

Incremental Resolution of Relative Adjectives: A DRT-based Approach

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Abstract. This paper is concerned with the incremental interpretation of exophoric referring descriptions with relative gradable adjectives, such as the description in the instruction ‘*Pick up the tall glass*’. Relative adjectives such as ‘*tall*’ are typically considered subsective with respect to the denotation of the head noun and thus pose a challenge to incremental approaches that operate strictly from left to right. However, psycholinguistic research within the eye-tracking paradigm has shown that relative adjectives are interpreted incrementally: listeners interpret them in an incremental manner as they encounter them during processing, without need to wait until the head noun has been heard. Our aim in this paper is to provide a formal account of the incremental interpretation of deictic descriptions with relative gradable adjectives that reflects the psycholinguistic evidence. We propose a DRT-based treatment that combines the approach to incremental interpretation developed by Poesio and Rieser (2010, 2011) with the main ingredients of Van der Sandt’s (1992) presupposition-as-anaphora theory, as implemented by Bos (2003).

1 Introduction

A growing amount of psycholinguistic evidence shows that linguistic interpretation is incremental: humans process language incrementally, in (at least) a word-by-word fashion, rather than in one go once an utterance or a constituent boundary has been reached (Tanenhaus et al. 1995, Moore et al. 2008). In recent years, (computational) linguists have started to develop theories and systems that are more consistent with incremental psycholinguistic models. For instance, theoretical frameworks such as PTT (Poesio and Traum 1997, Poesio and Rieser 2010) and Dynamic Syntax (Cann et al. 2005) have developed formalisms that aim to build up semantic representations incrementally. Within computational approaches, a substantial amount of work has been devoted to the incremental interpretation of referring descriptions. Early computational work on this topic (e.g., Mellish 1985, Haddock 1989) modelled incremental reference resolution as a process of constraint satisfaction, where predicates are associated with sets of constraints. The core idea (taken up and refined by more recent approaches) is that, as a referring expression is processed from left to right, the constraints introduced by each predicate in the expression progressively narrow down the

set of potential referents. For instance, when interpreting the referring description ‘*the black wooden chair*’, processing ‘*black*’ would eliminate from the set of potential referents those elements in the context that are not black; processing ‘*wooden*’ would narrow down that set further to the subset of black elements that are made of wood; while finally processing ‘*chair*’ would pick up the chairs among the black wooden elements.

Relative adjectives (such as ‘*small*’, ‘*wide*’, ‘*large*’ and ‘*tall*’) pose a challenge to this approach because their denotation, and hence the way in which they constrain the set of candidate referents, is context-dependent. For instance, in a description such as ‘*the tall glass*’, the denotation of the adjective ‘*tall*’ appears to depend (possibly among other things) on the denotation of the head noun ‘*glass*’. This may seem to question the viability of an incremental approach that operates strictly from left to right. However, psycholinguistic research within the eye-tracking paradigm (Sedivy et al. 1999) has shown that relative adjectives are interpreted incrementally in a similar fashion to other non-context dependent expressions: listeners do not wait until the head noun is heard to start assigning an interpretation to pre-nominal relative adjectives, but interpret them in an incremental manner as they encounter them during processing.

Our aim in this paper is to provide a formal account of the incremental interpretation of exophoric referring descriptions with relative gradable adjectives that reflects the psycholinguistic evidence. We propose a DRT-based treatment that combines the PTT approach to incremental interpretation developed by Poesio and Rieser (2010, 2011) with the main ingredients of Van der Sandt’s (1992) presupposition-as-anaphora theory, as implemented by Bos (2003).

2 Evidence from Eye-tracking

In the experiments by Sedivy and colleagues (Sedivy et al. 1999), subjects wearing a head-mounted eye-tracker are shown an array of objects and are asked to pick up one of them with instructions such as ‘*Pick up the tall glass*’. Since subjects direct their gaze towards potentially referred objects, the precise information provided by the eye-tracker offers direct evidence about the alternative referents that are being considered by a subject at precise points in time and about the point at which a commitment to an interpretation is made. The displays used in the experiments were such that upon hearing the adjective, more than one referent was possible. For instance, one sample scenario included two objects that could be qualified as *tall*—the target glass and a jug—plus a key and a folder. The results that are more relevant for our purposes here can be summarized as follows: (i) *incremental interpretation*: upon hearing the adjective subjects looked at the two objects for which the adjective was applicable (the glass and the jug) and discarded the other objects (the key and the folder); (ii) *contrast effect*: in scenarios where a contrasting object was also in the display (e.g., a shorter glass) a preference for the target glass over the jug could be observed before the head noun was uttered, regardless of the semantic indeter-

minacy. That is, in these contrasting scenarios (with e.g. two glasses of unequal height) the identification of the target object took place *earlier*.

