Abducing Definite Descriptions Links

Sérgio A. A. Freitas[1] **, José Gabriel P. Lopes**[2] **, Crediné S. Menezes**[3]

[1]Departamento de Engenharia Elétrica, Universidade Federal do Espírito Santo,
Av. Fernando Ferrari, sn - 29600-090 - Vitória - ES, Brasil

[2]Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa,
2825 - Monte da Caparica, Portugal

[3]Departamento de Informática, Universidade Federal do Espírito Santo,
Av. Fernando Ferrari, sn - 29600-090 - Vitória - ES, Brasil

sergio@inf.ufes.br,gpl@di.fct.unl.pt,credine@inf.ufes.br

Abstract. *In this article we propose a methodology to solve functional definite noun anaphora. Our approach uses an abductive scheme both to propose an antecedent and to find a possible relation between the anaphoric entity and its antecedent. The determination of the antecedent and the anaphoric relation uses among other informations: the gender, the number, the entity ontology and the focus in order to establish a set of pragmatic rules. Those pragmatic rules are used by the abductive scheme to solve the functional anaphora.*

1. Introduction

The resolution of an anaphoric definite noun phrase involves reasoning about the entities introduced by the discourse being interpreted by relating them with previously introduced entities. Take the following example [Sidner, 1979, pg. 42]:

(1) a. Horace got the picnic supplies out of the car.
b. The beer was warn.
b'. He had forgotten the beer.

Even though it is not explicitly conveyed, it is necessary to infer that there is a membership relation between the beer introduced in sentence (1b) and the picnic supplies in sentence (1a) (bridging phenomena [Heim, 1982]). It is also necessary to find an explanation for the definite noun phrases: *the picnic supplies* and *the car*, in the context where sentence (1a) occurs (assuming that there is no previous discourse).

Previous approaches to anaphora resolution namely: Focus Theory [Sidner, 1979], Centering [Grosz et al., 1995], and Carter's proposal [Carter, 1987], do not treat these phenomena (or they just treat them quite partially):

1. they assume an unique possible relation between the antecedent and the anaphoric particle: the *coref* relation. And this relation is not enough to treat phenomena such as the bridging occurring in sentence (1b): although the *picnic supplies* is the antecedent for the definite noun phrase *the beer*, the relation between these two entities should be: the beer is a member of the picnic supplies set.

2. when they try to analyse phenomena similar to bridging, they do not take in account the context influence on the anaphora resolution. In example (1), not all picnic supplies have beer in it and an automatic system should not waste time trying to predict all parts of a conveyed entity. We prefer to explain the relation of the most recently conveyed noun phrase in the context previously obtained by interpretation of previous sentences and beer is just an *optional* element that must be contextually related to the picnic supplies.

This led us to develop a methodology to solve definite noun anaphora (such as the bridging phenomena) in which the resolution process requires abductive inference of both: (1) the antecedent of an anaphoric particle, and (2) a plausible relation between them. For this we also build a discourse structure in order to organize the possible antecedents for an anaphora according to its salience (cf. [de Freitas and Lopes, 1994a]).

Previously, Hobbs et al [Hobbs et al., 1993] treated interpretation as an abduction problem. As a consequence, they solve some cases of definite reference, as a simple proof of their existence in a knowledge base, they lack to treat anaphoric phenomena where it is both needed to find an antecedent and a relation between the antecedent and the anaphoric particle. In this paper we concentrate in similar cases, proposing a methodology that abductively obtains both an antecedent and a plausible relation.

This paper is structured as follows: in section 2 we explain how a definite noun phrase is interpreted by our methodology. In section 3 we elaborate the abductive mechanism used for solving some cases of definite noun anaphora. In section 4 a non trivial example is used for illustrating the methodology previously introduced. In section 5 we discuss the usage of abduction to solve anaphora and, finally, in section 6, some conclusions are drawn.

