

# Modeling Human Syllogistic Reasoning: The Role of “No Valid Conclusion”

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No scientists are gods

No scientists are immortals

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What, if, anything, follows?

No scientists are gods

No scientists are immortals

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No Valid Conclusion

# Syllogistic Reasoning

- Quantified statements  
(All, Some, Some ... not, No)
- Two premises consisting of three terms  
(A, B, C)
- Premises are related via the middle  
term B
- Eight possible conclusions relating end  
terms A and C or “No Valid  
Conclusion” (NVC)
- Total of 64 distinct syllogisms

All A are B

Some B are not C

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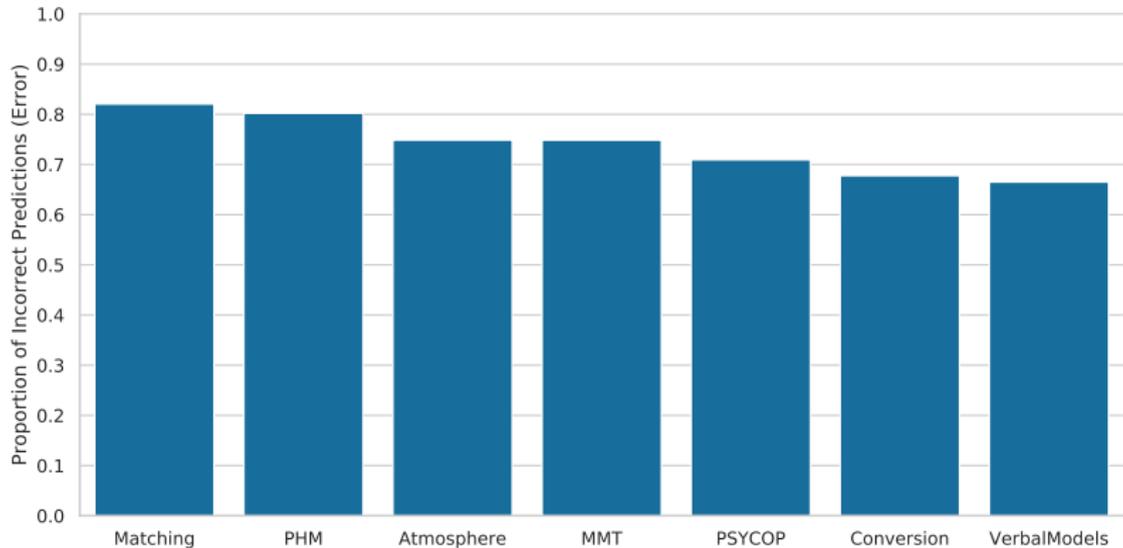
What, if anything, follows?

111 years

# Theories of the Syllogism (Khemlani & Johnson-Laird, 2012)

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

# Predictive Performance (Brand, Riesterer & Ragni, 2019)



# Observation: Predictive Performance

- Models predictions are suboptimal
- Theories well-founded in statistical and psychological phenomena
  - Focus on investigating isolated effects
  - Models created to be compatible
  - Often use logics as guiding principle
- However, current models make unsuitable predictions
  - Do not leverage predictive power of the effects
  - Lacking focus on predictive properties of the domain
  - Example: handling of invalid syllogisms

# No Valid Conclusion

Proportions of responses to syllogistic problems.

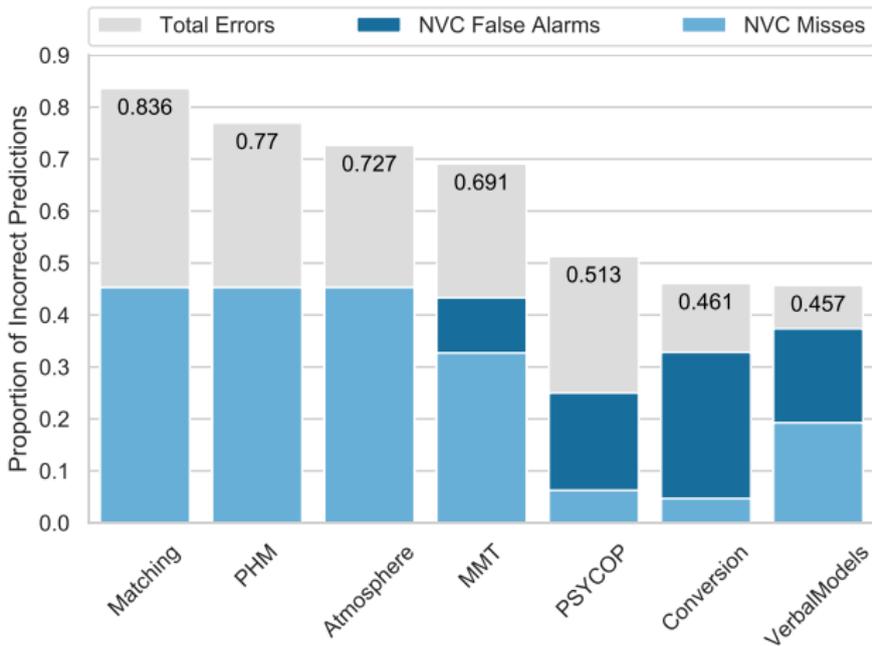
	Aac	Aca	Iac	Ica	Eac	Eca	Oac	Oca	<b>NVC</b>
Ragni2016 <sup>1</sup>	3%	2%	13%	11%	9%	8%	13%	13%	<b>28%</b>
Khemlani2012 <sup>2</sup>	4%	1%	13%	7%	13%	7%	12%	8%	<b>30%</b>

