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REFERENTIAL NETS WITH ATTRIBUTES

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One of the essential problems in natural language production and understanding is the problem of processing referential relations. In this paper I describe a model for representing and processing referential relations: referential nets with attributes. Both processes (analyzing and generating referential expressions) are controlled by attributes. There are two types of attributes, on one hand, the ones to the internal substitutes of the objects spoken about, on the other hand, the ones to the descriptions of these objects.

1. BASIC NOTIONS: KNOWLEDGE AND SEMANTIC REPRESENTATION

It is a well-known fact that (computational) models of human language production and understanding have to take the knowledge of the speaker and the listener into consideration. Thus, one of the main problems is to describe and represent this knowledge and to distinguish relevant subtypes. A suitable classification which I described in detail in Habel [7] distinguishes three subtypes:

- knowledge of facts or assertions, e.g. of states of the world, events, etc., the 'factual knowledge',
- knowledge of rules, e.g. of rule-like relations between objects or states of the world (or classes of such entities), the 'inferential knowledge',
- knowledge of objects, e.g. of persons in the world, the 'referential knowledge'.

(In this paper I give emphasis to the third type: referential knowledge represented by 'Referential Nets').

The common core for representing all these types of knowledge is the 'semantic representation language' SRL. From the formal point of view SRL is a (propositional) symbolic language as described by Kalish/Montague [8]. Well-formed SRL-expressions are generated by normal (recursive) formation rules. I distinguish - as usual - two kinds of meaningful expressions in SRL, terms and formulas. Thus we define:

TER - the set of well-formed terms
FOR - the set of well-formed formulas
SRL = <FOR, TER>

For the purpose of knowledge representation SRL contains some specific operators, e.g.

on the factual level: tenses, beliefs,.....
on the inferential level: entailment relation,...
on the referential level: description operators of various types.

Since SRL is a representation language, I now have to treat the central question of 'representation theory': What kinds of entities are represented by the different entities of SRL? Here I follow - with minor changes, which I will not discuss in this paper - Miller [10]: The expressions and entities of SRL represent cognitive concepts. The operators correspond to different types of 'concepts' in the Miller-approach, e.g. predicative , nominal and modifying concepts (this third class are the 'operators' of Miller.). E.g. by means of description operators it is possible to construct nominal concepts from

predicative concepts or other nominal concepts.
I shall now illustrate SRL with an example. In understanding and representing the sentence

(1) I will meet Barbara in the university tomorrow.

the act of referring to "I", "Barbara", and "the university" is to be processed, i.e. the (object-)orientation to them is the interesting problem from the referential point of view. The SRL representation of (1) is

(2) time (meeting (I,Barbara, ETA(x) :university(x)),tomorrow)

The arguments of "time" and "meeting" present the most relevant types of referential operators: "I" and "tomorrow" are deictic substitutes (personal or temporal), Barbara is a proper name and the expression "ETA(x): university(x)" is built up from the nominal concept "university" (representing a class of institutions for education and science) and the variable-binding description operator "ETA". "ETA(x): p(x)" has the meaning "an element from the class {x/p(x)}". ETA is an indefinite analogy to the IOTA-operator of formal logics (Similar operators are introduced by Hilbert as EPSILON- or ETA-operator.). The semantics of the description operators is given by a set of inference and evaluation rules. E.g. there is an inference rule which relates the ETA-expressions to expressions with existential quantification:

(3) p(ETA(x) : q(x)) ⊢ EX x : p(x) & q(x) 1*

Some evaluation rules will be described in the following chapters, e.g. 'creation of a referential object'. (Both types of rules are described in detail in Habel [5], [6].) Thus, ETA is the formal representative of one of the meanings of indefinite articles.
Further descriptions of the objects mentioned in (1) or in the SRL expression (2) can be generated by (focussing) transformations similar to the solution of algebraic equations: The university mentioned above is also the one described by

(4) ETA(x) :time (meeting(I,Barbara, $\overline{\text{university(x)}}$),tomorrow) 2*

or the natural language equivalent "a (the) university where Barbara and I will meet tomorrow". (The uniqueness of the ETA-description depends on the situational/textual context.)
Before we pass on to a detailed description of 'referential nets', I will make a short remark on discourse and communication. As mentioned above human language production and understanding is based on the speaker-listener's knowledge of the language, the world and particularly the participants in the communication. Thus, I assume a discourse model 3* which is based on tripartite knowledge (namely factual, inferential, and referential), each of these types is represented by structured sets of SRL-expressions.

