THE ℜEALIS MODEL OF HUMAN INTERPRETERS AND ITS APPLICATION IN COMPUTATIONAL LINGUISTICS

Gábor Alberti, Márton Károly and Judit Kleiber
Department of Linguistics, University of Pécs, 6 Ifjúság Street, Pécs, Hungary

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Abstract: As we strive for sophisticated machine translation and reliable information extraction, we have launched a subproject pertaining to modelling human interpreters. The model is based on ℜeALIS, a new "post-Montagovian" discourse-semantic theory concerning the formal interpretation of sentences constituting coherent discourses, with a *lifelong* model of lexical, interpersonal and cultural / encyclopedic knowledge of interpreters in its center including their *reciprocal* knowledge on each other. After the introduction of ℜeALIS, we provide linguistic data in order to show that intelligent language processing requires a realistic model of human interpreters. Then we put down some principles of the implementation (in progress) and demonstrate how to apply our model in computational linguistics.

1 ℜEALIS: THE THEORY IN THE BACKGROUND

ℜeALIS, *REciprocal And Lifelong Interpretation System*, is a new "post-Montagovian" (Kamp *et al.* 2005) theory concerning the formal interpretation of sentences constituting coherent discourses (Asher–Lascarides 2003), with a *lifelong* model (Alberti 2000) of lexical, interpersonal and cultural/ encyclopedic knowledge of interpreters in its center including their *reciprocal* knowledge on each other (Alberti 2004).

The decisive theoretical feature of ℜeALIS lies in a peculiar reconciliation of three objectives which are all worth accomplishing in formal semantics but could not be reconciled so far. The first aim concerns the exact *formal basis* itself, which is often mentioned as Montague's Thesis: human languages can be described as interpreted *formal* systems (we thus does not agree with the viewpoint of Cognitive Grammar: "That no attempt has yet been made to formalize Cognitive Grammar reflects the judgment that the cost of the requisite simplifications and distortions would greatly outweigh any putative benefits" (Langacker 200: 423)). The second aim concerns *compositionality*, practically postulating the existence of a homomorphism from syntax to semantics. In Montague's interpretation systems a traditional logical representation played the role of an intermediate level between the syntactic representation and the world model, but Montague argued that this intermediate level of representation can, and should, be eliminated. The post-Montagovian history of formal semantics, however, seems to have proven the opposite, some principle of "discourse representationalism": "some level of [intermediate] representation is indispensable in modeling the interpretation of natural language" (Dekker 2000).

The Thesis of ℜeALIS is that the two fundamental Montagovian objectives *can* be reconciled with the principle of "discourse representationalism" – by embedding discourse representations in the world model, getting rid of an intermediate level of representation in this way while preserving its content and relevant structural characteristics. This idea can be carried out in the larger-scale framework of embedding discourse representations in the world model *not directly* but as parts of the representations of interpreters' minds, i.e. that of their (permanently changing) information states.

The frame of the mathematical definition of ℜeALIS (whose 40 page long complete version is available here: http://lingua.btk.pte.hu/realispapers) is summarized here. As interpreters' mind representation is part of the WORLD MODEL, the definition of this model $\mathfrak{R} = \langle U, \mathbf{W_0}, W \rangle$ is a quite complex structure where

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- U is a countably infinite set: the UNIVERSE
- $W_0 = \langle U_0, \mathbf{T}, \mathbf{S}, \mathbf{I}, \mathbf{D}, \Omega, \mathbf{A} \rangle$: the EXTERNAL WORLD
- W is a partial function from $I \times T_m$ where W[i,t] is a quintuple $\langle U[i], \sigma[i,t]^{\Pi}, \alpha[i,t]^{\Psi}, \lambda[i,t]^{\Lambda}, \kappa[i,t]^{K} \rangle$: the INTERNAL-WORLD FUNCTION.

