Inference-based semantic analysis

Igor Boguslavsky
IITP, Russian Academy of Sciences
Universidad Politécnica de Madrid
igor.m.boguslavsky@gmail.com

Plan

1. Knowledge-based approach vs. Machine learning.
2. Inferences: implications and plausible expectations.
3. Semantic analyzer SemETAP.
4. Applications.
    1. Semantic Question Answering
    2. Winograd Challenge

Context

- Computational Linguistics vs. Natural Language Processing
- CL: basic science
  - Object: natural language and the way people use it
  - Method: computational modeling
- NLP: branch of engineering
  - Aim: useful applications that include language processing
- NLP may use some results and methods developed in CL
- CL may receive some incentives from NLP (but should not be biased towards building applications)
- One-way confusion
- Links between linguistics and NLP
  - Linguistics for NLP
  - NLP for linguistics

We are doing CL, not NLP

- Institute for Information Transmission Problems (RAS): Development of a functional computational model of natural language in the framework of the Meaning – Text approach (Mel’čuk, Apresjan)
  - Analysis: Text ⇒ Abstract (semantic) representation
  - Synthesis (generation): Semantic representation ⇒ Text
- For some (external) reasons, our model (ETAP) has been developed for a long time in the guise of a MT system. But ideologically, it has always been a theoretical product and served as a test-bed for linguistic descriptions.
- Our work on semantic analysis should be perceived along these lines.

Big picture

- **Aim**: modeling text understanding
- **Main working assumption**: the depth of understanding is determined by the number and the quality of inferences we can draw from the text. A text understanding model should take a text and represent its meaning so that all reasonable inferences are explicitly given.
- Inferences have two major sources:
  - Knowledge of meanings of linguistic units (words, constructions, morphological units)
  - Non-linguistic knowledge (common sense, domain, background knowledge)
- The task splits into two parts
  - Formulate and explicitly represent both types of knowledge
  - Implement a mechanism of building SemS which incorporate the inferences (both strong and weak) made on the basis of both types of knowledge.

Choice of the paradigm: Why not deep learning?

- The choice of the paradigm is determined by the task.
- *Snowstorm* vs. *Blizzard*
  - Discover semantic similarity: distributional semantics is adequate
  - Explicate the difference: no way
- Grammatical agreement:
  - Ensure correct agreement between N and A/Num: neural red is OK.
  - Produce a description that allows for comparison between the agreement in Polish and in Russian, or agreement in the XX and in the XVIII century: expert knowledge is needed.
- All other things being equal, a linguistic model based on expert knowledge has more explanatory power than a machine learning-based model.

Even more so when it comes to reasoning

- Black box reasoning is not comfortable for the users. We should trust the computer when it is performing reasoning.
  - Intelligent systems should be able to reason like humans, should use concepts familiar to humans and operate them in a way we can understand
  - They should be able to explain their reasoning to us
  - We should be able to probe computer's reasoning
  - We should be able to convince the computer to adopt a different position
- Explainable (Interpretable, Transparent) AI
  - Cf. IJCAI 2017 Workshop on Explainable Artificial Intelligence

General approach

1. Include the semantic module into the integrated model (begin with the text).
2. Knowledge acquisition bottleneck.
   - Trade-off between “wide and shallow” and “narrow and deep”.

- Our approach: successive coverage of different domains.
- Cf. studies by the commonsense reasoning community: logico-semantic modeling of different domains ranging from very narrow ones (breaking an egg) to larger ones (emotions, interpersonal relations, commonsense psychology, causality, change of state etc.)
- Our domains so far: football reports, mental states.

Inference of implicit knowledge

- Normally, the text does not express explicitly all the information we extract from it.
- A part of the information is presented implicitly or not presented at all and should be restored
- Our analyzer has 2 levels of semantic structure
  - Basic SemS
  - Enhanced SemS

Inference of implicit links

(1) *The birds dig a small hole in the sand* ***to bury their eggs***

(2) *They bought a small car* ***to go to work***

(3) *They sold their car* ***to buy a boat***

- The sentences are very similar and have similar BSemS: ‘to do something having a certain aim’
- But the inferences are different
  - … to bury the eggs **IN THIS HOLE**
  - … to go to work **IN THIS CAR**
  - **…** to buy a boat **WITH THE MONEY OBTAINED FROM SELLING THE CAR**
- What knowledge is needed in order to make these inferences?

