Toward a More Neurally Plausible Neural Network Model of Latent Cause Inference

Qihong Lu[1], Tan Nguyen[2], Uri Hasson[1], Thomas Griffiths[1], Jeffrey Zacks[2], Samuel Gershman[3], Kenneth Norman[1]

1. Princeton University; 2. Washington University in St. Louis; 3. Harvard University

SCAN ME

Main points

We developed a neural network model that uses a latent cause inference (**LCI**) to support context-dependent behavior.

- extract shared structure across LCs while avoiding catastrophic interference
- capture human data on curriculum effects on schema learning
- infer the underlying event structure when processing naturalistic videos of daily activities

Leverage the shared structure across tasks

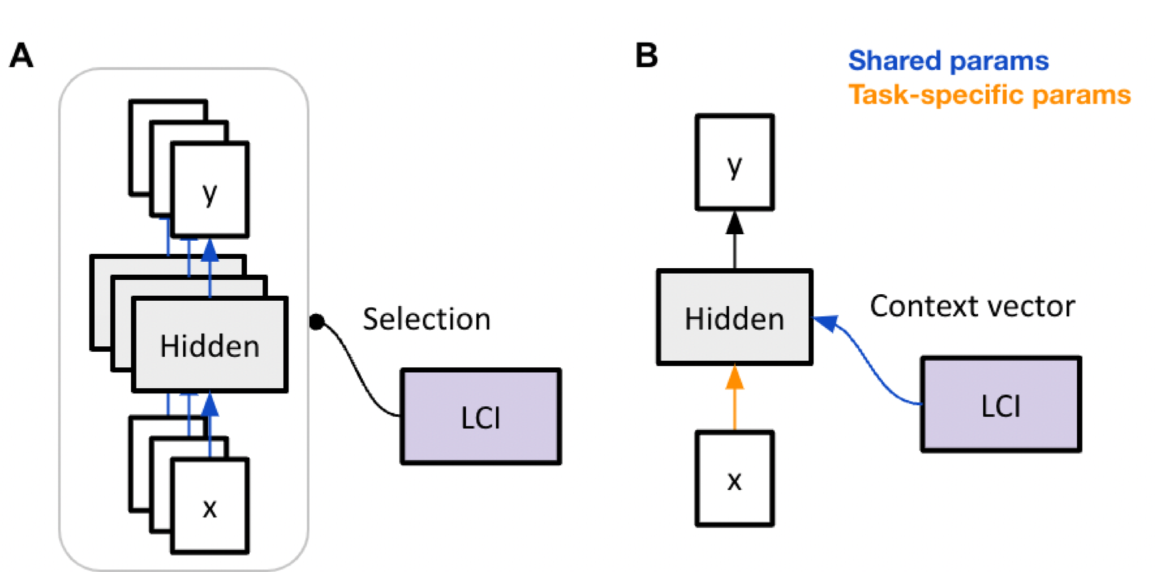

Figure 1:A) Structured event memory model (**SEM**; Franklin, et al. 2020); B) Latent Cause Network (**LCNet**)

We compared our model, called LCNet, versus SEM (Figure 1) on a functional learning task, where each function is the sum of a shared component and an idiosyncratic component (Figure 2A,B). We found that our model can...

- factor knowledge shared across tasks vs. task-specific knowledge (Figure 2C).
- overcome catastrophic interference (Figure 2D).
- encode knowledge shared across tasks to learn new tasks with fewer data (Figure 2E).