Our aim is to show that these findings can be explained by a formal theory of discourse if we assume a suitable lexical semantics for relative modifiers and adopt an incremental approach to reference resolution, as proposed by Poesio and Rieser (2011).

3 Lexical Semantics of Relative Gradable Adjectives

Within the Montague tradition, adjectives are typically treated as functions from properties to properties that take nouns as arguments $\langle\langle e, t \rangle, \langle e, t \rangle\rangle$. This acts as a general semantic type which arguably covers different classes of adjectives. For instance, it can be argued that predicative adjectives such as ‘*black*’ or ‘*wooden*’ are intersective: when they are combined with a noun, they yield the intersection of the denotation of the adjective and the denotation of the noun (a ‘*black chair*’ is both ‘*black*’ and a ‘*chair*’). Intersective adjectives can thus in practice be treated as simple one-place predicates and can easily be integrated within incremental models of interpretation that follow an incremental reference refinement approach. In contrast, relative adjectives such as ‘*tall*’ or ‘*small*’ have often been considered *subsective*—i.e., adjectives that, when combined with the noun they modify, denote a subset of the denotation of that noun. Treating relative adjectives as subsective noun modifiers, however, poses problems for strict incrementality because the denotation of the head noun (which has not yet been processed when the adjective is reached) is required as input to the adjectival function.

Kamp and Partee (1995), following up on earlier work by Kamp (1975) and Klein (1980), argue that relative adjectives, which at first sight appear to be subsective, are in fact intersective but context-dependent: their interpretation depends on a contextually provided *comparison class* C that does not need to be co-extensional with the head noun. For instance, even though the head noun accompanying ‘*tall*’ is the same in (1a) and (1b), the denotation of ‘*tall*’ seems to depend on a different comparison class in each of these examples.¹

- (1) a. My 2-year-old son built a really *tall snowman* yesterday.
- b. The linguistics students built a really *tall snowman* yesterday.

The idea behind this view is that, once C has been fixed by the context, relative adjectives can simply be treated as intersective. This is an attractive idea from the point of view of incrementality because (assuming a comparison class can be picked up from context) treating relative adjectives as context-dependent intersective predicates facilitates their incremental interpretation. Here we shall adopt this perspective and model relative gradable adjectives as triggers of a contrastive presupposition. In particular, we propose that relative adjectives presuppose the existence of a relevant comparison class, which they partition in

¹ Adapted from Kamp and Partee (1995, p. 142).

a non-trivial way: if an entity x is considered tall given a particular comparison class C , then there is some other entity y in C that is not considered tall and that acts as a sort of standard of comparison.²

We use the representation of presuppositions introduced in Bos (2003), which is based on Compositional DRT (Muskens 1996). A presuppositional expression is represented by an α -DRS, where the DRS on the left-hand side of the α operator is presuppositional and the DRS on the right-hand side corresponds to assertive content. For instance, (2) shows the lexical entries given by Bos (2003, p.195) for the definite article ‘*the*’ and the intersective adjective ‘*blue*’ (which is presupposition-free):

$$(2) \textit{the} : \lambda P. \lambda Q. (\left[\frac{x}{} \right]; P(x)) \alpha_x Q(x) \qquad \textit{blue} : \lambda P. \lambda x. (\left[\frac{}{\textit{blue}(x)} \right]; P(x))$$

The lexical entry we propose for the relative adjective ‘*tall*’ is given in (3). We use variables c, c_1, \dots, c_n for discourse referents that represent ontological categories or kinds. Here c stands for the comparison class, which is constrained to include at least one element y for which the relative property does not hold.

$$(3) \lambda P. \lambda x. (\left[\frac{y \ c}{\textit{is_a}(y, c)} \right] \alpha_{yc} \left[\frac{}{\textit{tall}(x)} \right]); P(x) \\ \left[\frac{}{\textit{tall}(y)} \right] \neg$$

In addition, we assume the following lexical axioms:

- (4) a. $\forall x. \textit{tall}(x) \rightarrow \textit{height_dim}(x)$
 b. $\forall x. \forall y. \forall c. [\textit{is_a}(x, c) \wedge \textit{is_a}(y, c) \wedge \textit{tall}(x)^c \wedge (y \geq_{\textit{height}} x) \rightarrow \textit{tall}(y)^c]$

