SITUATED PROCESSING OF PRONOMINAL ANAPHORA

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Summary

We describe a novel approach to the analysis of pronominal anaphora in Turkish. A computational medium which is based on situation theory is used as our implementation tool. The task of resolving pronominal anaphora is demonstrated in this environment which employs situation-theoretic constructs for processing.

Subject Areas: discourse, semantics

Word Count: 3418 (after `detex`'ing)

1. INTRODUCTION

In written/spoken discourse, people use certain instruments for 'pointing back' in the discourse context to individuals, objects, events, times, and concepts mentioned previously. Such anaphoric mechanisms comprise pronouns, definite noun phrases, and ellipsis. They are linguistic expressions which, instead of being interpreted semantically in their own right, make reference to something else for their interpretation; they direct the reader/hearer to look elsewhere in the discourse for their interpretation.

When a phrase or a sentence is semantically interpreted, it specifies a cognitive structure in the reader's mind. The reader uses the information carried by this structure, as well as the surrounding context, in order to construct a related structure for the anaphoric expression. Therefore, anaphora resolution can be seen as the task of forming a cognitive structure and defining its relationship with previously formed structures (Reinhart, 1983). Making this task computational is crucial for practical natural language understanding systems (Johnson and Kay, 1990; Sag and Hankamer, 1984). Computational aspects of anaphora resolution have been studied, especially for English (Webber, 1980), and some proposals have been implemented (Hobbs, 1986).

Situated processing of language has been an important area of research (Fenstad et al., 1987; Rooth, 1987; Stucky, 1989). In this regard, there have been attempts towards a treatment of anaphora in the framework of situation semantics (Barwise, 1987; Gawron and Peters, 1990a; Gawron and Peters, 1990b). However, no serious implementation is available to resolve anaphora by employing bona fide situation-theoretic constructs (Devlin, 1991). In this paper, we demonstrate the resolution of pronominal anaphora in Turkish within a situation-theoretic computational environment, called BABY-SIT. Compared to previous proposals for 'computational situation theory'—i.e., PROSIT (Nakashima et al., 1988) and ASTL (Black, 1992)—BABY-SIT strives to be 'purer.' In PROSIT and ASTL, we have observed a conceptual and philosophical divergence from the ontology of the situation theory (Barwise and Perry, 1983). By sticking to the most recent account of the theory (Devlin, 1991), we hope to achieve in BABY-SIT a truer representative of a situation-theoretic computational framework. BABY-SIT is currently being developed in KEE^{TM} (Intellicorp, Inc., 1988) on a SUN Sparc workstation. Currently, all the computational capabilities that will be mentioned in the sequel are available. More specifically, a semantic parser analyses each proposition provided by the user. A situation browser enables the creation of situations, addition/deletion of infons, and establishment of hierarchies among situations. The user can also issue queries about whether a situation supports a given infon or not.

According to situation theory (Devlin, 1991), individuals, properties, relations, spatio-temporal locations, and situations are the basic ingredients. All individuals, including spatio-temporal locations, have *properties* and stand in *relations* to one another. A sequence such as $\langle r, x_1, \ldots, x_n \rangle$ where r is an n-ary relation over the individuals $x_1, \ldots, x_n$ is called a *constituent sequence*. Suppose Alice was eating ice cream yesterday at home and is also eating ice cream now at home. Both of these situations share the same constituent ⟨*eats, Alice, ice cream*⟩. These two events, occurring at the same location but at different times, have the same *situation type* s. Situation types are partial functions from relations and objects to the values 0 and 1 (a.k.a. *polarity*). The situation type s, in our example, assigns 1 to the constituent sequence ⟨*eats, Alice, ice cream*⟩.

Meanings of expressions reside in systematic relations between different types of situations. They can be identified with relations on *discourse situations* d, *connections* c, the utterance φ itself, and the described situation e. Some public facts about φ (such as its speaker and time of utterance) are determined by d. The ties of the mental states of the speaker and the hearer with the world constitute c.

A discourse situation involves the expression uttered, its speaker, the spatio-temporal location of the utterance, and the addressee(s). Using a name or a pronoun, the speaker refers to an individual.

A situation s in which the referring role is uniquely filled is called a *referring (anchoring) situation*. An anchoring situation s can be seen as a partial function from the referring words to their referents. This function is the speaker's connections for a particular utterance.

The utterance of an expression φ 'constrains' the world in a certain way, depending on how the *roles* for discourse situations, connections, and the described situation are occupied. In interpreting the utterance of φ in a context u, there is a flow of information, partly from the linguistic form encoded in φ and partly from the contextual factors provided by the utterance situation u. These are combined to form a set of constraints on e. The meaning of φ and hence its interpretation are influenced by other factors such as stress, modality, and intonation. However, the situation in which φ is uttered and the situation e described by this utterance seem to play the most influential roles. For this reason, the meaning of an utterance is essentially taken to be a relation defined over φ, d, c, and e.

The constituents of φ do not describe a situation when uttered in isolation. Uttering a verb phrase in isolation, for example, does not describe e. Other parts of the utterance (of which this verb phrase is a part) must systematically contribute to the description of e by providing elements such as an individual or a location. For example, the situational elements for the utterance of the tenseless verb phrase 'running' provide a spatio-temporal location for the act of running and the individual who is to run. For the tensed verb phrase 'is running,' an individual must be provided. Such situational elements form the *setting* σ for an utterance. The elements provided by σ can be any individual, including spatio-temporal locations. The meaning of φ is a relation defined not only over d, c, and e, but also over σ.

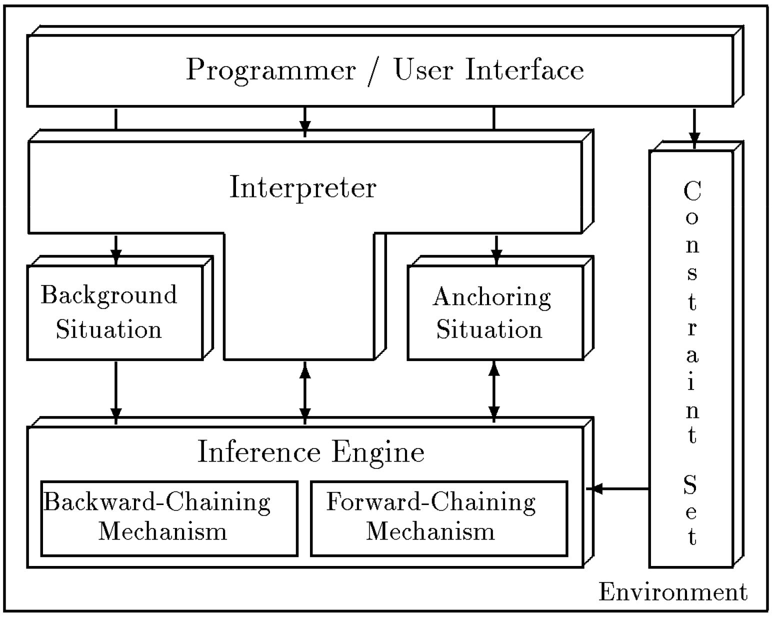

Figure 1: The architecture of BABY-SIT.

2. BABY-SIT: OUR COMPUTATIONAL MEDIUM

BABY-SIT is a general computational framework based on situation-theoretic constructs. It accommodates the basic features of situation theory (Devlin, 1991). The world is viewed as a collection of objects. This includes individuals, times, places, situations, relations, and parameters. Situations are 'first-class citizens' which represent limited portions of the world. Infons are discrete items of information which can be true or false, or may be left unmentioned by some situation. Situations are required to cohere, i.e., a situation cannot support an infon and its dual at the same time. Circularity is allowed in situations; a situation can contain infons which have the former as arguments. The architecture of BABY-SIT is composed of seven major parts: *programmer/user interface*, *environment*, *background situation*, *anchoring situation*, *constraint set*, *inference engine*, and *interpreter*. The interface allows interaction of the user with the system. One can develop and test his program, and enter queries about situations (Figure 1).

BABY-SIT allows the use of contextual information which plays a critical role in all forms of behavior and communication. Constraints enable one situation to provide information about another and serve as links between representations and the information they represent. Computation over situations occurs via constraints and is context-sensitive.