Inference is based on knowledge

- Ontology
  - ***hole*** is a Place
  - ***go*** is a Transportation-Event
  - ***car*** is an Instrument of Transportation-Event
- Semantics of concepts
  - ***bury***: locate the Object in a Place in order to hide it
  - ***sell:*** has getting money as a result
  - ***buy:*** has having money as a precondition
- If you have an aim (*to buy a boat*) that has a precondition (*having money*), then you may need to perform an action that has this precondition as a result (*selling something*)

Two types of inferences

- Implication: an inference that is necessarily true
  - *John broke the cup ==>* The cup is broken
- Plausible expectation: a certain state-of-affairs can be reasonably expected, but is not obligatory
  - *John dropped the cup ≈≈>* The cup is broken.
- An utterance may allow for both types of inference
  - *John went to the university at t*
  - BasicSemS: ‘at t John began moving towards the university with the aim of being there’

==> at t John ceased to be at the initial point

≈≈> it can be expected that at t1>t John will be at the university

Importance of plausible expectations for discourse interpretation

- *Mother asked me to repair the fence* does not entail 'I repaired the fence'
- … but it is an expectation activated by *asked*
- Therefore, the following dialogue is coherent:
  - Speaker A: *What were you doing yesterday?*
  - Speaker B: *Mother asked me to repair the fence.*
- The direct answer was not given and Speaker A tries to discover an indirect one based on plausible expectations.
- In SemETAP we pay special attention both to implicationas and to plausible expectations.

Knowledge sources

- Linguistic knowledge: Combinatorial dictionary
  - Syntactic and semantic features
  - Government pattern (= subcategorization frame)
  - Lexical Functions
  - Link to Ontology (default)
  - Rules of different kinds (including non-default semantic correlates)
- Extra-linguistic knowledge: Ontology, Repository of individuals, Common sense axioms
  - Ontology is a metalanguage of semantic description
  - Meaning of the concepts is defined by means of relations that connect them to other concepts or individuals (similar to semantic decomposition)

Inferences possible thanks to semantic definitions

- *The hunter killed the wolf* $\Rightarrow$

Inferences possible thanks to semantic definitions

- *The hunter killed the wolf* $\Rightarrow$

  The wolf is dead

Inferences are possible thanks to semantic definitions

- *The hunter killed the wolf* ⇒

  The wolf is dead

- *He forgot to make a call* ⇒

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- *The hunter killed the wolf* $\Rightarrow$

  The wolf is dead
- *He forgot to make a call* $\Rightarrow$

  He did not make a call

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  He did not make a call
- *He did not prevent Mary from leaving* $\Rightarrow$

Inferences are possible thanks to semantic definitions

- *The hunter killed the wolf* ⇒

  The wolf is dead
- *He forgot to make a call* ⇒

  He did not make a call
- *He did not prevent Mary from leaving* ⇒ Mary left
- *He promised to make a call* ⇒ it can be expected that he makes a call

Semantic descriptions

- Form: a set of rdf-tripples
  - `Mouse hasColour grey`
- Content: mostly, information, which can be useful for inference
- Similar to lexicographic definitions, but:
  - without details hardly needed for inference
  - supplied with (some) world knowledge

How are physical objects described?

- Objects
  - Physical parameters (size, colour, …)
  - Function
  - Parts (obligatory and typical)
  - Typical situations and role of the object in them
  - …

And events?

