ParseTalk about Functional Anaphora

Udo Hahn & Michael Strube

Computational Linguistics Group
Freiburg University
Europaplatz 1
D-79085 Freiburg, Germany
email: {hahn,strube}@coling.uni-freiburg.de

Abstract. We present a hybrid methodology for the resolution of functional anaphora. It incorporates conceptual proximity criteria applied to ontologically well-engineered domain knowledge bases and an approach to centering based on functional topic/comment patterns. We state grammatical predicates for functional anaphora and then turn to the procedural aspects of their evaluation within the framework of an actor-based implementation of a lexically distributed parser.

1 Introduction

Text phenomena, e.g., textual forms of pronominal, nominal and functional anaphora, are a particularly challenging issue for the design of natural language parsers, since lacking recognition facilities either result in referentially incohesive or invalid text knowledge representations. At the conceptual level, functional anaphora relates an anaphoric expression to its antecedent by conceptual attributes (or roles) associated with that antecedent (see, e.g., the relation between *"Zugriffszeit" (access time)* and *"ST-3141"* (a particular hard disk drive) in (4) and (3) below). Thus it complements the phenomenon of nominal anaphora (cf. Strube & Hahn 1995), where an anaphoric expression is related to its antecedent in terms of conceptual generalization (as, e.g., *"Rechner" (computer)* refers to *"LTE-Lite/25"* (a particular notebook) in (3) and (1) below). The resolution of text-level (pro)nominal anaphora contributes to the construction of referentially valid text knowledge representations, while the resolution of functional anaphora yields referentially cohesive text knowledge bases.

(1) *Der LTE-Lite/25* erweist sich als schneller als der LTE-Lite/20.
The LTE-Lite/25 runs faster than the LTE-Lite/20.

(2) *Der Prozessor* hat eine Taktfrequenz von 25 MHz.
The processor comes with a clock frequency of 25 MHz.

(3) Weiterhin wird *der Rechner* mit *der ST-3141* von Seagate ausgestattet.
Furthermore – is – *the computer* with *the ST-3141* from Seagate – equipped.

(4) *Die Zugriffszeit* ist mit 25 ms sehr kurz.
The access time – is – amounting to 25 ms – quite short.

(5) Durch *dieses neue Laufwerk* hat der Rechner ausreichend Platz für Windows-Programme.
Because of *this new hard disk drive* – has – the computer – sufficient storage for Windows programs.

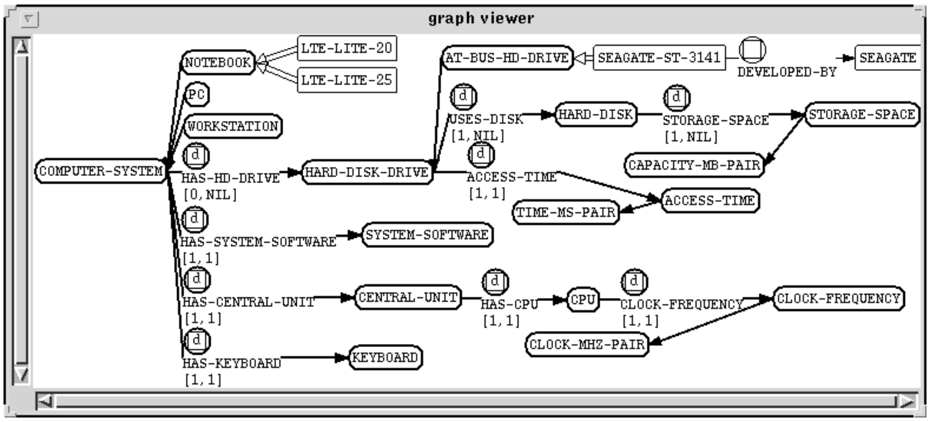


Fig. 1. Fragment of the Information Technology Domain Knowledge Base

In the case of functional anaphora, the conceptual entity that relates the topic of the current utterance to discourse elements mentioned in the preceding one is not explicitly mentioned in the surface expression. Hence, the missing conceptual link must be inferred in order to establish the local coherence of the whole discourse (for an early statement of that idea, cf. Clark (1975)). For instance, in (4) the proper conceptual relation between *"Zugriffszeit" (access time)* and *"ST-3141"* (preceding in sentence (3)) must be determined. This relation can only be made explicit if conceptual knowledge about the domain is supplied. It is obvious (see Fig. 1[1]) that the concept ACCESS-TIME is bound in a direct associative or aggregational relation, viz. *access-time*, to the concept HARD-DISK-DRIVE, while its relation to the instances LTE-LITE-25 and SEAGATE is not so tight (assuming property inheritance).

