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Computational Social Choice for Pronoun Resolution

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Disambiguation of pronoun reference has been an important issue for both theoretical and computational linguists. While linguistic theories on binding conditions eliminate impossible readings to a certain extent, many pronouns remain ambiguous between bound variable reading and coreference with salient discourse entities, as in *John said he broke his leg* where *he* can refer either to *John* or someone else previously mentioned [1]. This paper addresses such issues by application of computational social choice [2] and considers pronoun resolution as a social choice between the speaker and the hearer. Even when the rankings between the preferred readings differ between the addressor and the addressee, the speaker dictates the decision—the social welfare function returns the identical preference for any profile.

1. Binding Conditions

1.1 Conditions A, B, and C

Semantic ambiguity of pronouns is well known among linguists. While a reflexive *himself* unambiguously refers to the subject *John* in (1a), *himself* in (1b) may refer to either *Bill* in the embedded clause or *John* in the matrix clause. On the other hand, the pronoun *him* in (2a) unambiguously means someone other than *John*—some discourse-salient entity, such as *Bill*, whom the speaker is pointing to. But when *he* is embedded under the matrix clause as in (2b), the pronoun becomes ambiguous between *John* and someone else.

(1) a. John likes himself.
b. John said Bill likes himself.

(2) a. John likes him.
b. John said he likes himself.

Such (un)ambiguities have been captured by linguistic theories called binding theory [3, 1, 4]. Antecedents are called *binders*, which would include referential expressions such as *John* and *the student*, as well as quantifiers such as *every student*. Binders bind bindees that are anaphoric pronouns, such as *him* or *himself*.

- Condition A: reflexives should be bound by means of co-indexing and c-commanding relation in their local domain

(3) a. John_i likes himself_i.
b. *Himself_i likes John_i.

The coindexing symbol i indicates that *John* and *himself* refer to the same individual. C-command is an important notion in linguistics. It is roughly equivalent to precedence, with some restrictions.

(4) C-command: Node A c (constituent)-commands node B iff neither dominates the other, and every branching node that dominates A also dominates B.

Even though *John* in both (3a) and (3b) is coindexed with *himself*, John c-commands *himself* in (3a), while it does not in (3b), which explains the (un)grammaticalities of (3a) and (3b) respectively.

- Condition B: pronouns must be free in their local domain.

(5) a. *$[_{LD}$ John_i likes $\text{him}_i]$.
b. $[_{LD}$ John_i likes $\text{him}_j]$.
c. John_i said $[_{LD}\text{he}_i$ likes his_i dog$]$.

As predicted by Condition B, (5a) is ungrammatical due to *him*, which is inappropriately bound by John in the local domain (LD). In contrast, (5b) is grammatical because *him* is not coindexed with John, as suggested by the different coindex j, which indicates reference to someone else. *Him* in (5c) is also happy since *John* is far enough in the non-local domain even though the two are coindexed.

- Condition C: R (referential)-expressions should be free in their local domain.

(6) *$[_{LD}$ He_i likes $\text{John}_i]$.

In (6), the R-expression *John*, the proper noun, is wrongly bound by the c-commanding co-indexed pronoun *he*.

1.2 Limitations to Binding Theory

Binding conditions effectively contribute to anaphora resolution. See the following example:

(7) Bill_j is such a nice guy. John_i likes $\text{him}_{*i/\surd j}$ very much.

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If *John* and *him* are co-indexed, the second sentence is ungrammatical due to Binding Condition B. The context indicates that *him* is likely to be coreferential with *Bill* in the previous discourse. Thus, the above-mentioned binding conditions eliminate impossible readings from otherwise ambiguous sentences.

However, binding conditions are not by themselves sufficient. Consider another example:

(8) Anna: Bill_j is a good goalkeeper.
Kim: John_i said $\text{he}_{i/j}$ broke $\text{his}_{i/j}$ leg recently.

(8) is ambiguous in four ways and can have either one of the following interpretations:

(9) a. John broke John's leg
b. John broke Bill's leg.
c. Bill broke Bill's leg.
d. Bill broke John's leg.

He and *his* can be bound by either *John* or another salient discourse entity *Bill*. The binding theories have no way of disambiguating these pronouns since there is no way of knowing speaker intention only with these sentences.

2. Computational Social Choice Theory

2.1 Collective Decision Making

Computational social choice theory [2, 5] is a fairly new theory developed from the classical social choice theory [6, 7, 8, 9]. Social choice theory, which has been studied in economics and political science, explains decision making by a group of people. When each member has different views and preferences, aggregation of every individual's view results in a single view.

Typically, social choice theory explains collective decision making in case of voting. Elections may follow the *majority rule*, which ranks one candidate x above another candidate y if and only if a majority of the individuals do. When people vote for their preferred candidate according to their own ranking among the candidates, aggregation of people's preferences helps in selecting a certain candidate. Note that "$\alpha > \beta$" denotes α is preferred to β. For example, the dominating ranking in the situation in (10) would be "Obama > Clinton" and "Clinton > Mccain," that is, "Obama > Clinton > Mcain," which is a preferred ranking by the majority. However, this conflicts with "Mcain > Obama," which is also preferred by three people. Such a paradox has been called the Condorcet Paradox.