2. THE REFERENTIAL NET

Processing, e.g. storing or retrieving, referential relations is executed by a particular component of the discourse processing system, the 'referential procedures' (ReP). The RePs work on a memory structure which is adequate for the representation of knowledge about objects, the 'referential net' (RefN) 4*. A RefN consists of entities of three different types:

- referential objects (RefOs), which are the internal substitutes for the objects spoken about,
- descriptions, i.e. terms of SRL which describe the RefOs,
- attributes, i.e. properties of the description-relation between a RefO and one of its descriptions or properties of the RefO (see chap. 3).

After detecting a new indefinite description (as ETA(x) : university(x)) ReP creates a new "referential object" (RefO). During the discourse (after the identification process) further descriptions of the same RefO will be linked to this RefO. (The relation among the descriptions of the same RefO is the wellknown relation of coreference.) Thus we have, for example, the following set of descriptions of the RefO mentioned above :

(5) r.1 ⟵ d.11 — ETA(x) : university(x)
d.12 — ETA(x): time (meeting(I,Barbara,$\overline{\text{university(x)}}$),tomorrow)
d.13 — IOTA(x) : professor-at(Barbara,$\overline{\text{university(x)}}$)

For the description of the referential net I use SRL and in addition a "finite but extendable" set, REFO, of 'referential objects'. The referential objects are seen as a kind of basic term of SRL. The set REFO is analogous to the set of variables. The phrase "finite but extendable" is used to emphasize the dynamic aspect of the set REFO and the RefN. REFO consists of exactly those RefOs that are actually needed. It is necessary to distinguish two types of terms, one type which consists of the mental representatives, i.e. the RefOs, and the other which contains those terms which function as descriptions. Naming this set by D-TER we have TER = REFO ∪ D-TER. Thus, referential nets, RefNs, can be defined as

(6) RefN ⊂ D-TER x REFO .

For <d-ter, r.i> ∈ RefN I also use "d-ter descr r.i" , "d-ter is a description of r.i". In this way a description-relation is defined on the basis of the RefN. By means of referential nets it is possible, e.g. to arrive at one object (i.e. RefO) via different aspects, i.e. different descriptions, of this object. It is only by such aspects (cp. Schank's [11] way of memory discrimination), that a system is able to choose "a best description" of the objects which are the theme of the discourse (see below). The referential net (5) is simplified in two crucial points, first, that the descriptions of r.1 operate on MSRL expressions and not on RefOs, too. But this can be treated similarly to the focussing process of (4), which can be formalized now:

(7) p(r.i) ⟵ r.i — ETA(x) : p(x)

Using (7), the descriptions can be solved with respect to all RefOs, i.e. all arguments are filled by RefOs or open terms. Thus we can derive (8) from (5):

(8) r.1 ⟵ d.11 – ETA(x) : university(x)
d.12 – ETA(x): time (meeting(r.2, r.3, $\overline{\text{university(x)}}$), r.4)
d.13 – IOTA(x) : professor-at(r.3, $\overline{\text{university(x)}}$)
r.2 ——— d.21 – "I"
r.3 ——— d.31 – Barbara
r.4 ——— d.41 – "tomorrow"

Secondly, ReP has to explicate the referential links of deictic substitutes, e.g. "I" refers to the speaker, etc.. "_" stands for the specific ReP which evaluates deictic expressions, i.e. which instantiates deictic expressions with RefOs, e.g. "I" = SPEAKER(1) (cp. fn 6.). By the same methods new RefOs for "we" can be created, e.g. in the processing of "There we will discuss some papers." (We = Barbara + I)

3. ATTRIBUTES IN REFERENTIAL NETS

I will now extend the basic two-place relation between RefOs and descriptions to the more adequate concept of a many-place referential relation. The additional places will be called 'attributes'. In the first step of extention I give emphasis to 'attributes of descriptions'. They represent properties of the description relation, i.e. of pairs <d, r> ∈ RefN. Thus, the extention to an attributed RefN (ARefN) uses a set ATT of attributes and changes (6) to

(9) ARefN ⊂ ATT x D-TER x REFO .