Nevertheless, the association of concepts through conceptual roles is far too unconstrained to properly discriminate among several possible antecedents in the preceding discourse context. We therefore propose a basic heuristic for conceptual proximity, which takes the path length between concept pairs into account. It is based on the common distinction between concepts and roles in

[1] The following notational conventions apply to the knowledge base for the information technology domain to which we refer throughout the paper (see Fig. 1): Angular boxes from which double arrows emanate contain instances (e.g., LTE-LITE-25), while rounded boxes contain generic concept classes (e.g., NOTEBOOK). Directed unlabelled links relate concepts via the *isa* relation (e.g., NOTEBOOK and COMPUTER-SYSTEM), while links labelled with an encircled square represent conceptual roles (definitional roles are marked by *"d"*). Their names and value constraints are attached to each circle (e.g., COMPUTER-SYSTEM - *has-central-unit* - CENTRAL-UNIT, with small italics emphasizing the role name). Note that any subconcept or instance inherits the conceptual attributes from its superconcept or concept class (this is not explicitly shown in Fig. 1). Similarly, a conceptual role hierarchy relates roles and their value constraints in terms of generalization.

classification-based terminological reasoning systems (MacGregor 1991). Conceptual proximity takes only conceptual roles into consideration, while it does not consider the generalization hierarchy between concepts. The heuristic can be phrased as follows: If fully connected role chains between the concepts denoted by a possible antecedent and an anaphoric expression exist via one or more conceptual roles, that particular role composition is preferred for the resolution of functional anaphora whose path contains the least number of roles. Whenever several connected role chains of equal length exist, functional centering constraints which are based on topic/comment patterns apply for the selection of the proper antecedent. Hence, only under equal-length conditions is grammatical information from the preceding sentence brought into play (for a precise statement in terms of the underlying text grammar, cf. Table 7 in Section 4).

To illustrate the computation of conceptual proximity in terms of path lengths, consider the sentences (1)–(5), Fig. 1 and Table 1, where the conceptual distances between all relevant concept pairs are given with respect to the scoring function from Table 6.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.
1. LTE-Lite-25	∞	∞	2	3	∞	1	2	2	1	3	1
2. LTE-Lite-20	∞	∞	2	3	∞	1	2	2	1	3	1
3. CPU	2	2	∞	1	2	∞	∞	∞	∞	∞	∞
4. Clock-Frequency	3	3	1	∞	3	∞	∞	∞	∞	∞	∞
5. Computer-System	∞	∞	2	3	∞	1	2	2	1	3	1
6. ST-3141	1	1	∞	∞	1	∞	1	1	∞	2	∞
7. Seagate	2	2	∞	∞	2	1	∞	2	1	3	∞
8. Access-Time	2	2	∞	∞	2	1	2	∞	1	∞	∞
9. Hard-Disk-Drive	1	1	∞	∞	1	∞	1	1	∞	2	∞
10. Storage-Space	3	3	∞	∞	3	2	3	∞	2	∞	∞
11. System-Software	1	1	∞	∞	1	∞	∞	∞	∞	∞	∞

Table 1. Sample Conceptual Distance Matrix

2 Ontological Engineering and Functional Anaphora

Metrical criteria incorporating path connectivity patterns in network-based knowledge bases have often been criticized for lacking generality and introducing *ad hoc* criteria likely to be invalidated when applied to different domain knowledge bases (DKB). The crucial point about the presumed unreliability of path-length criteria addresses the problem of how the topology of such a network can be tailored “canonically” such that formal distance measures uniformly relate to intuitively plausible conceptual proximity judgments. Though we have no formal solution for this correspondence problem, we try to eliminate structural idiosyncrasies by postulating two *ontology engineering (OE) principles* (cf. also Simmons (1992) and Mars (1994)):