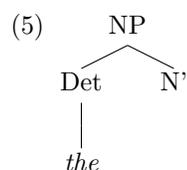
Axiom (4a) says that only entities which have a *height* dimension can be tall. We take *height_dim* to denote a set whose elements are ordered by $>_{\textit{height}}$. (4b) states an elemental fact about uni-dimensional gradable adjectives: if x is tall within a comparison class c , then any element in c with more height than x shall be considered tall as well (cf. Klein 1980). The idea behind this axiom is that even if we do not a priori know which elements count as tall in a domain, knowing the meaning of ‘*tall*’ implies knowing that (4b) holds.

4 Incremental Reference Resolution: Basics

To account for the psycholinguistic evidence regarding the incremental processing of relative adjectives in exophoric descriptions, we need to appeal to a theory of incremental interpretation. We adopt the PTT framework (Poesio and Traum

² This idea is behind most formal semantics approaches to relative gradable adjectives, those that use a degree semantics with standard thresholds (e.g., Kennedy 2007) as well as supervaluationist approaches such as Klein’s (1980).

1997, Poesio and Rieser 2010, 2011), which provides an account of incremental interpretation cast in terms of Compositional DRT. Unlike standard (S)DRT, in PTT the discourse context is incrementally updated whenever a new event is perceived, including events such as sub-sentential utterances, so-called *micro-conversational events* (MCEs). MCEs are characterized by lexical, syntactic, semantic, and discourse information. Poesio and Rieser assume the syntactic framework of Lexicalized Tree Adjoining Grammar. Thus, when a sub-utterance is processed, the discourse context is updated (among other things) with syntactic expectations about the ongoing utterance. For instance, processing an utterance of the definite article ‘*the*’ updates the context with the occurrence of an utterance of syntactic category Det and with the expectation that this MCE will be part of an NP that will include an utterance of syntactic category N’:



Semantic interpretation and reference resolution take place incrementally as syntactic expectations are being generated. Poesio and Rieser use the notion of *resource situation* familiar from Situation Semantics (Barwise and Perry 1983) to analyse deictic uses of definite NPs. The resource situation that supports the resolution of this kind of NPs corresponds to a context DRS that describes the visual situation in the attentional focus. Incremental resolution is then driven by one of the so-called *Principles for Anchoring Resource Situations*, PARS1, according to which, given a noun with semantics P , “the presence of an object Z of type P in a situation in mutual visual attention K_{mva} is grounds to hypothesize that K_{mva} is the resource situation of a definite description ‘*the P*’ and Z is the referent of the definite description” (Poesio and Rieser 2011, p. 251).

This default rule allows hearers to make hypotheses about the referent of an ongoing definite description, such as ‘*the apple on the mat*’, when the head-noun ‘*apple*’ is uttered. Note that PARS1 may be applied repeatedly: that is, if multiple referents are compatible with the description ‘*the apple...*’ in the resource situation, then multiple hypotheses are generated in parallel.

Although the focus of Poesio and Rieser is on nominals and pronouns, they briefly discuss an example of incremental reference resolution with a pre-nominal adjective, ‘*click on the red triangle*’ (§5.5). To account for the fact that processing ‘*red*’ may be sufficient to trigger reference resolution, they introduce a new default rule PARS1_{Adj}, which is equivalent to PARS1 except for the fact that the predicate P is not required to be the head of an NP but may be an adjective. How this approach could be applied to adjectives that are not plainly intersective, such as the relative gradable adjectives that concern us here, is considered an open question by the authors.

Note that we include a condition that describes the relative height of the objects in the display for which that dimension is applicable.⁴

- (7) Resource situation in visual setting with one glass (8) Resource situation in visual setting with two glasses of unequal height

v_0	x_0	y_0	z_0	c_1	c_2	c_3	c_4
$c_1 = \text{glass}$	$\text{is_a}(x_0, c_1)$						
$c_2 = \text{jug}$	$\text{is_a}(y_0, c_2)$						
$c_3 = \text{key}$	$\text{is_a}(z_0, c_3)$						
$c_4 = \text{folder}$	$\text{is_a}(v_0, c_4)$						
y_0	$>_{\text{height}} x_0$						

v_0	x_0	y_0	z_0	c_1	c_2	c_3
$c_1 = \text{glass}$	$\text{is_a}(x_0, c_1)$					
$c_2 = \text{jug}$	$\text{is_a}(y_0, c_2)$					
$c_3 = \text{key}$	$\text{is_a}(z_0, c_3)$					
					$\text{is_a}(v_0, c_1)$	
y_0	$>_{\text{height}} x_0$	$>_{\text{height}} v_0$				

