CCOBRA and the PRECORE Modeling Challenge

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- Long history of research in human reasoning
- Achievements:
    - Psychological phenomena
    - Statistical effects
- Cognitive models integrating theoretical assumptions

Some researchers are logicians
Some logicians are professors

What, if anything follows?

Some researchers are logicians
Some logicians are professors

No Valid Conclusion

The Atmosphere Theory (Woodworth & Sells, 1935)

- Conclusion is derived from premise quantifiers
- Feature extraction:
    - Universality: All/No vs. Some/Some ... not
    - Valence: All/Some vs. No/Some ... not
- Conclusion generation from combining the premise features
- No prediction about the direction of the conclusion terms

Quantifiers	All	Some	No	Some ... not
All	All	Some	No	Some ... not
Some	Some	Some	Some ... not	Some ... not
No	No	Some ... not	No	Some ... not
Some ... not	Some ... not	Some ... not	Some ... not	Some ... not

Heuristics	Formal Rules	Diagrams, Sets & Models
Atmosphere	PSYCOP	Euler Circles
Matching	Verbal Substitutions	Venn Diagrams
Conversion	Source-Founding	Verbal Models
Probability Heuristics	Monotonicity	Mental Models

Syllogism	Premises	Percentage of putative conclusions								
		Aac	Eac	Iac	Oac	Aca	Eca	Ica	Oca	NVC
AA1	Aab, Abc	81	2	6		1		1		1
AA2	Aba, Acb	35	1	3		48	1	4		1
AA3	Aab, Acb	47	1	6		7		1		31
AA4	Aba, Abc	49	1	12		10		4		22
AI1	Aab, Ibc	2	1	70	1			4		16
AI2	Aba, Icb	2	1	20				71		4
AI3	Aab, Icb	2	1	13	1			43		37

Table 7

Predicted Responses for Each Syllogism From Seven Theories of Syllogistic Reasoning

| Syllogism	Atmosphere	Matching	Conversion	PHM	PSYCOP	Verbal models	Mental models
				Valid syllogisms			
AA1	Aac, Aca	Aac, Aca	Aac, Aca	Aac, Aca, Iac, Ica	Aac, Iac, Ica	Aac	Aac, Aca, Ica
AA2	Aac, Aca	Aac, Aca	Aac, Aca	Aac, Aca, Iac, Ica	Aca, Iac, Ica	Aca	Aca, Aac, Iac
AA4	Aac, Aca	Aac, Aca	Aac, Aca	Aac, Aca, Iac, Ica	Iac, Ica	NVC, Aca	Aac, Aca, Iac, Ica
AI2	Iac, Ica	Iac, Ica, Oac, Oca	Iac, Ica	Ica, Oca	Iac, Ica, Oac, Oca	Ica	Ica, Iac
AI4	Iac, Ica	Iac, Ica, Oac, Oca	Iac, Ica	Iac, Oac	Iac, Ica, Oac, Oca	NVC, Ica	Iac, Ica
AE1	Eac, Eca	Eac, Eca	Eac, Eca	Eac, Oac	Eac, Eca, Iac, Ica, Oac, Oca	Eac	Eac, Eca
AE2	Eac, Eca	Eac, Eca	Eac, Eca	Eca, Oca	Oac, Iac, Ica	NVC, Eca	Eac, Eca, Oca, Oac, NVC
AE3	Eac, Eca	Eac, Eca	Eac, Eca	Eca, Oca	Eac, Eca	NVC, Eac, Eca	Eac, Eca
AE4	Eac, Eca	Eac, Eca	Eac, Eca	Eac, Oac	Oac, Iac, Ica	NVC, Eac	Eac, Eca, Oac, Oca, NVC
AO3	Oac, Oca	Iac, Ica, Oac, Oca	Oac, Oca	Oca, Ica	Oca, Ica, Iac	NVC, Oca	Oac, Oca, NVC
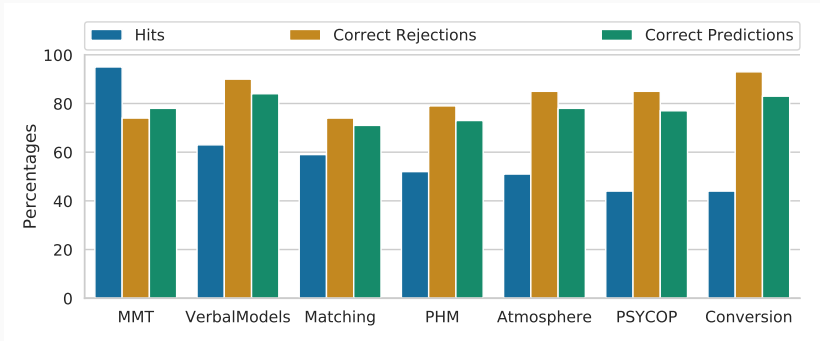
- Models are able to account for aggregate data well
- Suggests a fundamental grasp of the "average" reasoning processes
- But, recent work on group-to-individual generalizability suggests potential for problems

Can we apply current models to predict individual reasoning behavior?