3. RESOLUTION OF PRONOMINAL ANAPHORA

Resolving a pronominal anaphora is in fact the process of determining its intended antecedent and referent. When isolated sentences in Turkish are concerned, this process can be eased to some degree by syntactic and surface order analysis, as Erguvanli-Taylan observes (Erguvanli-Taylan, 1986). However, sentences normally do not appear in isolation; they are usually part of a linguistic discourse. Meaning of a sentence can thus change according to the participants of the discourse (Lascarides and Asher, 1991). When anaphora is viewed as a means for "allowing a language producer to maximize the rate of information flow out to a language receiver" (Webber, 1980, p. 142), the role of context in supplying an anaphoric expression with meaning as intended by the speaker becomes decisive. The syntactic and surface restrictions which rule out the anaphoric relations within sentence boundaries may not hold across sentence boundaries if a context is available. Consider

(1) BİLGE BANA [Ø HASTALANDIĞIN]-I SÖYLEDİ.
Bilge told me that he/she/it got sick.

In this sentence, the zero anaphor expression, Ø, as the subject of the embedded sentence can take the subject of the main sentence, BİLGE, as antecedent. However, given a particular discourse as in (2), Ø can express co-reference with the subject of the previous sentence rather than that of the same sentence:

(2) EROL MAÇA GELMEYECEK. BİLGE BANA [Ø HASTALANDIĞIN]-I SÖYLEDİ.
Erol will not come to the game. Bilge told me that he/she/it got sick.

Investigating the possible structures for the antecedents of an anaphoric expression is the most important issue in resolving anaphora. To our knowledge, there exists little work on anaphora in Turkish (Underhill, 1986). The available studies are mostly concerned with the syntactic nature of intra-sentence pronominal anaphora (Erguvanli-Taylan, 1986; Kurtboke, 1983). Contributions to Turkish linguistics (Enc, 1986; Kerslake, 1987) are, however, of essential use regarding inter-sentence anaphora, e.g., predicting what can be subject to pronominalization and deletion in the succeeding discourse. The discourse context certainly will provide the necessary information for removing ambiguities in resolving anaphora both within and across sentence boundaries. This can be made possible by using information flow provided by the constructs of BABY-SIT and the latter's constraint satisfaction mechanism. The examples below illustrate how pronominal anaphora in Turkish is resolved in our situation-theoretic framework and how computation over situations proceeds in BABY-SIT.

The programmer starts by writing a description of a given sentence. The use of a linguistic expression is an utterance situation. Hence, the programmer defines a type of utterance situation for each linguistic expression in the sentence. Consider

(3) AYNUR EROL'A Ø KARISINI SORDU.
Aynur asked Erol about his/her/its wife.

The zero pronoun Ø in this sentence is an anaphoric expression whose antecedent/referent is to be found. Figure 2 shows the representation of each particular utterance as BABY-SIT data structures. The compound noun phrase Ø KARISINI is defined to be a larger utterance situation which comprises Ø and KARISINI.

The situation for the whole sentence is defined as a composition of situations of its sub-utterances. The utterance of (3) describes a situation whose location temporally precedes the location of the utterance (Figure 3). An anchoring situation—which will either partially or fully

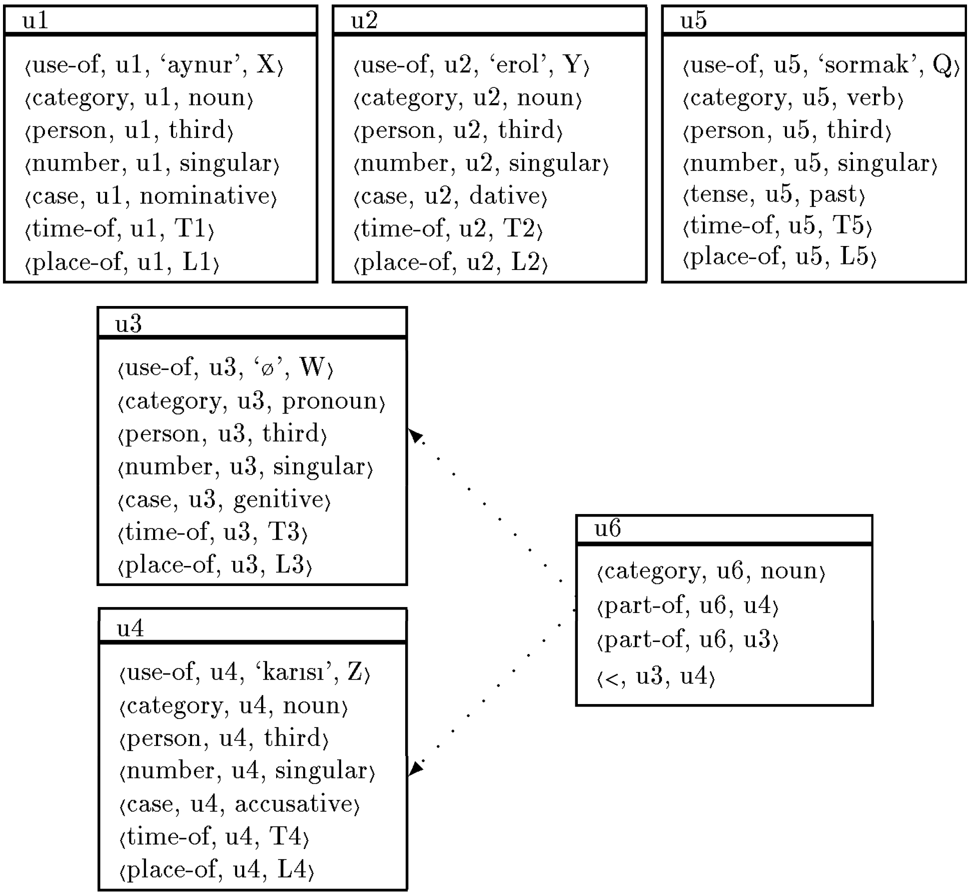

Figure 2: Component utterance situations for (3).

anchor parameters in these situations—is created automatically by BABY-SIT. The programmer asserts anchoring infons of the form ⟨*anchor*, arg_1, arg_2; *pol*⟩ where arg_1 is a parameter, arg_2 is a structure of appropriate type, and *pol* is the polarity (omitted if 1). The anchoring situation for (3) is illustrated in Figure 4(a). Assume constraints of the following form:

```
*U⊨⟨use-of, *U, ‘aynur’, *X⟩ ⇒ ANCH⊨⟨human, *X⟩, ANCH⊨⟨male, *X; 0⟩.

*U⊨⟨use-of, *U, ‘erol’, *X⟩ ⇒ ANCH⊨⟨human, *X⟩, ANCH⊨⟨male, *X⟩.

*U⊨⟨use-of, *U1, ‘Ø’, *X⟩,
*U⊨⟨use-of, *U2, ‘karısı’, *Y⟩,
```

u7
⟨category, u7, sentence⟩
⟨part-of, u7, u1⟩
⟨part-of, u7, u2⟩
⟨part-of, u7, u6⟩
⟨part-of, u7, u5⟩
⟨<, u1, u2⟩
⟨<, u2, u6⟩
⟨<, u6, u5⟩
⟨subject, u7, u1⟩
⟨direct-object, u7, u2⟩
⟨indirect-object, u7, u6⟩
⟨verb, u7, u5⟩
⟨<, s2, u7⟩
⟨describes, u7, s2⟩

s2
⟨ask, X, Y, Z⟩
⟨wife-of, Z, W⟩
⟨time-of, s2, T6⟩
⟨place-of, s2, L6⟩

Figure 3: The complete utterance situation, u7, and its described situation, s2.

$$\texttt{*U}\models\langle\texttt{<, *U1, *U2}\rangle \Rightarrow \texttt{ANCH}\models\langle\texttt{human, *X}\rangle\texttt{, ANCH}\models\langle\texttt{male, *X}\rangle\texttt{,}$$
$$\texttt{ANCH}\models\langle\texttt{human, *Y}\rangle\texttt{, ANCH}\models\langle\texttt{male, *Y; 0}\rangle\texttt{.}$$

These constraints place restrictions on the parameters, which cannot be violated in the current anchoring situation, **ANCH**, of the existing environment. (The first constraint, for example, states that if there is an utterance situation of the word 'Aynur,' then it must represent a female human being.) Upon assertions of utterance situations, all these constraints are satisfied and their consequent parts are asserted into the anchoring situation. The final state of the anchoring situation is shown in Figure 4(b). It should be noted that the background situation may contain, for example, information about the speaker and the addressee, inherited by all utterance situations. Figure 5 illustrates the case on the present version of BABY-SIT desktop.