- Preconditions of the event
  - *Peter thanks Mary* --- ‘Mary did something good to Peter’
- Participants of the event
- Their objectives
  - Attacker: has the objective to place the ball into the goal area of the opposite team
  - Goalkeeper: has the objective to prevent the ball from getting into his goal area
- Subevents of the event and their temporal order
  - Breathing – Inhaling, Exhaling
- Result of the event (obligatory or typical)
- Assessment of the event and its participants from the viewpoint of different participants
  - Helping, Winning the match (cf. sentiment analysis)

Helping

Informally:

- Agent1 has the goal of doing Action1 or obtaining Object1.
  - *He helped her to solve the problem*
- Agent2 has the goal of facilitating this to Agent1.
- Therefore Agent2 is doing Action2 or is giving Object2 to Agent1.
  - *He helped her by speaking to the Dean. He helped her with money.*
- It is good for Agent1 that Agent2 is doing this.

NOTE THAT:

- in the lexicon, *to help* usually has no more than 3 arguments ("who helps whom to do what').
- in a description aiming at inferences it should have more (2 Agents, 2 Actions, 2 Objects)

Inference

If *HELP* = past,perf, then Agent2 performed Action2 and Agent1 performed Action1.

- *Peter helped Masha solve the problem* --> ‘Masha solved the problem’
- ‘He helped me with the lodging’ --> ‘I got the lodging’

If *HELP* = pres,imperf, then Agent2 performs Action2 and

a) if Action1 is atelic, then Agent1 performs Action1 (*Peter helps Masha walk* ==> Masha walks)

b) if Action1 is telic, then it can be expected that Agent1 will achieve the goal of Action1 *(Peter helps Masha solve the problem* ==> it can be expected that Masha will solve the problem).

Implications vs. Plausible expectations

- Each proposition has some degree of EpistemicModality
  - MaximalDegree: the proposition is definitely true
  - MediumDegree: it can be expected that the proposition is true
- *Peter helped Masha solve the problem*
  - EpistModality of “Masha solved the problem” is Maximal
- *Peter helps Masha solve the problem*
  - EpistModality of “Masha will solve the problem” is Medium

Why should the definitions be detailed?

- They enable inferences
- Knowing the objectives of the participants helps
  - *The attack was not successful* ($\Rightarrow$ Goal-Event did not take place)
  - *The goalkeeper was not equal to the situation* ($\Rightarrow$ Goal-Event took place)
- Recognize the whole event when only some of its parts are mentioned
  - *Messi received the ball and the score becomes 1:0*
  - *In 10 minutes the ball finds itself three times in the goal of Bayern*

Lexical Functions as a source for inference

- LiquFunc0: ‘to cause to cease to exist’.
  - *to stop (the aggression), to lift (the blockade), to dispel (the clouds), to demolish (the building), to disperse (the crowd), to avert (the danger), to cure (the disease), to close (the dispute), …*
- LiquFact0: ‘to cause to cease functioning according to its destination’
  - *close (the eyes), stop (the car), land (the airplane), depose (the king), switch off (the lamp), neutralize (the poison), empty (the bucket), shut down (the factory).*

LF-based inference

- *The blockade is lifted* (=LiquFunc0) $\Rightarrow$ it does not exist anymore.
- *The dispute is closed* (=LiquFunc0) $\Rightarrow$ it does not exist anymore.
- *The eyes are closed* (=LiquFact0) $\Rightarrow$ they do not see.
- *He fulfilled* (= Real1) *the promise to buy a bicycle* $\Rightarrow$ *He bought a bicycle.*

Interpretation of a sentence by means of a series of inferences

- *Aršavin tak i ne smog spasti matč* ‘Aršavin could not save the match’.
- What is the result of the match?

Knowledge at our disposal:

1. The verb *smoč* ‘be able’, in the perfective aspect, is implicative. Therefore, *X smog P* 'X could do P' implies that P took place, while *X ne smog P* 'X could not do P' implies that P did not take place.
2. The phrase *spasti matč* 'save the match' is interpreted as 'prevent the defeat of one's team'.
3. 'Prevent' is also an implicative predicate, but of a different type than ‘be able’. *X prevented P* implies that P did not take place.

