A Gold Anaphora Annotation Layer on an Eye Movement Corpus

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Abstract

Anaphora resolution is a complex process in which multiple linguistic factors play a role, and this is witnessed by a large psycholinguistic literature. This literature is based on experiments with hand-constructed items, which have the advantage to filter influences outside the scope of the study, but, as a downside, make the experimental data artificial. Our goal is to provide a first resource allowing to study human anaphora resolution on natural data. We annotated anaphorical pronouns in the Dundee Corpus: a corpus of $\sim$ 50k words coming from newspaper articles read by humans of whom all eye movements were recorded. We identified all anaphoric pronouns — in opposition to non-referential, cataphoric and deictic uses — and identified the closest antecedent for each of them. Both the identification of the anaphoricity and the antecedents of the pronouns showed a high inter-annotator agreement. We used our resource to model reading time of pronouns to study simultaneously various factors of influence on anaphora resolution. Whereas the influence of the anaphoric relation on the reading time of the pronoun is subtle, psycholinguistic findings from settings using experimental items were confirmed. In this way our resource provides a new means to study anaphora.

Keywords: Dundee Corpus, Personal Pronouns, Mixed Effects Modeling, Eye-Tracking

1. Introduction

How the human mind interprets pronouns has been a subject studied in psycholinguistics for a long time now. Many linguistic features have been shown to be of influence. They were discovered using experimental setup, for example by using ambiguous sentences and asking participants to choose an interpretation:

(1) Fred loves Pete, because he is always smiling.

In (1), people could be asked who the pronoun *he* refers to, and most would answer *Pete*, whereas in fact both *Fred* and *Pete* are possible answers. The preference for *Pete* depends mostly in this case on the verb *loves*, which belongs to the family of *implicit causality verbs* (Garvey and Caramazza, 1974). When reading (1), people automatically wonder what is so lovely about Pete. By manipulating different features in experiments (e.g. syntactic role, semantic role, information structure, implicit causality), many factors of influence were discovered. The effect of some factors is quite robust and was confirmed by studies using various experimental methods. However, we are not aware of any study on these factors that did not used hand-constructed experimental items. This is a reason why we wanted to test whether factors of influence on anaphora resolution would also show in other settings, like natural text reading. Finding an influence of these factors would strengthen the proof of their robustness, because —unlike in an experimental setting— unwanted properties cannot be filtered out. As natural data we used the English part of the Dundee Corpus: a resource of eye movement data from ten participants reading newspaper articles. We annotated all anaphoric personal pronouns in this corpus by identifying their antecedent. We then used the reading times from the corpus combined with our anaphora annotation to study the time course of the resolution of anaphorical pronouns. With a first series of models we focused particularly on the influence of distance between the anaphor and the antecedent, frequency of the antecedent and grammatical function of the antecedent and of the anaphor. In the remainder of this introduction we say a few words about these three factors; in section 2., we present our annotation layer and various measures of its quality; in section 3., we present a series of linear models we used, that show the benefits that can be drawn from our resource.

1.1. Distance

The distance between the pronoun and the antecedent is assumed to play an important role in pronoun resolution. Theories providing a saliency account for pronoun resolution, such as *Centering Theory* (Grosz et al., 1983; Grosz et al., 1995) or *Accessibility Theory* (Ariel, 1988; Ariel, 1991) state that (all other things being equal) a shorter distance between the pronoun and the antecedent makes the latter more *salient*. This means that the antecedent is easier to retrieve from memory. The influence of distance was studied in various psycholinguistic experiments (Clark and Sengul, 1979; Ehrlich and Rayner, 1983, e.g.) that confirmed that a longer distance increases comprehension, or reading times.