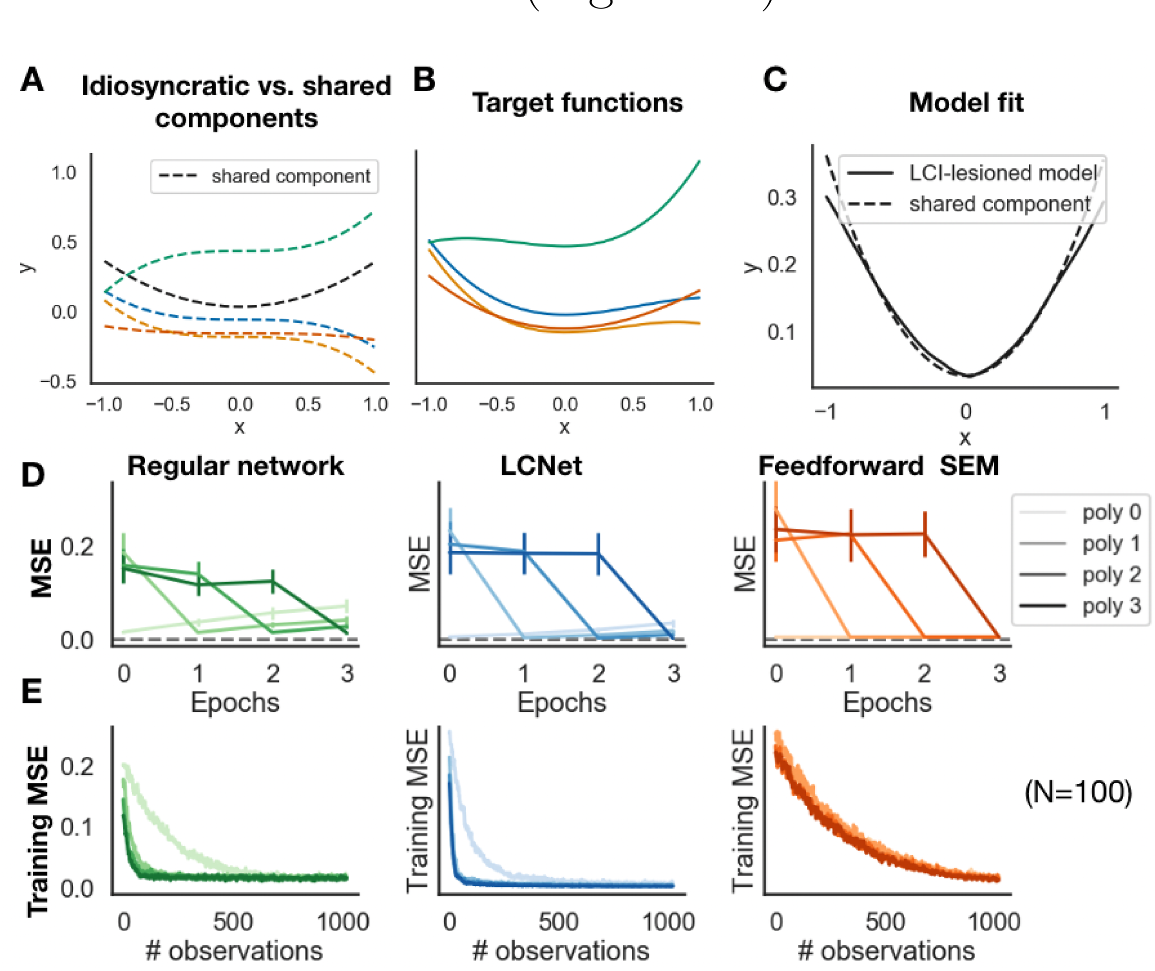

Figure 2:A, B) The target functions that the model had to learn. C) An LCI-lesioned LCNet reconstructs the shared component. D) Test MSE for all polynomials plotted separately over epochs in a blocked learning setting – the model was only trained on the i-th polynomial at epoch i. E) MSE for each polynomial plotted separately over the number of samples.

