Recursive Models: A Computational Tool for the Semantics of Natural Language Utterances

Stefano Mizzaro

Dipartimento di Matematica e Informatica
Università di Udine
Via delle Scienze, 206 — Loc. Rizzi — Udine — Italy
Ph: +39 (432) 55.8456 — Fax: +39 (432) 55.8499
e-mail: `mizzaro@dimi.uniud.it`

Abstract

Recursive models, a computational tool for representing the meaning of natural language utterances at a semantic/pragmatic level are described and compared with relevant work.

Recursive models are not only a theorical instrument, but an effective tool: they have been used in TOBI (Temporal presuppositions and counterfactuals: an Ontological Based Interpreter), a natural language processing system for modelling temporal presuppositions and counterfactuals, linguistic phenomena situated on the boundary line between semantics and pragmatics and common to many languages.

1 Introduction

This paper describes a computational tool, named *recursive model* (RM), that can be used for representing, at a semantic-pragmatic level, the meaning of natural language utterances. The paper is structured in the following way: in Section 2 the class of computable models is described, in Section 3 the RMs are presented as an instance of computable models, in Section 4 related work is discussed, and Section 5 concludes the work.

2 Computable models

From a computational perspective, two approaches are possible for representing the semantics of a discourse,[1] and for using such representation in finding implications between the discourse and following utterances. In the first 'inferential' approach, the discourse is translated into a theory (a set of logical formulas) Γ; the same happens to a following utterance, obtaining, say, the logical formula ϕ; then, to discover if the discourse implies the utterance, an inference procedure $\vdash$ is used for testing if $\Gamma \vdash \phi$.[2]

In the second 'model-theoretic' approach, the discourse is used to build a model M, and an evaluation function (usually denoted by $\models$ in mathematical logic) is used in order to test if $M \models \phi$.

These are two quite different approaches: in the former the central notions are a set of axioms (to which further ones can be added for taking into account new utterances) and a set of inference rules; the latter is based on the two functions that, respectively, *integrate* (*int* in the following) a previous model with the information of a new utterance, and *evaluate* (*eval* in the following) an utterance in a previously built model.

If the representation of the semantics of a discourse has to be used by an algorithm, both the approaches reveal some decidability problems. In the inferential approach, this happens when neither the utterance (ϕ) nor its negation ($\neg\phi$) are an entailment of the discourse (Γ), and this is a common situation, in that the logical theory Γ is not necessarily *complete*. The standard solution is to abort the inference process when it is too long, the length of the process being the number of inference steps or the computation time. In the model-theoretic approach, similar decidability problems arise when the evaluation function is not computable. This leads to a constraint on the models: their expressiveness has to be sacrificed, for obtaining a computable *eval* function. I shall call the models with such property *computable models*.

In the next section I will propose an instance of computable models, the RMs. The computability of the corresponding *eval* function has not been formally proved; instead, the approach has been empirically tested by utilizing RMs in TOBI (Temporal presuppositions and counterfactuals: an Ontological Based Interpreter) system [18, 19], a natural language processing system capable of handling temporal presuppositions and corresponding counterfactuals [8, 10, 11, 13, 15, 16], linguistic phenomena situated on a semantic-pragmatic boundary.

3 Recursive models

Roughly speaking, an RM is constituted by *instances* of classes of an encyclopedia and *relations* among those instances. Therefore, an *encyclopedia* is needed, that is a taxonomy of *categories* and *concepts*. The encyclopedia is a knowledge base, and is needed in order to know for instance that Mary and John are persons, hence living

---

[1] A *discourse*, or a *text*, can be defined as a sequence of utterances.

[2] For an explanation of these and following concepts derived from mathematical logic, see for instance [5, 7].

beings, etc.; that the meeting of Mary and John is an event; and so on.

Using the operation of *instantiation* it is possible to create a *token* for each individual mentioned in the utterance. Consider for instance the utterance

“Mary met John before she left”. (1)

There will be tokens for ‘Mary’, ‘John’ (instances of the class `person`), ‘met’ and ‘left’ (instances of the class `event`). Every token has an associated identifier; I use uppercase letters for instances of objects (`M` for ‘Mary’, `J` for ‘John’), and lower case letters for events (`m` for ‘met’, `l` for ‘left’, etc.). As usual, tokens inherit *slots* from their parent concepts, so `M` is the value of the slot `agent` of `m` and `J` is the value of the slot `theme` of `m`. Moreover, between tokens `m` and `l` there is a temporal *relation* to indicate that the meeting took place before the leaving.