2. Interpreting Definite Noun Phrases

Let $D = s_1, s_2, ..., s_{i-1}, s_i, s_n$ be a discourse and $s_1, s_2, ..., s_n$ its constituent sentences. The interpretation of a sentence s_i and of its definite noun phrases is achieved in two steps:

First, at the sentence level, a sentence s_i is translated into a DRS [Kamp and Reyle, 1993]. Indefinite noun phrases introduce discourse referents and adequate conditions on those referents and verbs introduce discourse conditions[1]. Definite noun phrases and null determiner noun phrases introduce discourse referents and the special condition **anchor(Atribs:Ref)**, which means that the referent *Ref* introduced by the noun phrase, needs to be anchored in the context provided by previously interpreted discourse.

Each entity is represented by a referent, *Ref*, and its associated attributes, $Atribs$. Entity attributes are a set of semantic pairs $< F, A >$, where F is a feature chosen among the set of 38 feature types for nouns (color, function, relation, place, size, etc.) presented by the Naive Semantics [Dahlgren et al., 1989], and A is the feature value. The appropriate features of a referent are the features that are most likely to express the semantic

[1]In this paper, we do not consider the referents introduced by the tense interpretation: the eventuality and the time interval referents [Rodrigues and Lopes, 1994].

attributes of the corresponding entity. For example, the features for a door (place, material, size, color) are different from those of a dog (name, owner, sex, size, color).

The resulting representation $DRS^i_{sentence}$ of a sentence s_i is a tuple: $< Refs_i$, $Conds_i, Anchored_i >$, where $Refs_i$ are the discourse referents and $Conds_i$ are the discourse conditions. Take the representation for each sentence in the following text:

(2) a. John bought a dog.
b. The animal barks a lot.

which is represented as:

$$DRS^{2a}_{sentence} =< \{X, Y\}, \{john(A : X), dog(B : Y), buy(A : X, B : Y)\} >$$
$$DRS^{2b}_{sentence} =< \{Z\}, \{animal(C : Z), anchor(C : Z), bark\_a\_lot(C : Z)\} >$$

During the second step, at the pragmatic interpretation level, each sentence semantic representation, $DRS^i_{sentence}$, is interpreted in the context $DRS^{i-1}_{discourse}$ provided by the interpretation of the previous $i-1$ sentences. All conditions **anchor(Atribs:Ref)** of $DRS^i_{sentence}$ must be abductively proved in the knowledge base[2] $Kb^{i-1}_{discourse}$. That is, given k conditions, $anchor^j_i(Atribs^i_j : Ref^i_j), j = 1, 2, ..., k$, of sentence s_i, one must abductively prove these conditions.

$$Kb^{i-1}_{discourse} \cup Ab_{anchor} \models \bigcup_{j=1}^{k} anchor^j_i(Atribs^i_j : Ref^i_j) \tag{3}$$

where Ab_{anchor} is the set of abduced literals that are necessary for proving those conditions and the abductive proof of the union of anchors requires the proof of each of the anchors.

As it will be further elaborated the abductible predicates are: **part_of, member_of, coref**.

If a condition $anchor^j_i(Atribs^i_j : Ref^i_j)$ of $DRS^i_{sentence}$can not be abductively proved in the context $Kb^{i-1}_{discourse}$ this is because either: (1) there is no previous discourse referent *Ref* that can be used as an antecedent, or (2) there is no suitable relation that can be abducted between Ref^i_j and its antecedent. In both cases, the entity denoted by Ref^i_j is assumed to be new information (like the referents introduced by an indefinite noun phrase [Kamp and Reyle, 1993, Heim, 1982]) and is simply accommodated in the discourse representation. This is represented by the following logic rules:

$$\begin{array}{ll} anchor(Atrib : Ref) & \leftarrow definite(Atrib : Ref). \\ anchor(Atrib : Ref) & \leftarrow indefinite(Atrib : Ref). \\ indefinite(Atrib : Ref) & \leftarrow not\, definite(Atrib : Ref). \end{array} \tag{4}$$

An entity, represented by referent *Ref*, having semantic attributes *Atrib*, is anchored in a discourse context if: (1) it can be proved to be a definite entity in this discourse, or (2) it is an indefinite entity in this discourse. An entity is indefinite if it can not be proved that it is definite. *not* is the default negation in Logic Programming.