Capture curriculum effect on schema learning

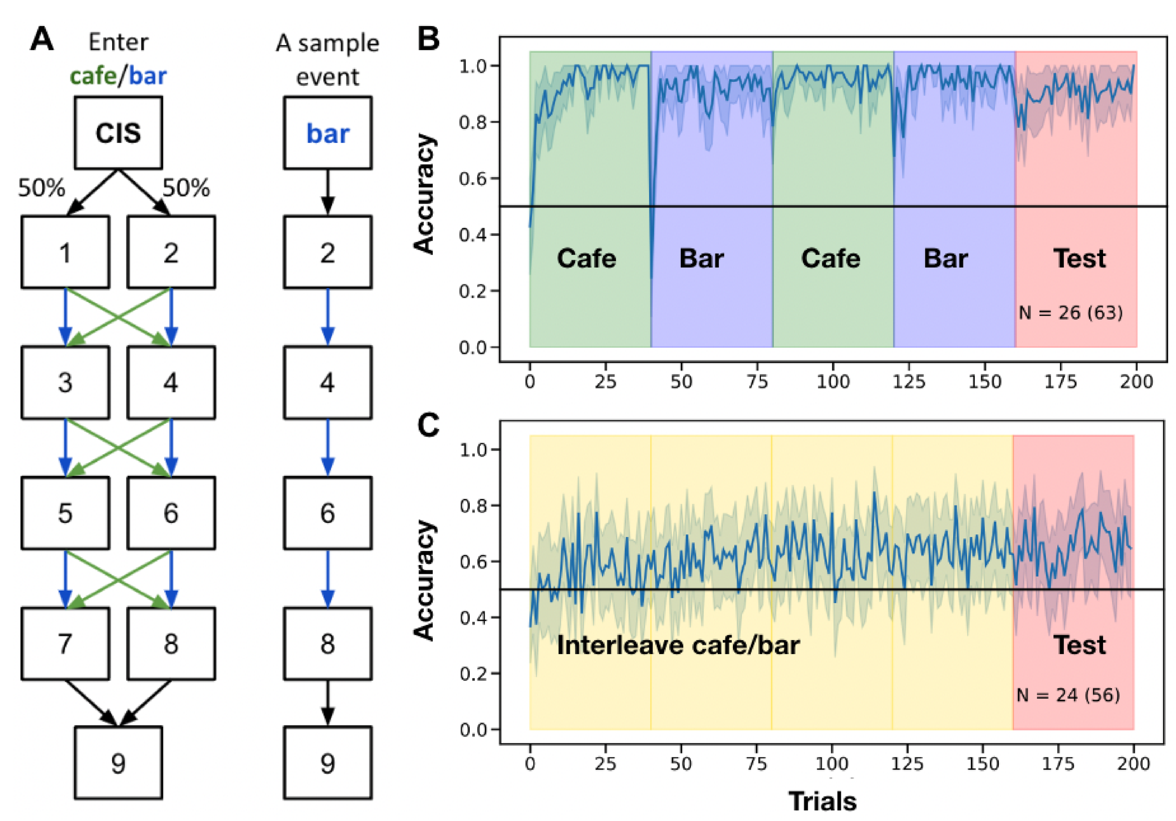

Figure 3:Human data; A) The state-transition graph used in Beukers et al. 2023. B) Empirically, humans learned much better under the blocked curriculum than the interleaved curriculum (Beukers et al. 2023).

We found that LCNet can ...

- account for human data (Figure 3), because LCI was more accurate (Figure 2 E) in the blocked curriculum than in the interleaved curriculum.