1. **Clustering into Basic Categories.** Specifications of the upper level of some domain ontology (e.g., information technology (IT)) should be based

on a stable set of abstract, yet domain-oriented *ontological categories* inducing an *almost complete* partition on the entities of the domain at a *comparable* level of generality (e.g., hardware, software, companies in the IT world). Each specification of such a basic category and its taxonomic descendents constitutes the common ground for what Hayes (1985) calls *clusters* and Guha & Lenat (1990) refer to as *micro theories*, i.e., self-contained descriptions of conceptually related proposition sets about a reasonable portion of the commonsense world *within* a single knowledge base partition (subtheory).
2. **Balanced Deepening.** Specifications at lower levels of that ontology, which deal with concrete entities (e.g., notebooks, laser printers, hard disk drives in the IT world), must be carefully balanced, i.e., the extraction of attributes for any particular category should proceed at a uniform degree of detail at each decomposition level. The ultimate goal is that any subtheory have the *same* level of representational granularity, although these granularities may differ among various subtheories (associated with different basic categories).

Given an ontologically well-engineered DKB, the functional anaphora resolution problem, finally, has to be projected from the knowledge to the symbol layer of representations. By this, we mean the abstract implementation of knowledge representation structures in terms of concept graphs and their emerging path connectivity patterns. At this level, we draw on early experiments from cognitive psychologists such as Rips et al. (1973) and more recent research on similarity metrics (Rada et al. 1991) and spreading-activation-based inferencing, e.g., by Charniak (1986). These studies have in common that the definition of proximity in semantic networks in terms of the traversal of typed edges (e.g., only via generalization or via role links) and the corresponding counting of nodes that are passed on that traversal are methodologically valid for computing semantically plausible connections between concepts.[2]

The OE principles mentioned above are supplemented by the following linguistic regularities which hold for functional anaphora:

1. **Adherence to a Focused Context.** Valid antecedents of functionally anaphoric expressions mostly occur *within subworld boundaries* (i.e., they remain within a single knowledge base cluster, micro theory, etc.). Given the OE constraints (in particular, the one requiring each subworld to be characterized by the same degree of conceptual density), path length criteria make sense for estimating the conceptual proximity.
2. **Limited Path Length Inference.** Valid pairs of possible antecedents and functionally anaphoric expressions denote concepts in the DKB whose conceptual relations (role chains) are constructed on the basis of rather *restricted path length* conditions (in our experiments, no valid chain ever exceeded unit length 5). This corresponds to the implicit requirement that these role chains be efficiently computable.

[2] An alternative to simple node counting for the computation of semantic similarity within generalization hierarchies, which is based on a probabilistic measure of information content, has recently been proposed by Resnik (1995).

3 Functional Centering Principles

Conceptual criteria are of tremendous importance, but they are not sufficient for the proper resolution of functional anaphora. Additional criteria have to be supplied in the case of equal role length for alternative antecedents. We therefore incorporate into our model various functional criteria in terms of topic/comment patterns which originate from (dependency) structure analyses of the underlying utterances. The framework for this type of information is provided by the well-known centering model (Grosz et al. 1995). Accordingly, we distinguish each utterance's backward-looking center ($C_b(U_n)$) and its forward-looking centers ($C_f(U_n)$). The ranking imposed on the elements of the C_f reflects the assumption that the most highly ranked element of $C_f(U_n)$ is the most preferred antecedent of an anaphoric expression in the utterance U_{n+1}, while the remaining elements are (partially) ordered according to decreasing preference for establishing referential links.

The main difference between the original centering approach and our proposal concerns the criteria for ranking the forward-looking centers. While Grosz et al. assume (for the English language) that *grammatical* roles are the major determinant for the ranking on the C_f, we claim that for German – a language with relatively free word order – it is the *functional* information structure of the sentence in terms of topic/comment patterns. In this framework, the *topic* (*theme*) denotes the given information, while the *comment* (*rheme*) denotes the new information (for surveys, cf. Daneš (1974) and Dahl (1974)). This distinction can easily be rephrased in terms of the centering model. The *theme* then corresponds to the $C_b(U_n)$, the most highly ranked element of $C_f(U_{n-1})$ which occurs in U_n. The theme/rheme layers in U_n are determined by the $C_f(U_{n-1})$: elements of U_n which are contained in $C_f(U_{n-1})$ (*context-bound* discourse elements) are less rhematic than elements of U_n which are not contained in $C_f(U_{n-1})$ (*unbound* elements). The distinction between context-bound and unbound elements is important for the ranking on the C_f, since bound elements are generally ranked higher than any other non-anaphoric elements.