1.2. Frequency

When a pronoun is processed, the antecedent has to be recovered and its lexical frequency is of influence. However, several psycholinguistic studies found different effects of the frequency of the antecedent, in line with competing theories on the effect of frequency (Van Gompel and Majid, 2004). One, called *Full Reaccess Hypothesis*, predicts that the reactivation of the antecedent when the pronoun is read is very similar to normal lexical access during reading (Shillcock, 1982). Hence, an infrequent antecedent will provoke longer reading times. The other is called the saliency account and predicts that antecedents with lower lexical frequency are more salient (better marked) and therefore easier to recover, evoking shorter reading times (Pynte and Colonna, 2000).

1.3. Grammatical Function

Grammatical functions seems to play an important role in anaphoric resolution: on one hand, the ease of retrieving an antecedent seems to depend on its grammatical function. Many experiments —at least for English— found faster processing when the antecedent was in the subject position (Broadbent, 1973; Clancy, 1980; Frederiksen, 1981; Hobbs, 1976). On the other hand, the comparison of the function of the pronoun and its antecedent is also influential: an effect that has frequently been found is a faster processing of the pronoun when the anaphor and the antecedent have the same syntactic function (Maratsos, 1973; Sheldon, 1974; Smyth, 1994). We leave aside this last factor in this paper.

2. Language Resource

Our resource's name is APADEC: *Anaphorical Pronouns and their Antecedents in the Dundee Eye-Tracking Corpus* (Seminck and Amsili, 2017)[1]. It is an annotation layer on the English part of the Dundee Corpus (Kennedy and Pynte, 2005) which records eye-movement measures for English and French. Ten participants read 20 articles[2] of *The Independent* for a total of 51 502 tokens, 9 776 types and 2 368 sentences (Barrett et al., 2015). In total there are 2 123 personal pronouns in the corpus, from which 1 109 were labelled anaphoric (the other 1 014 being either deictic, non-referential, cataphoric, or having a split antecedent).

2.1. Annotation

We chose to have the corpus manually annotated by two annotators. We searched for instances of personal pronouns using a part-of-speech tag annotation of the corpus provided by Frank and others (2009) and Barrett et al. (2015). We then selected the pronouns that were used anaphorically, and annotated for each of them the closest mention of the antecedent, by marking its span of words (Table 1).

Table 1: An antecedent annotation example from the corpus

word nb	word form	POS	antecedent
1800	if	[IN]	
1801	the	[DT]	
1802	voters	[NNS]	
1803	did	[VBD]	
1804	not	[RB]	
1805	care	[VB]	
1806	about	[IN]	
1807	that,	[DT, ,]	
1808	they	[PRP]	1801-1802
...	...	...	...

First and second person pronouns were considered as non-anaphoric, as they have a deictic function. We did not annotate the referents of cataphoric pronouns and we also excluded split antecedent anaphoric pronouns from our data. We used the following procedure for annotation:

- Annotator 1 annotated the entire corpus.
- Annotator 2 was instructed by Annotator 1 and annotated separately 36 232 words of the corpus.
- Annotator 1 and 2 compared their annotations and decided upon all cases they did not agree on.
- Annotator 1 corrected the $\sim$ 15 000 remaining words of the corpus for mistakes.

2.2. Evaluation

To evaluate the inter-annotator agreement for distinguishing anaphoric from non-anaphoric pronouns, we used Cohen's κ, a measure of agreement adjusted for chance (Cohen, 1960; Artstein and Poesio, 2008). We found $\kappa = 0.88$ (Pedregosa et al., 2011) for the 36 232 words Annotator 1 and 2 annotated separately. This indicates a very good agreement. Second, we evaluated the identification of antecedents. Because this task consisted in giving the span of words that corresponds to the antecedent, there is no obvious set of labels available for this task, and therefore Cohen's κ is an inadequate measure. Even, if it were possible to consider every possible span of words in a text as a potential label, this does not resolve the problem that the spans two annotators identify can overlap, without being exactly the same. A metric that can handle non-categorical data is Krippendorff's α (Krippendorff, 1980). α is 1 minus the ratio between observed and expected agreement. Passonneau (2004), Passonneau (2006) and Artstein and Poesio (2008) propose various ways to adapt Krippendorff's α to the situation in which labels are sets. Disagreement can be quantified by various distance metrics to account for set similarity. See Table 2. We applied the α-metric to our data using the implementation provided in the NLTK-library (Bird et al., 2009), considering antecedent spans as sets of words. The scores are given in Table 2.