- These facts underlie the following inference chain:
  - Aršavin could not save the match ⇒
  - does not take place: Aršavin saved the match ⇒
  - does not take place: Aršavin prevented the defeat of his team ⇒
  - does not take place: the team for which Aršavin played was not defeated ⇒
  - the team for which Aršavin played was defeated.

Interaction of different knowledge sources

- Combinatorial dictionary – Ontology – Repository of Individuals
- *Korner u vorot xozjaev polja zaveršaetsja udarom Netsida v upor, no* ***Dikan' okazyvaetsja na vysote*** 'the corner kick at the goal of the home team resulted in the kick point blank by Necid, but **Dikan was up to the mark**'.
- We want to know if a goal has been scored. To answer this question, we will have to resort to three sources of information:
  - Combinatorial dictionary tells us that the expression *byt' na vysote* 'be up to the mark' corresponds to the concept `EqualToOccasion`, interpreted as 'do well what one is expected to do';
  - Repository of individuals contains the information that Andrei Dikan is a goalkeeper of Spartak Football Club;
  - Ontology describes the goalkeeper role as preventing the ball from penetrating the goal of his team.

Cont.

- These three pieces of information allow the reasoner to infer that Dikan, being a goalkeeper, performed well his function of preventing a goal.
- Consequently, a goal has not been scored.
- Obviously, if the Repository of individuals had told us that Dikan had the position of a forward, then, given that the Ontology specifies the function of a forward as scoring goals, the overall conclusion would have been the opposite.
- A conclusion concerning scoring a goal has been made in the context which does not mention the word *goal* nor any of its synonyms.

Common sense axioms

<u>Axiom1</u>: no Object cannot be in different Places at the same time

<u>Axiom2:</u> if an Object is moving to a Place at t, it can be expected that it will be in Place at t1>t

Cf. *Ivan went to London* vs. *Ivan came to London*

Common sense axioms

Ontology:

ClientServingOrganization < Organization

hasUserAction Action

Library

hasUserAction   Reading   (as Agent)

Hospital

hasUserAction   MedicalTreatment (as Object)

<u>Axiom 3</u>: if a Human is in a Client-serving-organization, it can be expected that Human performs UserAction

Where is Ivan? He is in the hospital (in the library).

What did you do yestaerday? I went to the cinema.

Immediate applications

- Semantic search
- Question answering
- Machine reading
- Commonsense reasoning applications
- Virtual agents
- Other

Winograd Schema Challenge

- Turing test of computer’s intelligence.
- What is tested is not the computer’s intelligence, but its ability to fool the human.
- New variant of Turing test (H. Levesque): a set of multiple choice questions where the answers are fairly obvious to a layperson, but ambiguous for a machine without a human-like reasoning ability.
- *The trophy would not fit in the brown suitcase because it was too big <small>.*

Example

1. *Joan made sure to thank Susan for all the help* ***she*** *had given*
2. *Joan made sure to thank Susan for all the help* ***she*** *had received*

Knowledge

- *A helps B* => What A is doing is good for B
- *A thanks B for Q* => B performed Q, and this is good for A

She = Susan

- *Joan thanked Susan for the help Susan (=she) has given (to her)* => Susan gave help to Joan and this help is good for Joan (**confirmed**)
- *Joan thanked Susan for the help Susan (=she) has received (from her)* =>

  Joan gave help to Susan and this help is good for Joan (**not confirmed**)

She=Joan

- *Joan thanked Susan for the help Joan (=she) has given (to her)* =>

  Joan gave help to Susan and this help is good for Joan (**not confirmed**)
- Joan thanked Susan for the help Joan (=she) has received (from Susan) (**confirmed**)

SemETAP - 1

- Semantic module of ETAP-4
- ETAP-4 is a multifunction linguistic processor
  - MT
  - Treebank annotation (SynTagRus, an integral part of Russian National Corpus)
  - Synonymous paraphrasing of utterances in terms of LFs
  - Translation to and from the interlingua UNL
- SemETAP reuses its non-semantic components (morphology, surface syntax, deep syntax, combinatorial dictionary)