[2]The set of all conditions of a discourse DRS is represented in a knowledge base Kb.

After the interpretation of $DRS^{i}_{sentence}$ in $Kb^{i-1}_{discourse}$ the resulting discourse representation will be:

$$DRS^{i}_{discourse} = < Refs_i, Conds_i, Anchored_i > \tag{5}$$

where $Refs = Refs(DRS^{i-1}_{discourse}) \cup Ref(DRS^{i}_{sentence})$, $Conds = Conds(DRS^{i-1}_{disc}) \cup Conds(DRS^{i}_{sentence}) \cup Ab_{anchor}$, and $Anchored$ is the list of referents whose anchor conditions were abductively proved to be definite in $Kb^{i-1}_{discourse}$.

An example is the interpretation of $DRS^{2b}_{sentence}$ in the context produced by $DRS^{2a}_{discourse} = DRS^{2a}_{sentence}$:

$$\begin{aligned} DRS^{2b}_{discourse} = \ & < \{X, Y, Z\}, \\ & \{john(A:X), dog(B:Y), buy(X,Y), animal(C:Z), \\ & bark\_a\_lot(Z), \mathbf{coref(Z, Y)}\}, \\ & \{Z\} > \end{aligned} \tag{6}$$

The abduced relation $\mathbf{coref(Z, Y)}$ is a plausible relation that could be assumed between the entity introduced by the definite noun phrase *the animal* and the previous introduced entity *dog*.

3. The abductive mechanism

Abduction [Kakas et al., 1992] is a form of reasoning in which given a set of sentences T (a theory presentation), a sentence G (an observation) and a set of sentences I (Integrity Constraints) the abductive task can be characterized as the problem of finding a set of sentences Ab (abductive explanation for G) such that:

1. $T \cup Ab \models G$,
2. $T \cup Ab$ satisfies I or $T \cup Ab \cup I$ is coherent

These rules characterize the Kowalsky's abductive scheme [Kakas et al., 1992] [Damásio et al., 1994], which is represented as the triple $< H, Ab, I >$, where H is a logic program such: $H \leftarrow L_1, ..., L_n$,where each L_i is either an atom A_i or its default negation $\sim A_i$, and H is an atom.

Abduction can be computed in a logic program H by extending the SLD and SLDNF resolution in such case that instead of failing in a proof when a selected subgoal fails to unify with the head of any rule, the subgoal can be viewed as a hypothesis. This is similar to viewing abducibles Ab as askable conditions which are treated as qualifications to answers to queries. As the set of abducibles are limited, the exponential problem presented by abduction inference can be reduced.

Kowalsky also proposes that a set of rules called Integrity Constraints I should be used to guarantee the coherence of the resulting knowledge base ($H \cup Ab \cup I$). The set of Integrity Constraints are user defined.

3.1. The Logic Program

In our approach, the logic program is the set of the conditions represented in $Kb^{i-1}_{discourse}$, the world knowledge about the entities and their semantic attributes, and the pragmatic rules that characterize the abductive mechanism (that will be showed in the following sections). $Kb^{i-1}_{discourse}$ represents the context in which the anchor conditions present at $DRS^{i}_{sentence}$ must be abductively proved.

3.2. The Set of Abductibles

We take as abducibles the following items:

member-of(Ref,Ref2), the entity denoted by referent *Ref* is a member of the entities denoted by *Ref2* if their attributes, $Atribs$ and $Atribs2$, respectively, are such that:
$features(Atribs) = features(Atribs2)$,
That is, the set of feature types for *Ref* is identical to the set of features types for *Ref2*, although their feature-values need not to be the same.
For example:

(7) a. The bus driver opened the doors.
b. The passengers used the back door to go out.
c. (and) the driver used the front door.

