support Inference.
- The capability to validate or to prove whether a proposition is True or False from a knowledge base.
- In this section, we discuss how it can achieve by using **Modus Ponens** – one of the most important and fundamental method of inferencing.

Modus Ponens

- Modus Ponens – is a mode of reasoning from a hypothetical proposition according to which if the antecedent be affirmed the consequent is affirmed.
- In logic reasoning, Modus Ponens is the Deductive Reasoning in the form: "P implies Q. P is true. Therefore: Q must also be true."
- The modus ponens rule may be written in sequent notation as:
  - $P \rightarrow Q$ or $P \vdash Q$ (5.12)
  - where P, Q and $P \rightarrow Q$ are statements (or propositions) in a formal language and $\vdash$ is a metalogical symbol meaning that Q is a syntactic consequence of P and $P \rightarrow Q$ in some logical system.
- The justification rule of modus ponens in classical two-valued logic is given by the following Truth Table:
- Note: In instances of modus ponens we assume as premises that $p \rightarrow q$ is true and p is true. Only one line of the truth table—the first—satisfies these two conditions (p and $p \rightarrow q$). On this line, q is also true. Therefore, whenever $p \rightarrow q$ is true and p is true, q must also be true.

P	Q	$P \rightarrow Q$
T	T	T
T	F	F
F	T	T
F	F	T

Fig. 5.6 Truth table of Modus Pones in 2-valued logic

Example of Inferencing using FOPC

- In the following example, we using the Tesla Car as live example to demonstrate how FOPC works in logic inference:

$$\frac{\begin{array}{l}\text{ElectricCar(Tesla)}\\ \forall x\ \text{ElectricCar}(x) \rightarrow \text{Fuel}(x, \text{Electricity})\end{array}}{\text{Fuel(Tesla, Electricity)}} \qquad (5.13)$$

- The above predicate ElectricCar(Tesla) matches the antecedent of the rule, so based on Modus Ponens (simple deduction) to conclude that "Fuel(Tesla, Electricity)" is a True clause.
- Forward vs. Backward Reasoning
  - In practical use, Modus Ponens can be applied in two reasoning modes: Forward and Backward Reasoning.
  - Forward Reasoning (FR): Normal mode: MP is used in normal situation in which by adding all "facts" into the KB, FR try to invoke all applicable implication rules to check the correction of the clause or a new knowledge is needed to add.
  - Backward Reasoning (BR): MP is run in the "reverse mode" to prove specific proposition, or what we called "query" in Computer Science world. That is, to check fi the query formula is True by checking whether it is present in the KB, or no "negative implication" or "facts" exist, to return the query results.

Summary

- Start with the main notion of Meaning in Human Language.
- Interpret Meaning Representation and describe the FOUR core meaning representation models:
  - First Order Predicate Calculus (FOPC)
  - Semantic Net
  - Conceptual Dependency Diagram (CDD)
  - Frame-based Representation
- Discuss basic requirements for Meaning Representation
- Discuss the Fillmore's Case Roles Theory and its implication to Meaning Representation.
- Basic concepts and modelling of First-Order Predicate Calculus
- Provide basis for us to enter the world of Semantics in Semantic Analysis in the next Chapter.

Next

NLP#09 Semantic Analysis