Uncertainty and Processing Difficulty in Artificial Grammar Learning

Ross Kempner, Pyeong Whan Cho, Richard Lewis

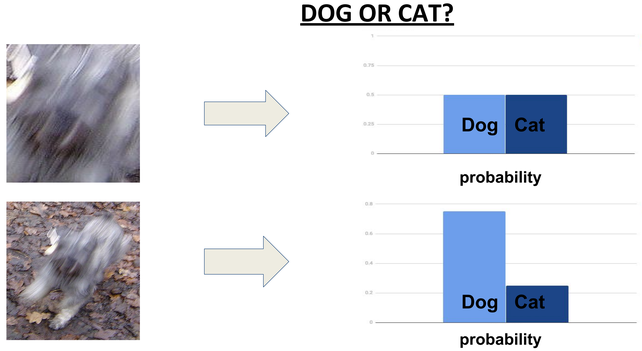
University of Michigan, Ann Arbor, MI, USA

INTRODUCTION

- **Background:** Psycholinguists want to understand the underlying cognitive mechanism causing some words to be more difficult to process.
- **Information Theoretic Complexity Metrics:** Quantifies how difficult it is to process linguistic input.
- **Behavior and Processing Difficulty:** Psycholinguists propose that longer reading times, greater reaction times, and pupil size are indicators of processing difficulty.
- **Surprisal vs. Entropy Reduction:** Psycholinguistic experiments support that two complexity metrics, surprisal and entropy reduction, are predictors of processing difficulty.
- **Experimental Question:**

> Do surprisal and entropy reduction predict different patterns of behavior & processing difficulty?

Understanding Surprisal and Entropy Reduction:
DOG OR CAT?



METHODS & DESIGN

- **Overview:** Task uses eye fixations to hit targets on computer screen (Fig. 1).
- **Behavioral Indicators of Processing Difficulty: (1) Reaction Time-** measured by **Onset** to target and **Arrival** at target. **(2) Dwell Time-** total fixation time on target. **(3) Pupil Size.**
- **Equipment:** Eye tracker measures eye gaze location and pupil size in real time.
- **Artificial Grammar:** Targets represent symbols which appear based on probabilities dictated by the artificial grammar (Fig. 2).
- **Why Artificial?** Greater control of surprisal and entropy reduction values.

Computer Display During Task

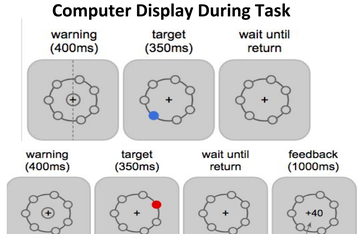


Fig. 1

Probabilistic Artificial Grammar

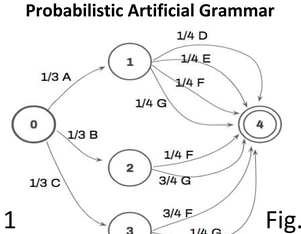


Fig. 2

PREDICTED RESULTS & DATA ANALYSIS

Predictions for Relationships between Dependent Variables and Complexity Metrics

+: positive correlation -: negative correlation	Onset	Arrival	Dwell	Pupil Size
Surprisal	+	+	+	-
Entropy Reduction	-	-	+	-

Fig. 3

Surprisal and Entropy Reduction Calculations for Word Pairs in Artificial Grammar

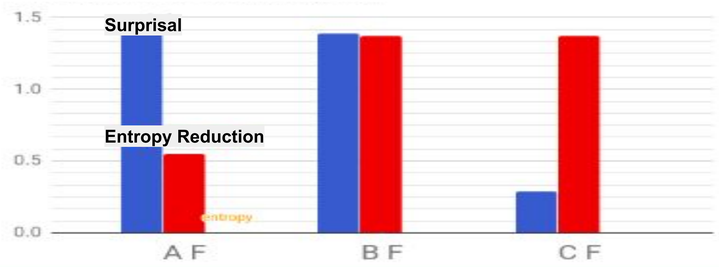


Fig. 4

- Specific trials have surprisal and entropy reduction making opposite predictions.
- Will plot dwell, onset, arrival, and pupil size values for these trials.

Visualization of Fixations in Trial and Complexity Metrics/Dependent Variables

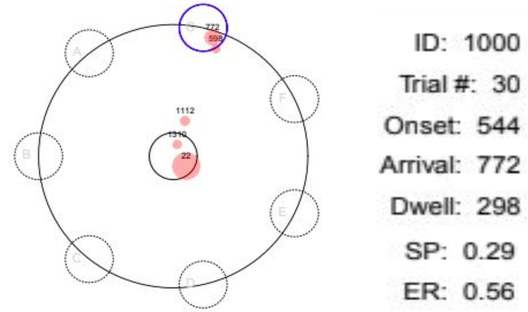


Fig. 5

- Visualization of fixations will assist in understanding the causes of behavioral data.

NEXT STEPS & CONCLUSION

- After collecting behavioral data, task will be done during brain imaging to look for neural correlates of surprisal and entropy reduction.
- Previous experiments have investigated the effects of surprisal and entropy reduction on processing difficulty over natural language.
- Artificial grammar creates contexts where surprisal and entropy reduction make different predictions, which is rare in natural language.
- Furthering the knowledge of the role of surprisal and entropy reduction in processing difficulty is important for psycholinguists to understand the underlying cognitive mechanism of language processing.

REFERENCES

Armeni, K., Willems, R. M., & Frank, S. (2017). Probabilistic language models in cognitive neuroscience: Promises and pitfalls. *Neuroscience and Biobehavioral Reviews,83*, 579-588.
Hale, J. (2016). Information-theoretical Complexity Metrics. *Language and Linguistics Compass, 10*(9), 397-412.
Harrison, L., Duggins, A., & Friston, K. (2006). Encoding uncertainty in the hippocampus. *Neural Networks, 19*(5), 535-546.
Levy, R. (2008). Expectation-based syntactic comprehension. *Cognition, 106*(3), 1126-1177.
O'Reilly, J. X., Schuffelgen, U., Cuell, S. F., Behrens, T. E., Mars, R. B., & Rushworth, M. F. (2013). Dissociable effects of surprise and model update in parietal and anterior cingulate cortex. *Proceedings of the National Academy of Sciences, 110*(38).