Applying PARS1_{Adj} to (6) involves evaluating whether the adjectival predicate holds of particular objects in the resource situation. This requires generating hypotheses about the resolution of at least two anaphoric/presuppositional discourse referents: a comparison class c and a standard of comparison y . According to Van der Sandt’s (1992) theory of presupposition as anaphora resolution, resolving presuppositional elements is subject to either *binding* or *accommodation*. Binding proceeds by identifying the presupposed discourse referents with accessible referents, while accommodation creates an antecedent when a suitable antecedent cannot be found. In ambiguous situations, binding is preferred over accommodation—a preference that Bos (2003) implements as a scoring function over candidate interpretations.

We now have in place the main ingredients we need to account for the reference resolution behaviour observed in the eye-tracking experiments. Clearly, the two resource situations corresponding to the two different visual settings afford different resolution possibilities. In (7), c can be bound by either c_1 or c_2 and x by either x_0 or y_0 , respectively. Neither of these two binding possibilities, however, offers an antecedent for y , which therefore needs to be accommodated. This accommodation could correspond, for instance, to retrieving from memory a general standard of comparison, such as the prototypical height of glasses or jugs.⁵ In scenario (8), in contrast, resolving c to c_1 and x to x_0 allows y to be resolved via binding (to v_0) instead of via accommodation. In this case, the shorter

⁴ We assume ontological knowledge specifying that *height* is not applicable to ‘key’ and ‘folder’.

⁵ We can consider an additional possibility: the accommodation of a more abstract category such as “object” as antecedent for c . This would allow binding y to x_0 (the glass) and x to y_0 (the jug, which is taller than the glass). Assuming that “object” is not a salient category readily available in the resource situation, each of these resolution possibilities involves accommodation and hence there is in principle no reason to prefer one over the others. This is born out by the fact that in scenario (7), according to Sedivy et al. (1999), no clear fixations on a single object are observed until the noun is processed.

glass is considered the most contextually salient standard of comparison.⁶ The preference of binding over accommodation thus predicts that this candidate interpretation, which does not resort to accommodation, will be preferred—which is in line with the observed gaze fixations on the taller glass in contrasting scenarios such as (8), even before the onset of the head noun has been heard.

6 Conclusions

The challenge faced by any model of the interpretation of relative gradable adjectives in deictic definite descriptions lies in reconciling the relative character of these predicates (whose denotation is thought to depend on the denotation of the head noun they modify) with the experimental evidence showing, on the one hand, that they are interpreted incrementally, even before the head noun has been uttered, and, on the other, that contrastive contexts favour particular interpretations.

In this paper we have shown that this challenge can be addressed by integrating several independently motivated proposals. Firstly, we have followed Kamp and Partee (1995) in treating relative adjectives as intersective predicates that rely on a contextually provided comparison class with particular properties. Secondly, we have proposed that, given the semantics adopted, the early interpretation of relative adjectives can be explained in terms of the principles for incremental reference resolution put forward by Poesio and Rieser (2011), which account for the online generation of hypotheses regarding potential referents. Finally, we have shown that a basic principle of Van der Sandt’s (1992) theory of presupposition according to which binding is preferred over accommodation can act as a pruning mechanism that allows us to select a preferred interpretation amongst the generated hypotheses.

The current proposal is exploratory in many respects, if only because formal theories of incremental interpretation are still in its early stages. In spite of the highly promising recent developments within PTT regarding reference resolution, how semantic representations are built incrementally remains largely an open question (how should we represent the meaning of a fragment such as ‘*the tall...*’?). It seems clear that, regardless of the representations we work with and how they are built, incremental interpretation requires dealing with parallel hypotheses. How these hypotheses are ranked in terms of their plausibility also asks for further investigation. Here we have appealed to known mechanisms for anaphora/presupposition resolution, while in previous work we have suggested that mechanisms related to scalar implicature may be at play in other contexts (Fernández 2010). Overall, more theoretical and experimental work is needed, which ideally should not only look at English but take into account evidence from a variety of languages that differ in word order.

⁶ See DeVault and Stone (2004) for an implemented treatment of dynamic standards of comparison.

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