Tokens, slots, and relations are not sufficient to obtain a complete RM, since by using only these components one would obtain the same RM for

“Mary did not meet John before she left” (2)

and this is clearly a problem. To deal with event occurrence and object existence, other elements are introduced in the RM: *spaces*, *attachments*, and *signs*.

A *space* is needed because not only an object exists, or an event takes place; it is more correct to say that an object exists (or an event takes place) *in a world.* Consider the utterance

“Mary met John before she left and he persuaded her to stay at home”. (3)

Mary did not leave in the *real world*, but Mary left in the counterfactual world in which she did not meet John. Such world is illustrated by the *counterfactual utterance*

“If Mary had not met John, she would have left”. (4)

Analogously, it is possible to say that Donald Duck does not exist in the real world, but he exists in Walt Disney’s world.

So, a space is a formal tool for representing alternative worlds. I indicate the real world with `[]`. It is possible to represent the object existence and the event occurrence *attaching* every token to the right world: the relation between token and world is named *attachment.* Finally, attachments are labelled with a *sign* in order to deal with non-existence and non-occurrence, both of which are represented by a negative sign, whereas a positive sign obviously means existence and occurrence.

The occurrence of an event may be certain (the meeting of (1)) or uncertain (the leaving of (1), as demonstrated by (3)); this can be dealt with using *certain* and *uncertain* signs. In the RM of (1), the signs labelling the attachments of the tokens for ‘met’ and ‘left’ are both positive, but the former is certain, and the latter is uncertain.

The RM for (1) is illustrated in Figure 1. Only the portion of the encyclopedia needed to build the RM of the utterance is represented (in the upper gray area, while in the lower white area the proper RM is sketched): each rectangle stands for a concept. The relations *is-a* (between two concepts) and *instance-of* (between a concept and a token) are represented by labelled grey arcs, tokens are shown as circled letters, slots are illustrated by means of oriented arcs, relations, as usual in entity-relationship diagrams used in data base theory, are represented by arcs labelled with a rhombus (the symbol `<` stands for ‘precedes temporally’), a dashed arc represents an attachment, a bold sign is certain, and a plain text sign is uncertain. For the sake of simplicity, in the graphic representation the names of the slots are not illustrated.

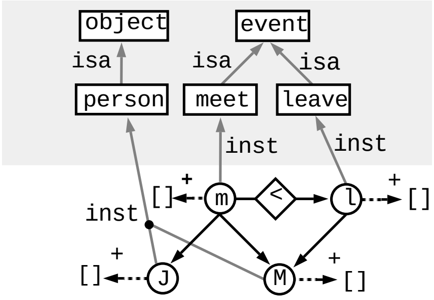

Figure 1: Graphic representation of the RM of (1).

The RM in Figure 1 models the meaning of (1). Nevertheless, there is another element to add for dealing with the *causal links* relating the occurrence (or non-occurrence) of events: for instance, in utterances (3) and (4) the occurrence of the meeting with John causes the occurrence of the event ‘Mary stayed at home’.

The elements used in RMs to represent such causal relations are named *justifications*, and are represented by curved arcs. As signs, also justifications may be certain or uncertain. In order to understand the role of these new elements, consider Figure 2, in which the RM of (3) is represented. Here and in the following, for the sake of simplicity, I have omitted the representation of the encyclopedia (i.e. the classes and the `isa` and `inst` relations): the letters labelling the tokens should be sufficient for understanding which class each token is instance of. Furthermore, the token `p` is assumed to be an instance of the ad-hoc class `persuade to stay at home`.

The justification between the signs of tokens `m` and `p` is uncertain (graphically represented by a thin curved line), whereas the one that links the signs of `p` and `l` is certain (thick curved line). The reason for this distinction is that the meeting implies persuading in a very weak sense (it is a precondition), while persuading (to stay at home) entails not leaving.

Note furthermore that in Figure 2 `l`’s attachment is labelled with two signs: the positive one (uncertain) models the presupposition of the leaving and the negative one

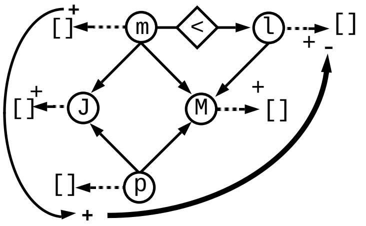

Figure 2: Graphic representation of the RM of (3).

(certain) reflects the fact that the leaving actually did not take place. The last sign is the *preferred* sign (and it overcomes the uncertain one); graphically, this is represented putting it near to the end of the arc.