(10) a. Anna: Obama > Clinton > Mcain
b. Kim: Clinton >Mcain> Obama
c. Heather: Obama > Clinton > Mcain
d. George: Mcain > Obama > Clinton
e. Nathan: Mcain > Clinton > Obama

2.2 Axiomatic Methods

Axiomatic methods of social choice theory [6] have tackled the above-mentioned problems of aggregation.

Let N be a finite set of individuals or voters and χ be a nonempty set of alternatives or candidates. In our model in (10), N consists of five individuals and χ has three members. Let $L(\chi)$ denote the set of all linear orders on χ. A profile R is a vector of linear orders, or preferences. R_i is a vector of preferences of an individual i. $N^R_{x>y}$ denotes the set of individuals that prefers the candidate x to y. Supposing R the profile given in this model, $N^R_{o>c}$ is a set of people who prefers Obama to Clinton, that are, Anna, Heather and George.

(11) a. Anna: a, Kim: k. Heather: h, George: g, Nathan: n, Obama: o, Clinton: c. Mcain: m
b. N = {a, k, h, g, n}
c. χ = {o, c, m}
d. $R = (R_a,\ R_k,\ R_h,..) \in L(\chi)^N$
e. $N^R_{o>c}$ = {a, h, g}

2.3 Social Welfare Function

Individual's preferences are aggregated somehow and returns a single preference order, that results in collective decisions. Even though people's choice differs, a winning candidate is selected. A *social welfare function* (SWF) F is a function which takes individual's preferences and returns collective preference which is supposed to represent people.

(12) SWF F: $L(\chi)^N \rightarrow L(\chi)$

An axiom called *Pareto condition* may be satisfied by a given SWF.

(13) Pareto condition: A SWF F satisfies the Pareto condition if, whenever

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all individuals rank x above y, then so does society: $N^R_{x>y} = N$ implies <x, y> $\in F(R)$

Independence axiom states that the relative ranking of two candidates remain unchanged regardless no matter how other candidates are ranked.

(14) Independence of irrelevant alternatives (IIA): A SWF F satisfies (IIA) if the relative social ranking of two alternatives only depends on their relative individual rankings: $N^R_{x>y} = N^{R'}_{x>y}$ implies <x, y> $\in F(R) \Leftrightarrow$ <x, y> $\in F(R')$

When an individual's preference dominates the collective preference, that individual is called a dictator. *Dictatorship* is a SWF that maps any member's profile to a single individual profile.

(15) Theorem: Any SWF for three or more alternatives that satisfies the Pareto condition and IIA must be a dictatorship. [6]

2.4 Computational Social Choice

Computational social choice theory implements a social choice by modeling the mechanism. Formalization of social choice theory has been attempted in the social software program [10]. [11] defines modal logic for reasoning about SWFs.

3. Application of Computational Social Choice Theory to Pronoun Resolution

3.1 Anaphora Resolution as Social Choice

Since the referents of pronouns can be ambiguous as we have discussed in section 1, pronoun resolution can be compared with voting by two voters—in this case, the speaker and the hearer. The candidates or choices would be each interpretation of the sentence. There are two candidates, that is, the interpretation of the pronoun by the speaker and the one by the hearer.

For example, the first sentence in the following dialogue in (16) is ambiguous between two interpretations. The first candidate is that the pronoun refers to *John*, and the second choice is that *him* means someone else, who is salient in the discourse.

(16) Dialogue 1
Chris: John likes him. I mean, John likes Bob.
Naomi: I thought you meant John liked himself.

Such ambiguity actually does not exist at all since the first reading is impossible, as Binding Condition B properly eliminates the first reading. As discussed in the section 1, the pronoun *him* should be free in the locality.

Consider the following dialogues in (17) and (18). The referent of the pronoun *him* is ambiguous between *John*, the binder, and some other discourse referent. Suppose that the speaker meant the referent of *him* to be *Bob* who appeared in their previous discourse, while the hearer interpreted *him* to be *John*.

(17) Dialogue 2
Chris: John said he broke his leg.
Naomi: Did he? John looked fine when I saw him this morning.
Chris: It is Bob who broke his leg.
Naomi: I thought you were talking about John.

(18) Dialogue 3
Naomi: I saw Bob's car dented.
Chris: John said he met with an accident.
Naomi: John, too?
Chris: I mean, it was Bob who met with an accident.
Naomi: I thought you said John was hit.