The external world consists of the following components:

- U_0 is the EXTERNAL UNIVERSE ($U_0 \subset U$), whose elements are called ENTITIES
- $\mathbf{T} = \langle T, \Theta \rangle$ is a structured set of TEMPORAL INTERVALS
- $\mathbf{S} = \langle S, \Xi \rangle$ is a structured set of SPATIAL ENTITIES
- $\mathbf{I} = \langle I, Y \rangle$ is a structured set of INTERPRETERS
- $\mathbf{D} = \langle D, \Delta \rangle$ is a structured set of LINGUISTIC SIGNS (practically performed morph-like entities and bigger chunks of discourses)
- where $T \subset U_0$, $S \subset U_0$, $I \subset U_0$, $D \subset U_0$
- $\Omega \subset T \times U_0{}^*$ is the set of CORE RELATIONS (with time intervals as the first argument of all core relations)
- **A** is the INFORMATION STRUCTURE of the external world (which is nothing else but relation structure Ω reformulated as a *standard simple information structure*, as is defined in Seligman–Moss (1997:245); its basic elements are called the INFONS OF THE EXTERNAL WORLD

The above mentioned *internal-world function* W is defined as follows:

- The relation structure W[i,t] is called the INTERNAL WORLD (or INFORMATION STATE) of interpreter i at moment t
- $U[i] \subset U$ is an infinite set: interpreter i's INTERNAL UNIVERSE (or the set of i's REFERENTS, or INTERNAL ENTITIES); U[i'] and U[i"] are disjoint sets if i' and i" are two different interpreters
- what changes during an interpreter i's lifespan is not her referent set U[i] but only the four relations among the (peg-like) referents, listed below, which are called i's INTERNAL FUNCTIONS:
- $\sigma[i,t]^{\Pi} : \Pi \times U[i] \rightarrow U[i]$ is a partial function: the EVENTUALITY FUNCTION (where Π is a complex label characterizing argument types of predicates)
- $\alpha[i,t]^{\Psi} : \Psi \times U[i] \rightarrow U[i] \cup U_0$ is another partial function: the ANCHORING FUNCTION (α practically *identifies* referents, and Ψ contains complex labels referring to the legitimizing grammatical factors)
- $\lambda[i,t]^{\Lambda} : \Lambda \times U[i] \rightarrow U[i]$ is a third partial function: the LEVEL FUNCTION (where elements of Λ are called LEVEL LABELS); the level function is intended to capture the "box hierarchy" among referents in complex Kampian DRS boxes (Kamp *et al.* 2005) enriched with some rhetorical hierarchy in the style of SDRT (Asher–Lascarides 2003)
- $\kappa[i,t]^{K} : K \rightarrow U[i]$ is also a partial function: the CURSOR, which points to certain temporary reference points prominently relevant to the interpreter such as "Now", "Here", "Ego", "Then", "There", "You"
- The temporary states of these four internal functions above an interpreter's internal universe serve as her "agent model" in the process of (static and dynamic) interpretation.

Suppose the information structure **A** of the external world (defined above as a part of model $\Re = \langle U, \mathbf{W_0}, W \rangle$) contains the following infon: $\iota = \langle$PERCEIVE, t, i, j, d, s$\rangle$, where i and j are interpreters, t is a point of time, s is a spatial entity, d is a discourse (chunk), and PERCEIVE is a distinguished core relation (i.e. an element of Ω). The INTERPRETATION of this "perceived" discourse d can be defined in our model relative to an external world $\mathbf{W_0}$ and internal world W[i,t].

The DYNAMIC INTERPRETATION of discourse d is essentially a mapping from W[i,t], which is a temporary information state of interpreter i, to another (potential) information state of the same interpreter that is an *extension* of W[i,t]; which practically means that the above mentioned four *internal functions* (σ, α, λ, κ) are to be developed monotonically by *simultaneous recursion*, expressing the addition of the information stored by discourse d to that stored in W[i,t].

The new value of eventuality function σ chiefly depends on the *lexical items* retrieved from the interpreter's internal mental lexicon as a result of the perception and recognition of the words / morphemes of the interpreter's mother tongue in discourse d. This process of the identification of lexical items can be regarded as the first phase of the dynamic interpretation of (a sentence of) d. In our ℜeALIS framework, extending function σ corresponds to the process of accumulating DRS condition rows containing referents which are all – still – regarded as different from each other.