Justifications are needed not only by abstract completeness considerations, but also to deal with counterfactual utterances, like (4), that can be evaluated in the RM of (3). The details of this evaluation, together the algorithms implementing the *eval* and *int* functions (both defined by structural recursion on the *logical form* [1] of the utterance), are not described here; see [18, 19] for details.

4 Related work

In this section, research on *discourse models* and *discourse representation theory* (DRT) are briefly compared with RMs, and it is shown how RMs can be extended in a simple way for handling *beliefs* and *situations.*

RMs can be seen as models of previous discourse context, into which information from sentences is merged, and against which queries are evaluated. There are a lot of studies on *discourse models* that investigate how the various structures that can be individuated in a discourse ought to be used to understand the meaning of the sentences forming such discourse: see for instance [9, 14, 17, 20, 21, 22]. RMs could be a new instrument for this research, even if it might be more appropriate to say that RMs are a computational tool for modeling the meaning of utterances, and that they do not seem to suffer from any intrinsic limitation for being used at the level of discourse.

RMs are also comparable to DRS (Discourse Representation Structures), the 'models' used in DRT [12], but also here there are some differences. First of all, Kamp and Reyle themselves say in their book on DRT [12, page 627] that they do not consider the phenomena of temporal presupposition and counterfactuals, on which basis the RMs have been designed and implemented:

> There exists the possibility of using before-phrases in a kind of "virtual" sense which is not possible for prepositional phrase with after. In a case where the sentence "George died before the completion of his novel" is true, the completion of the novel presumably never took place. [...] This use of before has given semanticists a good deal of trouble. [...] It is an issue which we will not pursue here.

Notwithstanding that, one might try to treat temporal presuppositions in DRT, but he will encounter some difficulties. Consider for instance Figure 3, reporting the standard DRS of

"Mary left before meeting John", (5)

(the DRS is divided in 3 groups, separated by empty lines: the first one models the main clause, the second one the word 'before', and the third one the subordinate clause). In such DRS there is nothing representing the facts that the event e_2 (the meeting one) is only presupposed (and then uncertain), that it has not happened, that there is a causal link between the occurrence of the two events; moreover, there is no 'first-class' object representing the occurrence of the events. From an epistemological point of view, RMs make explicit some considerations about the use of the *negation* by human (or more generally living) beings [3, 4]. In fact, the first way that one can imagine for representing the non-existence of an object (or the non-occurrence of an event) is probably the use of a slot 'existence' ('occurrence'), with the opportune value for each token. In RMs, the more general mechanism of spaces, attachments, and signs allows not only to deal with existence and occurrence, but also to explicitly represent the fact that the causal relations hold between occurrences (or non-occurrence) of events, and not merely between events.

$t_1\ n\ e_1\ x\ t_2\ e_2\ y$
$t_1 < n$
$e_1 \subseteq t_1$
$mary(x)$
$e_1 : leave(x)$
$t_1 < t_2$
$t_2 < n$
$e_2 \subseteq t_2$
$john(y)$
$e_2 : meet(x, y)$

Figure 3: DRS for utterance (5).

Obviously, DRS could be extended in the direction indicated by RMs, but this is not so simple, in that in DRS there is nothing like spaces, attachments, signs, and justifications, central concepts in RMs. So, DRSs might be situated at a semantic level, while RMs work on the semantic-pragmatic boundary: a DRS is more similar to a logical form than to a RM.

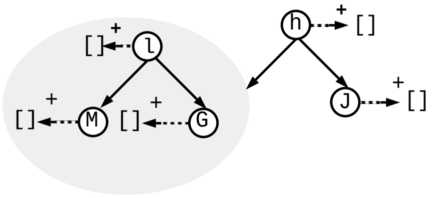

Figure 4: Situations in RMs.

RMs can be extended in a natural way for taking into account the concepts of *beliefs* and *propositional attitudes* [2, 6]. For instance, spaces allow to easily represent Mary's *intention* to leave in utterances (1) and (3): it is sufficient to attach the token `l` in Figures 1 and 2 to a space, `[int(M)]`, representing the world of the events that should have happened if everything had gone as presupposed. In this way, one can create a family of operators on worlds (`int(X)` for intentions, `bel(X)` for beliefs, and so on), indexed on the tokens of the RM. These operators can transform one world (for instance `[]`) in other ones (`[int(M)]`, `[bel(M)]`, etc.)

Finally, RMs might easily be improved for handling utterances like

"Mary left with George. This hurt John" (6)

in which it is not the mere event that 'hurt John', but the whole context. In order to treat this kind of utterances, it will be necessary to introduce the concept of *situation* [2, 6] in RMs: the RM of this utterance could look like the one in Figure 4, where the grey circle is the graphic representation of 'what hurt John'.