SemETAP - 2

- The main features of SemETAP:
  - Strict separation of linguistic representation levels
    - MorphS, SyntS, NormSyntS, BasicSemS, EnhancedSemS.
  - Balance between the static and dynamic resources.
  - Linguistic and world knowledge (Combinatorial dictionary+Linguistic rules, Ontology+Axioms+Repository of Individuals)
- Focus on inference

Stage 1: preparing semantization

- Input: Normalized Syntactic Structure
  - Strongly governed Pr/Conj, auxiliary verbs deleted
  - Zero copulas ⇒ *BYT’* ‘to be’
  - Lexical functions identified
  - Antecedents of anaphoric pronouns found, etc.
- At this stage, among other things:
  - Substitution of antecedents for anaphoric pronouns
  - Processing of support verbs (LFs)
    - *Spartak pobedil Dinamo* 'Spartak defeated Dinamo' *= Spartak oderžal pobedu nad Dinamo* 'Spartak gained a victory over Dinamo' *= Spartak nanjos poraženie Dinamo* lit.‘Spartak inflicted a defeat on Dinamo' *= Dinamo poterpelo poraženie ot Spartaka* 'Dinamo suffered a defeat from Spartak'.
  - Transformation of the passive into the active
  - …

Stage 2: constructing BSemS

- Semantic interpretation of words, syntactic constructions and morphological features by means of ontological elements
  - *gol* ‘goal’ ⇒ `GoalEvent`
  - *vratar’* ‘goalkeeper’ ⇒

    `Human hasRole GoalkeeperRole`

Stage 3: constructing EnSemS

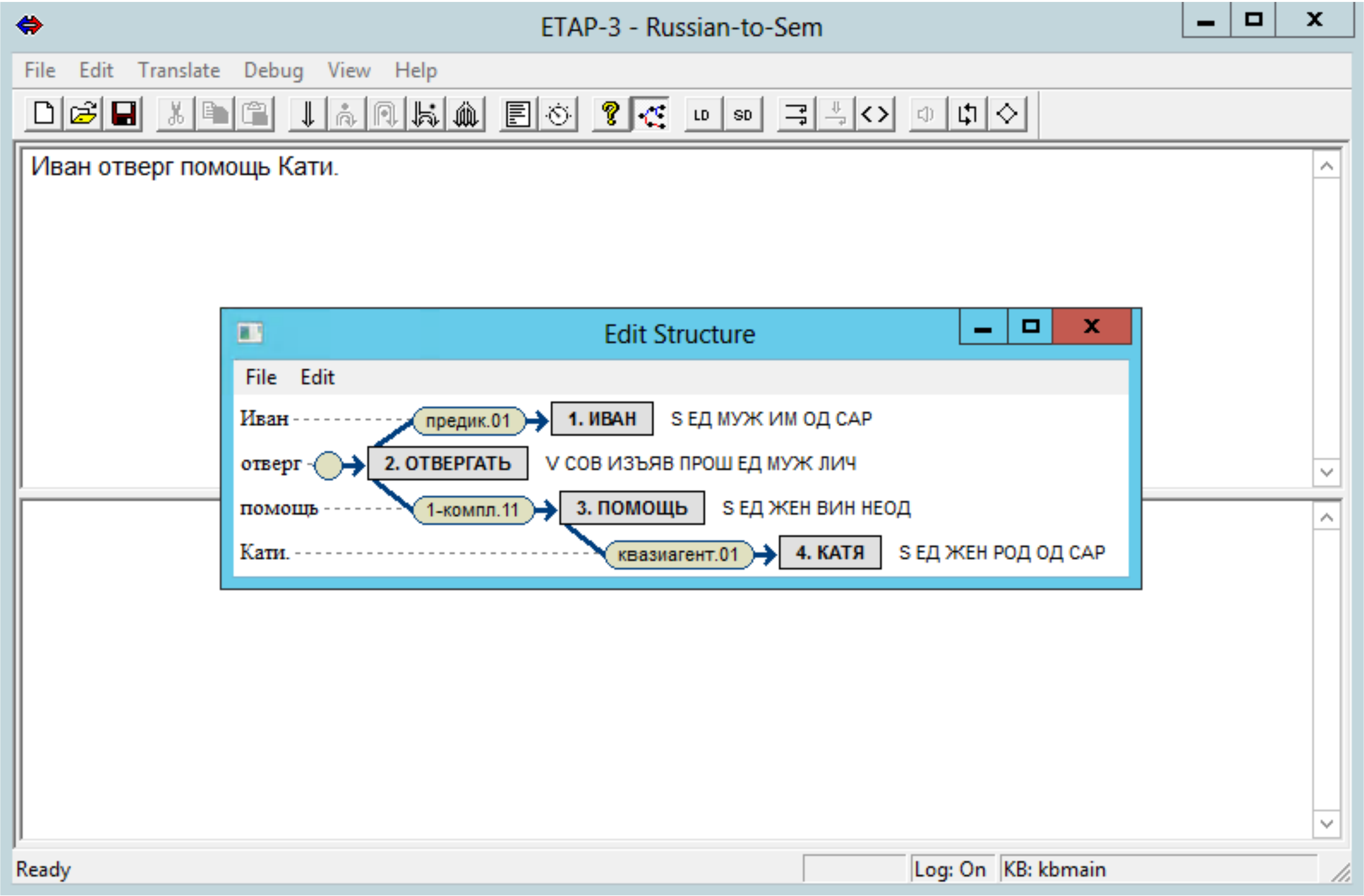
- Decomposing concepts and other inferences
- `GoalEvent ⇒ …`
- Ensures much deeper comprehension
  - Where is the ball?
  - Did the score change? How?
  - Sentiment analysis: good for one team, bad for another.
  - *Udar pjatkoj, i mjač v setke vorot* ‘a kick with the heel, and the ball is inside the goal’.
- `Prevent P ⇒ P does not take place`