Here, both back door and front door can be members of a set of doors although they don't have the same value for the feature place.

coref(Ref,Ref2), the entity denoted by referent *Ref* corefers the entity denoted by *Ref2* if their associated semantic set, $Atribs$ and $Atribs2$, respectively, are such that:

1. $features(Atribs) \supseteq features(Atribs2)$,
2. $\forall F_1, F_2 (F_1 \in features(Atribs) \& F_2 \in features(Atribs2) \& F_1 = F_2 \& \exists A_1, A_2 \mid A_1 = value(F_1) \& A_2 = value(F_2) \& A_1 = A_2)$.

For example:

(8) a. John bought a BMW.
b. The car arrived yesterday.

Both the car and BMW have have the same features, for example, *function.* Also the features' values are the same.

part-of(Ref,Ref2), the entity denoted by referent *Ref* is part of the entity denoted by *Ref2* as in:

(9) a. John bought a car.
b. The engine crashed yesterday.

Note that there is no need the engine's features to be directed related to the car's features. The classical solution will claim that there is a semantic network linking them. We claim that examples like (1) do not have a previous representation, instead there are clues the hearer uses to establish a link: the focus structure[de Freitas and Lopes, 1994b], the lexical information [de Freitas and Lopes, 1996], the usage of a definite article and a taxonomy of features.

3.3. The Integrity Constraints

The set of the integrity constraints used to test if $Kb_{discourse}$remains consistent after the abductive interpretation of $DRS^{i}_{sentence}$ in the context provided by $DRS^{i-1}_{discourse}$ are:

$$\begin{aligned}&\Leftarrow \text{member-of}(Ref, Ref2), \sim \text{member-of}(Ref, Ref2).\\ &\Leftarrow \text{coref}(Ref, Ref2), \sim \text{coref}(Ref, Ref2).\\ &\Leftarrow \text{part-of}(Ref, Ref2), \sim \text{part-of}(Ref, Ref2).\end{aligned} \tag{10}$$

It is not possible to state that a relation $\mathbb{R}$ (member-of, is-a, coref or part-of) between *Ref* and *Ref2* in $Kb_{discourse}$ and its negation hold at the same time for the same knowledge base. Also these relations can not be reflexive:

$$\begin{aligned}&\Leftarrow \text{member-of}(Ref, Ref2), \text{member-of}(Ref2, Ref).\\ &\Leftarrow \text{part-of}(Ref, Ref2), \text{part-of}(Ref2, Ref).\end{aligned} \tag{11}$$

3.4. The mechanism

For the abductive mechanism an entity is anaphoric if it can be proved as definite in the previous discourse (as showed in (4)):

$$anchor(\mathcal{A} : Ref) \Longleftarrow definite(\mathcal{B} : Ref). \tag{12}$$

Where *Ref* denotes a referent with semantic attributes $\mathcal{A}$. This is done by finding a previous entity *Ref2* with semantic attributes $\mathcal{B}$, and by testing their attribute sets: $\mathcal{A}$ and $\mathcal{B}$ (features and values). Depending on the kind of relation Ψ (set identity, subset, superset) that can be coherently established between the attribute sets, a relation R between *Ref* and *Ref2* is abducted to complete such proof. This is summarized by the following rule:

$$\begin{aligned}definite(\mathcal{A} : Ref) \Longleftarrow\ & exists(\mathcal{B} : Ref2),\\ & \mathcal{A}\Psi\mathcal{B},\\ & \mathcal{R}(\mathbf{Ref}, \mathbf{Ref2}).\end{aligned} \tag{13}$$

The following table describes the relations that could be abducted depending on how referents, *Ref* and *Ref2,* and their semantic attributes, $\mathcal{A}$ and $\mathcal{B}$, can be related:

	$value(A)$ valid-in $value(B)$	$value(A)$ not valid-in $value(B)$
$features(A) = features(B)$	member-of(*Ref,Ref2*) coref(*Ref,Ref2*)	member-of(*Ref,Ref2*)
$features(A) \subset features(B)$	part-of(*Ref, Ref2*)	—
$features(A) \supset features(B)$	coref(*Ref, Ref2*)	part-of(*Ref, Ref2*)

Tabela 1: Abductive Relations

Some notes about the above table:

1. $value(\mathcal{A})$ is valid in $value(\mathcal{B})$ iff for all features $F \in features(\mathcal{A}) \wedge F \in features(\mathcal{B})$, $value(\mathcal{A}) \in VV(\mathcal{B})$, where VV is the set of all valid values of a features F in $\mathcal{B}$. For example, if we try to relate a back door with a set of doors, the feature "place", although not instantiated, have valid features: back, front, middle, so the feature for the individual door, is still a valid one in the set of doors.
2. There are entries in the above table that have more that one possible abductible relation. This occurs because in some situations, it is not possible to predict which is the preferred relation, as in the example (1), where the entity *beer* could also be a $part\,of$ *the picnic supplies* (in this context). One could argue that this is not a valid relation: a part of relation must be established between entities that are constituents of each other. This is valid only if the entities and possible relations are previously represented at the world knowledge, what is not our case.
3. The part-of relation is very frequent. It expresses the idea in conversation that when we are sure that an object is related with another one, but we can not preciously state the relation, we assume that one is part of the other.

4. An example

Now we show how this works with the following example.

(14) a. A bus arrived at 5 pm.
b. The driver opened the doors.
c. The passengers used the back door to go out.

Lets consider the following representation for sentences (14a) and (14b):

$$DRS^{14a}_{sentence} = DRS^{14a}_{discourse} \boxed{\begin{array}{l} \text{X} \\ \text{bus(A:X)} \\ \text{arrive(A:X)} \end{array}}$$

$$DRS^{14b}_{sentence} = \boxed{\begin{array}{l} \text{Y, Z} \\ \text{driver(B:Y), anchor(B:Y)} \\ \text{doors(C:Z), anchor(C:Z)} \\ \text{open(B:Y,C:Z)} \end{array}}$$

In sentence (14b) the sentence interpretation of the definite noun phrases *the driver* and *the doors* introduce two anchor conditions and their respective semantic attributes $\mathcal{B}$ and $\mathcal{C}$. Now we must interpret $DRS^{14b}_{sentence}$ in the context provided by $DRS^{14a}_{discourse}$. This interpretation involves joining the referents of both DRSs, joining the common conditions of both DRSs, and finally accommodating each entity represented by the anchor conditions of $DRS^{14b}_{sentence}$. Such accommodation involves the abductive proof that both driver and doors are already definite in the previous knowledge base $Kb^{14a}_{discourse}$provided by the set of conditions of $DRS^{14a}_{discourse}$ plus the pragmatic rules presented in section (3).

The only possible antecedent for both is *the bus* introduced by sentence (14a). The resulting comparison between the semantic set for *the bus* ($\mathcal{A}$) and $\mathcal{B}$ and $\mathcal{C}$, are:

- they don't have the same feature set, and

- the features that are valid for $\mathcal{B}$ and $\mathcal{C}$ are not valid for $\mathcal{A}$.

So, the possible relation that could be abducted between $\mathcal{A}$ and $\mathcal{B}$, and $\mathcal{A}$ and $\mathcal{C}$ are the $part\,of$ relation. The result is the following representation:

$$DRS^{14b}_{discourse} = \boxed{\begin{array}{l} \text{X, Y, Z} \\ \text{bus(X),arrive(A:X)} \\ \text{driver(B:Y),part-of(X,Y)} \\ \text{doors(C:Z),part-of(X,Z)} \\ \text{open(B:Y,C:Z)} \end{array}} \{Y, Z\}$$

where {Y,Z} represent the elements that have been anchored, and could be used for future revision.