context-bound element(s) $\gtrdot_{TC_{base}}$ unbound element(s)
(pro)nominal anaphora $\gtrdot_{TC_{boundtype}}$ antecedent of functional anaphora $\gtrdot_{TC_{boundtype}}$ functionally anaphoric expression
nominal head$_1$ $>_{prec}$ nominal head$_2$ $>_{prec}$ ... $>_{prec}$ nominal head$_n$

Table 2. Functional Ranking on C_f Based on Topic/Comment Patterns

The rules for the ranking on the C_f are summarized in Table 2. They are organized at three layers. At the top level, $\gtrdot_{TC_{base}}$ denotes the basic relation for the overall ranking of topic/comment *(TC)* patterns. The second relation in Table 2, $\gtrdot_{TC_{boundtype}}$, denotes preference relations exclusively dealing with multiple occurrences of *bound* elements in the preceding utterance. The bottom level of Table 2 is constituted by $\gtrdot_{prec}$, which covers the preference order for multiple occurrences of the *same* type of *any* topic/comment pattern, e.g., the occurrence of two anaphora or two unbound elements (all heads in a sentence are ordered by linear precedence relative to their text position). The proposed ranking, though developed and tested for German, *prima facie* not only seems to account for other free word order languages as well but also extends to fixed word order languages like English, where grammatical roles and information structure, unless marked, coincide.

Given these basic relations, we may define the composite relation $\succ_{TC}$ (cf. Table 3). It summarizes the criteria for ordering the items on the forward-looking centers C_f (x and y denote lexical heads).

$\succ_{TC}$:= { (x, y) |
if x and y both represent the same type of TC patterns
then the relation $\succ_{prec}$ applies to x and y
else if x and y both represent different forms of bound elements
then the relation $\succ_{TC_{boundtype}}$ applies to x and y
else the relation $\succ_{TC_{base}}$ applies to x and y }

Table 3. Global Topic/Comment Relation

Table 4 illustrates the application of these centering criteria to the sentences (1)–(5) from Section 1. It not only contains the backward- and forward-looking centers of the corresponding utterances (each tuple separated by colons denotes a pair of a concept identifier and its associated lexical item), but also incorporates the transition types between two adjacent utterance pairs (as defined by Walker et al. 1994).

(1)	**Cb:** LTE-LITE-25: *LTE-Lite/25* **Cf:** [LTE-LITE-25: *LTE-Lite/25*, LTE-LITE-20: *LTE-Lite/20*]	CONTINUE
(2)	**Cb:** LTE-LITE-25: – **Cf:** [LTE-LITE-25: –, CPU: *Prozessor*, CLOCK-FREQUENCY: *Taktfrequenz*, CLOCK-MHZ-PAIR: *25 MHz*]	CONTINUE
(3)	**Cb:** LTE-LITE-25: *Rechner* **Cf:** [LTE-LITE-25: *Rechner*, SEAGATE-ST-3141: *ST-3141*, SEAGATE: *Seagate*]	CONTINUE
(4)	**Cb:** SEAGATE-ST-3141: – **Cf:** [SEAGATE-ST-3141: –, ACCESS-TIME: *Zugriffszeit*, TIME-MS-PAIR: *25 ms*]	SMOOTH-SHIFT
(5)	**Cb:** SEAGATE-ST-3141: *Laufwerk* **Cf:** [SEAGATE-ST-3141: *Laufwerk*, LTE-LITE-25: *Rechner*, STORAGE-SPACE: *Platz*, SYSTEM-SOFTWARE: *Windows-Programme*]	CONTINUE

Table 4. C_b/C_f Data for Sentences (1)–(5)

4 Grammatical Predicates for Functional Anaphora

We here build on the *ParseTalk* model, a fully lexicalized grammar theory which employs default inheritance for lexical hierarchies (Hahn et al. 1994). The grammar formalism is based on dependency relations between lexical heads and modifiers at the sentence level. The dependency specifications[3] allow a tight integration of linguistic knowledge (grammar) and conceptual knowledge (domain model), thus making powerful terminological reasoning facilities directly available for the parsing process. Accordingly, syntactic analysis and semantic interpretation are closely coupled.