			α
binary distance	d_b =	0 if $s_1 = s_2$ 1 if $s_1 \neq s_2$	0.71
Jaccard distance	d_j=	$1 - \frac{\lvert s_1 \cap s_2 \rvert}{\lvert s_1 \cup s_2 \rvert}$	0.78
MASI-distance	d_M =	$d_j * M$, with $M =$ 0 if $s_1 = s_2$; $\frac{1}{3}$ if $s_1 \subset s_2$ or $s_2 \subset s_1$; $\frac{2}{3}$ if $s_1 \cap s_2 \neq \emptyset$ but $s_1 \not\subset s_2$ & $s_2 \not\subset s_1$; 1 if $s_1 \cap s_2 = \emptyset$	0.75

Table 2: Values of Krippendorff's α given various distances. s_1 and s_2 are sets of words

It is often assumed that $\alpha > 0{,}67$ is enough to support "cautious conclusions". In that light our annotation seems rather reliable. However, Passonneau (2006) and Artstein and Poesio (2008) warn that this is not a hard value and that it is heavily dependent on the data. We therefore also measured the reliability of the annotations by comparing both annotations to the final gold standard of our corpus. In the field of anaphora resolution, the information retrieval metrics of precision and recall (see Table 3) are often used to measure the quality of coreference chains (Vilain et al., 1995; Artstein and Poesio, 2008). For every anaphoric pronoun in our corpus, we calculated the precision and the recall by comparing the annotations of both annotators to the

[1] Freely available: `http://www.llf.cnrs.fr/apadec`

[2] It seems rather to be 20 sessions of reading, each session containing multiple articles.

gold standard. Every word in the annotated span that was also in the gold span was counted as a *true positive (tp)*. If a word occurred in the annotated span, but not in the gold span, it was treated as a *false positive (fp)*. A word that was in the gold span, but not in the annotated span was counted as a *false negative (fn)*. Table 3 gives the mean precision and recall of all the anaphoric pronouns in the corpus. Both annotators seem to obtain good scores. The differences between the scores can be explained by the fact that Annotator 2 sometimes annotated the right antecedent, but not its closest mention. Another reason is that Annotator 2 is an undergrad student, whereas Annotator 1 is a PhD student in linguistics.

	precision $\frac{tp}{tp+fp}$	recall $\frac{tp}{tp+fn}$	F_1
Annotator 1	0,93	0,92	0,93
Annotator 2	0,83	0,81	0,82

Table 3: precision/recall, annotators *vs.* Gold Standard.

3. Experiment

In this experiment we show how reading times for anaphoric pronouns can be modeled using our resource. Modeling reading times for pronouns is not straightforward, because they are often not fixated (Rayner, 1998). But this does not necessarily mean they are not read and processed. Kennedy and Pynte (2005) found evidence that unfixated words can be processed — at least on a lexical level — when they occur in the parafoveal vision. Another question is whether pronominal anaphora are processed the moment they are fixated in foveal (or parafoveal) vision, or whether the processing takes place later on in time. In their studies on pronoun reading, Ehrlich and Rayner (1983) and Van Gompel and Majid (2004) concluded that the retrieving process of the antecedent is initiated where the pronoun is encoded (a fixation on the pronoun itself, or a fixation very near to the pronoun on an adjacent word), but that the processing can be continued later.

3.1. Regions, Reading Time and Preprocessing

We used six regions to study the processing of the anaphoric pronoun: the word before, the pronoun itself and four words following. The word before the pronoun was included, because the pronouns we studied are often so short that they can be read in parafoveal vision when the word before the pronoun is fixated. For this first exploration of our corpus, we studied *first pass reading time*, a very commonly used measure. First pass reading time is the sum of all fixations from the moment a region is entered for the first time, until the eyes move to another region. To prepare for the modeling, we followed previous studies on the Dundee Corpus (Demberg and Keller, 2008; Frank and Bod, 2011) to clean the data. Fixations on words that had punctuation, or clitics attached were eliminated. We also eliminated fixations on words with capital letters. For our six regions we had between 2 593 and 4 173 data points left per region. Two other preprocessing steps we applied were a log-transformation on the reading times and scaling on numeric variables.

3.2. Mixed Effects Model

We used mixed effect models from the lme4 R-package (Bates et al., 2015) to study the factors having an influence on pronoun resolution. For each region a new model was made.

3.3. Factors

We can distinguish three types of factors in our study: random factors, control factors and the factors special to anaphoric relationships we introduced before (distance, frequency and grammatical role). Participants and instances of anaphoric pronouns are modeled with a random intercept. Our control factors are factors that are known to be of influence on reading times, such as word frequency and word length. Following other studies (Demberg and Keller, 2008; Frank and Bod, 2011) on the Dundee Corpus, we used the following control factors: for forward and backward probability from an n-gram model (Frank and Bod, 2011), length in characters of the region, log-frequency of the word in the region in the corpus itself and in the British National Corpus[3], log-frequency of the word previous to the region in the same two corpora and finally the launch and the landing position of the fixation with repect to the number of characters in the word in the region. The control factors are local for each region, in opposition to the factors of distance, frequency and grammatical function. These factors are constant over the six regions, because they consider the anaphoric relation that is not marked specifically on one of the words of the six regions. These factors are briefly presented below:

- dist-ant-begin: the distance in words between the antecedent and the beginning of the text
- same-sent-as-ana: the anaphor and the antecedent are in the same sentence
- dist-ant-ana-words: distance in words between the anaphor and its antecedent
- log-freq-dundee-head-ant: the log frequency of the syntactic head of the antecedent in the Dundee Corpus
- log-freq-bnc-head-ant: the log frequency of the syntactic head of the antecedent in the British National Corpus
- syntactic-role-ana: the grammatical function of the pronoun (subject, direct object or other)
- syntactic-role-head-of-antecedent: the grammatical function of the head of the antecedent (subject, direct object or other)

3.4. Results and Discussion

The results of the models can be found in Table 4. Each column under a region — 0 for the pronoun — represents a model for that region. The numbers for each factor are the model's coefficient estimate for that factor. A positive estimate indicates that a higher score for the factor increases the reading time. Collinearity did not play a major role within our pronoun-related factors. We will shortly discuss the distance, frequency and grammatical function factor below. Due to limited space here we will not discuss the

[3]The BNC counts were taken from: `https://www.kilgarriff.co.uk/bnc-readme.html`

Table 4: Models for the six regions for prediction first pass reading time.

Region	-1		0		1		2		3		4	
(Intercept)	5.481	***	5.350	***	5.385	***	5.399	***	5.411	***	5.412	***
forward probability	0.001		0.018		-0.009		0.002		-0.001		-0.004	
backward probability	-0.003		0.007		0.044	***	0.010		0.011		-0.008	
length in characters	-0.008		0.000		-0.021	**	-0.005		0.018	*	-0.005	
log-freq-dundee	-0.025	**	-0.014		-0.008		-0.002		0.005		-0.011	
log-freq-dundee previous word	-0.009		0.003		-0.015		0.024		-0.004		0.002	
log-freq-bnc	0.010		-0.011		-0.006		-0.019	*	0.010		0.001	
log-freq-bnc previous word	-0.110	**	-0.006		-0.013		-0.025	*	-0.001		0.002	
launch-pos-first-fix	-0.013	*	-0.011	*	-0.016	***	-0.012	*	-0.009		-0.008	
land-pos-first-fix	0.004		0.004		-0.002		0.005		-0.002		-0.009	
Distance Factors												
dist-ant-begin	-0.009		-0.001		0.011	*	0.004		-0.001		-0.001	
same-sent-as-ana True	-0.023		0.009		-0.013		-0.013		-0.015		-0.019	
dist-ana-ant-words	-0.010	*	0.005		0.002		0.003		0.009	*	0.005	
Frequency Factors												
log-freq-dundee-head-ant	0.002		0.005		0.006		0.006		-0.014		-0.022	*
log-freq-bnc-head-ant	0.001		0.003		-0.002		-0.000		0.010		0.016	
Grammatical Function Factors												
syntactic-role-ana subj	0.022		-0.007		-0.021		-0.049	*	-0.022		-0.014	
syntactic-role-ana other	0.005		0.006		-0.002		-0.006		-0.031		-0.026	
syntactic-role-head-of-antecedent subj	-0.008		-0.007		0.030		0.012		0.019		0.007	
syntactic-role-head-of-antecedent other	0.002		0.002		0.047	*	0.003		0.028		-0.015	

Significance : *** for $p < 0.001$; ** for $p < 0.01$ and * for $p < 0.05$.

control factors. Let's first have a look at the distance factors. It seems that a higher distance between the antecedent and the beginning of the text matters: antecedents early in the text are retrieved faster than those further in the text (see Table 4, region 1, $p < 0.05$). This could be explained by mechanisms such as the *first mention preference* that attributes greater saliency to early mentioned antecedents. There is also an effect of the distance between the pronoun and its antecedent. We observe that the word before the pronoun is read faster when the distance is longer (distance antecedent & pronoun, region -1, $p < 0.05$) and that the reading slows down later (region 3, $p < 0.05$). We think this means that the resolution of pronouns at a longer distance is delayed. Pronouns that are close to their antecedent could be resolved more immediately. When we have a look at our two frequency factors, we see that only the factor that takes into account the frequency of head of the antecedent in the Dundee Corpus is significant (region 4, $p < 0.05$) and the frequency of the head of the antecedent in the British National Corpus does not show significant effects. This result has a negative estimate, thus indicates that a higher frequency in the Dundee Corpus leads to faster reading times. However, we think that this finding cannot be interpreted as a result in favor of a theory that states that memory retrieval of the antecedent is similar to normal lexical retrieval. The frequencies in the Dundee Corpus are not very representative of general word-frequencies of the English language, because of the small size of the corpus. Therefore, we suggest that the effect is driven rather by the presence of the antecedent in a particular text. When we consider grammatical function we see that when the pronoun has a subject function, there is a speed up in region 2 ($p < 0.05$), in line with the saliency account, suggesting that pronouns are expected in the subject position. Finally, when looking at the grammatical function of the antecedent, we see that antecedents in a position other than the subject or object are processed slower (region 1, $p < 0.05$). This last result is also in line with the saliency account that states that subjects and direct objects are easier to retrieve from memory than other grammatical functions. With our first series of models we demonstrate how our resource APADEC can be used to study anaphoric pronoun resolution in a natural setting. The patterns we find in the results may serve to tease apart various psycholinguistic theories. We plan to use our resource to test more factors of influence, including also less-well studied factors, in the near future.

4. Conclusion

Many factors play a role in pronoun interpretation. The field of psycholinguistics revealed these factors in an experimental setting. Yet, the study of the interaction of these factors in a natural setting is new. Our resource APADEC — an annotation layer of anaphorical pronouns in the Dundee Eye-Tracking Corpus — provides a means to take a first step in this direction. Using the data from APADEC, we built mixed effect models to predict the first pass reading time. In our data we find significant effects of Distance, Frequency and Grammatical Role. The effects of the anaphoric relation on reading times are subtle, but despite this fact we were able to obtain significant results, showing the robustness of the effects and confirming psycholinguistic literature.

5. Acknowledgements

We thank Amandine Martinez for her help with the annotation. We thank Saveria Colonna, Barbara Hemforth and Yair Haendler for their helpful suggestions and comments. This work was supported by the Labex EFL (ANR-10- LABX-0083) and the Ecole Doctorale Frontières du Vivant (FdV) — Programme Bettencourt.

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