Monotonicity in quantifier verification

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Monotonicity is considered to be one of the key properties of languages both in logic and linguistics. In model theory it contributes to definability (see e.g. Väänänen and Westerståhl, 2002), in linguistics it is used, among other applications, to explain the phenomenon of negative polarity items (see e.g. Ladusaw, 1979). There are also strong links between monotonicity and learnability (see e.g. Tiede, 1999). Moreover, there are good reasons to believe that it is crucial for processing natural language expressions, as has already been suggested by psychologists (see e.g. Moxey et al., 2001), linguists and logicians (see e.g., Barwise and Cooper, 1981). In fact, Geurts (2003) shows that when it comes to reasoning in natural language downward monotone quantifiers, e.g., “No boy”, are more difficult than upward monotone quantifiers, e.g., “Every boy”.

Additionally, it has been shown by Just and Carpenter (1971) in sentence-picture verification experiments that processing time of negative quantifiers (incl. downward monotone) is greater than affirmative quantifiers (incl. upward monotone). Many theories have been proposed in psycholinguistic literature to account for these data. Most notably Clark and Chase (1972) introduced comparison model. In the model both a sentence and a picture are encoded in a positive propositional form and then compared in the verification process. The model explains variations among different sentences w.r.t. negativity. However, it is not clear how the model can be extended to cover generalized quantifiers. Furthermore, there is dissociation between negativity/affirmativity degrees and monotonicity. For example, both “at most 5” and “few” are downward monotone but while the first one is positive the second one is negative. Therefore, the model cannot really account for the monotonicity influence in the verification of quantifier sentences and in the paper we propose alternative model in the spirit of automata theoretic approach of van Benthem (1984) (see also Szymanik and Zajenkowski, 2010) with elements of Clark’s and Chase’s (1972) comparison theory.

In the paper we are interested in the influence of monotonicity on language comprehension. In our experiments we studied 2 groups of only affirmative quantifiers: numerical quantifiers (“more than 7”, “fewer than 8”) and proportional quantifiers (“more than half”, “fewer than half”). The first quantifier from every pair is upward monotone while the second is downward monotone. The task used in the study consisted of sixteen grammatically simple propositions in Polish containing a quantifier that probed a color feature of a car on a display (e.g. "more than half of the cars are red"). Subjects were asked to decide if the proposition accurately described the presented picture. We conducted two experiments.

The studies allow drawing the following conclusions. First of all, downward monotone numerical quantifiers are more difficult to verify than upward monotone numerical quantifiers. This is consistent with previous findings of Just and Carpenter (1971). However, our outcome differs from Just’s and Carpenter’s data. They found differences between negative and affirmative proportional quantifiers while there is no significant monotonicity effect in the case of the proportional quantifiers in our data. Therefore, we claim that the differences in latencies reported by Just and Carpenter are rather due to negativity effect than monotonicity. Moreover, Just’s and Carpenter’s material consisted of rather vague quantifiers (“majority”, “minority”, “about”, “large proportion”, “small proportion”) in comparison to determiners used in our tests. Therefore, those quantifiers can trigger different verification strategies, e.g., approximation vs. precise counting (cf. Hackl, 2009, Pietroski et al., 2009).

Moreover, we observed that the number of elements to count is crucial for the latency. In tasks when subjects had to count up to 8 (true “more than 7” statements and false “fewer than 8” statements) the answers were delayed comparing to the situation were counting only up to 7 was performed (false
“more than 7” statements and true “fewer than 8” statements). Moreover, there were no differences in tasks with proportional quantifiers which demand counting and comparing all objects in the universe.

Finally, we observed that in general proportional quantifiers are more difficult than numerical quantifiers. This is consistent with Szymanik and Zajenkowski’s (2010) theory which predicts complexity difference between numerical and proportional quantifiers. The first group of quantifiers can be recognized by finite-automata while for the second group one needs more powerful computational devices enriched by a form of working memory, like push-down automata. The results of the experimental studies verify the complexity based hypothesis by showing a significant increase in subjects’ reaction time between two groups of quantifiers. In the present studies effect size of reaction time analysis accounts for around 45% of variance, but in (Szymanik and Zajenkowski, 2010) that was over 90%. Therefore, from the difficulty perspective complexity distinction on quantifier classes with respect to the minimal automata explains more than monotonicity differences within quantifier classes.

References: