Situated Processing of Pronominal Anaphora*

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Abstract. 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.

Zusammenfassung. Wir beschreiben einen neuartigen Ansatz für die Analyse pronominaler Anaphern im Türkischen. Für die Implementation wird eine situationstheoretisch fundierte Entwicklungsumgebung verwendet. Mithilfe dieser Umgebung, die situationstheoretische Konstrukte unterstützt, demonstrieren wir die Auflösung pronominaler Anaphern.

Keywords. Computational situation theory, situation semantics, anaphora

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. Making this task computational is crucial

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for practical natural language understanding systems. Computational aspects of anaphora resolution have been studied, especially for English [11], and some proposals have been implemented [5].

There have also been attempts towards a treatment of anaphora in the framework of situation semantics [4]. However, no serious implementation is available for resolving anaphora computationally by employing bona fide situation-theoretic constructs [2]. In this paper, we demonstrate the resolution of pronominal anaphora in Turkish within a situation-theoretic computational environment, called BABY-SIT [7, 8]. Compared to previous proposals for computational situation theory [10]—i.e., PROSIT [6] and ASTL [1]—BABY-SIT strives to be 'purer.' BABY-SIT is currently being developed in KEE^{TM} on a SUN Sparc workstation.

2 Terminology

According to situation theory [2], individuals, properties, relations, spatio-temporal locations, and situations are the basic ingredients. The world is viewed as a collection of objects, sets of objects, properties, and relations. *Individuals* are conceived as invariants; having properties and standing in relations, they persist in time and space. *Objects* are not synonymous with individuals. Individuals are among our primitives; objects can be complex as well as simple. (Words are also objects, i.e., invariants across utterances.) All individuals, including spatio-temporal locations, have *properties* and stand in *relations* to one another. A sequence such as $\ll r, x_1, \ldots, x_n \gg$ where r is an n-ary relation over the individuals $x_1, \ldots, x_n$ is called a *constituent sequence*.

According to situation theory, meanings of expressions reside in systematic relations between different types of situations. They can be identified with relations on *discourse situations* d, *(speaker) 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 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 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. 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.

3 BABY-SIT: Our Computational Medium

BABY-SIT is a general computational framework employing situation-theoretic constructs [7]. It accommodates the basic features of situation theory [2]. The world is viewed as a collection of objects. This includes individuals, times, places, labels, 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 [7, 8, 9]: *programmer/user interface*, *environment*, *background situation*, *anchoring situation*, *constraint set*, *inference engine*, and *interpreter*.

The interface allows interaction of the user with the system. The environment initially consists of static situation structures and their relationships. These structures can be dynamically changed and new relationships among situation types can be defined as the computation proceeds. Information conveyance among situations is made possible by defining a *part-of* relation among them. In this way, a situation s can have information about another situation s' which is part of s. The background situation contains infons which are inherited by all situation structures in the environment.

A situation in the environment can be realized if its parameters are anchored to objects in the real world. This is made possible by anchoring situations which allow a parameter to be anchored to an object of appropriate type—an individual, a situation, a parameter, etc. A parameter must be anchored to a unique object. On the other hand, more than one parameter may be anchored to the same object. Restrictions on parameters assure anchoring of one parameter to an object having the same qualifications as the parameter.

In addition to the *part-of* relation among situations, constraints are potent means of information conveyance between and within situations. They link various types of situations. Constraints may be physical laws, linguistic rules, law-like correspondences, conventions, etc. In BABY-SIT, they are realized as forward-chaining constraints or backward-chaining constraints, or both. Assertion of a new object into BABY-SIT activates the forward-chaining mechanism. Once their antecedent parts are satisfied, consequent parts of the forward-chaining constraints are asserted into BABY-SIT, unless this yields a contradiction. The interpreter is the central authority in BABY-SIT. Anchoring of parameters, evaluation of constraints, etc. are all controlled by this part of the system.

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.

4 Resolution of Pronominal Anaphora in BABY-SIT

Resolving 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 Erguvanlı-Taylan rightly observes [3]). 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. When anaphora is viewed as a means for "allowing a language producer to maximize the rate of information flow out to a language receiver" [11, 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 [3]. Consider

(1) BİLGE BANA [∅ HASTALANDIĞIN]-I SÖYLEDİ.
Bilge I-DAT get-sick-NOM-3SG-ACC tell-PAST-3SG.
Bilge told me that he/she/it got sick.

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

(2) EROL MAÇA GELMEYECEK. BİLGE BANA [∅ HASTALANDIĞIN]-I SÖYLEDİ.
Erol game-DAT come-NEG-FUT-3SG.

Bilge I-DAT get-sick-NOM-3SG-ACC tell-PAST-3SG.
Erol will not come to the match. 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. 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 information flow provided by the constructs of BABY-SIT and the latter's constraint satisfaction mechanism [9]. The examples below illustrate how pronominal anaphora in Turkish can be resolved in a 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 ∅ KARISINI SORDU.
Aynur Erol-DAT wife-POSS-3SG-ACC ask-PAST-3SG.
Aynur asked Erol about his/her/its wife.

The zero pronoun ∅ in this sentence is an anaphoric expression whose antecedent/referent is to be found. Figure 1 shows the representation of each particular utterance in BABY-SIT data structures. The compound noun phrase ∅ KARISINI is defined to be a larger utterance situation which comprises ∅ 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 2). The programmer creates an anchoring situation, viz. `anchor1`, which will either partially or fully anchor parameters in these situations and asserts anchoring infons of the form $\ll anchor,\ arg_1,\ arg_2,\ pol \gg$ where arg_1 is a parameter, arg_2 is a structure of appropriate type, and pol is the polarity. The anchoring situation for (3) is illustrated in Figure 3(a). Assume constraints of the following form:

$$?\mathrm{U} \models \ll \texttt{use-of, ?U, `aynur', ?X, 1} \gg\ \Rightarrow\ \texttt{anchor1} \models \{\ll \texttt{human, ?X, 1} \gg,\ \ll \texttt{male, ?X, 0} \gg\}.$$

$$?\mathrm{U} \models \ll \texttt{use-of, ?U, `erol', ?X, 1} \gg\ \Rightarrow\ \texttt{anchor1} \models \{\ll \texttt{human, ?X, 1} \gg,\ \ll \texttt{male, ?X, 1} \gg\}.$$

$$?\mathrm{U} \models \{\ll \texttt{use-of, ?U1, `}\emptyset\texttt{', ?X, 1} \gg,\ \ll \texttt{use-of, ?U2, `karısı', ?Y, 1} \gg,\ \ll \texttt{<, ?U1, ?U2, 1} \gg\ \Rightarrow\ \texttt{anchor1} \models \{\ll \texttt{human, ?X, 1} \gg,\ \ll \texttt{male, ?X, 1} \gg,\ \ll \texttt{human, ?Y, 1} \gg,\ \ll \texttt{male, ?Y, 0} \gg\}.$$

These constraints place restrictions on the parameters and these restrictions cannot be violated in the anchoring situation `anchor1`. (The first constraint, for example, states that if there is an utterance situation of the word 'aynur,' then a female human being is meant.) 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 3(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.

For the resolution of Ø, we need inference rules which encode syntactic control of zero anaphora in sentence boundaries. As noted by Erguvanlı-Taylan [3, p.228] and illustrated in Table 1, the choice of zero/pronominal anaphora can be ruled out for intra-sentence anaphora. For demonstrative purposes, we will use the rule for anaphoric expressions which are possessors of genitive constructions throughout this paper. This rule can be represented (in the constraint set) with constraints which are forward-chaining:

```
?U1⊨{≪use-of, ?U2, ?A1, ?X1, 1≫,
      ≪category-of, ?U2, zero-pronoun, 1≫,
      ≪case-of, ?U2, genitive, 1≫,
      ≪category-of, ?U3, noun, 1≫,
      ≪use-of, ?U3, ?A2, ?X2, 1≫,
      ≪<, ?U3, ?U2, 1≫} ⇒ anchor1⊨≪anchor, ?X1, ?X2, 1≫.

?U1⊨{≪use-of, ?U2, ?A1, ?X1, 1≫,
      ≪category-of, ?U2, zero-pronoun, 1≫,
      ≪case-of, ?U2, genitive, 1≫},
?U1⊭{≪subject-of, ?U2, ?U1, 1≫,
      ≪category-of, ?U3, noun, 1≫,
      ≪<, ?U3, ?U2, 1≫},
?U1⊨{≪category-of, ?U4, noun, 1≫,
      ≪subject-of, ?U4, ?U1, 1≫,
      ≪use-of, ?U4, ?A2, ?X2, 1≫,
      ≪<, ?U2, ?U4, 1≫} ⇒ anchor1⊨≪anchor, ?X1, ?X2, 1≫.
```

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 and `≪anchor, W, X, 1≫` is to be asserted into `anchor1`. However, in order for a parameter to be anchored to the other in an anchoring situation, the restrictions asserted for them in this anchoring situation must be pairwise unifiable. But `≪male, W, 1≫` cannot be unified with `≪male, X, 0≫`. Therefore, the rule is not applied. 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, 1≫` is asserted into `anchor1`. This results in the soft 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,`

Table 1: Choice for zero/pronominal anaphora representation

Representation	*Anaphoric Expression*	*Antecedent*
Zero	Subject of embedded S	Subject of main S Non-subject NP* of main S
Zero	Possessor of a genitive construction	Subject NP Non-subject NP*
Pronominal	Non-subject NP	Any NP c-commanding it
Free	Possessor of a genitive construction in an embedded structure	Non-subject NP*

* NP must precede the anaphora when more than one potential antecedent is present.

