Computational Insights into Meaning

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AIMS OF THE TALK

- To illustrate the research:
  - Without going into technicalities.
  - By means of intuitive examples.
- 2 pieces:
  - Common idea: meaning is a computation.
  - Empirical ongoing research and formal study.
- To show that there is a link with external world.

Plan

1. Quantifiers' comprehension
   - Experiment
   - How computations can account for that?
2. Computational perspective on collectives
   - Introduction
   - Main observation (with J. Kontinen)

Outline

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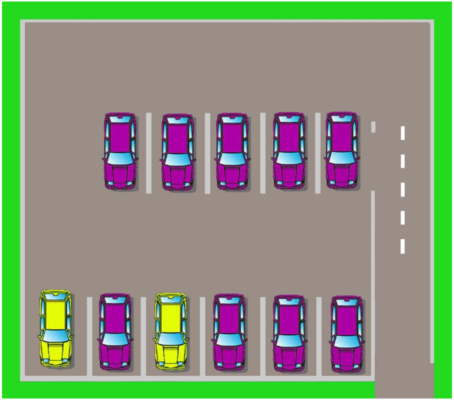
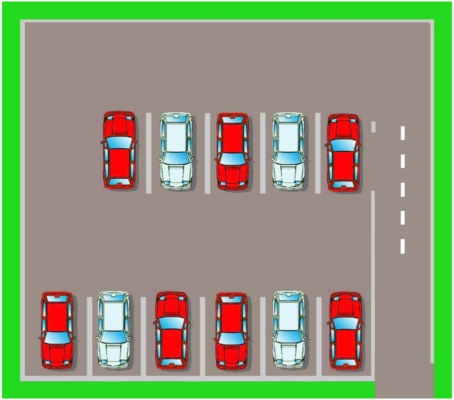
Task 1

Some cars are yellow.



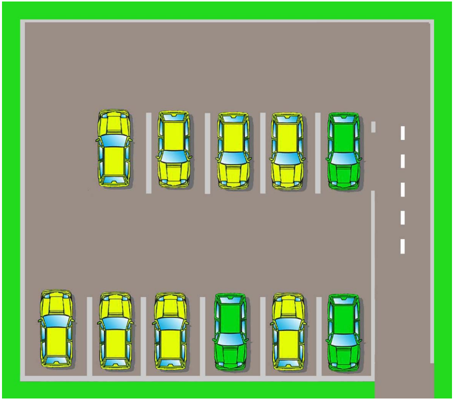
Task 2

At most 6 cars are red.



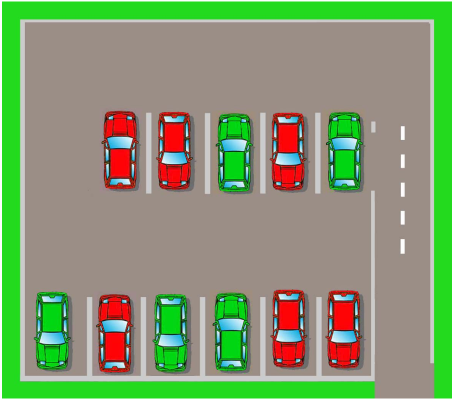
Task 3

An even number of cars is yellow.



Task 4

Most of the cars are green.



NEUROIMAGING RESULTS

- McMillan et al. (2005) measured brain activity.
- Subjects were judging the truth-value of sentences.
- They compared FO and non-FO quantifiers.
- FO judgments: 92,3% , non-FO: 84,5%.
- FO and non-FO recruit right inferior parietal cortex – the region of brain associated with number knowledge.
- Only non-FO recruit right dorsolateral prefrontal cortex – the part of brain associated with working memory.

