Resolving Discourse Deictic Anaphors in Tutorial Dialogues

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Abstract

Most of the anaphoric resolution algorithms developed so far focus on anaphors with NP antecedents, be it inter-sentential or intra-sentential. The main focus of this paper is to resolve various other types of anaphors such as discourse deictic anaphors found in computer-mediated tutorial dialogues on physics. We do this first through a corpus-based study of physics tutoring dialogues. Our approach is to examine the syntactic and semantic environments under which deictic anaphors can occur in the physics discourse and identify the relevant discourse cues, which in turn, are used to formulate a set of constraints and preferences inspired by Centering Theory (Grosz et al. 1995) and the theory of discourse structure (Grosz and Sidner 1986). We propose an algorithm to resolve discourse deictic anaphors in dialogues which is also capable of distinguishing deictic anaphors from individual and expletive anaphors.

1. Introduction

Recent years have seen the extensive use of corpora for exploring linguistic generalization and also for building different types of algorithms to solve various grammatical phenomena. Anaphoric resolution is one such phenomenon that has attracted various scholars from different perspectives. "The study of anaphora considerably broadens the scope of natural language metaphysics, and it also refines and verifies our provisional typology of abstract objects with another sort of data" (Asher1993:35). Anaphoric expressions have a relationship with an existing antecedent in the discourse. One type of anaphor is a pronoun. The pronoun refers to an object that has already been introduced into the discourse. The antecedents need not always be individual noun phrases. Other constructions such as verb phrases or sentences, and propositions or events present in the discourse can also be antecedents.

Most of the anaphoric resolution algorithms developed so far focus on anaphors with NP antecedents, be it inter-sentential or intra-sentential. The aims and objectives of this paper are to resolve various other types of anaphors found in computer-mediated tutorial dialogues on physics. We do this first via a corpus-based study of physics tutoring dialogues. We employ various linguistic techniques to collect all possible antecedent candidates and to identify the appropriate antecedent for a given anaphor in a Referring Expression (RE)[1]. This analysis has offered us new prospects for interpreting the different types of anaphoric relations that exist in the discourse.

Our main focus is on the discourse deictic anaphors or what Asher (1993) calls as `Abstract Entity Anaphors' with non-NP antecedents such as a discourse segment (could be a VP, S, propositions, facts, events etc.). These anaphors usually denote abstract entities with the help of three different types of overt pronouns namely *this, that, and it.*

Consider the following

(1)
[S:] [so the torso and the head move forward]$_i$?
[T:] In order for [this]$_i$ to happen what should the torso do?

(2)
[T:] Good. And what is [the horizontal distance covered by the runner in this time T]$_i$?
[S:] [the same as the pumpkin X (runner) = V (horizontal) * t]$_j$
[T:] [That]$_{i+j}$'s right.

[1] In our context, a discourse segment that contains either an anaphor or its antecedent is called as a `Referring expression'.

(3)

[T:] What will happen to [the horizontal component of the pumpkin's velocity]$_i$?

[S:] {[It]$_i$ remains constant}$_j$

[T:] [That]$_j$'s right.

Deictic anaphors can be event anaphoric as in (1) or propositional anaphoric as in (2). The antecedent of 'that' in (2) is a summation of the previous two propositions. It is also possible for anaphors to share their antecedents as in (3) where the antecedent of 'it' serves as the antecedent of 'that' as well.