`?X1, ?X2, 1`≫. The answer is:

s2⊨≪`wife-of, Z, W, 1`≫,
anchor1⊨≪`anchor, W, Y, 1`≫,
anchor1⊨≪`anchor, Y, e, 1`≫.

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, 1`≫ in `u1` by ≪`use-of, u1, 'ahmet', X, 1`≫ in order to have an utterance situation in which the word 'Ahmet' is used.

(4) AHMET EROL'A Ø KARISINI SORDU.
Ahmet Erol-DAT wife-POSS-3SG-ACC ask-PAST-3SG.
Ahmet asked Erol about his/her/its wife.

This causes all infons containing the parameter `X` to be deleted, and assuming the constraint

?U⊨≪`use-of, ?U, 'ahmet', ?X, 1`≫ ⇒ anchor1⊨{≪`human, ?X, 1`≫,
≪`male, ?X, 1`≫}

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, 1`≫ and ≪`anchor, W, Y, 1`≫ 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 yesterday get-marry-PAST-3SG.

Erol got married yesterday.

Existence of the forward-chaining constraint creates a new situation in which we can now talk about Erol's wife:

$$\begin{array}{rl}
\texttt{?S1} \models \ll \texttt{get-married, ?X1, ?X2, 1} \gg, & \\
\texttt{anchor1} \models \ll \texttt{male, ?X1, 1} \gg \;\Rightarrow & \texttt{?S2} \models \ll \texttt{wife-of, ?X2, ?X1, 1} \gg, \\
& \texttt{?S1} \models \ll \texttt{part-of, ?S2, ?S1, 1} \gg.
\end{array}$$

The utterance situations for (5) and the situation they describe are not illustrated here. The forward-chaining constraint above automatically assigns a parameter, say $\texttt{P}_1$, to the variable `?X2`. Hence, an abstract situation containing the infon $\ll \texttt{wife-of, P}_1\texttt{, Y, 1} \gg$ 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 would be:

$$\begin{array}{l}
\texttt{?U1} \models \ll \texttt{describes, ?U1, ?S, 1} \gg, \\
\;\texttt{?S} \models \ll \texttt{wife-of, ?X1, ?X2, 1} \gg, \\
\texttt{?U2} \models \{ \ll \texttt{use-of, ?U3, `}\emptyset\texttt{', ?X3, 1} \gg, \ll \texttt{case-of, ?U3, genitive, 1} \gg, \\
\qquad \ll \texttt{use-of, ?U4, `karısı', ?X4, 1} \gg, \ll <\texttt{, ?U3, ?U4, 1} \gg \}, \\
\texttt{?U5} \models \ll <\texttt{, ?U1, ?U5, 1} \gg \;\Leftarrow\; \texttt{anchor1} \models \ll \texttt{anchor, ?X3, ?X2, 1} \gg.
\end{array}$$

Turning back to our ambiguous parameter anchoring, the inference mechanism will try to prove each anchoring 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 support the fact that Erol has a wife directly, but indirectly through conveyance of information from its sub-situation. Since only the infon $\ll \texttt{anchor, W, Y, 1} \gg$ 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 such as:

$$\begin{array}{r}
\texttt{?U1} \models \ll \texttt{describes, ?U1, ?S, 1} \gg, \\
\texttt{?S} \models \ll \texttt{wife-of, ?X1, ?X2, 1} \gg, \\
\texttt{?U2} \models \{ \ll \texttt{use-of, ?U3, `}\emptyset\texttt{', ?X3, 1} \gg, \ll \texttt{case-of, ?U3, genitive, 1} \gg, \\
\ll \texttt{use-of, ?U4, `karısı', ?X4, 1} \gg, \ll <\texttt{, ?U3, ?U4, 1} \gg \}, \\
\texttt{?U5} \models \ll <\texttt{, ?U1, ?U5, 1} \gg, \\
\texttt{anchor1} \models \ll \texttt{anchor, ?X3, ?X2, 1} \gg \;\Rightarrow\; \texttt{anchor1} \models \ll \texttt{anchor, ?X4, ?X1, 1} \gg.
\end{array}$$

Issuing the same query as before yields:

```
     s2|=<<wife-of, Z, W, 1>>,
anchor1|=<<anchor, W, Y, 1>>,
anchor1|=<<anchor, Y, e, 1>>,
anchor1|=<<anchor, Z, P1, 1>>.
```

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.

