

Dynamic Social Choice for Anaphora Resolution

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Abstract

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 inter-sentential anaphora remain ambiguous. Nishiguchi (2011, 2012a,b, 2014, 2016a,b) consider pronoun resolution as a social choice among discourse participants which obeys Arrow's Impossibility Theorem (Arrow 1963). This paper further discusses discourse update of Social Welfare Function which provides updated variable assignment.

In (1), *she* has multiple candidates for its antecedent—Emma, Lisa and Lisa's mom. Proximity and saliency of antecedents have been considered to be key factors to decide (Leass 1991). In (1), the most proximate antecedent *her (Lisa)'s mom* is identified to be the antecedent for *she*.

- (1) Frances: ...Not while Emma's not here. You know Emma
Billy: Mm.
Frances: she's, she was walking with Lisa and I weren't there and her Mum sh- jus- , like *she* muc- , *she* mucks about a lot and she told Leigh that if he don't serve her he's gonna die, she's gonna punch him right!

However, proximity does not always resolve referential ambiguity of pronouns. *Him* in (2a) unambiguously means someone other than the closest *John*—some discourse-salient entity. In (2b), the pronoun is ambiguous.

- (2) a. John_i likes him_{*i/j≠i}.
b. John_i said he_{i/j} likes himself_{i/j}.

In linguistic binding theory (Chomsky 1981, Reinhart 1983), antecedents are called *binders*, which bind bindees that are anaphoric pronouns, e.g., *him* or *himself*. Condition B is that pronouns must be free in their local domain, meaning that they are not bound by the antecedent by means of coindexing and c-commanding relation. *C-command* is roughly equivalent to precedence, with some restrictions.

However, (3) is ambiguous in four ways and can have either one of the following interpretations: i) John broke John's leg, ii) John broke Bill's leg, iii) Bill broke Bill's leg, or iv) Bill broke John's leg. *He* and *his* can be bound by either *John* or *Bill*. The binding theories have no way of disambiguating these pronouns since there is no way of knowing speaker intention. Proximity does not predict the different readings in (3) either.

- (3) Anna: Bill_j is a good goalkeeper.
Kim: John_i said he_{i/j} broke his_{i/j} leg recently.

1 Social Choice Theory

Although Social Choice Theory (Arrow 1963, Moulin 1988, Taylor 2005, Gaertner 2009) has only been briefly mentioned in van Rooij (2011) in relation with interadjective comparison, Arrow's Impossibility Theorem is obeyed in a social choice of pronominal reference. Typically, social choice theory explains collective decision making in case of voting and has solved the problems with majority decision. Preferences are ordering between alternatives and should satisfy the following axioms. When R stands for a knowledge of all pairs and x, y and z for alternatives,

Axiom 1. For all x and y, either xRy or yRx.

Axiom 2. For all x, y, and z, xRy and yRz imply xRz.

Axiom 1 states that the relation R is connected—every candidate is related to each other. Relations that satisfy Axiom 2 are transitive. In (4), N , a finite set of individuals or voters, consists of five individuals and χ , a nonempty set of alternatives or candidates, 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 . $N_{x>y}^R$ denotes the set of individuals that prefer the candidate x to y . Supposing R the profile given in this model, $N_{o>c}^R$ is a set of people who prefers Obama to Clinton, that are, Anna, Heather and George (cf. Endriss 2016).

(4) a. $N = \{a, k, h, g, n\}$

b. $\chi = \{o, c, m\}$

c. $R \in L(\chi)^N$

d. $N_{o>c}^R = \{a, h, g\}$

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

A *social welfare function* (SWF) F is a function which takes individual's preferences and returns collective preference. Arrow demonstrated that any SWF for three or more alternatives the following conditions must be a dictatorship. Condition 2 states that the relative ranking of two candidates remains unchanged regardless of other candidates.