- Logically correct conclusion for the majority of tasks ( $37/64 \approx 58\%$ )
- Most-frequently selected response for a large part of the domain (Ragni2016:  $28/64 = 44\%$ , Khemlani2012:  $24/64 = 38\%$ )
- Most-frequently selected response overall
- Ambiguous interpretation possible

<sup>1</sup><https://github.com/CognitiveComputationLab/ccobra>

<sup>2</sup>Khemlani & Johnson-Laird, 2012 (additionally contains 6% "Misc" responses)

# Model Predictions



# Mental Models Theory: mReasoner (Khemlani & Johnson-Laird, 2013)



No B are A  
No B are C

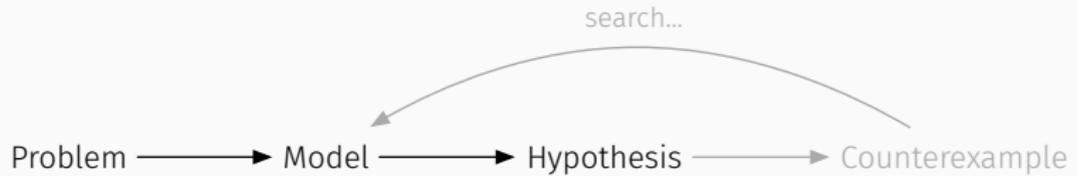
# Mental Models Theory: mReasoner (Khemlani & Johnson-Laird, 2013)



No B are A
No B are C

-A	B	-C
A		
		C

# Mental Models Theory: mReasoner (Khemlani & Johnson-Laird, 2013)

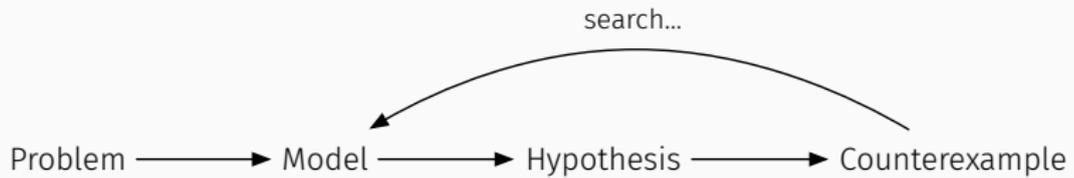


No B are A  
No B are C

-A	B	-C
A		
		C

No A are C

# Mental Models Theory: mReasoner (Khemlani & Johnson-Laird, 2013)



No B are A  
No B are C

-A	B	-C
A		
		C

No A are C

A	-B	C
-A	B	-C

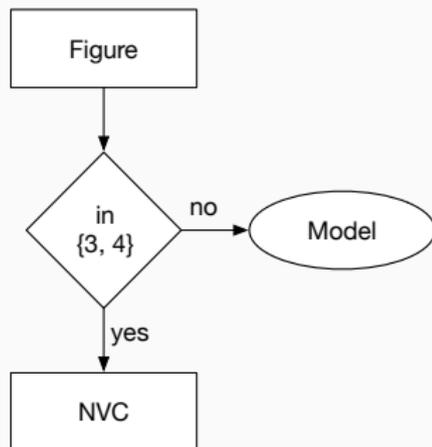
- NVC is a major source of error for syllogistic models
- Suggests suboptimal approaches for handling NVC:
  - Termination criterion for search exhaustion (e.g., mental models theory)
  - Completely ignored (most heuristics)
- Few heuristics to directly infer NVC exist