For <att, d, r > ∈ ARefN I also say "att is an attribute of d with regard to r". Some possible attributes are (Note the fact that this list is not complete and not fully adequate):

- syntactic and semantic features of the description, e.g. gender, number, sexus, etc.
- numerical values, e.g. "grades of relevance of a description", "degrees of 'being the TOPIC / being in the FOCUS' ", "recency". 5* A simple strategy for de-/coding is: "Use/try the description or RefO with highest degrees !"
- names of persons, e.g. participants of earlier discourses. By this attribute it is possible to find a description relevant to speaker and listener (Cp. Clark / Marshall's [1] co-presence triples).
- situations in which the description / RefO is relevant or was introduced (cp. Webber's [12] 'evoke'-predicate).
- links to the factual knowledge; thus we can answer such questions as "What will Barbara do tomorrow?"

Before I explain the concept of 'attributes to descriptions' by some examples, I will now sketch some aspects of function and status of the attributes. Firstly, in both processes, analysis as well as generation of referential expressions, it is necessary to take into consideration a set of alternatives. All of them are possible candidates to be the referent (in analyzing) or to be a good description (in producing) respectively. The goal of the ReP is to choose exactly one from the alternatives, namely 'the best'. It is obvious that trying to choose the best can fail. Then the decision has to be revised afterwards. (But this is a total different problem.) In other words, the function of the attributes is to point to the most appropriate (or being more careful: to that which seems to be the most appropriate) of the alternatives. Secondly, I think that, on one hand, knowing and processing attributes is part of human natural language processing, and therefore, these attributes have to be part of the discourse processing model. On the other hand, knowledge of attributes is different (cp. the list of possible attributes, above) from the factual or referential knowledge. Thus, I propose a strict separation between descriptions and their attributes. This strict distinction contrasts to Webber's [12] solution: her use of the 'evoke'-predicate mixes the concepts of descriptions and their attributes in a cognitive inadequate manner.
Now I shall continue with examples of the use of attributes . Let us suppose a situation in which a questioner Q asks:

(10) Where can I study Computational Linguistics?

and the answerer A knows that the university which is (internally) represented by r.1 is a good university to study CL. The selection of the best description of r.1 depends on Q and A (and the situational context). I assume the following attributes to the descriptions of r.1 (from (5), (8)):

(11)

descr.	general	relevant to:	time of relevance:
-d.11	'unspecified'		
-d.12		SPEAKER(1), LISTENER(1), Barbara	NEIGHBOR(r.4) 6*
-d.13		SPEAKER(1), LISTENER(1), KNOW(Barbara)	always

(11) describes a situation, in which the name / location of the university in question is not represented, e.g. since the information about the possibility to study CL was given by an earlier utterance of Barbara "We have some courses in CL" but A (whose RefN is represented by (11)) does not know where Barbara teaches. The best description can be chosen by comparing the attributes of Q with those of the descriptions of r.1. If Q knows Barbara, .i.e. <KNOW(Barbara)> ATT (Q) 7*, then the best description will be:

(12) d.13 - "The university where Barbara teaches (as a professor)."

Ranking d.13 higher / better than d.12 depends on the dimension 'time of relevance'. Furthermore, if Q knows more about r.1 it is possible that Q will react with,

(13) "Well, at Amherst."

and now A is able to extend his/her RefN with a further description of r.1

(14) r.1 - d.14 - Amherst — 'general high relevance' 'always'

(This attribute depends on the fact that proper names have high relevance in general.)
Anagously we can use attributes in the decoding process. Look at the following pair of sentences (similar to (1)).

(15) a. I will meet the head of the linguistic department tomorrow.
b. She is a specialist for Montague grammar.

