BSCS5002: Introduction to Natural Language Processing

Meaning Representation: Logical Semantics & Semantic Role Labelling

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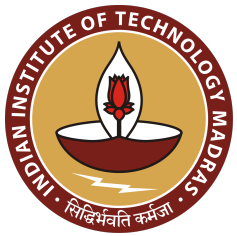

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Introduction to Meaning Representation

- Meaning Representation involves representing the meaning of natural language in a form that machines can process and manipulate.
- It is crucial for enabling deeper understanding and inference in tasks like machine translation, question answering, and summarization.
- Two major approaches in meaning representation:
  - Logical Semantics
  - Semantic Role Labeling (SRL)

Challenges in Meaning Representation

- Natural language is ambiguous, context-dependent, and flexible.
- Meaning must be captured in a formalized, precise structure to enable:
  - Inference
  - Reasoning
  - Question answering
- Complexities include handling negation, quantifiers, modality, and disambiguation.

Logical Semantics Overview

- Logical Semantics is the study of meaning using formal logic.
- It provides a precise, unambiguous structure for representing sentence meaning.
- It helps us answer questions like:
  - What are the truth conditions of a sentence?
  - How do we represent meaning in a form that computers can process?
- The most common formalism is First-Order Logic (FOL).

Components of First-Order Logic (FOL)

- Constants: Represent specific entities (e.g., ‘John‘).
- Predicates: Express properties or relations between entities (e.g., $\text{Loves}(\text{John}, \text{Mary})$).
- Variables: Represent arbitrary entities (e.g., $\forall x$, $\exists y$).
- Quantifiers: Express quantities (e.g., $\forall x$, $\exists y$).
- Connectives: Logical operators (e.g., AND, OR, NOT).

Example of First-Order Logic (FOL)

Sentence: *John loves Mary.*

- Logical Form: ‘Loves(John, Mary)‘
- Predicate: ‘Loves‘
- Arguments: ‘John‘ and ‘Mary‘
- Interpretation: This formal representation can be used for reasoning, querying, and making inferences.

Quantifiers in First-Order Logic (FOL)

- Universal Quantifier ($\forall$): Indicates that the statement applies to all entities.
  - Example: *All humans are mortal* can be written as $\forall x(\text{Human}(x) \rightarrow \text{Mortal}(x))$.
- Existential Quantifier ($\exists$): Indicates that the statement applies to at least one entity.
  - Example: *There exists a person who loves Mary* can be written as $\exists x(\text{Person}(x) \wedge \text{Loves}(x, \text{Mary}))$.

Logical Semantics and Truth Conditions

- Truth Conditions: Logical semantics can be used to define when a statement is true or false.
- A sentence like ‘Loves(John, Mary)‘ is true if, in the world, John loves Mary.
- This is essential for building systems that can reason about the truth of statements or make inferences.

What is Semantic Role Labeling (SRL)?

- Semantic Role Labeling (SRL) is a process that identifies the roles of words in a sentence (who did what to whom).
- It captures the relationships between the predicate (verb) and its arguments (subject, object, etc.).
- SRL helps in understanding the meaning of sentences in tasks like machine translation, summarization, and question answering.

Importance of Semantic Role Labeling (SRL)

- SRL enables machines to understand who is doing what to whom, when, and where.
- It abstracts away from surface syntax, focusing on the deeper semantic structure of sentences.
- SRL is widely used in NLP tasks like information extraction, machine translation, and textual entailment.

Key Concepts in SRL

- Predicate: The main verb or action in the sentence.
- Arguments: The participants involved in the action.
- Semantic Roles:
  - Agent: The doer of the action.
  - Patient: The entity affected by the action.
  - Instrument: The tool used to perform the action.
  - Location: Where the action occurs.