Theorem 1 (General Possibility Theorem (Impossibility Theorem)). *If there are at least three alternatives which the members of the society are free to order in any way, then every social welfare function satisfying Conditions 1 and 2 and yielding a social ordering satisfying Axioms 1 and 2 must be either imposed or dictatorial.*

Condition 1 (Pareto condition). *A SWF F satisfies the Pareto condition if, whenever all individuals rank x above y , then so does society: $N_{x>y}^R = N$ implies $xF(R)y$*

Condition 2 (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: $N_{x>y}^R = N_{x>y}^{R'}$ implies $xF(R)y \Leftrightarrow xF(R')y$*

Condition 3 (Nondictatorship). *There is no individual i such that for every element in the domain of rule f , $\forall x, y \in X: xP_iy \rightarrow xPy$ (Sen 1979)*

2 Application to Pronoun Resolution

SWF for pronoun resolution satisfies Arrow's Impossibility Theorem, or General Possibility Theorem, by satisfying Axioms 1, 2, Pareto Condition and IIA but demonstrating dictatorship. Pronoun resolution is compared with voting by multiple voters, discourse participants. The candidates or choices would be different interpretation of the sentence. In (5), the referent of *he* is ambiguous. Chris meant *he* to be *Bob*, while Naomi interpreted *him* to be *John*. As the disagreement on pronominal reference is consolidated in the discourse, pronoun resolution is certainly a social choice and Social Choice Function (SCF) decides the antecedent.

(5) 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.

When individuals $I = \{c, n\}$, candidates $\chi = \{j, b\}$, Chris and Naomi's ordering is $jR_c b \wedge bR_n j$, denote the set of linear orders on χ by $L(\chi)$. Preferences (or ballots) are taken to be elements of $L(\chi)$. A profile $R \in L(\chi)^I$ is a vector of preferences. SCF or voting rule is a function $F: L(\chi)^I \rightarrow 2^X \setminus \emptyset$ mapping a given profile to a nonempty set of winners; e.g., a singleton set $\{b\}$ for (5). SWF is a function $F: L(\chi)^I \rightarrow L(\chi)$ mapping any given profile to a (single) collective preference order. Although the preferences between the candidates vary between the individuals, SWF returns a single preference order and ambiguities are resolved during the conversation.

There are three possible antecedents for *she* in (1)—Emma (e), Lisa (l) and Lisa's mother (m). Let us say that Billy (b) prefers e to l, and also l to m to be the antecedent. On the other hand, the speaker Francis (f) prefers m to l, and l to e according to the proximity. All three candidates are ordered in accordance with Axiom 1, i.e., $eR_b l \wedge lR_b m$ and $mR_f l \wedge lR_f e$. Transitivity also holds for pronoun antecedent preferences. Each of them implies $eR_b lR_b m$ and $mR_f lR_f e$. SWF for pronoun resolution also meets Pareto condition. When the interpretation of the addressees agrees with the one of the speaker, the decision of the society follows. It is unlikely that pronouns refer to someone

else other than speaker's intention and hearer's interpretation. A SWF F satisfies IIA if the relative social ranking of two alternatives only depends on their relative individual rankings. Let us say that the preference relations are denoted by R and R' . Assume that IIA does not hold and consider a dialogue in (7) where the relative rankings between Bob and John is affected by irrelevant candidate Victor's ranking. The social decision differs from the relative ranking between John and Bob of speaker and hearer, which does not happen, in (8).

(6) Chris: Bob is a good skier. But John said he broke his leg.

Naomi: Did he? Poor Bob!

(7) Chris: Victor is a good skier and so is Bob. But John said he broke his leg.

Naomi: Did he? Poor Bob!

(8) $bR'_c vR'_c j \wedge bR'_n jR'_n v \not\rightarrow jF(R)b$

Then, $N_{b>j}^R = N_{b>j}^{R'}$ implies $bF(R)j \Leftrightarrow bF(R')j$

The speaker's decision on pronominal reference dictates the social preference. Even when there is disagreement or misunderstanding, the speaker corrects unifies interpretation in general, as in (9). Pronoun resolution is dominated, or dictated, by the speaker's meaning.

(9) Chris: Bob is a good skier. But John said he broke his leg.

Naomi: Did he? Poor Bob!

Chris: No. I mean John broke his leg.

(10) $xP_c y \rightarrow xP_y$

Proof. Suppose: $xP_c y \rightarrow \sim xP_y$, that is, $xP_c y \rightarrow yR_x$, where R is weak preference. However, the dialogue normally proceeds $jP_c b \rightarrow jP_b$ as in (10). Contradiction. \square

Lemma 1. *The social welfare function for pronoun resolution is IIA and Pareto but is dictatorial.*

3 Dynamic Update of SCF

In linguistic literature, a variable assignment function g has been assumed to assign the referent to indices indexed to pronouns. For example, g may assign John to the variable x : $g(x) = \text{John}$. Now, g can be considered to be SCF which selects a referent for a pronoun socially. Let us define g and the space as in (11). The assignment function g is updated throughout the discourse as in (12).