The resolution of functional anaphors is based on two criteria, a structural and a conceptual one. The structural condition is embodied in the predicate *isPotentialFuncAnaAntecedent* (cf. Table 5). The relation of functional anaphora between two lexical items is restricted to pairs of nouns. The func-

$$\boxed{\begin{array}{l} \textsf{isPotentialFuncAnaAntecedent}\ (x, y, n) :\Leftrightarrow \\ \quad x\ isa_C{}^*\ \textsf{Noun} \wedge y\ isa_C{}^*\ \textsf{Noun} \\ \quad \wedge\ \exists\ z{:}\ (y\ \textsf{head}\ z \wedge z\ isa_C{}^*\ \textsf{DetDefinite}) \\ \quad \wedge\ y \in U_n \wedge x \in C_f(U_{n-1}) \end{array}}$$

Table 5. Grammar Predicate for a Potential Antecedent of a Functional Anaphor

tionally anaphoric expression which occurs in the n-th utterance is restricted to a definite NP, the antecedent must be one of the forward-looking centers of the preceding utterance. The function *ProximityScore* (cf. Table 6) captures the

$$\boxed{\begin{array}{l} \textsf{ProximityScore}\ (\text{from-concept, to-concept}) \\ := \begin{cases} n \in \mathbb{N} \text{ if } \exists\ x_0, \ldots, x_n \in \mathcal{F}{:}\ \exists\ r_0, \ldots, r_{n-1} \in \mathcal{R}{:} \\ \qquad x_0 = \text{from-concept} \wedge x_n = \text{to-concept} \\ \qquad \wedge\ \forall\ i \in [0, n\text{-}1]{:}\ (x_i, r_i, x_{i+1}) \in permit \\ \infty \text{ else} \end{cases} \end{array}}$$

Table 6. Conceptual Distance Function

[3] We assume the following conventions to hold: $\mathcal{C}$ = {Word, Nominal, Noun, DetDefinite,...} denotes the set of word classes, and $isa_{\mathcal{C}}$ = {(Nominal, Word), (Noun, Nominal), (DetDefinite, Nominal),...} $\subset \mathcal{C} \times \mathcal{C}$ denotes the subclass relation which yields a hierarchical ordering among these classes. The concept hierarchy consists of a set of concept names $\mathcal{F}$ = {COMPUTER-SYSTEM, NOTEBOOK, ACCESS-TIME, TIME-MS-PAIR,...} (cf. Fig. 1) and a subclass relation $isa_{\mathcal{F}}$ = {(NOTEBOOK, COMPUTER-SYSTEM), (ACCESS-TIME, TIME-MS-PAIR),...} $\subset \mathcal{F} \times \mathcal{F}$. The set of role names $\mathcal{R}$ = {*has-part, has-hd-drive, has-property, access-time,...*} contains the labels of admitted conceptual roles. These role names are also ordered in terms of a conceptual hierarchy, viz. $isa_{\mathcal{R}}$ = {*(has-hd-drive, has-part), (access-time, has-property),...*} $\subset \mathcal{R} \times \mathcal{R}$. The relation *permit* $\subset \mathcal{F} \times \mathcal{R} \times \mathcal{F}$ characterizes the range of possible conceptual roles among concepts, e.g., (HARD-DISK-DRIVE, *access-time*, ACCESS-TIME) $\in$ *permit*. Furthermore, object.c refers to the concept c denoted by object, while head denotes a structural relation within dependency trees, viz. x being the head of y.

basic conceptual condition in terms of the role-related distance between two concepts. More specifically, there must be a connected path linking the two concepts under consideration via a chain of conceptual roles.

