Understanding Quantifiers in Language

Jakub Szymanik     Marcin Zajenkowski

CogSci’09
**Motivations**

**Quantifiers and Minimal Automata**

**The Experiment**

**Conclusions and Perspectives**
COMPUTABILITY AND COGNITION

- A cognitive task is a computational task.
- Computational restrictions should be taken seriously:
  - Tsotsos, “Analyzing vision at the complexity level”, 1990
  - Frixione, “Tractable competence”, 2001
  - van Rooij, “The tractable cognition thesis”, 2008
  - CogSci09: Müller, van Rooij, & Wareham; Beal & Roberts.
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QUANTIFIERS DETERMINE EXPRESSIVITY

- All poets have low self-esteem.
- Some dean danced nude on the table.
- At least 3 grad students prepared presentations.
- An even number of the students saw a ghost.
- Most of the students think they are smart.
- Less than half of the students received good marks.
Brain activity during the comprehension of quantifiers:

- All quantifiers are associated with numerosity: recruit right inferior parietal cortex;
- Only higher-order activate working-memory capacity: recruit right dorsolateral prefrontal cortex;

- McMillan et al., “Neural basis for generalized quantifiers comprehension”, 2005
- Clark & Grossman, “Number sense and quantifier interpretation”, 2007
- Szymanik and Zajenkowski, “Improving methodology of quantifier comprehension experiments”, 2009
1 Motivations

2 Quantifiers and Minimal Automata

3 The Experiment

4 Conclusions and Perspectives
Aristotelian quantifiers

“all”, “some”, “no”, and “not all”

correct correct, incorrect

$q_0$ incorrect $q_1$

All sentences in my paper are grammatically correct.
CARDINAL QUANTIFIERS

E.g. “at least 3”, “at most 7”, and “between 8 and 11”

true, false

At least 3 sentences are false.
E.g. “an even number”, “an odd number”

An even number of the sentences in my paper is false.
**Proportional quantifiers**

- E.g. “most”, “less than half”, “one third”
- There is no finite automaton recognizing those quantifiers.
- We need internal memory.
- A push-down automata will do.
1 Motivations

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- RT will increase along with the computational resources.
Predictions

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- Parity qua. < cardinal qua. of high rank.
PARTICIPANTS

- 40 native Polish-speaking adults (21 female).
- Volunteers: undergraduates from the University of Warsaw.
- The mean age: 21.42 years (SD = 3.22).
- Each participant tested individually.
80 grammatically simple propositions in Polish, like:

1. Some cars are red.
2. More than 7 cars blue.
3. An even number of cars is yellow.
4. Less than half of the cars are black.
More than half of the cars are yellow.

An example of a stimulus used in the first study

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**PROCEDURE**

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- Each quantifier was presented in 10 trials.
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- Each quantifier problem was given one 15.5 s event.
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- Subjects were asked to decide the truth-value.
## Analysis of Accuracy

<table>
<thead>
<tr>
<th>Quantifier group</th>
<th>Examples</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aristotelian FO</td>
<td>all, some</td>
<td>99</td>
</tr>
<tr>
<td>Parity</td>
<td>odd, even</td>
<td>91</td>
</tr>
<tr>
<td>Cardinal FO</td>
<td>less than 8, more than 7</td>
<td>92</td>
</tr>
<tr>
<td>Proportional</td>
<td>less than half, more than half</td>
<td>85</td>
</tr>
</tbody>
</table>

The percentage of correct answers
Analysis of RT

- Increase in RT was determined by the quantifier type ($F(2.4, 94.3) = 341.24; p < 0.001; \eta^2 = 0.90$)
- Pairwise comparisons: all four types of quantifiers differed significantly from one another.
- The mean reaction time increased as follows: Aristotelian, parity, cardinal, proportional.
COMPARISON OF REACTION TIMES

Average reaction times in each type of quantifiers

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CONCLUSIONS

- Plausibility of the model.
- Aristotelian easier than parity:
  loops influence the complexity of cognitive tasks.
- Cardinal harder than parity:
  number of states influences hardness more than loops.
- Proportional quantifiers involve working-memory capacity.
- Humans are constrained by computational resources.
PERSPECTIVES

- Comprehension strategies?
Comprehension strategies?
Comprehension and working memory?
Perspectives

- Comprehension strategies?
- Comprehension and working memory?
- Comprehension and brain?
Thank you!