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FEEDING COMPUTER

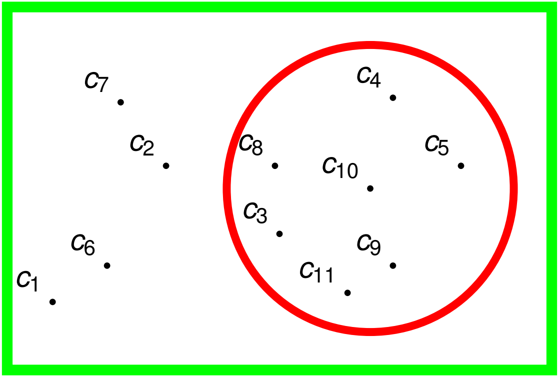
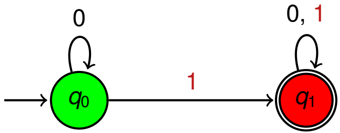


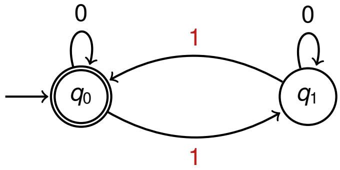
FIGURE: This model is uniquely described by $\alpha_M = 00111001111$.

Computing quantifiers

- Some of the digits are 1s.



- There is an even number of 1s.



- Most of the digits are 1s.

In general

definability	example	recognized by	memory
FO	some	acyclic FA	finite
$FO(D_n)$	even	FA	finite but reused
Pr	most	PDA	unbounded

TABLE: Johan van Benthem (1986), Marcin Mostowski (1998).

Ongoing project (with Warsaw Psychology Lab)

- Verify neurological findings by:
  - Reaction time;
  - Memory overload;
- Apply fine-grained complexity distinctions.
- Not only FO vs. non-FO but also:
  - Aristotelean vs. cardinal quantifiers;
  - Divisibility vs. most.

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Motivations

- Complexity depends on the quantifiers.
- Mainly distributive determiners are considered.
- However, plural objects are becoming important.
- E.g. in game-theory, where groups of agents are acting.

TWO EXAMPLES

(1.) Tikitu and Samson lifted the poker table together.

(2.) Most groups of students played Hold'em together.

SHIFTING STRATEGY

(1.) Five people lifted the table.

(1'.) $\exists^{=5} x[\text{People}(x) \wedge \text{Lift}(x)]$.

(1''.) $\exists X[\text{Card}(X) = 5 \wedge X \subseteq \text{People} \wedge \text{Lift}(X)]$.

(2.) Some students played poker together.

(2'.) $\exists X[X \subseteq \text{Students} \wedge \text{Play}(X)]$.

OUTLINE

Collective "Most"

(1.) Most groups of students played Hold'em together.

(1'.) $\textsc{Most}\, X, Y[\mathrm{Students}(X), \mathrm{Play}(Y)]$.

Definition

$\textsc{Most} = \{P, S \subseteq \mathcal{P}(M) \text{ and } \mathrm{card}(P \cap S) > \mathrm{card}(P \setminus S)\}$.

Theorem

Theorem

If the quantifier MOST *is definable in second-order logic, then counting hierarchy,* CH *is equal polynomial hierarchy,* PH*. Moreover,* CH *collapses to its second level.*

Proof.

The logic FO(MOST) can define complete problems for each level of the CH (Kontinen&Niemisto'06). If MOST would be definable in SO, then FO(MOST) $\leq$ SO and therefore SO would contain complete problems for each level of the CH. This would imply that CH $=$ PH and furthermore that CH $\subseteq$ PH $\subseteq C_2P$. □

Conclusions

- All lifts studied in the literature are SO-definable.
- It is unlikely that *any* SO-lift can do the job.
- Type-shifting strategy is probably not general enough.
- We observed it through computational complexity.

More details in:

J. Szymanik
A Note on Some Neuroimaging Study of Natural Language Quantifiers Comprehension.
Neuropsychologia, Volume 45, Issue 9, 2007, pp. 2158–2160.

J. Kontinen and J. Szymanik
A Remark on Collective Quantification,
Journal of Logic, Language and Information , Volume 17, Number 2, 2008, pp. 131–140.