Finally, the predicate *PreferredConceptualBridge* (cf. Table 7) combines both criteria. A lexical item x is determined as the proper antecedent of a functionally anaphoric expression y if it is a potential antecedent and if there exists no alternative antecedent z whose *ProximityScore* either is below that of x or, if their *ProximityScore* is equal, whose strength of preference under the *TC* relation is higher than that of x.

$$
\begin{array}{l}
\textsf{PreferredConceptualBridge}\ (\mathrm{x, y, n}) :\Leftrightarrow \\
\textsf{isPotentialFuncAnaAntecedent}\ (\mathrm{x, y, n}) \\
\wedge\ \neg\exists\ \mathrm{z} : \textsf{isPotentialFuncAnaAntecedent}\ (\mathrm{z, y, n}) \\
\quad \wedge\ (\ \textsf{ProximityScore}(\mathrm{z.c, y.c}) < \textsf{ProximityScore}(\mathrm{x.c, y.c}) \\
\qquad \vee\ (\ \textsf{ProximityScore}(\mathrm{z.c, y.c}) = \textsf{ProximityScore}(\mathrm{x.c, y.c}) \wedge \mathrm{z} \succ_{TC} \mathrm{x}\ )\ )
\end{array}
$$

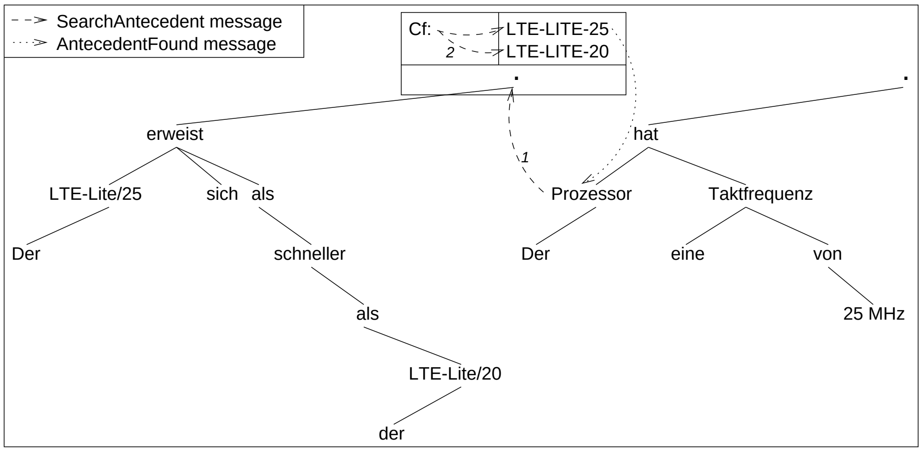
Table 7. Preferred Conceptual Bridge for Functional Anaphora

5 The Resolution of Functional Anaphora

The actor computation model (Agha & Hewitt 1987) provides the background for the procedural interpretation of lexicalized grammar specifications in terms of so-called word actors (Hahn et al. 1994). Word actors communicate via asynchronous message passing; an actor can only send messages to other actors it knows about, its so-called aquaintances. The arrival of a message at an actor triggers the execution of a method that is composed of grammatical predicates, as those given in the previous section.

The resolution of functional anaphora depends on the results of the resolution of nominal anaphora and on the termination of the semantic interpretation of the current sentence. A *SearchFuncAnaAntecedent* message will only be triggered at the occurrence of the definite noun phrase *NP* when *NP* is not a nominal anaphor and *NP* is not already connected via a *POF*-type relation (e.g., *property-of, physical-part-of*)[4].

[4] Associated with the set $\mathcal{R}$ is the set of inverse roles $\mathcal{R}^{-1}$. This distinction becomes crucial for already established relations like *has-property* (subsuming *access-time*, etc.) or *has-physical-part* (subsuming *has-hd-drive*, etc.) insofar as they do not block the initialization of the resolution procedure for functional anaphora (e.g., HARD-DISK-DRIVE – *access-time* – ACCESS-TIME), whereas the existence of their inverses, we here refer to as *POF-type relations*, viz. *property-of* (subsuming *access-time-of*, etc.) and *physical-part-of* (subsuming *hd-drive-of*, etc.), does (e.g., HARD-DISK-DRIVE – *hd-drive-of* – LTE-LITE-25). This is simply due to the fact that the semantic interpretation of a phrase like *"the access time of the hard disk drive"*, as opposed to that of its elliptified counterpart *"the access time"* in sentence (4), where the genitive object is zeroed, already leads to the creation of the *POF*-type relation the resolution mechanism for functional anaphora is supposed to determine. This blocking condition has been proposed and experimentally validated by Katja Markert.



Der LTE-Lite/25 erweist sich als schneller als der LTE-Lite/20. Der Prozessor hat eine Taktfrequenz von 25 MHz.
The LTE-Lite/25 runs faster than the LTE-Lite/20. The processor comes with a clock frequency of 25 MHz.