It will be the next phase of dynamic interpretation to *anchor* these referents to each other (by function α) on the basis of different grammatical relations which can be established due to the recognized *order* of morphs / words in discourse d and the *case*, *agreement* and other markers it contains. In our approach two referents will never have been *identified* (or deleted), they will only be anchored to each other; but this anchoring essentially corresponds to the identification of referents in DRSs.

The third phase in this simplified description of the process of dynamic interpretation concerns the third internal function, λ, the level function. This function is responsible for the expression of intra- and inter-sentential scope hierarchy (Reyle 1993) / information structure (Szabolcsi 1997) / rhetorical structure (Asher–Lascarides 2003), including the embedding of sentences, one after the other, in the currently given information state by means of rhetorical relations more or less in the way suggested in SDRT.

It is to be mentioned that the information-state changing dynamic interpretation and the truth-value calculating *static interpretation* are mutually based upon each other. On the one hand, static interpretation operates on the *representation* of sentences (of discourses) which is nothing else but the output result of dynamic interpretation. On the other hand, however, the above discussed phases of dynamic interpretation (and chiefly the third phase) include subprocesses requiring static interpretation: certain *presuppositions* are to be verified (Kamp *et al.* 2005).

The interpreter's fourth internal function, cursor κ, plays certain roles during the whole process of dynamic interpretation. *Aspect*, for instance, can be captured in our approach as the resetting or retaining of the *temporal* cursor value as a result of the interpretation of a sentence (→ non-progressive / progressive aspect, respectively). It can be said in general that the input cursor values have a considerable effect on the embedding of the "new information" carried by a sentence in the interpreter's current information state and then this embedding will affect the output cursor values.

DYNAMIC INTERPRETATION in a ℜeALIS model $\mathfrak{R}=\langle U, \mathbf{W_0}, W\rangle$, thus, is a partial function Dyn which maps a (potential) information state W° to a discourse d and an information state W[i,t] (of an interpreter i):

- $\mathrm{Dyn}(d) : \langle \mathfrak{R}, W[i,t]\rangle \mapsto \langle W°, \underline{e}°, \mathbf{U}°\rangle$,

where **U°**, shown up in the output triple, is the COST of the given dynamic interpretation (coming from presuppositions legitimized by *accommodation* instead of *verification*), and $\underline{e}°$ is the eventuality that the output cursor points to (this is the eventuality to be regarded as representing the content of discourse d). Function Dyn(d) is *partial*: where there is no output value, the discourse is claimed to be ill-formed in the given context. Due to the application of cost, ill-formedness is practically a gradual category in ℜeALIS.

The STATIC INTERPRETATION of a discourse d is nothing else but the static interpretation of the eventuality referent that represents it. The recursive definition of static interpretation is finally based upon anchoring internal entities of interpreters to external entities in the external universe, and advances from smaller units of (the sentences of) the discourse towards more complex units.

2 SENTENCES AND DISCOURSES

Let us take the problem of *translation*. For example, a Hungarian text (1a) can only be translated by someone who has the Then (1b-c) and Now (1d) *cursor* values while being aware of the world around him/her.

Example 1: Knowledge about the world and the temporal cursors.

a. Megjelen-t *az elnök*, de nem válaszol-t a kérdés-ek-re.
appear-Past the president but ~~he/she~~ not answer-Past the questions-Pl-onto
b. *The President* appeared but *he/she* answered no questions.
c. *Der Präsident/Die Präsident-in* stell-te sich ein, aber *er/sie* hat keine Frage-n be-antwort-et.
the president / the president-Female to.place-Impf Refl in, but he/she has no question-s prefix-answer-Perf
d. The President will appear but *he/she* is not going to answer any questions.