He in the embedded clause can be considered as a bound variable bound by *John* in the mechanism demonstrated in (19) in dominant theory [12]. *John* is raised and binds its trace and the coindexed pronoun. That is how *he* comes to refer to *John*. Such variable binding has been typically used to explain pronoun binding by quantifiers such as *every student* as in (20a). *Every student* undergoes so-called quantifier raising and binds its trance and the pronoun as illustrated in (20b).

(19) John 1. t_1 said he_1 met a car accident.

(20) a. Every student called her mother.
b. Every student 1. t_1 called he_1's mother.

Since both variable binding and coreference with salient discourse entities are available, ambiguities remain. Binding Conditions alone do not eliminate such ambiguity.

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3.2 Axiomatic Method in Social Choice Theory

Now, I claim that the Social choice theory proves to be useful for disambiguation of pronouns.

(21) a. Two voters: speaker *Chris* and hearer *Naomi*
Individuals I = {c, n}
b. Two candidates: *him* refers to either *John* or *Bob*
Candidates χ = {j, b}
c. Preference:
Speaker: John > Bob
Hearer: Bob > John
Denote the set of linear orders on χ by $L(\chi)$. Preferences (or ballots) are taken to be elements of $L(\chi)$.
d. A profile R = (R_1, . . . ,R_n) $\in L(\chi)^N$ is a vector of preferences
e. A social choice function (SCF) or voting rule is a function F : $L(\chi)^N \rightarrow 2^{\chi} \setminus \{\emptyset\}$ mapping any given profile to a nonempty set of winners.
f. A social welfare function (SWF) is a function F : $L(\chi)^I \rightarrow L(\chi)$ mapping any given profile to a (single) collective preference order.

3.3 Dictatorship

What is called the plurality rule does not apply to pronoun resolution. The plurality rule is one to elect the candidate ranked first most often. Although voting usually satisfies the plurality rule, the selection of possible interpretation of pronouns does not depend on the sum of the discourse participants who share the same interpretation. Rather, pronoun resolution is dominated, or dictated, by the speaker's meaning.

(22) Dictator: speaker c $\in$ I
The speaker dominates the choice of referents and reserves right to correct the hearer's interpretation.
$F(R) = R_c$ for any profile R, that is, the outcome is always identical to the preference supplied by the dictator.

3.4 Preferences

When the interpretation of pronouns differs between the speaker and the hearer, It appears that the preference rankings among Binding Conditions, variable binding, and coreference with salient discourse entities alternate between them. In Dialogue 1 mentioned in section 3.1, Chris meant the salient discourse entity *Bob* to be the referent of the pronoun. This option does not violate Condition B; however, it ignores local variable binding. In contrast, Naomi's choice is that *him* refers to *John*, which utilizes local variable binding ignoring Condition B violation. The preference rankings between Condition B and variable binding alternate between the speaker and the hearer.

Dialogue 1

John_i likes $\text{him}_{i/j}$.	Chris	Naomi	Condition B	Local Variable Binding
him_i	*	√	*	√
him_j	√	*	√	*

(23) Preference related to Dialogue 1
Chris: Condition B > Local binding
Naomi: Local Binding > Condition B

In Dialogue 3, Chris prefers pronoun binding by the matrix subject *John* to coreference with cross-sententially salient *Bob*. On the contrary, the hearer Naomi chooses to refer to *Bob* who appears in the context rather than non-local binding by *John*.

Dialogue 3

John_i said $\text{he}_{i/j}$ met an accident.	Chris	Naomi	Non-local Variable Binding	Cross-sentential Saliency
he_i (John)	√	*	√	*
he_j (Bob)	*	√	*	√

(24) Preference related to Dialogue 3
Chris: Variable Binding > Saliency
Naomi: Saliency > Variable Binding

Hence, alternatives are differently ranked between the speaker and the hearer in pronoun resolution. Nevertheless, corrections made by the speaker in dialogues suggest that the speaker dictates the decision. The different preference rankings are aggregated to a single choice made by the speaker. The hearer is forced to interpret the speaker utterance as he meant.

3.5 More Than Two Alternatives

So far, we have discussed choosing out of two alternative interpretations. How-

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ever, the choices are not always between two candidates but there could be more than two alternative interpretations.

[4] considers the context as an assignment function for pronouns. According to the definition below, some pronouns are evaluated by a context, c.

(25) $[\![she]\!]$ = the most salient female person in c if there is one, undefined otherwise

[4, 136]

The assignment function c assigns a contextually salient entity for the value of pronouns. [4] calls assignment by context to be R-theory, which originates in [1].

However, when there is more than one salient entity in the discourse, c cannot decide on which. If the pronoun is embedded under the matrix clause, the reference would be more than two-way ambiguous. Even in such cases, social choice theory predicts the right results. It states that the dictator, the speaker's choice is constantly reflected in the collective choice.

4. Conclusion

This paper is the first attempt to apply social choice theory to linguistic problems in my knowledge. While anaphora resolution has been a problem for natural language processing and theoretical linguistics, the application of social choice theory and explanation by dictatorship effectively disambiguate pronoun references.

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