Anaphoric reference in examples of these kind is restricted to elements adjacent to the utterance containing the anaphor, i.e., those on the right frontier of the discourse structure tree (Webber, 1991; Asher, 1993). Though various discourse-oriented theories have been developed to classify these abstract objects and the anaphoric reference rules governing them, very few algorithms have been built so far for resolving discourse anaphors in dialogues. Grosz et al. (1983 and 1995) present a centering framework to explain the coherence of local discourse segments in which the speaker's focus of attention is related to referring expressions. This showed great success in monologues. Byron and Stent (1998) later extended this approach to resolve anaphors in spoken dialogues. Eckert and Strube (1999) proposed an alternative to centering by using dialogue acts and an evaluation of their approach showed a precision of 66.2% and a recall rate of 68.2%. Martínez-Barco et al. (1999) used discourse topic for the resolution of anaphors in Spanish dialogues. Our approach is to examine the syntactic, semantic and pragmatic environments under which deictic anaphors can occur in the physics discourse and identify the relevant discourse cues, which in turn, are used to formulate a set of constraints and preferences inspired by Centering Theory as described by Grosz et al. 1995. We propose an algorithm to resolve discourse deictic anaphors in dialogues which is also capable of distinguishing deictic anaphors from individual and expletive anaphors, which are pronouns that do not refer. Finally, we present the empirical results of manually applying this algorithm on 40 referring expressions that occur in physics dialogues.

2. Types of Anaphors in the Why2 Corpus

Anaphora can be inter-sentential or intra-sentential. A careful examination of the computer-mediated dialogues collected in the Why2 corpus[2] reveals that referring expressions in these dialogues contain:

1. Individual anaphors which have NP-antecedents
2. Discourse deictic anaphors which have non-NP antecedents such as a discourse segment (could be a VP, S, propositions, facts, events etc.)
3. Vague anaphors and expletives which are non-referring pronouns.
4. VP-Ellipsis and
5. "one" anaphora

Individual anaphors

Individual anaphors have NP-antecedents. They are very common and most anaphora resolution algorithms have focused on this type of anaphor very widely. The antecedents can be either intra-sentential or inter-sentential as in the examples below:

(4)

[T:] Forces originate in objects. Can you identify anything which exerts a horizontal force on the *pumpkin*$_i$ after *it*$_i$ is released?

[S:] Not quite sure. I would think there is a *force*$_i$ resisting the motion of the *pumpkin*$_j$ forward but I don't know what *it*$_i$ is from.

In some cases, as in (5), a singular anaphoric pronoun refers to a plural NP antecedent and the syntactic agreement in this case will be misleading.

(5)

[T:] You have not been given anything about the forces$_i$ on the runner, so you (need) not say anything about it$_i$.

[2] The Why2 corpus is a collection of tutorial dialogues on physics collected while building and evaluating a natural language tutoring system. (VanLehn et al. 2002).The human tutor in this corpus presents students with qualitative physics problems and encourages them to write answers along with justifications. The tutor then discusses the student's explanation with him and attempts to help him produce a more complete explanation.

Consider an example of intra-sentential 'it" in (6) (where (6) repeats (4) and continues it).

(6)
[T:] Forces originate in objects. Can you identify anything which exerts a horizontal force on the *pumpkin*$_i$ after *it*$_i$ is released?
[S:] Not quite sure. I would think there is a *force*$_i$ resisting the motion of the pumpkin forward but I don't know what *it*$_i$ is from. I thought *it*$_i$ would be air resistance b/c of the shape of the pumpkin.

Quantified and Plural individual anaphors

Quantified individual anaphors as in (7) and plural anaphors as in (8) have antecedents in the previous utterance

(7)
[S:] Would the *pumpkin* have the same velocity and land on the *runner*?
[T:] yes. Since *both*$_i$ have the same constant horizontal velocity, what will *their*$_i$ displacements be at any time?

(8)
[T:] what can you say about [*the horizontal velocity of the egg compared to the horizontal velocity of the clown*]$_i$?
[S:] aren't *they*$_i$ the same?