(11) a. $g = \{ \langle x, i \rangle : x \text{ refers to } i \}$

b. Information state σ consists of Social Welfare Function F , Social Choice Function g for variable assignment, individual's preferences R , individuals in the discourse X , a set of indices such as i , a set of discourse participants V , and relation between decisions B .

$\Sigma = \langle F, G, R, X, I, V, B \rangle$

(12) σ_1 There were ooh's and aah's when he_{x1} finished, and some unbridled laughter. Aileen_a was looking dubiously at her_{y1} husband_h but he_{x2} was in no mood to disapprove.

σ_2 He_{x3} winked at the Duke_d and called across to him_{x4}, 'What a grand thing, your Honour, to have a wedding without a minister!' The Duke_d did his_{x5} stately bow at that and then Donald_m was calling for another song.

σ_3 Some of the veterans_v were on the point of giving tongue but young Donald McCulloch_m was on his_{x6} feet and moving into the middle of the ring, he_{x7} was full of himself_{x8}, sparkling with mischief but with an undertow of ardour.

σ_4 'Duncan Ban MacIntyre_b wrote a song for his_{x9} wife Mary_r.

σ_5 I do not know if Alex_l used it to court his₁₀ Mary_r – he_{x11} must have used something — 'The joke was unconscious but crowing laughter came from the young men_n beside the whisky jar. (BNC A0N1311-1315, *King Cameron*)

(13) a. $g_1 = \{ \langle y_1, a \rangle, \langle x_2, h \rangle \}$

$I = \{ a, r \}$ (a: author, r: reader)

$S = \{ a, h \}$

b. $g_2 = \{ \langle x_3, h \rangle, \langle x_4, d \rangle \}$

$S = \{ a, h, d, m \}$

c. $g_3 = \{ \langle x_6, m \rangle, \langle x_7, m \rangle, \langle x_8, m \rangle \}$

$S = \{ a, h, d, v, m \}$

d. $g_4 = \{ \langle x_9, b \rangle \}$

$S = \{ a, h, d, v, m, b, r \}$

$$e. g5 = \{ \langle x10, l \rangle, \langle x11, l \rangle \}$$

$$S = \{ a, h, d, v, m, b, r, l, n \}$$

$$f. \llbracket her_y \rrbracket^{g1} = a$$

G is regarded as SCF. Also, the set of best elements S' can be called its choice set of the whole set of alternatives, and is denoted g(S', R) (cf. Sen 1979) R is a sequence of individual's preferences where R_x is a preference ordering of x.

$$(14) g1(S, R) = \{ a, h \}$$

$$g2(S, R) = \{ h, d \}$$

$$g3(S, R) = \{ m \}$$

$$g4(S, R) = \{ b \}$$

$$g5(S, R) = \{ l \}$$

As the author's dynamic preferences change in the discourse as in (15a), g is updated throughout the discourse by means of a relation B.

$$(15) a. \sigma 2: hR_a d \text{ for } he_{x3} \wedge dR_a h \text{ for } he_{x4} \wedge dR_a h I_a m \text{ for } he_{x5} \text{ (aI}_x \text{b: x is indifferent between a and b, } \wedge \text{: dynamic conjunction)}$$

$$b. \text{ Social Decision: } hRd \wedge dRh \wedge dRhIm$$

$$c. B(g_n, g_{n+1})$$

(16) Dynamic Social Welfare Function:

$$F_n B F_{n+1} B F_{n+2}, \dots$$

4 Comparison with Other Studies

Dynamic Predicate Logic (Groenendijk and Stokhof 1991) consider update semantics where two states differ with respect to variable assignment. When $h[x]g$, the state g is updated with respect to the assignment to x. The current paper consider an abstract function B between two SCFs. Parkes and Procaccia (2013) model dynamic decision making under constantly changing preferences using Markov decision processes, in which the states coincide with preference profiles and a policy corresponds to a social choice function.

5 Detection of Speaker Intention

In order to implement Dynamic Social Choice for pronoun disambiguation, speaker's intention needs to be detected from the text. The phrases such as "I mean" are used to resolve ambiguity of pronominal reference in the discourse. as in (17).

(17) '...And Sarah Morgan likes the idea of Angela marrying someone in the government.' McLeish considered this cold and rational assessment. 'When did you last see **her**? **Miss Angela Morgan, I mean.**' (BNC AB9)

Out of 18 instances of "I mean PNP" (PNP stands for proper name") found with the query "I mean N" in BNC, 7 instances had a preceding pronoun, the caraphor.

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