# NVC Heuristics

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Rule	Description
Figural	Syllogism of Figure 3 or 4
Negativity	Both quantifiers in { <i>Some...not</i> , <i>No</i> }
Particularity	Both quantifiers in { <i>Some</i> , <i>Some...not</i> }
PartNeg	Both quantifiers in { <i>Some</i> , <i>Some...not</i> , <i>No</i> }
EmptyStart	Transitive path starts with <i>No</i>

- Figural Bias Effect<sup>3</sup>:  
The order of terms influences solutions.
- NVC is preferred for
  - AB-CB (Figure 3)
  - BA-BC (Figure 4)

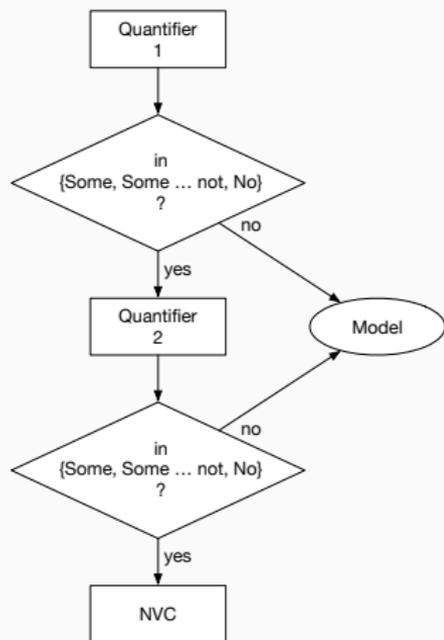


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<sup>3</sup>Johnson-Laird & Bara, 1984

# Particularity, Negativity & PartNeg

- Informativeness<sup>4</sup>:
  - All > Some > No  $\approx$  Some...not
  - Non-informative (negative) quantifiers do not add information (Negativity)
- Similar response insecurity possible for particular quantifiers (Particularity)
- PartNeg combines both Negativity and Particularity



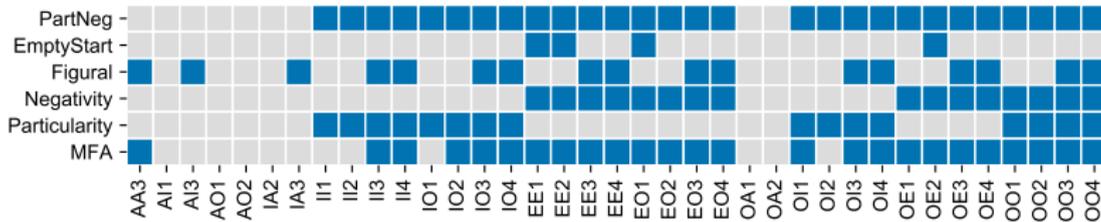
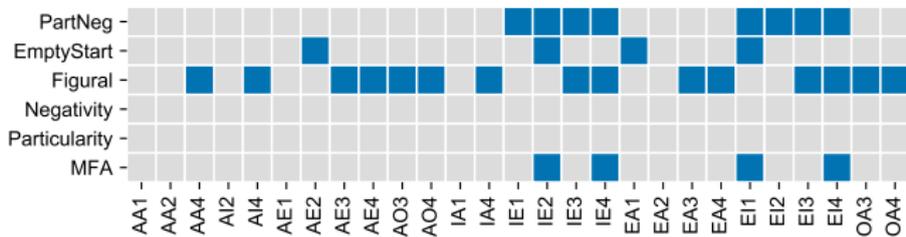
PartNeg rule.

<sup>4</sup>Probability Heuristics Model (Chater & Oaksford, 1999)

# Analysis

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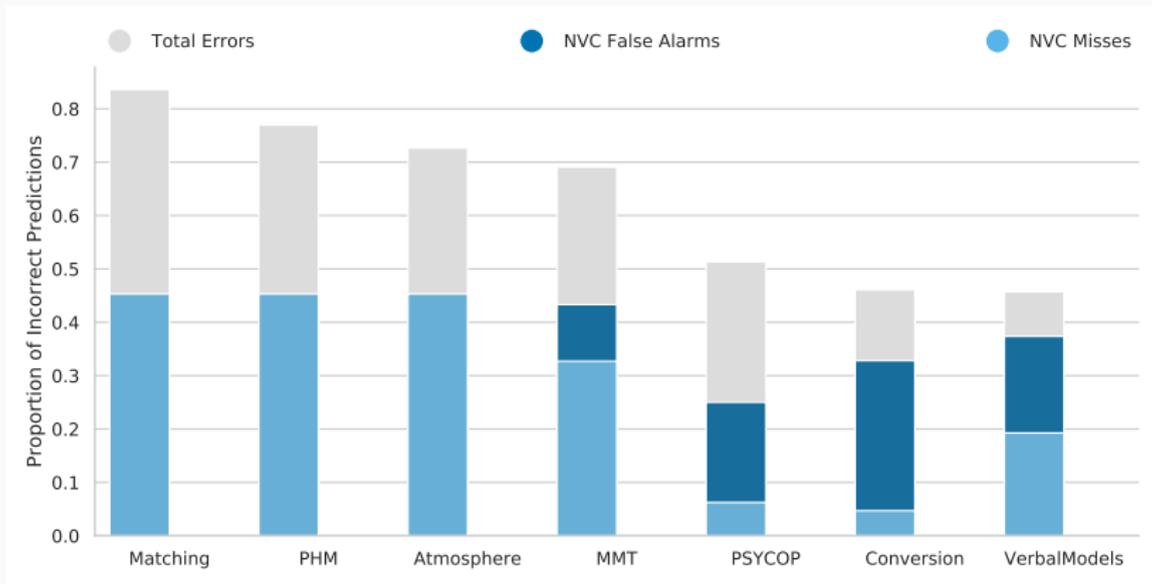
# NVC Predictions