Inference rules

- Written in Etalog
- At the moment, there are 300+ inference rules (both for general concepts and football)
- Much more in the future
- Rules are applied by the RDFox environment developed at Oxford University (https://www.cs.ox.ac.uk/isg/tools/RDFox/)

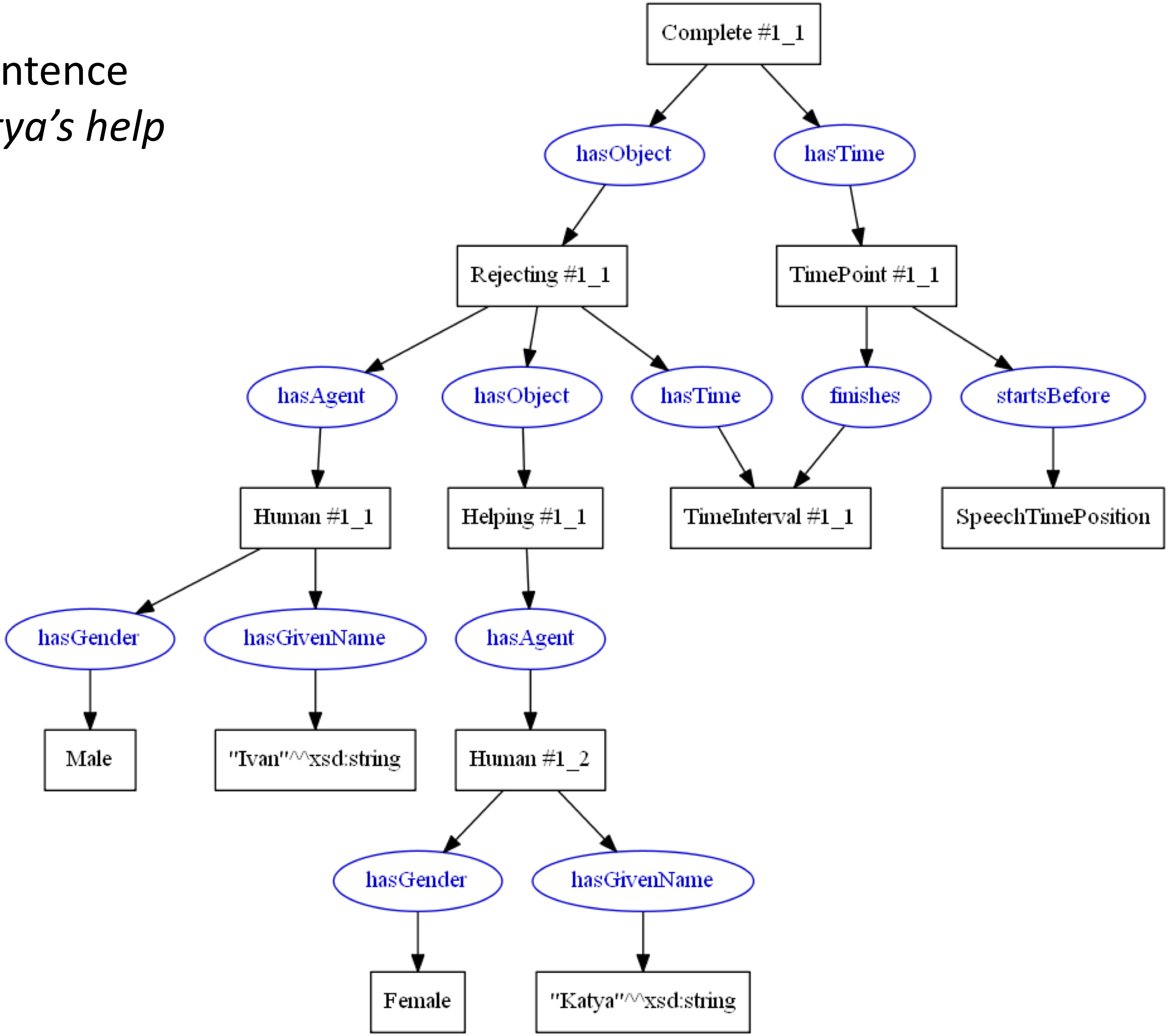
Иван отверг помощь Кати
‘Ivan rejected Katya’s help’

- Syntactic Structure
- Basic Semantic Structure
- Inference rule in Etalog
- Result in the Question answering mode


ETAP-3 - Russian-to-Sem
File Edit Translate Debug View Help
LD SD
Иван отверг помощь Кати.
Edit Structure
File Edit
Иван
предик.01
1. ИВАН
S ЕД МУЖ ИМ ОД САР
отверг
2. ОТВЕРГАТЬ
V СОВ ИЗЪЯВ ПРОШ ЕД МУЖ ЛИЧ
помощь
1-компл.11
3. ПОМОЩЬ
S ЕД ЖЕН ВИН НЕОД
Кати.
квазиагент.01
4. КАТЯ
S ЕД ЖЕН РОД ОД САР
Ready
Log: On
KB: kbmain

