

UNDERSTANDING QUANTIFIERS IN LANGUAGE

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CogSci'09

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OUTLINE

- 1 MOTIVATIONS
- 2 QUANTIFIERS AND MINIMAL AUTOMATA
- 3 THE EXPERIMENT
- 4 CONCLUSIONS AND PERSPECTIVES

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- 1 **MOTIVATIONS**
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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.

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.

PREVIOUS INVESTIGATIONS

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, “A note on a neuroimaging study of natural language quantifiers comprehension”, 2007



Szymanik and Zajenkowski, “Improving methodology of quantifier comprehension experiments”, 2009

OUTLINE

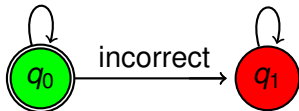
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ARISTOTELIAN QUANTIFIERS

“all”, “some”, “no”, and “not all”

correct

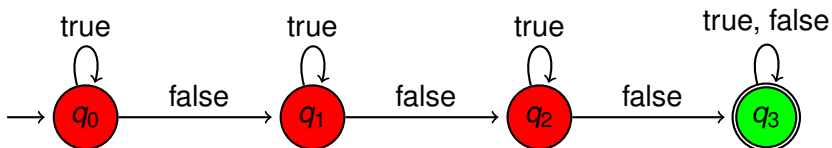
correct, incorrect



All sentences in my paper are grammatically correct.

CARDINAL QUANTIFIERS

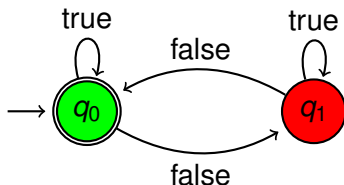
E.g. “at least 3”, “at most 7”, and “between 8 and 11”



At least 3 sentences are false.

PARITY QUANTIFIERS

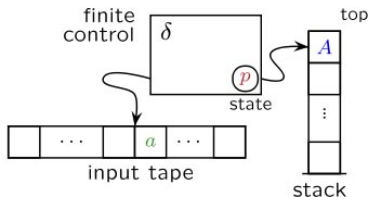
E.g. “an even number”, “an odd number”



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.



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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.

MATERIALS

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.

MATERIALS CONTINUED

More than half of the cars are yellow.



An example of a stimulus used in the first study

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- **Quantity of target items near the criterion of validation.**
- Practice session followed by the experimental session.
- Each quantifier problem was given one 15.5 s event.
- Subjects were asked to decide the truth-value.

ANALYSIS OF ACCURACY

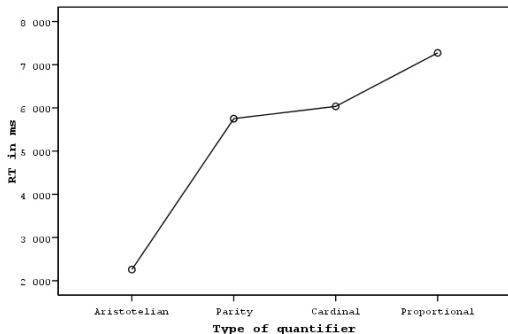
Quantifier group	Examples	Percent
Aristotelian FO	all, some	99
Parity	odd, even	91
Cardinal FO	less than 8, more than 7	92
Proportional	less than half, more than half	85

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?

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- Comprehension and working memory?

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- Comprehension strategies?
- Comprehension and working memory?
- Comprehension and brain?

Thank you!