Discourse Deictic Anaphors

As mentioned in Section 1, *this, that* and *it* are the discourse deictic anaphors which have non-NP antecedents. Unless we apply certain linguistic cues, we are unable to distinguish the discourse deictic anaphors from the individual anaphors. For example, consider the following:

(9)

a) S: The force of [the car hitting from behind]$_i$.
b) T: Is [*that* car]$_i$ touching or in contact with the [person inside the car]$_m$?
c) S: No, {the person is [in the car *that* get's hit]$_m$ which has to be in contact with the car}$_j$.
d) T: {*That*}$_j$*'s* the point.[The object which is in contact with the person can only exert a contact force on him/her]$_k$. What is [*that* object]$_k$?
e) S: [The seat of the car]$_k$.

In the above discourse segment, three of the "that's" refer to NP antecedents, the car that hits in (b) indexed with i, and the car that gets hit indexed with m in (b) and (c), and to the seat of the car and the referential object indexed with k in the second 'that' in (d). But, the first 'that' in (d) refers to a whole proposition and thus constitutes a discourse deictic anaphor. It is very important to disambiguate these senses and identify the exact referent in order to have a meaningful dialogue. The above example is from a human-human transcript and we do not observe the dialogue participants having any difficulties with the semantic interpretation of these expressions. Thus we strive for a computer tutor that is likewise capable of resolving these anaphors during automatic discourse processing analysis so that it is more likely to be able to direct the student more effectively with appropriate tutor turns.

Vague anaphors and Expletives

There are some instances of vague anaphors and expletives too in the Why2 corpus. Vague anaphors usually refer to a general topic during the discourse. They do not refer to a specific clause or phrase as an antecedent as in

(10)
[T:] *It* is a good practice to give reasons first and conclusion last.

Expletives are used here in the sense of Postal and Pullum (1988). These are non-referring pronouns that cannot be questioned as in (11).

(11)
[S:] When *it* comes to Newton's laws of motions, I always get confused with the numbers.

VP-ellipsis and One-Anaphora

VP-ellipsis anaphora[3] is less frequent in our corpus. Some examples:

(12)
[T:] What exerts force on him/her?
[S:] The seat or the seat belt does Ø

(13)
[T]: Fine. What causes that decrease?
[S]: gravity Ø

[3] Resolving VP-ellipsis is by itself a large research topic which deserves more extensive analysis than we can afford in this paper. Thus we leave it for future work.

One-anaphora

Example (14) is a case where there are double anaphors referring to the same null abstract referent. From the context of the dialogue, we know both the tutor and the student are referring to the same discourse entity "next problem" to be solved. This type of anaphor is also less frequent in our corpus.

(14)
[T]: OK, the next one$_i$ is a bit of a pain in the neck, literally, but have a try.
…
[s]: That$_i$ was a pain.

3. Resolution of Discourse Deictic Anaphors

There are a number of theories that address the problem of anaphora resolution: Discourse Representation Theory (Heim 1982 and Kamp 1981) and the theory of the discourse structure (Grosz and Sidner 1986) are two popular theories in this context, each viewing the problem at different angles when characterizing anaphoric possibilities in a discourse. Both theories have provided the basis for formulating many other frameworks. For example, Centering Theory (Grosz et al.1995) is one such theory that is based on discourse structure theory. Most of the algorithms and theories that emerged from the theory of discourse structure tend to share many characteristics among themselves. The terminology used in these theories may vary but can still be related to each other. Grosz and Sidner's "local attentional state", "focus" in a discourse segment is what is called as "local focus" and "center" respectively in Centering Theory.

In this section, we outline the linguistic and discourse constraints and preferences that are necessary to resolve individual and discourse deictic anaphors. The theoretical background for our algorithm is a hybrid of: "centering theory" (Grosz et al. 1995) and the theory of discourse structure (Grosz and Sidner 1986). We also expand upon some notions of Pfleger et al. (2003) on the structure of focus stacks.