Individual Results
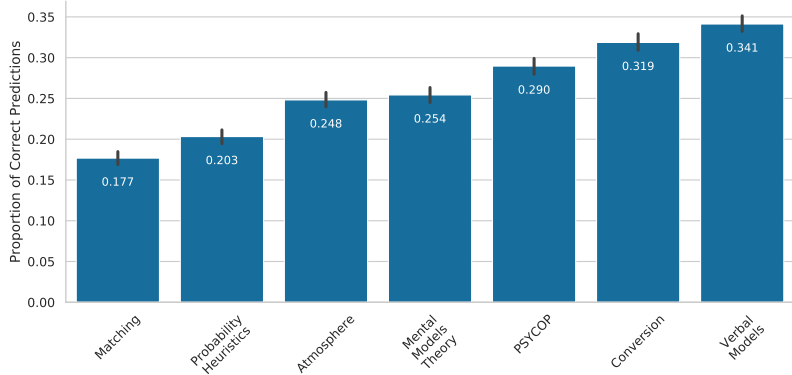
- Aggregate performance does not generalize well to individual reasoning
- Why is this the case?
    - Noisy data?
    - Suboptimal implementation (focus on aggregates)?
    - Lacking theoretical assumptions?
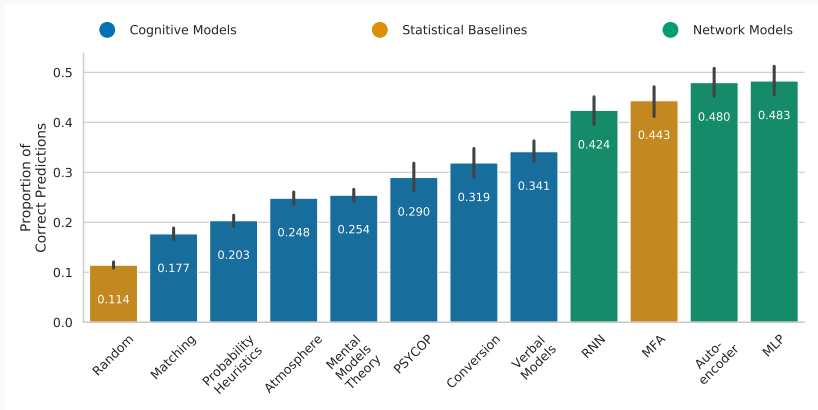
We need to establish benchmarks of cognitive models on individual (trial-based) data and improve model implementations!

What should we expect from cognitive models?

What is a Cognitive Model

"Cognitive scientists seek to understand how the mind works. That is, we want to describe and predict people's behavior, and we ultimately wish to explain it, in the same way that physicists predict the motion of an apple that is dislodged from its tree (and can accurately describe its downward path) and explain its trajectory (by appealing to gravity)."

[Farrell & Lewandowsky, 2018]

"Cognitive modeling is an area of computer science that deals with simulating human problem-solving and mental processing in a computerized model. Such a model can be used to simulate or predict human behavior or performance on tasks similar to the ones modeled and improve human-computer interaction."

[Margaret Rouse, SearchEnterprise.ai]

A cognitive model should be descriptive, predictive, and explanatory, and should focus on simulating human problem-solving and mental processing.

"What I Cannot Create, I Do Not Understand"
                                    [Richard Feynman]

Cognitive Models are Descriptive ✔
Cognitive Models are Predictive
Cognitive Models allow for Simulation

Cognitive Models are Descriptive ✔
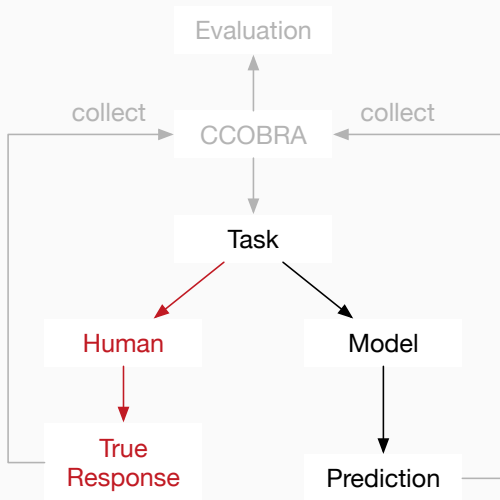Cognitive Models are Predictive ?
Cognitive Models allow for Simulation

Cognitive Models are Descriptive ✔

Cognitive Models are Predictive ?

Cognitive Models allow for Simulation ✘

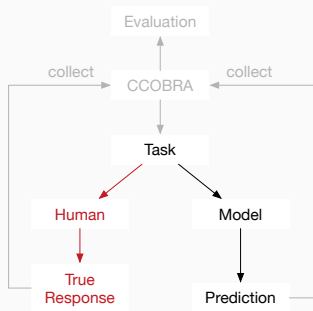We need to establish simulatory predictive benchmarks for cognitive models.