To solve this referential problem (and not to be puzzled by the pronoun 'she') we need further background knowledge, e.g. "Barbara is the head of the linguistic department.". With this prior knowledge and the additional (theoretical) concept of 'attributes to RefOs' 8* as described in

(16) 'female' 'local TOPIC'- r.3 — d.31- Barbara
\ d.32- IOTA(x) : head-of(x ,linguist. dept.)

the referential problem of (15) is easy to solve. A system (human listener or machine) has to match the pattern corresponding to the pronoun 'she' which is induced by the context (15.b) against the descriptions, their attributes and the attributes of the RefO's. The crucial attribute is here 'female' for both 'she' and 'r.3'.
This type of congruence between gender of the pronoun and sexus of the RefO, i.e.

between attributes of descriptions and those of the RefOs, is very important in German. In spite of the syntactic incongruence (neutr. vs. fem.) it is possible (in colloquial German) to say:

(17) Ich traf gestern ein Maedchen. Sie hatte rote Haare.
I met yesterday a girl . She had red hair .
neutr. ⟷ fem.

4. CONCLUDING REMARKS

By means of an extended referential net (with attributes both of descriptions and RefOs) it is possible to describe how to store and process referential entities (and expressions) in a cognitive adequate and powerful way.
Following the principles and concepts described above a system for anaphora resolution has been implemented (Guenther [3]), which will be a component of the next version of the BACON-system (cp. fn 3).

FOOTNOTES:

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1* From a formal point of view 'inference rules' are transformation rules on SRL. Their cognitive and philosphical status, which is analogous to Miller's [10] 'conceptual entailment', is described in Habel [7].
Here, i.e. in (3), and in the focussing rule (7) 'p' stands for all types of concepts which are represented by open formulas.

2* The focussing transformation mentioned above is based on the concept of referential nets and therefore its description will be postponed to the following chapter. In (4) a special 'bar-convention' is used, which I do not want to explain in detail here. In case a term is necessary as argument, e.g. of "meeting", the 'bar' will change the open formula "p(x)" to an 'open term' "$\overline{p(x)}$".

3* Cp. Habel [7] and Gust / Habel / Rollinger [4]. This model is the theoretical basis of the natural language QAS BACON (Berlin Automatic COnstruction of semantic Nets), developed at the Technical University of Berlin, which was supported by a grant from the Federal Government since 1978. It should not be confused with the BACON-system of Carnegie-Mellon University (we chose the same name at the same time).

4* The concept of referential nets is similar to discourse referents (Karttunen [9]), reference diaries (Clark/Marshall [1]) and discourse models (Webber [12]). The most relevant difference between referential nets and the other approaches and the main advantage of referential nets consist in the further attributes described below.
Note the fact that the acronyms ReP, RefN, etc. can stand for the respective concept, e.g. 'referential net', as well as for a specific instantiation, e.g. the RefN (5) or (8). Furthermore ReP concerns the system of referential procedures as well as the individual procedures. In all these cases the meaning of the acronym is obvious through context.

5* In this paper TOPIC / FOCUS are used in an informal and intuitive way. (For a detailed investigation of these concepts cp. Grosz. [2]) Note that the attribute 'time of relevance' in (11) is part of TOPIC / FOCUS.

6* SPEAKER(1) stands for 'the speaker of utterance (1)', i.e. this attribute gives more information than Webber's [12] 'evoke(1)'. 'KNOW(_)' represents 'people knowing _'. 'NEIGHBOR(_)' stands for 'points / periods of time near to the point of time being the argument'. I do not want to explain the underlying 'logic of time' here.

7* I will not explain the concept of 'attributes of a person / participant' here. I use it in a straightforward and intuitive manner.

8* The extention to attributes of RefOs is analogous to that from (6) to (9):
AARefN $\subset$ ATT.1 x D-TER x (REFO x ATT.2) .
ATT.1 stands for the attributes of descriptions, ATT.2 for the attributes / properties of RefOs. AARefN is a 'double attributed RefN'. Note the fact that some of the attributes of the RefOs will be computed from those of descriptions, e.g. 'female' from a attribute of 'Barbara'.

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