For the resolution of Ø, we need inference rules which encode syntactic control of zero anaphora in sentence boundaries. As noted by Erguvanli-Taylan (Erguvanli-Taylan, 1986, p. 28), the appropriate rule for (3) can be given as follows: "If the anaphoric expression represented by zero pronoun is a possessor noun phrase of a genitive construction, then its antecedent is either subject

anchor1
⟨anchor, X, a⟩
⟨anchor, Y, e⟩
⟨anchor, T1, t1⟩
⟨anchor, L1, l1⟩
⟨anchor, T2, t2⟩
⟨anchor, L2, l2⟩
⟨anchor, T3, t3⟩
⟨anchor, L3, l3⟩
⟨anchor, T4, t4⟩
⟨anchor, L4, l4⟩
⟨anchor, T5, t5⟩
⟨anchor, L5, l5⟩

(a)

anchor1
⋮
⟨anchor, L4, l4⟩
⟨anchor, T5, t5⟩
⟨anchor, L5, l5⟩
⟨human, X⟩
⟨male, X; 0⟩
⟨human, Y⟩
⟨male, Y⟩
⟨human, Z⟩
⟨male, Z; 0⟩
⟨human, W⟩
⟨male, W⟩

(b)

Figure 4: The snapshot of the anchoring situation: (a) initially, and (b) after parameter restriction.

noun phrase or non-subject noun phrase. The non-subject noun phrase must precede the anaphoric expression when more than one potential antecedent is present.” This rule can be represented (in the constraint set) by constraints which are forward-chaining:

```
 *U1⊨⟨use-of, *U2, ‘Ø’, *X1⟩,
 *U1⊭⟨subject, *U2, *U1⟩,
 *U1⊨⟨case, *U2, genitive⟩,
 *U1⊨⟨subject, *U1, *U3⟩,
 *U1⊨⟨use-of, *U3, *C1, *X2⟩,
ANCH⊨⟨equal, *X1, *X2⟩ ⇒ ANCH⊨⟨anchor, *X1, *X2⟩.

 *U1⊨⟨use-of, *U2, ‘Ø’, *X1⟩,
 *U1⊭⟨subject, *U1, *U2⟩,
 *U1⊨⟨case, *U2, genitive⟩,
 *U1⊭⟨subject, *U1, *U3⟩,
 *U1⊨⟨category, *U3, noun⟩,
 *U1⊨⟨<, *U3, *U2⟩,
 *U1⊨⟨use-of, *U3, *C1, *X2⟩,
ANCH⊨⟨equal, *X1, *X2⟩ ⇒ ANCH⊨⟨anchor, *X1, *X2⟩.
```

Unification on the first constraint yields `*U1/u7`, `*U2/u3`, `*X1/W`, `*U3/u1`, `*C1/‘aynur’`, and `*X2/X`. The utterance situation `u7` satisfies the conditions of the first constraint except the condition

ANCH⊨⟨equal, W, X⟩. For the two parameters to be equal, the restrictions asserted for them must be pairwise unifiable. However, ⟨male, W⟩ cannot be unified with ⟨male, X; 0⟩. Therefore, the rule is not satisfied. For the second constraint, variables are instantiated in a similar way except *U3/u2, *C1/'erol', and *X2/Y. The utterance situation u7 satisfies all conditions of the second constraint and ⟨anchor, W, Y⟩ is asserted into ANCH. This results in the binding of Ø with the non-subject noun phrase 'Erol' of the given sentence.

One can ask questions about the situations. For example, the following query asks who is the wife of who in the described situation s2: s2⊨⟨wife-of, *X1, *X2⟩.

The answer is:

```
      s2⊨⟨wife-of, Z, W⟩,
anchor1⊨⟨anchor, W, Y⟩,
anchor1⊨⟨anchor, Y, e⟩.
```

In s2, e has a wife, but it is not known who she is; the result conveys partial information about the situation. Now assume that we replace ⟨use-of, u1, 'aynur', X⟩ in u1 by ⟨use-of, u1, 'ahmet', X⟩ in order to have an utterance situation in which the word 'Ahmet' is used.