BSemS of the sentence

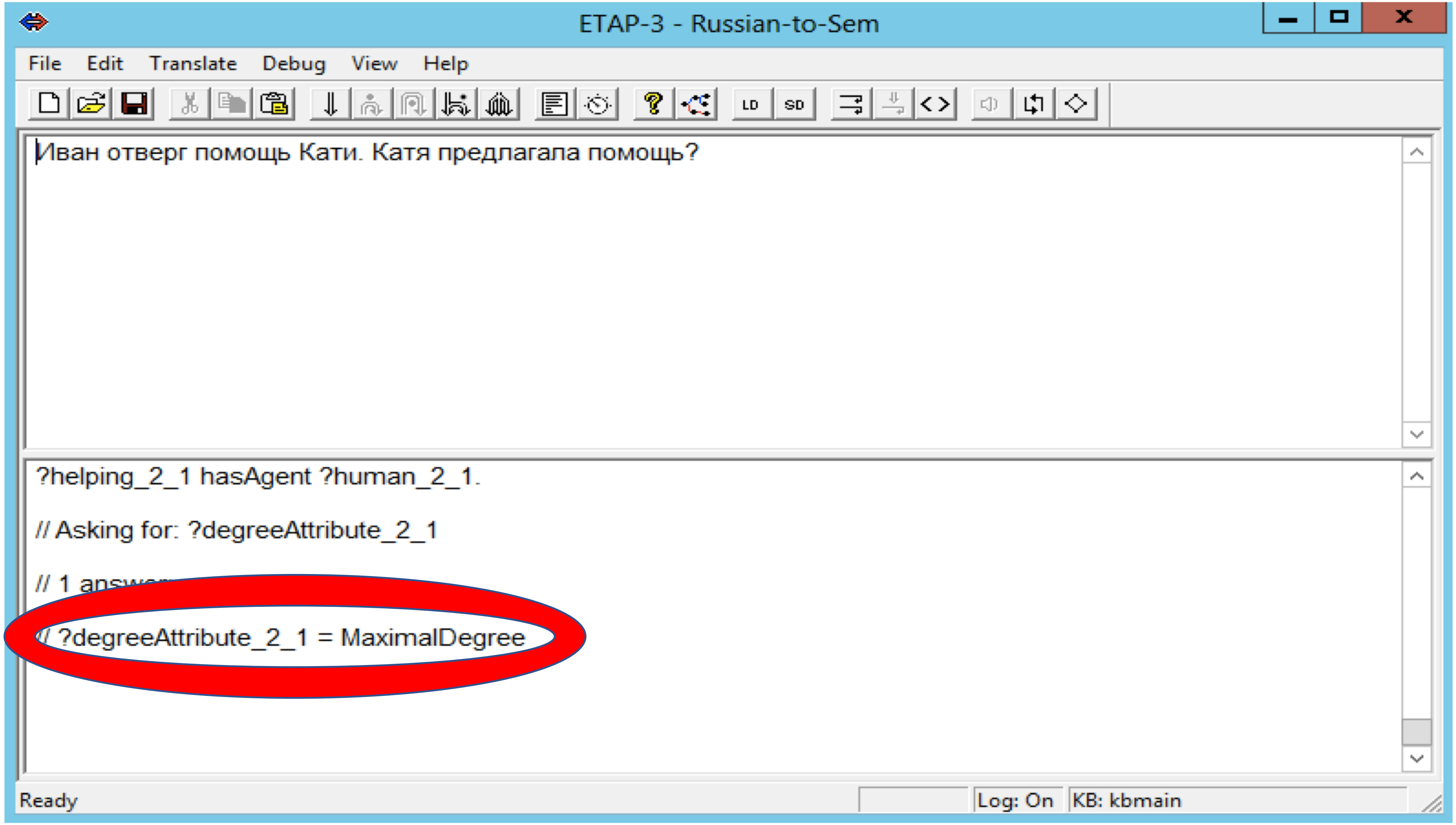
Ivan rejected Katya's help



Inference rule in Etalog

```
Rule Rejecting:
// reject somebody´s offer to do something
Rejecting ?reject
->
?reject
        hasAgent (Agent ?agent)
        hasRecipient (Agent ?recipient)
        hasObject (Event ?event)
        hasPreconditionComplete
          (Offering ?offer   hasAgent ?recipient
                             hasRecipient ?agent
                             hasTopic ?event)
        hasFollowingEvent (Negation hasObject ?event)
        isObjectOf (EvalModality
                        hasBeneficiary ?recipient
                        hasDegree LowDegree)
        // being rejected is bad for ?recipient
```

Ivan rejected Katya´s help. Did Katya offer help? Answer: Yes (EpistemicMod has MaxDegree)



Conclusions

- SemETAP is an option of the ETAP-3 linguistic processor aiming at producing in-depth semantic interpretation of texts by making a wide range of inferences.
- Makes use of both linguistic and background knowledge.
- Distinguishes between strict implication and plausible expectations.
- Can infer implicit information, which can be used in question answering, story understanding, and dialogue processing.