The CCOBRA Framework

- Simulate the data-generating experiment
- Models predict individual responses
- No restrictions wrt. formalisms (e.g., probabilistic, logic)
- Evaluation based on accuracy of predictions

Learning/Fitting Phases

- Pre-Training:
  - General parameter fitting
  - Unrelated dataset
  - Before entering prediction phase
- Individual Adaption:
  - After predictions are generated
  - CCOBRA provides true participant response
  - Allows for the integration of inter-individual effects

Prediction Phase

1. Iterate over participants in the dataset
2. Iterate over individual trials for this participant
3. Query model for a precise prediction
4. Compare prediction with true response (hits/misses)

Available Online

- Syllogistic Reasoning
- Spatial-Relational Reasoning
- Propositional Reasoning

In Preparation

- Conditional Reasoning
- Modal Reasoning
- Nonmonotonic Reasoning

CCOBRA is focused on easy extensibility.

The PRECORE Challenge

The PRECORE Challenge

- Invite researchers from different fields (AI, CogSci, ...)
- Establish a future-proof benchmarking challenge
- Create a well-defined goal for research

- Modeling Task:
  Predict individual human syllogistic reasoning

- Model Input:
  - Task: `"Some;models;managers/All;models;clerks"`
  - Choices: nine syllogistic response options

- Model Output:
  Specific syllogistic conclusion (one out of the nine choices)

Two Novel Models for Syllogistic Reasoning

- Dr. Emmanuelle-Anna Dietz Saldanha & Robert Schambach
  - Weak-Completion Semantics (WCS)[1]
  - Nonmonotonic three-valued logics
  - Individulization by de-/activating inference principles
- Marco Wilhelm
  - Max. Entropy Model
  - Novel approach to modeling syllogistic reasoning
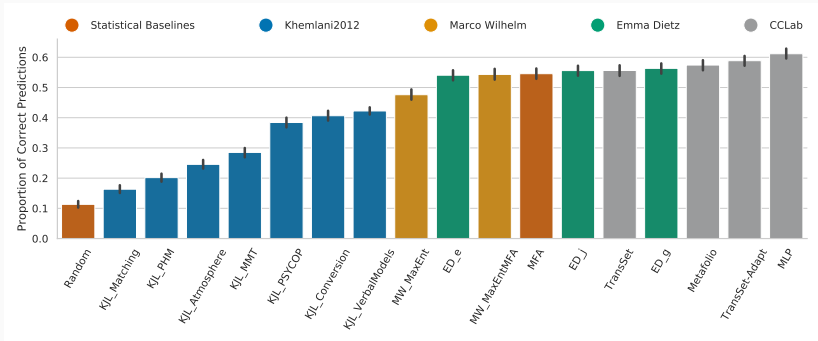 - Will be presented in the next talk

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[1]da Costa et al. (2017)

Evaluation Setting

- Unpublished dataset:
  - Lab experiment at the university of Freiburg
  - $N = 53$ participants
  - Responses for all 64 syllogisms
- Leave-one-out crossvalidation:
  - Evaluate predictions for 1 participant, train on the 52 remaining ones
  - Cycle through all participants and report the average result
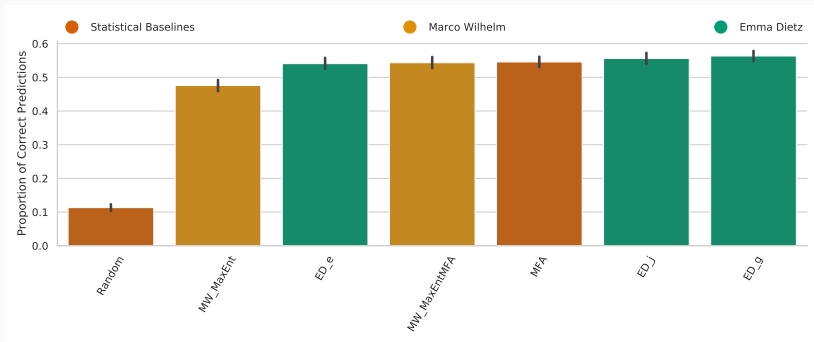
- Predictive modeling of syllogistic reasoning is possible!
  - Predictions should be at the core of model evaluation
  - Integration of more and more effects should necessarily lead to better predictions
- There is potential left for better cognitive models
- Researchers should not be afraid to investigate novel approaches
  - Formal logics (MaxEnt, WCS)
  - Subsymbolic approaches

References

da Costa, A. O., Dietz Saldanha, E. A., Hölldobler, S., & Ragni, M. (2017). A
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behavior. *Cambridge University Press*.

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meta-analysis. *Psychological bulletin*, 138(3), 427–457.

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Human Cognition: Upper Bounds and a New Perspective on Performance. In
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Journal of Experimental Psychology, 18, 451–460.

Find CCOBRA on

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https://github.com/CognitiveComputationLab/ccobra
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