The interpretation of the sentence (14c) will lead the following representation:

$$DRS^{14c}_{sentence} = \boxed{\begin{array}{l} \text{W, S} \\ \text{passengers(D:W), anchor(D:W)} \\ \text{back\_ door(E:S), anchor(E:S)} \\ \text{get\_ out\_ through(D:W,E:S)} \end{array}}$$

Now we must abductively prove that the entities *passengers* and *back door* are already defined in the previous discourse $DRS^{14b}_{discourse}$. The semantic attributes of the passengers can not be related to the semantic attributes of the previous introduced entities, so the part-of relation is abduced to prove that the passengers are already defined in the discourse.

The attribute set of the entity back door $\mathcal{E}$ has the same set of features of the previously introduced entity, the doors $\mathcal{C}$, and all value for $\mathcal{E}$'s features are valid in $\mathcal{C}$'s features, so the $member\,of$ relation is abduced. The resulting representation is:

$$DRS^{14c}_{discourse} = \boxed{\begin{array}{l} \text{X, Y, Z, S, W} \\ \text{bus(X),arrive(A:X)} \\ \text{driver(B:Y),part-of(X,Y)} \\ \text{doors(C:Z),part-of(X,Z)} \\ \text{open(Y,Z)} \\ \text{passengers(D:W),part-of(X,Y)} \\ \text{back\_ door(E:S),member-of(S,Z)} \\ \text{get\_ out\_ through(D:W,E:S)} \end{array}} \{Y, Z, S, W\}$$

5. Using Abduction

Abduction was previously used as a tool to the natural language processing: temporal reasoning [Filho and de Freitas, 2003, Rodrigues, 1995] and discourse interpretation [Hobbs et al., 1993]. But why use it to solve anaphora?

We think that the answer is in Hobbs' et al article [Hobbs et al., 1993] where they propose an impressive integrated framework to solve some linguistic phenomena. Abduction is used to reason where there is incomplete information. Most of the human daily reasoning use incomplete information. If someone observes the wet grass, the fact that it rained yesterday can be used as an explanation to the observation. Hobbs states this explanation as the new information the speaker transmits to the hearer.

We mostly agree with him, but also have two "observations": (1) in the daily reasoning, the explanation is only required if there is a need to it "if someone look at the wet grass and there is no need to reasoning about that, he could simply concluded that *the grass is wet*" and (2) Hobbs' usage of weighted abduction led to another problem "how weights can be determined?".

Kowalsky's abductive scheme [Kakas et al., 1992] implemented at Damasio, Alferes and Pereira's framework [Alferes and Pereira, 2002, Damásio et al., 1994] do not have these problems: only the observations that need explanation can be achieved and there is no weights.

This led us to our basic proposal: if an anaphora is observed there must be an explanation, which can be stated as "find an entity already introduced and link between this entity to the anaphora".

To the readers that want a more theoretical discussion about abduction (as a concept introduced by Charles Peirce) look at Deutscher's paper [Deutscher, 2002] where he discusses the (mis)use of abduction in linguistics.

6. Conclusion

We have shown that the abductive approach we have proposed for the definite noun anaphora resolution is a powerful methodology. It takes advantage of abductive mechanism and both determines a previous antecedent and a suitable relation with the anaphor. In this paper we have concentrated on the relations (part-of, member-of, coref), because the antecedents are determined using a focus structure which is not presented in this paper. The methodology incorporates both the pronominal anaphora and the definite nominal anaphora in the same framework.

The identified relations between the anaphoric entity and its antecedent are important because they give a more powerful interpretation to the anaphoric problem, enabling during a revision process to revise both a wrong antecedent or its relation with the anaphoric entity. We think that this relation revision process could be incorporated in a process for identifying and correcting misunderstandings (at discourse level) like the one proposed by McRoy and Hirst [McRoy and Hirst, 1995].

Although the set of possible relation that we use is small, we think it is sufficient to cover a large range of text.

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