The Hybrid Approach

Centering theory assumes that discourses consist of constituent segments and each segment is represented in a discourse model. It can be explained as follows: Suppose U_n and U_{n+1} are two consecutive utterances in a discourse, then the potential next centers C_f (forward looking centers) are an ordered list of all the discourse entities in U_n. The set of the forward-looking centers, C_f is ranked according to discourse salience and the highest ranking entity is called as the preferred next center denoted as C_p. C_b is the backward looking center of the next utterance U_{n+1} and it is a special member of the set of C_f as it represents the discourse entity that U_n most centrally concerns and is similar to what is commonly called as 'topic" in the linguistic literature.

The basic idea is that discourse has a focus or center which remains the same for a few sentences, then shifts to a new entity. The center or focus is normally pronominalized. Thus, it is important for us to identify the foci elements in a referring expression.

We identify two types of focus structures in our dialogues: a global focus and a local/current focus. We expand on some insights from Pfleger et al. (2003) in designing the structure of the dynamic "focus stacks"[4] which is shown in Figure 1.

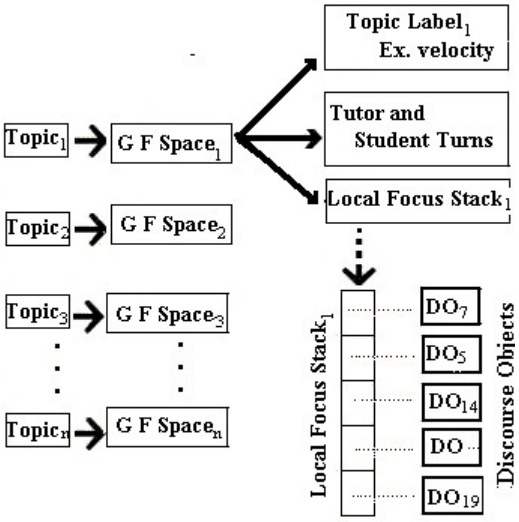

Figure 1: Focus Stacks

The global focus denotes the topic of the discourse. For each topic introduced in the

[4]We do not adopt their entire multimodal context representation model; we restrict ourselves only to the focus structures and discourse objects which are adequate for our purpose. These focus stacks are also similar to that of Grosz and Sidner (1986).

discourse, a global focus space is created, which in turn comprises information about the topic label (for example, "velocity"), the student and tutor turns it covers, and its corresponding local focus stack. If a set of new student and tutor turns correspond to a previously introduced topic, it should be part of the same global focus space.

The topmost space of a global focus stack serves as the currently active focus space. This is the preferred focus (C_p in terms of centering theory). Each time a global focus space opens to accept new turns, it is pushed to the top of the stack irrespective of its previous position. A local focus stack in our context refers to the Discourse Objects (DO), the potential antecedent candidates that are ordered by salience. It is also maintained in the same manner as the global focus space. For each student or tutor turn concerning a specific topic, the stack is created with all mentioned discourse entities that serve as potential antecedent candidates.

The structure and machinery behind these focus stacks is similar to that of Pfleger et al. (2003) except for the following differences: discourse objects in our model refer to non-NP antecedents as well. We also use sub-categorization information to identify these antecedent candidates and rank them according to their frequency of occurrence in the discourse. Unlike Pfleger et al. (2003), we do a mapping of the DOs into the forward-looking, backward-looking and the preferred next centers (C_f, C_p and C_b) of Centering Theory which in turn helps us find the most appropriate antecedents for a given anaphor. This is a short-cut method to mark the centers which we found to be simple and easy to handle.

Constraints and Preferences

It is important to distinguish the individual anaphors from the discourse deictic ones in order to apply the appropriate rules, constraints and preferences when building the focus stacks. For this purpose, we extract linguistic and discourse cues from various sources of knowledge that include:

- morphological agreement
- syntactic context
- semantic information and
- topical knowledge.

Morphological agreement:

We filter the antecedent candidates that are incompatible morphologically (gender, number, and person).

Syntactic context:

The antecedents of discourse deictic anaphors arise from six linguistic constructions (Asher 1993:226):

1) That clauses
2) Infinitival phrases
3) Gerund phrases
4) Naked infinitive complements
5) Noun phrases that appear to denote Proposition -like entities
6) Clauses with parasitic gaps and implicit "chunks" of the text.