Thematic Role	Definition	Example
Agent	The volitional causer of an event	*The waiter* spilled the soup.
Experiencer	The experiencer of an event	*John* has a headache.
Force	The non-volitional causer of the event	*The wind* blows debris from the mall into our yards.
Theme	The participant most directly affected by an event	Only after Benjamin Franklin broke *the ice*...
Result	The end product of an event	The city built *a regulation-size baseball diamond*...
Content	The proposition or content of a propositional event	Mona asked "*You met Mary Ann at a supermarket?*"
Instrument	An instrument used in an event	He poached catfish, stunning *them with a shocking device*...
Beneficiary	The beneficiary of an event	Whenever Ann Callahan makes hotel reservations *for her boss*...
Source	The origin of the object of a transfer event	I flew in *from Boston*.
Goal	The destination of an object of a transfer event	I drove *to Portland*.

Table: Thematic roles with their definitions. [1]

[1] Speech and Language Processing. Daniel Jurafsky & James H. Martin.

Example of Semantic Role Labeling (SRL)

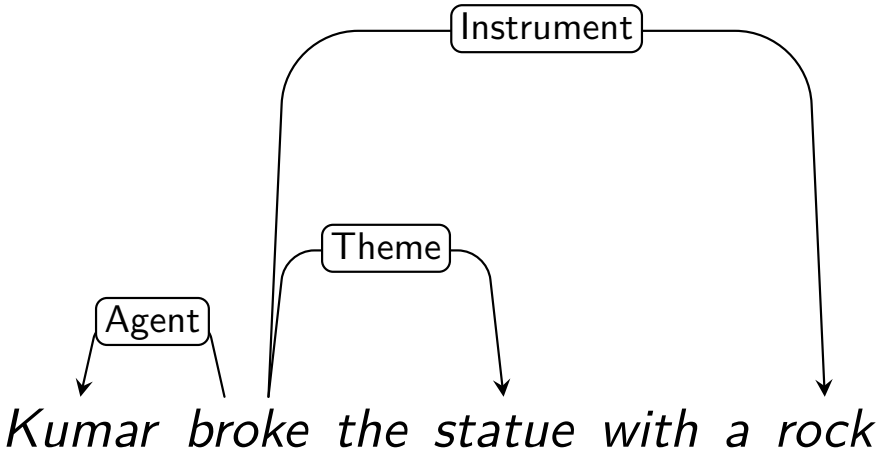


Figure: 1

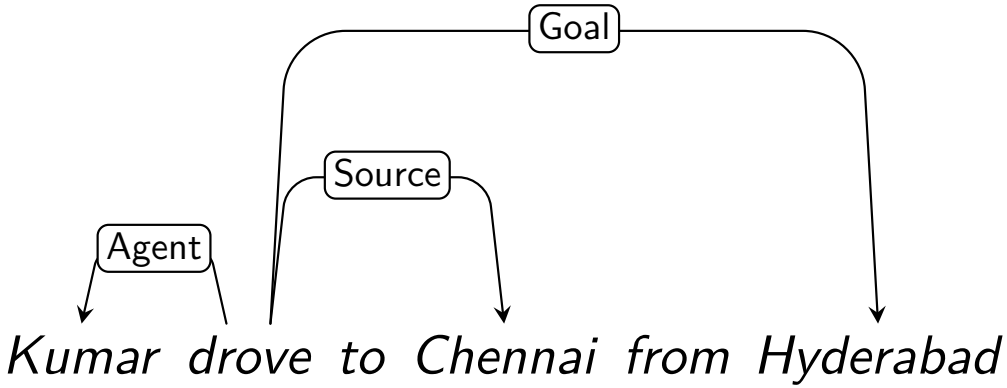
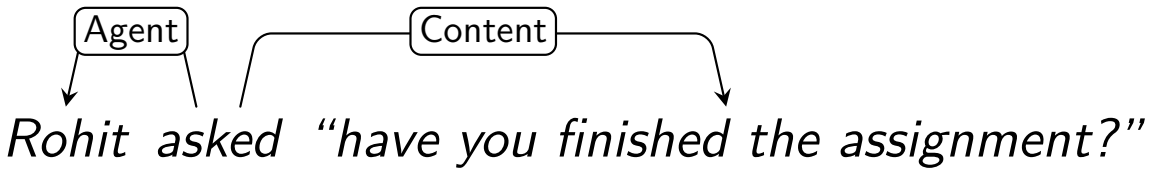