In example (2a) below, the *temporal cursor* will jump (forward), just like the *spatial cursor*: the fridge is taken to be the one at Peter's home (2b). When describing states, we shall keep the position of the temporal (and the spatial) cursor (2c). Besides fitting patterns onto the real world, the *worldlet* concerning the *intention* of the actor and that of the *expectation* of the speaker also play a role. The temporal cursor can stand not only in the *cumulative* phase, but also in the *preparation* phase of the given eventuality type (2d); the event mentioned in the discourse will never happen but it is there in the worldlet concerning the *belief* of the Patient.

Example 2: Progressive aspect, imperfective paradox, result state – the interpreter's cursors and worldlets.

a. Peter travelled home. He drank a beer.
b. Peter travelled home. He wanted to drink a beer but the fridge was empty.

c. Peter was travelling home. He was drinking a beer.

The interpreter has numerous “famous” referents in his/her cultural/encyclopedic knowledge (stored in an appropriate hierarchy structured by functions α and λ, demonstrated in Section 1), which can be invoked by a *name* (3a). Although a name can refer to another entity (3b). A rich *ontology* concerning the world is also available (3c). The interpreter also stores non-logical relations (3d), to be applied while building stories again and again —typically based on already-built similar stories (3d-e)) and while searching for contacts between *temporal*, *eventual* and normal referents. Discourse (3e) is ambiguous: if the eventuality referent e” belonging to John’s pushing Peter is taken to stand in a Narrative relation with referent e’ of Peter’s falling, the temporal referent t” belonging to e” *follows* t’ (belonging to e’) chronologically, whilst if e” is construed as the Reason of e’ then t” *precedes* t’ (Asher and Lascarides 2005). A *topic cursor* can also play a role while building discourses (3f): it is made explicit in Hungarian by the lack or presence of a pronoun which participant is taken to be the *topic* of a sentence relative to the preceding sentence.

Example 3: Different sorts of knowledge

a. *Mozart* had a powerful influence on the work of *Beethoven*. *Beethoven* knew much of *Mozart's* work.
b. J. G. Leopold Mozart (November 14, 1719 – May 28, 1787) was a composer, conductor, teacher, and violinist. *Mozart* is best known today as the father and teacher of Wolfgang Amadeus Mozart.
c. a I have a half-St. Bernard and half-Scottish Shepherd, a Dalmatian and a parrot. The two *dogs* often frighten the poor *bird*.
d. Peter married yesterday. *The priest* spoke very harshly.
e. Peter fell. John pushed him.
f. Péter-nek van egy unokahúg-a. Kedvel-i őt. / *Az* kedvel-i őt.
Peter-DAT is a niece-PossSg3 Like-Sg3def him/her / *That* like-Sg3def him/her
’Peter has a niece. He likes her. / She likes him.’

Our last set of examples concerns the rich and explicit Hungarian system of operators to be interpreted logically (Kiss 2001). Based on his/her background knowledge and the “relevant set” as a part of it, one can infer the presence and place of some unnamed participants from the operator and the named participants of the discourse.

Example 4: Operators and claims about the relevant participants not mentioned in the discourse

a. Tizenkét unokatestvér-em van, de *csak* Annát és Beá-t hív-t-am meg a születésnap-i parti-m-ra.
twelve cousin-PossSg1 is but *only* Ann-ACC and Bea-ACC invite-Past-Sg1def Perf the birthday-DerAdj party-PossSg1-onto
‘I have twelve cousins but I invited only Ann and Beatrice to my birthday party.’
b. Lát-om, a ↑nővér-em-et (bezzeg) meg-hív-t-ad!
see-Sg1def the sister-PossSg1-ACC (contr.top.) Perf-invite-Past-Sg2def
‘But, as for my sister, I see that you invited her!’
c. Meg-hív-hat-t-ál volna mindannyiunk-at!
Perf-invite-may-Past-Sg2 PastCond all.of.us-ACC
‘You could have invited all of us.’
d. Meglep, hogy a nővér-em-et is meg-hív-t-ad.
surprise that the sister-PossSg1-ACC also Perf-invite-Past-Sg2def
‘It surprises me that you invited my sister, too.’