5 Conclusions

Recursive models, an instance of computational models for representing the meaning of natural language utterances have been described and compared with related proposals.

The work presented here is a part of a more general research about utterances containing temporal presuppositions and counterfactuals [18, 19], in which: a corpus of examples has been identified; the language fragment containing such phenomena has been defined at a level (called abstract syntax) adequate for most (European) languages; the different kinds of knowledge (linguistic *vs.* extra-linguistic, certain *vs.* uncertain, etc.) that must be taken into account for understanding temporal presuppositions and counterfactuals have been analyzed; the RMs have been built and formally specified; and TOBI, a system using RMs for interacting in natural language with the user has been implemented.

Acknowledgements

I am indebted to Marco Colombetti for long and stimulating discussions, and to Paolo Giangrandi and Fabio Rinaldi for useful comments on a draft of this paper.

References

[1] J. Allen. *Natural Language Understanding.* The Benjamin/Cummings Publishing Company, Inc., 2nd edition, 1994.

[2] J. Barwise and J. Perry. *Situations and attitudes.* MIT Press, Cambridge, MA, 1983.

[3] G. Bateson. *Steps to an Ecology of Mind.* Chandler Publishing Company, 1972.

[4] M. D. S. Braine. On the relation between the natural logic of reasoning and standard logic. *Psychological Review*, 85(1):1–21, 1978.

[5] C. C. Chang and H. J. Keisler. *Model Theory.* Studies in Logic. North Holland, Amsterdam, 1973.

[6] K. Devlin. *Logic and information.* Cambridge University Press, 1991.

[7] H. B. Enderton. *A Mathematical Introduction to Logic.* Academic Press, New York, 1972.

[8] G. Gazdar. *Pragmatics: Implicature, presupposition and logical form.* Academic Press, 1979.

[9] B. Grosz and C. L. Sidner. Attention, intentions, and the structure of discourse. *Computational Linguistics*, 12(3):175–204, July–September 1986.

[10] O. Heinämäki. Before. In P. M. Peranteau, J. N. Levi, and G. C. Phares, editors, *Papers from the Eighth Regional Meeting of the Chicago Linguistic Society*, Chicago, Illinois, 1972. University of Chicago.

[11] O. Heinämäki. *Semantics of English Temporal Connectives.* PhD thesis, Department of Linguistics, University of Texas at Austin, Austin, Texas, 1974. Reproduced by Indiana University, Linguistic Club, November 1978.

[12] H. Kamp and U. Reyle. *From Discourse to Logic.* Kluwer Academic Publisher, Dordrecht, The Netherlands, 1993.

[13] L. Kartunnen. Presuppositions of coumpound sentences. *Linguistic Inquiry*, 4(2):169–193, 1973.

[14] A. Lascarides and N. Asher. Discourse relations and defeasible knowledge. In *Proceedings of 29th Annual Meeting of the ACL*, pages 55–62. University of California at Berkeley, June 1991.

[15] A. Lascarides and J. Oberlander. Temporal connectives in a discourse context. In *Proceedings of the European ACL*, pages 260–268, 1993.

[16] S. C. Levinson. *Pragmatics.* Cambridge University Press, Cambridge, 1983.

[17] W. C. Mann and S. A. Thompson. Rhetorical structure theory: A theory of text organization. Reprint ISI/RS-87-190, Information Science Institutes, University of Southern California, June 1987.

[18] S. Mizzaro. TOBI - An Ontological Based Interpreter for Temporal Presuppositions and Counterfactuals. In R. Trappl, editor, *Cybernetics and Systems '94*, volume 2, pages 1879–1886, Singapore, 1994. World Scientific. Proceedings of the 12th EMCSR.

[19] S. Mizzaro. Recursive models: A computational tool for the semantics of temporal presuppositions and counterfactuals in natural language. Technical Report UDMI/11/96/RR, Dipartimento di Matematica e Informatica, Università di Udine, 1996.

[20] L. Polanyi. A formal model of the structure of discourse. *Journal of Pragmatics*, 12:601–638, 1988.

[21] R. Scha, B. Bruce, and L. Polanyi. Discourse understanding. Technical Report 391, Bolt Beranek and Newman Inc., 10 Moulton Street, Cambridge, MA, October 1986.

[22] B. L. Webber. Discourse deixis and discourse processing. Technical Report MS-CIS-88-75, Department of Computer and Information Science, University of Pennylvania, Philadelphia, PA 19014, September 1988.