Figure: 2

Example of Semantic Role Labeling (SRL)



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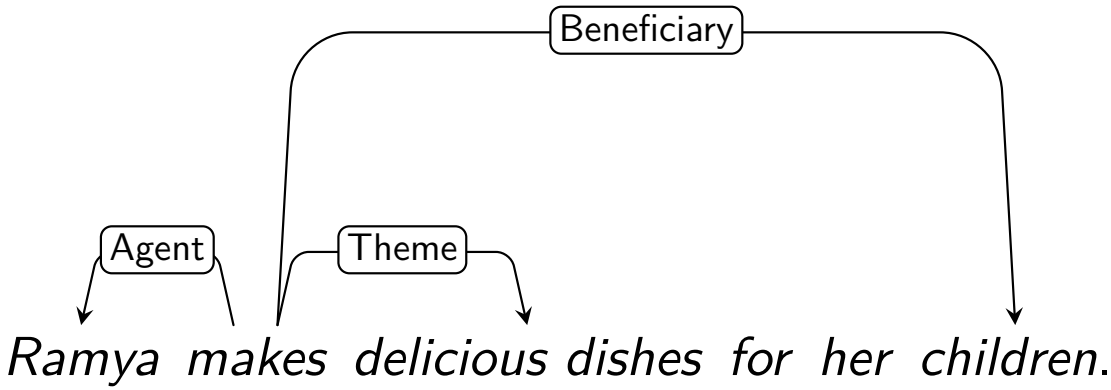

Figure: 4

Example of Semantic Role Labeling (SRL)

Sentence: *John gave Mary a book.*

- Predicate: Gave
- Agent (Who): John (the giver)
- Recipient (To whom): Mary (the receiver)
- Theme (What): A book (the item given)
- SRL Tags: [John] (Agent) [gave] (Predicate) [Mary] (Recipient) [a book] (Theme)

Semantic Role Sets

- Different semantic role sets are used in SRL systems:
  - PropBank: Focuses on predicate-argument structures for verbs.
  - FrameNet: Uses a broader set of semantic roles based on frames and scenarios.
- These role sets help standardize the labeling of different roles in sentences.

PropBank and FrameNet

- PropBank: Annotates predicates and their arguments based on verb-specific roles (e.g., ‘Arg0‘, ‘Arg1‘ for subject and object roles).
- FrameNet: Groups words into semantic frames that capture relationships between different participants in a scenario.
- Both frameworks are commonly used in SRL tasks to represent meaning in a structured way.

SRL and Machine Learning

- Supervised learning is often used to train SRL models.
- These models learn to identify semantic roles by training on labeled data (e.g., PropBank annotations).
- Techniques include Conditional Random Fields (CRF), Recurrent Neural Networks (RNNs), and Transformers.

Evaluation Metrics for SRL

- Precision: Proportion of correctly identified roles out of all roles identified.
- Recall: Proportion of correctly identified roles out of all true roles.
- F1 Score: Harmonic mean of precision and recall.

Logical Semantics vs. SRL

- Logical Semantics: Focuses on truth conditions and logical structure of sentences.
- Semantic Role Labeling: Focuses on identifying the roles of participants in an action.
- Both approaches contribute to understanding meaning, but they do so in different ways.

Applications of Logical Semantics and SRL

- Logical Semantics: Used in formal reasoning, query systems, and ontology mapping.
- Semantic Role Labeling: Used in information extraction, machine translation, and summarization.
- Both techniques are essential for enabling machines to "understand" natural language.

Conclusion

- Meaning representation is crucial for building systems that can understand and reason with natural language.
- Logical Semantics provides a formal structure for reasoning about truth conditions.
- Semantic Role Labeling (SRL) captures relationships between words in a sentence, focusing on "who did what to whom."