(4) AHMET EROL'A Ø KARISINI SORDU.
Ahmet asked Erol about his/her/its wife.

This causes all infons containing the parameter X to be deleted and assuming a constraint of the following form:

```
*U⊨⟨use-of, *U, 'ahmet', *X⟩ ⇒ ANCH⊨⟨human, *X⟩, ANCH⊨⟨male, *X⟩,
```

new restrictions on X, stating that X is a male human being, are asserted into the anchoring situation. Forward-chaining mechanism finds out that the two constraints above are satisfied and both ⟨anchor, W, X⟩ and ⟨anchor, W, Y⟩ are to be asserted into the anchoring situation. This, however, will cause an inconsistency since a parameter can only be anchored to a unique structure. Therefore, we require the existence of related contextual information. Assume that the following has been uttered before (4):

(5) EROL DÜN EVLENDİ.
Erol got married yesterday.

Now, a forward-chaining constraint of the following form creates a new situation in which we can talk about Erol's wife:

```
 *S1|=⟨get-married, *X1, *X2⟩,
ANCH|=⟨male, *X1⟩ ⇒ *S2|=⟨wife-of, *X2, *X1⟩, *S1|=⟨part-of, *S1, *S2⟩.
```

The utterance situations for (5) and the situation they describe are not illustrated here. But we assume that the forward-chaining constraint above automatically assigns a parameter, say P_1, to the variable *X2. Hence, an abstract situation containing the infon ⟨wife-of, P_1, Y⟩ is created.

From the current utterance, one can make predictions about the future occurrence of pronouns in the succeeding sentences. For example, it is possible that Erol and his wife will be pronominalized in the future. One of these ways might be via a noun phrase such as Ø KARISI where Ø is a genitive construction. Such predictive information can be encoded in a constraint which will be used as a backward-chaining constraint for a *contextual proof* of the assertions. An example constraint could be:

```
*U1|=⟨describes, *U1, *S⟩,
 *S|=⟨wife-of, *X1, *X2⟩,
*U2|=⟨use-of, *U3, 'Ø', *X3⟩,
*U2|=⟨case, *U3, genitive⟩,
*U2|=⟨use-of, *U4, 'karısı', *X4⟩,
*U2|=⟨<, *U3, *U4⟩,
*U5|=⟨<, *U1, *U5⟩ ⇐ ANCH|=⟨anchor, *X3, *X2⟩.
```

Returning to our ambiguous parameter anchoring, the inference mechanism will try to prove each assertion via backward-chaining constraints. In addition to the existence of an utterance situation for (5) in our environment, we assume that its property of being temporally preceding (4) is asserted into the background situation. The utterance situation for (5) and the situation it describes satisfy the antecedent part of the backward-chaining constraint above. The described situation does not directly support the fact that Erol has a wife, but through conveyance of information from its sub-situation. Since only the infon ⟨`anchor, W, Y`⟩ can be proved to be supported by the anchoring situation, it is asserted, resolving the ambiguity. Then, the system finds out that the wives of Erol must be the same individual. It asserts this fact into the anchoring situation as well by using a forward-chaining constraint similar to the following:

```
 *U1⊨⟨describes, *U1, *S⟩,
  *S⊨⟨wife-of, *X1, *X2⟩,
 *U2⊨⟨use-of, *U3, ‘∅’, *X3⟩,
 *U2⊨⟨case, *U3, genitive⟩,
 *U2⊨⟨use-of, *U4, ‘karısı’, *X4⟩,
 *U2⊨⟨<, *U3, *U4⟩,
 *U5⊨⟨<, *U1, *U5⟩,
ANCH⊨⟨anchor, *X3, *X2⟩ ⇒ ANCH⊨⟨anchor, *X4, *X1⟩.
```

Issuing the same query as before yields:

```
      s2⊨⟨wife-of, Z, W⟩,
 anchor1⊨⟨anchor, W, Y⟩,
 anchor1⊨⟨anchor, Y, e⟩,
 anchor1⊨⟨anchor, Z, P1⟩.
```

It is still not known who the wife of `e` is. However, it is known that she is the person referred by the parameter P_1 of the previous utterance.

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