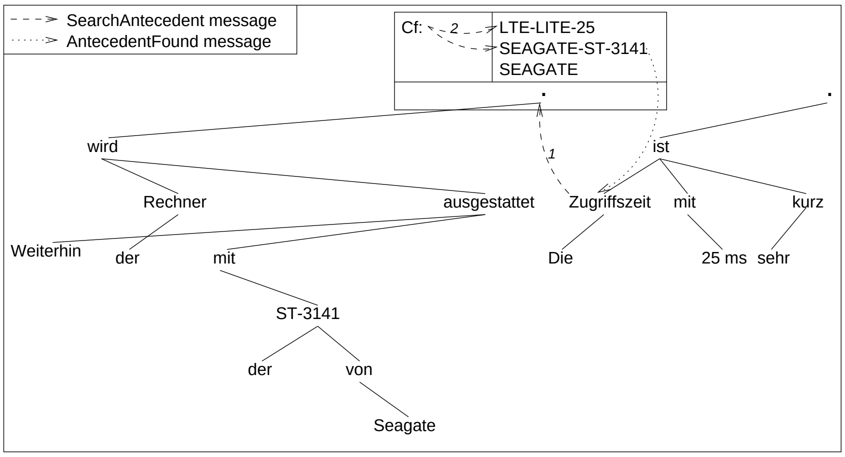
Fig. 2. Sample Parse for the Resolution of Functional Anaphora (I)

The message passing protocol for establishing cohesive links based on the recognition of *functional anaphora* consists of two phases:

1. In *phase 1*, the message is forwarded from its initiator to the sentence delimiter of the *preceding sentence*, where its state is set to *phase 2*.
2. In *phase 2*, the sentence delimiter's acquaintance C_f is tested for the predicate *PreferredConceptualBridge*.

Note that only nouns and pronouns are capable of responding to the *SearchFuncAnaAntecedent* message and of being tested as to whether they fulfil the required criteria for functional anaphora. If the grammar predicate *PreferredConceptualBridge* succeeds, the determined antecedent sends a *FuncAnaAntecedentFound* message to the initiator of the *SearchFuncAnaAntecedent* message. Upon receipt of the *AntecedentFound* message, the discourse referent of the functionally anaphoric expression is conceptually related to the antecedent's referent via the most specific (common) *POF*-type relation, thus preserving local coherence at the conceptual level of text propositions.

We now turn to the discussion of two examples for the resolution of functional anaphora. They feature the contribution of conceptual and functional criteria under varying conditions — in the first parse (Fig. 2), same path lengths are resolved by functional centering constraints, in the second parse (Fig. 3), different path lengths are overridden by functional centering constraints. In Fig. 2 we illustrate the protocol for anaphora resolution by referring to the already introduced text fragment (1)–(2), which is repeated at the bottom line of Fig. 2. Sentence (2) contains the definite NP *der Processor (the processor)*, which conceptually refers to CPU. Since, at the conceptual level, CPU does not subsume



Weiterhin wird der Rechner mit der ST-3141 von Seagate ausgestattet. Die Zugriffszeit ist mit 25 ms sehr kurz.

Furthermore - is - the computer - with the ST-3141 from Seagate - equipped. The access time - is - amounting to 25 ms - quite short.

Fig. 3. Sample Parse for the Resolution of Functional Anaphora (II)

any lexical item in the preceding text (cf. Fig. 1), the nominal anaphora test fails. The conceptual correlate of *der Prozessor* has also not been integrated in terms of a *POF*-type relation into the conceptual representation of the sentence as a result of the semantic interpretation. Consequently, a *SearchFuncAnaAntecedent* message is created by the word actor for *Prozessor*. That message is sent directly to the sentence delimiter of the previous sentence (phase 1), where the predicate *PreferredConceptualBridge* is evaluated for the acquaintance C_f (phase 2). The concepts, LTE-LITE-25 and LTE-LITE-20, are examined in the order given by the C_f, for unit length 1 without success, while for unit length 2, LTE-LITE-25 immediately succeeds. The search process terminates, since no shorter path can be found in the remainder of the C_f. Since LTE-LITE-25 has been tested successfully, a *FuncAnaAntecedentFound* message is sent to the initiator of the *SearchAntecedent* message. An appropriate update links the corresponding instances, viz. LTE-LITE-25 and CPU, via the role *physical-part-of* (i.e., the most specific common role for *central-unit-of* and *cpu-of* in the conceptual role hierarchy). Thus, local coherence is established at the conceptual level of the text knowledge base.