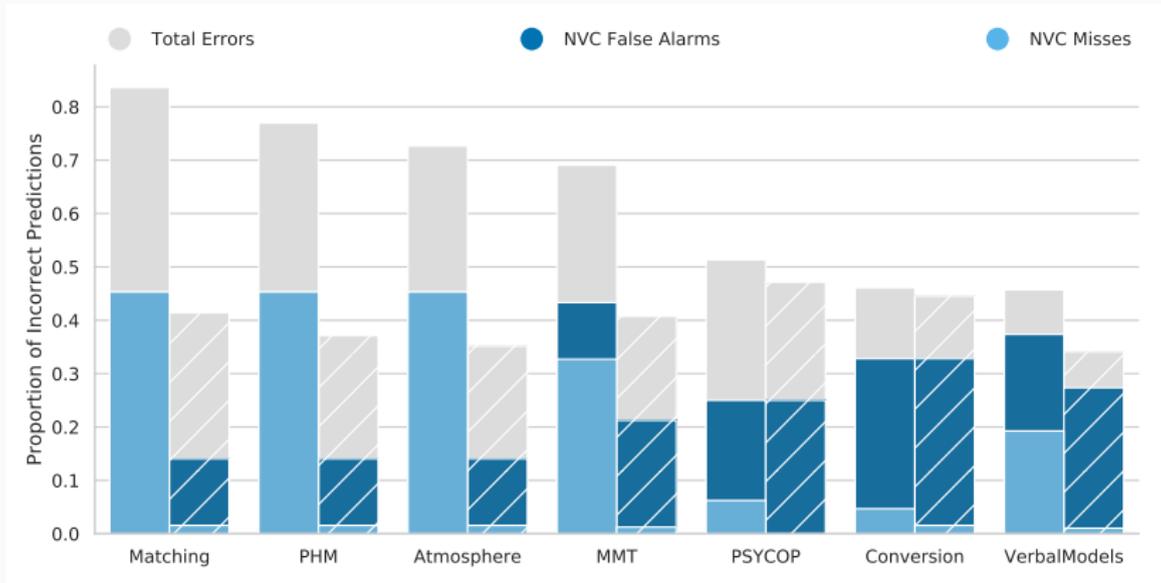
NVC rule predictions for valid (top) and invalid (bottom) syllogisms. MFA (bottom row) shows the syllogisms for which NVC is the most-frequent answer by participants (Ragni2016 dataset).

- Rules cover different parts of the NVC prediction space
  - Rule quality may differ on an individual level
- PartNeg is the best overall heuristic (matches MFA best)

# Augmented Models



# Augmented Models



## Results: Augmented Models

- NVC heuristics improve predictive performance
  - PartNeg rule achieves overall best improvement (up to 40%)
    - Misses are reduced (up to 28/64 syllogisms)
    - Only few false alarms are introduced (up to 8/64 syllogisms)
- Main difference of predictive powers due to NVC
- Results highlight NVC as a major weakness of current models

1. Invalid syllogisms are handled poorly by current models
  - PartNeg attachment boosted predictive accuracy by up to 40%
  - Future model iterations should integrate better NVC strategies
2. Isolation of details as an important strategy for model development
  - Suggests potential for future improvement of cognitive models
  - More properties to investigate (e.g., conclusion direction)
3. Model development must take predictions into consideration
  - Reasoning **models must be able to predict** conclusions
  - Models benefit from integrating inter-individual differences

## References

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- Störring, G. (1908). Experimentelle untersuchungen über einfache Schlussprozesse. W. Engelmann.



## Code on GitHub:

<https://github.com/nriesterer/syllogistic-nvc>