A Probabilistic Approach for Discourse Interpretation

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Bayesian Reasoning Workshop

Discourse Interpretation
- A representation of the speaker’s discourse in terms of the addressee’s own beliefs and inferences

Example
- S: Can you please go to the bakery? We need some croissants
- A:
  - which bakery?
  - S wants me to go to this bakery
  - when I am at the bakery, I need to buy croissants
  - how many croissants?

How do we Select an Interpretation?
- We often balance several factors, e.g.,
  - how well the interpretation matches the discourse
  - how reasonable it is
  - how feasible it is

Probabilistic Model Selection Approach
- Implementation of Occam’s Razor
  - "The simplest interpretation that fits the discourse well is preferred”
- Cast discourse interpretation as a trade-off between conflicting factors
  - Model complexity against data fit
  - Two types of model complexity against each other

BIAS (Bayesian Interactive Argumentation System)
- Bayesian network (BN) as a reasoning platform
- Nodes in the BN
  - represent propositions known to the system
  - have beliefs derived from observed evidence
- The network structure represents the system’s inference patterns
Interaction with BIAS

- User
  - explores the domain and
  - inputs an argument
- BIAS generates an interpretation of the argument

Domain Exploration (1): Police Report

Yesterday, Mr. Body was found dead in his bedroom. Fatal bullet wounds were found in Mr. Body's chest.

Broken glass was found inside the bedroom window. A gun was found in the garden outside the house, and fingerprints were found on the gun.

Fresh footprints were found near the house, and some peculiar indentations were observed in the ground.

Domain Exploration (2): Victim's Bedroom

BIAS: Exploring

Mr. Body's bedroom

User's Argument

- BIAS generated an interpretation of the argument

Elements of our Approach

- Definition of an interpretation
- Algorithm for postulating an interpretation
- Probabilistic formulation for selecting an interpretation
What is an Interpretation?

- A representation of a user's utterances in terms a computer can work with
  - Interpretation Graph (IG) – a structure that
    - connects between the propositions in the discourse
    - comprises propositions and inferences from the system's knowledge base

Interpretation: A Simple Example

Since Mr Green was in the garden at 11, he probably had the opportunity to murder Mr Body.

Interpretation: Another Simple Example

Since Mr Green was in the garden at 11, he probably had the opportunity to murder Mr Body, but he possibly did not kill Mr Body.

What is an Interpretation? (II)

- An interpretation is a tuple \( \{IG, SC\} \)
  - IG: Interpretation Graph
  - SC: Supposition Configuration

What is an Interpretation? (III)

- An interpretation is a tuple \( \{IG, SC, EE\} \)
  - IG: Interpretation Graph
  - SC: Supposition Configuration
  - EE: Explanatory Extension

Elements of our Approach

- Definition of an interpretation
- Algorithm for postulating an interpretation
- Probabilistic formulation for selecting an interpretation
How do we Generate an Interpretation?

- We have an exponential problem
- We need a real time solution
  ➔ Anytime algorithm

Algorithm GenerateInterpretations(Discourse)

while there is time
{
  1. Propose a Supposition Configuration SC
  2. Propose an Interpretation Graph IG
  3. Propose Explanatory Extensions EE
  4. Evaluate interpretation \{IG,SC,EE\}
  5. Retain top K interpretations (Selection)
}

Algorithm GenerateInterpretations: Example

Discourse (connected propositions)

SC1 —— SC2 —— SC3

IG1 —— IG2 —— IG5 —— IG3 —— IG4 —— IG6

EE1 —— EE2 —— EE5 —— EE3 —— EE4 —— EE6

Proposing a component

- If first time, propose the simplest component
- Else decide whether to re-use a previous component or make a new one
  □ If re-using, select from a pool
  □ If making a new component, pick among the "children" of the used components

Generating “children” of an Interpretation Graph: Example

Argument: \textbf{A implies G}

Elements of our Approach

- Definition of an interpretation ✓
- Algorithm for postulating an interpretation ✓
- Probabilistic formulation for selecting an interpretation
Probabilistic Formulation – Selecting an Interpretation

**Occam’s Razor:** "If you have two theories which both explain the observed facts, then you should use the simplest until more evidence comes along."

Three Basic Elements

- Background knowledge
- Model
- Data

Selecting an Interpretation

The best interpretation is that with the highest posterior probability

$$\text{IntBest} = \arg\max_{i=1,\ldots,n} \Pr(I_i|SC, EE, \text{Discourse})$$

$$\Pr(I_i|SC, EE, \text{Discourse}) = \frac{\alpha \Pr(\text{Discourse} | I_i, SC, EE) \times \Pr(I_i, SC, EE)}{\text{Probability that the user said Discourse when intending the interpretation}}$$

Model Complexity

- The prior probability of the model in light of the background knowledge
  - Structural – probability of extracting the interpretation structure from the background knowledge
  - Numerical – probability of the beliefs in the model given the corresponding beliefs in the background knowledge

Data Fit

- The probability of the data given the model
  - Structural – probability of “extracting” the discourse structure from the interpretation
  - Numerical – probability of stating the beliefs in the discourse when intending the corresponding beliefs in the interpretation

Estimating the Probability of an Interpretation Graph (Structure)

- Heuristics for assigning probabilities to nodes
  - Generally, smaller interpretations have a higher probability
  - Nodes that are familiar to the user are more probable than unfamiliar nodes
  - Some nodes may remind users of other nodes
- The probabilities of arcs depend on the structure of the BN and the nodes in the graph
Accounting for an Interpretation

- Interpretation Graph
  - Model complexity versus data fit
- Supposition Configuration
  - More informed model
- Explanatory Extensions
  - More background knowledge

Basic Formalism: Interpretation Graphs

- Background knowledge:
  - facts known to the system and the speaker
  - inferential patterns
- Model: \( IG \)
- Models with more complex structure should have a better **structural** data fit with the discourse
- What about beliefs?

Interpretation Graph: Example

*Since Mr. Green was in the garden at 11, he had the opportunity to murder Mr. Body*

![Interpretation Graph Example](image1)

A More Informed Model: Supposition Configurations

- Background knowledge:
  - facts known to the system and the speaker
  - inferential patterns
- Model: \( IG, SC \)
- Suppositions increase model complexity
- Models with suppositions should have a better **belief** data fit with the discourse

Supposition Configuration: Example

*Since Mr. Green was in the garden at 11, he had the opportunity to murder Mr. Body*

![Supposition Configuration Example](image2)

Additional Background Knowledge: Explanatory Extensions

- Background knowledge:
  - facts known to the system and the speaker
  - inferential patterns
  - people's preferences about inference patterns
- Model: \( IG, SC, EE \)
- Explanatory Extensions
  - reduce belief model complexity
  - increase structural model complexity
Explanatory Extension: Example

*Mr Green probably had the opportunity to murder Mr Body, but he possibly did not kill Mr Body*

- GreenHadMeans [ProbablyNot]
- GreenHadMotive [EvenChance]

Mr Green probably had the opportunity to murder Mr Body, but he **probably did not have the means**, therefore he **possibly did not kill Mr Body**

Mr Green probably had the opportunity to murder Mr Body, but he **maybe had a motive**, therefore he **possibly did not kill Mr Body**

Evaluation?

- **YES**
- Interpretation Graphs 🤝
- Supposition Configurations 😊
- Explanatory Extensions 😊

Conclusion

- A probabilistic formalism for discourse interpretation that
  - casts the generation of an interpretation as a model selection task
  - accounts for different aspects of interpretations
- Extensions:
  - dialogue
  - spoken interactions with robots