Table 1 summarizes the logical implicature of the Hungarian operators (apart from *topic* (3f), whose interpretation is not of logical nature). Let ‘every’ (4c) be our starting-point: this operator practically retrieves the set of participants mentioned earlier as the ‘relevant set’ e.g. ‘all of us’), and it is claimed that what is predicated is predicated of *each* member of the relevant set. Operator ‘also’ (4d) refers to the *existence* of an unnamed participant satisfying what is predicated (at least according to the speaker). The contrastive topic (4b) refers to the *existence* of an unnamed participant *not* satisfying what is predicated, whilst the focus (4a) refers to the fact that *each* unnamed participant is such that he/she/it does *not* satisfy what is predicated.

Table 1: The system of Hungarian operator meanings ($R_n = R \setminus R_m$, where R_m: mentioned participants, R: every participant which could have played the role played by the mentioned participants).

	P(x)	¬P(x)
$\exists x \in R_n$	operator ‘also’ (4d)	contrastive topic (4b)
$\forall x \in R_n$	operator ‘every’ (4c)	focus (4a)

3 PRINCIPLES OF THE IMPLEMENTATION

The most basic data elements represented in the implementation are the *referents*, which are assigned to the grammatical components during the process of the semantic analysis. In this article, which demonstrates a “work in progress”, we shall only put down the principles of a potential implementation (in a greatly simplified manner), focusing onto the four basic functions (σ, α, λ and κ; see Section 1) and mention some possible applications of such discourse-analyzing systems.

By default, each part of the sentence has its own referents which do not depend on any referents belonging to other parts of the sentence (the function α will search for dependencies). Most of these referents (belonging to certain interpreters in the richly structured worldlet system defined in Section 1: r_1, r_2 ,...) refer to entities existing in the external world, while other referents can be eventual (e_i), temporal (t_j) or spatial (s_k).

An *eventual referent* must be assigned to all verbs, nouns, adjectives and adverbs (parts of speech which can, in principle, play a predicative role in the sentence). For example, the noun *banker* and the adjective *clever* both can be treated as eventualities "being a banker" and "being clever". Function σ, taking the label Π into account (which, as mentioned in Section 1, contains information on the already-analyzed *syntactic structures*), assigns the argumental (r_i), temporal and spatial referents to the eventual referent of the regent and forms the structure pred(e, t, s, r_1, r_2, …) (one should note that only a small part of the referents play a significant role in the actual discourse).

The anchoring function α assigns the referents to each other in different worldlets, thereby declaring some referents as *identical*, which induces an equivalence relation. This process, however, should be aided by an *ontology* (apart from the information collected during the syntactic analysis) as mentioned in section 2. The ontology can have an arbitrary structure – for example, if we take the basics of psycholinguistics into account, the semantic web of the mental lexicon could be modeled by a *neuron network* (and, in general, RL could be used to handle lexical semantics). The mental lexicon has multiple dimensions on its own, and these dimensions can be regarded as multiple relation types in the network – or, even more precisely, a network of networks. If we have no ontology at all, only the referents of literally identical syntactic entities (and, in some cases, pronouns) can be anchored to each other.

The ontology is also used when we try to determine whether the discourse being analyzed is coherent or not. In (3d), the computerized equivalent of the *semantic web* should be used to determine coherence (by using a metric to measure the distance between the concepts (semantic categories) WEDDING and PRIEST). If the (semantic) distance is sufficiently low, the discourse can be regarded as coherent. Of course, if we use RL technology to create our ontology, the semantic proximity between two (or more) concepts must be pre-taught. Summarizing the above, the actual identity of referents can be determined by using the relation types (such as synonimity, semantic priming etc.) and distance metrics in the network.

The set of *temporal* referents (t_i) can be regarded as a partially ordered set (see, say, (3e)). As we mentioned above, referents can be identified by using a *distance metric* on the semantic web, thereby *fuzzifying* the process of determining discourse coherence. Many temporal adverbs are fuzzy by their nature (e.g. *nowadays*, *a long time ago*, *shortly*) and they are not even culturally independent. But even if we only handle well-defined temporal referents, the system still has some important applications (see Section 4 below).