Consider, on the other hand, Fig. 3 which contains a parse for the sentences (3)–(4). Sentence (4) contains the definite NP *die Zugriffszeit (the access time)*. As the triggering conditions for a *SearchFuncAnaAntecedent* message are met in the same way as in the first example, that message is also sent directly to the sentence delimiter of the previous sentence (phase 1), where the predicate *PreferredConceptualBridge* is evaluated for the acquaintance C_f (phase 2). The concepts are examined in the order given by the C_f, first LTE-LITE-25 (unit length 2), then SEAGATE-ST-3141 (unit length 1). Since no path shorter than that with unit length 1 can exist, the test immediately terminates. Even if another item in the centering list following SEAGATE-ST-3141 would have this shortest possible length, it would not be considered due to the functional preference given to SEAGATE-ST-3141 in the C_f. Since SEAGATE-ST-3141 has been tested successfully, a *FuncAnaAntecedentFound* message is sent to the initiator of the *SearchAntecedent* message. An appropriate update links the corresponding instances via the role *access-time-of*.

6 Comparison with Related Approaches

As far as the treatment of functional anaphora is concerned, none of the standard grammar theories (e.g., HPSG, LFG, GB, CG, TAG) covers this issue. This is not surprising at all, as their advocates pay almost no attention to the text level of linguistic description (with the exception of several forms of pronominal anaphora) and also do not take conceptual criteria as part of grammatical descriptions seriously into account. More specifically, they lack any systematic connection to well-developed reasoning systems accounting for conceptual knowledge of the underlying domain. This latter argument also holds for the framework of DRT, although Wada (1994) deals with restricted forms of functional anaphora in the DRT context.

Perhaps, the earliest constructive approach to deal with functional anaphora in a natural language understanding system is due to Grosz (1977). Based on the notion of focus spaces she allows for the resolution of functional anaphora by means of implicit focusing in a dialog setting. Technically, the focus constraint she proposes is based on the partitioning of a semantic network into spaces and their hierarchical organization in terms of so-called vistas. Some use is made of reachability constraints for the items in the focus and constraints are set up for the traversal of typed links. However, neither are explicit formal conditions stated how focus partitionings are constructed in a general way and what levels of the focus have to be searched (or excluded from the search) for the determination of referents, nor is the work particularly sensitive to the influences resulting from the linguistic structure of discourse. As another example of the use of focus mechanisms for dealing with functional anaphora, consider the PUNDIT system (Palmer et al. 1986), which provides an informal solution for a particular domain based on a variety of very specialized, highly interactive rules. We consider our proposal superior, since it provides a more general, domain-independent treatment (cf. our proposal in terms of conceptual proximity scores, Table 6) at the level of a formalized text grammar (cf. the definition of the topic/comment relations in Table 3 and the combination of both criteria by the "bridge" predicate in Table 7). The approach reported in this paper also extends our own previous work on functional anaphora (Hahn 1989) by the incorporation of a more general proximity metric and an elaborated model of functional preferences on C_f elements which constrains the set of possible antecedents according to topic/comment patterns.

7 Conclusion

In this paper, we have outlined a model for the resolution of functional anaphora. It considers conceptual criteria to be of primary importance and provides a proximity measure in order to assess various possible antecedents for consideration of proper bridges (Clark 1975) to anaphoric expressions. In addition, functional constraints based on topic/comment patterns contribute further restrictions on the antecedents of a functional anaphor.

The module which handles pronominal and nominal (Strube & Hahn 1995) as well as functional anaphora has been implemented in Smalltalk as part of a comprehensive text parser for German. Besides the information technology domain, experiments with this parser have also been successfully run on medical domain texts, thus indicating that the grammar predicates we developed are not bound to a particular domain (knowledge base). The current lexicon contains a hierarchy of approximately 100 word class specifications with nearly 3.000 lexical entries and corresponding concept descriptions from the LOOM knowledge representation system (MacGregor & Bates 1987) — 900 and 500 concept/role specifications for the information technology and medicine domain, respectively.

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