There is yet another construction in which discourse deictic anaphors can occur (Yu 2005): *NPs denoting abstract meaning* such as "a story", "a list", "an essay", etc. These can occur in the same predicate environment as other linguistic units used in the sense of abstract referents.

The individual anaphors on the other hand, can be distinguished from the deictic anaphors primarily by the semantic restriction imposed upon the pronoun by its governing verbs (Cornish 1986).

We use the sub-categorization information that can be obtained from a syntactic parser to identify the type of the constructions mentioned above. This information is maintained in the focus stacks to facilitate identification of the "non-NP" antecedent candidates from the NP ones and also the "individual" from the "discourse deictic" ones.

Semantic information:

Abstract anaphor resolution models built using only syntactic information (for example, Eckert and Strube, 1999) cannot deal efficiently with NPs denoting abstract entities. Hence, it is important to include semantic information for this task. Byron (2004) describes a system that can resolve abstract entity anaphors using semantic constraints. Her word lists cover 73 verbs from spoken corpora that denote either an individual entity or an abstract entity. We have

yet to explore if this set has good coverage of verbs for our physics corpus containing abstract entity expressions. However, we recognize some semantic restrictions on the types of the verbs commonly occurring in the physics domain which are maintained along with the syntactic sub-categorization information.

Ranking of grammatical functions is also utilized because it plays an important role in determining the relative salience of a discourse entity. Moreover, the set of forward-looking centers, C_f is ranked according to this discourse salience.

Since the syntactic and semantic context outlined above is not sufficient to identify the antecedent of a discourse deictic anaphor, we also use additional constraints and rules from Centering Theory.

Constraints:

1. There is precisely one backward-looking center $Cb(U_n)$.

2. $Cb(U_{n+1})$ is the highest ranked element of $Cf(U_n)$ that is realized in U_{n+1}.

Rules:

1. Pronoun rule: same pronoun within the same discourse segment will refer to the same center.

2. Typology of transitions that can be used to measure the coherence of the discourse segment: a transition relation holds between the utterances U_n and U_{n+1} in a discourse segment. There are four transition states whose preference-order is shown in Figure 3. This is based on (i) whether the C_b is the same for U_n and U_{n-1}, and (ii) whether the C_b of U_n = C_p of U_n. If both (i) and (ii) are true, then the utterances are related by a 'continue" transition. If (i) is true but (ii) does not hold, then there is a "retain" transition where the speaker intends to "shift" into a new entity in the next utterance and signals this by realizing the current center in a lower-ranked position on the forward-looking center (Walker et. al. 1998). Discourses that "continue" centering the same entity are more coherent than the ones "shifting" from one center to another.

Preferences are unique for each type of anaphor and hence they are listed separately here.

In the case of individual anaphora, the preferences are for:

DOs in the same turn as that of the anaphor
DO in the previous turn
proper nouns or indefinite NP - DOs
DOs that have been repeated more than once
DOs that appeared more than once in construction with the verb in construction with the anaphor
DOs in the same position as the anaphor with reference to the verb (before or after)
DOs that are the nearest neighbors to the anaphor

Figure 2: Preferences for Individual Anaphors

In the case of discourse deictic anaphors:

ordering of centers
highest preferred center- the topmost active stack
next center & so on
Preferences on the center-transitions
Continue >
Retain >
shift to Cp >
shift to Other.

Figure 3: Preferences for Discourse Deictic Anaphors

In addition to the above mentioned rules, constraints and preferences, we also make use of domain knowledge about the topic, included in the respective global focus spaces.

4. The Anaphora Resolution Algorithm

In this section we present our algorithm for handling three types of anaphors: individual anaphors, discourse deictic anaphors and vague/expletive anaphors. As is evident from the description that follows it is a very simple algorithm written in the spirit of the hybrid approach discussed in section 3.