The level function λ (practically) assigns the referents to certain worldlets of interpreters (such as those of their beliefs, desires, intentions, dreams). The entities of the external (real) world (model) always exist and they are "seen" and referenced by all interpreters. But during the syntactic analysis, *level-changing* words (mostly adverbs or particles) are found, expressing *modality.* "*If only* Mary had a car! Me, too, *could* drive *it* occasionally."

The phrase "*if only*" refers to the speaker's desire, rendering *all* referents in its scope to a *different* level, also a different worldlet (expressing a *desire* of the speaker). Entities on this level do *not* exist in the real world but the speaker *must* refer to them in order to express his/her *desire.*

Certain values of the *cursor* κ can be regarded as quasi-constant since they do not depend on the actual discourse flow directly and, in most cases, they do not need to be set during the analysis. "Then" is set at the beginning of a story and, for example, "You" can point to the user, who (as an *agent*) must always be considered as an active participant in the discourses being analyzed. Many applications of the system are based on this. We will show some of them in the next section.

4 APPLICATONS AND PLANS

As we mentioned above, the aim of our $\Re$eALIS model is *automatic discourse analysis.* To do this, we need to implement all the above-described tasks and functions. But why should an interpreter based on $\Re$eALIS be implemented?

First, *expert systems* can be created by implementing the $\Re$eALIS model. This depends on the *ontology* on which the function α is based. The ontologies need not to include everything or be overcomplicated. For example, ontologies concerning a special field combined with the $\Re$eALIS model (which is responsible for the syntactic and semantic analysis) could form an *expert system* or a *decision-supporting system* together. *Questions* could be asked or *predicates* could be stated to the program in a *natural* language – the system extracts information and prints it in a readable form (preferably also in a natural language, for example, if we want to do machine translation backed by $\Re$eALIS).

One possible application of the $\Re$eALIS model is to use it as a *legal* expert system to aid lawyers. Backed by a legal ontology, temporal referents (t_i) could even be handled in a *simplified* way (see above), because temporal adverbs tend to be much less fuzzy in legal texts than in general stories. For example, confessions and evidences given by participants of a court case could be analyzed according to the current laws (which are integrated into the ontology) to facilitate judgement, or even laypersons could use the system if they consider taking legal action.

Machine translation, too, can be based on $\Re$eALIS. It was already implemented, although in a greatly simplified manner, in its predecessor (Alberti *et al.* 2004) which was able to translate simple Hungarian sentences into grammatically correct English. In the process of translating entire discourses, however, references always play a key role, as illustrated in Section 2. Translating certain *pronouns* is only possible after having analyzed large parts of the discourse while recording the position of the *topic cursor* (3f). The same applies for the *tense and aspect system* of certain languages. Here, the precise handling of the temporal cursor seems to be far more problematic than in the case of doing a "mere" discourse analysis (e.g. when functioning as an expert system). If the actual position of the temporal cursor can not be exactly reproduced in the target language, the translation process is especially difficult, if at all possible.

5 CONCLUSIONS

We have based a subproject pertaining to the modeling of human interpreters (of our project whose chief aims are machine translation and information extraction) upon $\Re$eALIS, *REciprocal And Lifelong Interpretation System* (Section 1), because a large scale of linguistic data (Section 2) shows that intelligent language processing requires a realistic model of human interpreters. Then we put down some principles of the implementation (in progress) and sketch how to apply our model in computational linguistics (Sections 3-4).

The initial state of the model of our ideal interpreter's mind can practically be regarded as an enormous, unstructured set of peg-like *referents* in Landman's style (1986), which is then permanently being enriched, due to the input of linguistic information (to be worked up in different ways), with an intricate structure "spanned" by four functions, σ, α, λ and κ, responsible for, respectively, the assignment of eventuality referents to statements about temporal, spatial and "normal" referents (σ), the identification of co-referring ones (α), the decision of a scopal/modal relation system among the referents (λ), and the highlighting of those playing some distinguished role at a certain moment of working up a discourse (κ).

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