5 Conclusion

In this paper, we have described a linguistic application—resolution of pronominal anaphora in Turkish—within the general framework of a programming environment for situation theory, viz. BABY-SIT [7, 8, 9]. While there have been, in situation semantics, other attempts towards similar applications, ours is probably the first computational account which employs the information-oriented features of situation theory in an essential manner.

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u1

≪use-of, u1, ‘aynur’, X, 1≫
≪category-of, u1, noun, 1≫
≪person-of, u1, third, 1≫
≪number-of, u1, singular, 1≫
≪case-of, u1, nominative, 1≫
≪time-of, u1, T1, 1≫
≪place-of, u1, L1, 1≫

u2

≪use-of, u2, ‘erol’, Y, 1≫
≪category-of, u2, noun, 1≫
≪person-of, u2, third, 1≫
≪number-of, u2, singular, 1≫
≪case-of, u2, dative, 1≫
≪time-of, u2, T2, 1≫
≪place-of, u2, L2, 1≫

u3

≪use-of, u3, ‘∅’, W, 1≫
≪category-of, u3, pronoun, 1≫
≪person-of, u3, third, 1≫
≪number-of, u3, singular, 1≫
≪case-of, u3, genitive, 1≫
≪time-of, u3, T3, 1≫
≪place-of, u3, L3, 1≫

u5

≪use-of, u5, ‘sormak’, Q, 1≫
≪category-of, u5, verb, 1≫
≪person-of, u5, third, 1≫
≪number-of, u5, singular, 1≫
≪tense, u5, past, 1≫
≪time-of, u5, T5, 1≫
≪place-of, u5, L5, 1≫

u4

≪use-of, u4, ‘karısı’, Z, 1≫
≪category-of, u4, noun, 1≫
≪person-of, u4, third, 1≫
≪number-of, u4, singular, 1≫
≪case-of, u4, accusative, 1≫
≪time-of, u4, T4, 1≫
≪place-of, u4, L4, 1≫

u6

≪category-of, u6, noun, 1≫
≪part-of, u4, u6, 1≫
≪part-of, u3, u6, 1≫
≪<, u3, u4, 1≫

Figure 1: Component utterance situations for (3)

u7
≪category-of, u7, sentence, 1≫
≪part-of, u1, u7, 1≫
≪part-of, u2, u7, 1≫
≪part-of, u6, u7, 1≫
≪part-of, u5, u7, 1≫
≪<, u1, u2, 1≫
≪<, u2, u6, 1≫
≪<, u6, u5, 1≫
≪subject-of, u1, u7, 1≫
≪direct-object-of, u2, u7, 1≫
≪indirect-object-of, u6, u7, 1≫
≪verb-of, u7, u5, 1≫
≪<, s2, u7, 1≫
≪describes, u7, s2, 1≫

s2
≪asks, X, Y, Z, 1≫
≪wife-of, Z, W, 1≫
≪time-of, s2, T6, 1≫
≪place-of, s2, L6, 1≫

Figure 2: The complete utterance situation, u7, and its described situation, s2

anchor1
≪anchor, X, a, 1≫
≪anchor, Y, e, 1≫
≪anchor, T1, t1, 1≫
≪anchor, L1, l1, 1≫
≪anchor, T2, t2, 1≫
≪anchor, L2, l2, 1≫
≪anchor, T3, t3, 1≫
≪anchor, L3, l3, 1≫
≪anchor, T4, t4, 1≫
≪anchor, L4, l4, 1≫
≪anchor, T5, t5, 1≫
≪anchor, L5, l5, 1≫

(a)

anchor1
⋮
≪anchor, L4, l4, 1≫
≪anchor, T5, t5, 1≫
≪anchor, L5, l5, 1≫
≪human, X, 1≫
≪male, X, 0≫
≪human, Y, 1≫
≪male, Y, 1≫
≪human, Z, 1≫
≪male, Z, 0≫
≪human, W, 1≫
≪male, W, 1≫

(b)

Figure 3: The snapshot of the anchoring situation: (a) initially, and (b) after parameter restriction