1. For Individual anaphors:
Let Anaphora = X in U_n
List1a = list of all NPs in U_{n-1}
List1b = list of all NPs in U_{n+1}

A: For each NP in List1a apply morpho-syntactic constraints
- Compare it with X's morpho-syntactic conditions
- If they match, put them in "List2"
- Do until end of List1a

If no match found in List1a
Repeat A for List1b
For each NP in List2 do until |List2| = 1
apply linguistic, discourse, pragmatic constraints and preferences
Result: the NP remaining in List2 = the desired antecedent

2. For Discourse Deictic Anaphors:

Let Anaphora = Y
Referring Expression = RE
Sentence = S
List3 = {this, that, it}
List4 = all utterances/sentences within the same discourse segment

Check RE for members of List3:

(a) If RE has `that' then
- Get a complete Previous S (could be a summation of propositions too!)
- Substitute Previous S as an argument for the Predicate in RE
  - If substitution complete and coherent, then Previous S = Antecedent of Y
  - Else for each member of List4
    - Substitute member as an argument for the Predicate in RE
    - If substitution semantically incompatible, Remove from List4
    - Do until |List4| = 1
  - If |List4| = 1 then List4 member = Antecedent of Y

End.

(b) If RE has `this' then
- Get a complete Previous S (could be a summation of propositions too!)
- Substitute Previous S as an argument for the Predicate in RE
  - If substitution complete and coherent, then Previous S = Antecedent of Y
  - Else get `Center' of the discourse from the focus stacks
    - Check for compatibility of Center with (GFocus and LFocus)
    - If compatible then GFocus/LFocus is the Antecedent of Y

End.

(c) If RE has `it' then
- Get a complete Previous S (could be a summation of propositions too!)
- Substitute Previous S as an argument for the Predicate in RE
  - If complete and coherent, then Previous S = Antecedent of Y
  - Else for each member of List4
    - Substitute member as an argument for the Predicate in RE
    - If substitution semantically incompatible, Remove from List4
    - Do until |List4| = 1
    - If |List4| = 1 then List4 member = antecedent of Y.

End.

3. For Vague and Expletive `It':

- If RE has `it' &
- if it is non-referring (failure of 2c)
  - then it is an `Expletive or Vague Pronoun'.

End.

5. Conclusions

In this paper, we discussed the various types of anaphors present in the Why2 corpus of physics tutorial dialogues. We proposed an algorithm, which is based on our hybrid approach, and hand-tested it against 40 referring expressions found in the Why2 corpus of naturally occurring dialogues. Table 1 presents the empirical results. The overall resolution accuracy is: 88.6% and type-wise accuracy is 82% and 91% for

individual and discourse deictic anaphors respectively.

Type of Anaphor		Actual Occurrences in the corpus %	Resolved Using our algorithm%
Individual		**27.5**	**82**
Discourse deictic	This	20.0	75
	That	27.5	100
	It	7.5	100
	Total	**55.0**	**91**
Vague/Expletive		**5.0**	**100**
VP-ellipsis		7.5	-
One-anaphora		5.0	-

Table 1: Results of the resolution accuracy

The failed cases (total 4) are due to the following reasons: (i) due to a grammatical error made in the morphological agreement by a participant (see Example (5) in section 2), (ii) difficult semantics of the verb, (iii) 'this' referring to an abstract entity "essay" that is not mentioned explicitly and (iv) involves sequential resolution of two "this" anaphors - multiple resolutions seem to be a problem for the current algorithm.

These preliminary results encourage us to further explore the problem of discourse deictic anaphora in depth. We plan to implement the approach and evaluate it on a larger corpus of referring expressions found in our dialogues. We also intend to construct a rich semantic classification of the verbs found in our corpus and formulate the necessary semantic constraints which would help us to further improve the algorithm.

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