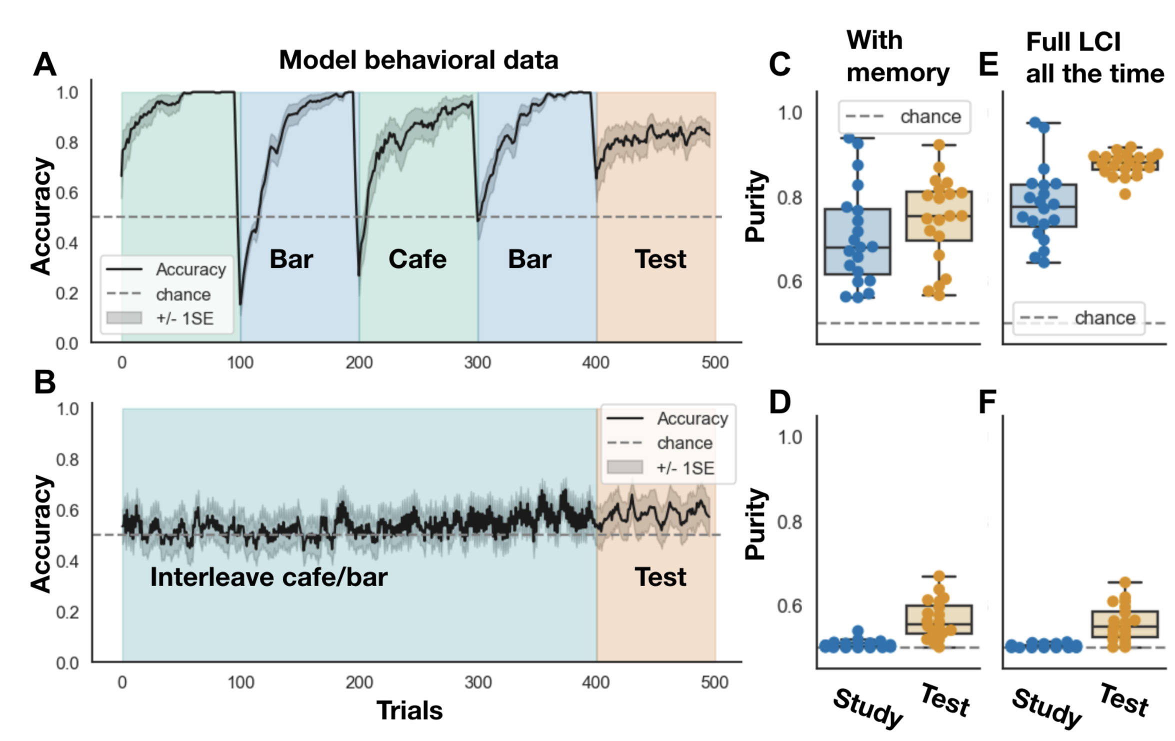

Figure 4:Model data; A, B) LCNet qualitatively replicated human behavioral data. C, D) LCI was much more accurate in the blocked condition, and episodic memory can reduce full inference time by 94%. E, F) LCI performance with full inference.

Episodic memory was implemented as a mapping from the input states to inferred latent causes (from the full LCI process). We found that ...

- though memory-based inference is not as accurate as full LCI (Figure 4), the model was able to recapitulate the human data (Figure 2) while saving 94% of full inferences, making the LCNet significantly more computationally feasible.

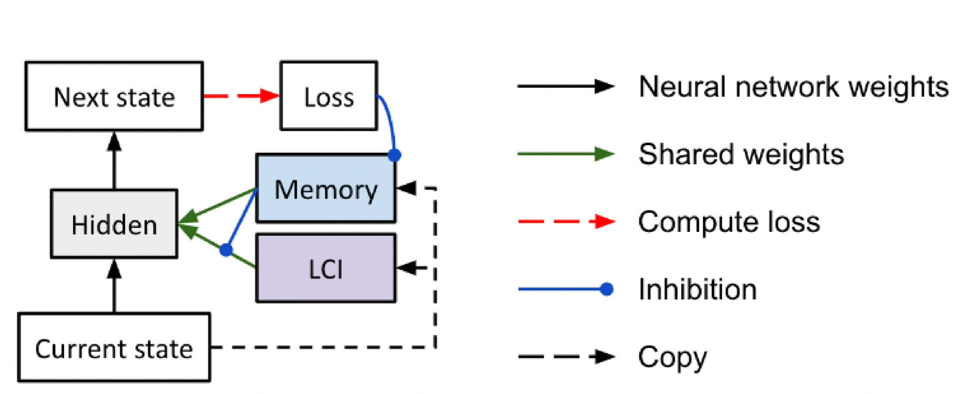

Figure 5:Use episodic memory as a shortcut for full LCI – LCNet can recall previously used latent causes assigned based on the current input state, instead of performing the laborious full inference. The full inference procedure is only turned on when the current loss is too high.

Infer the event structure of naturalistic videos

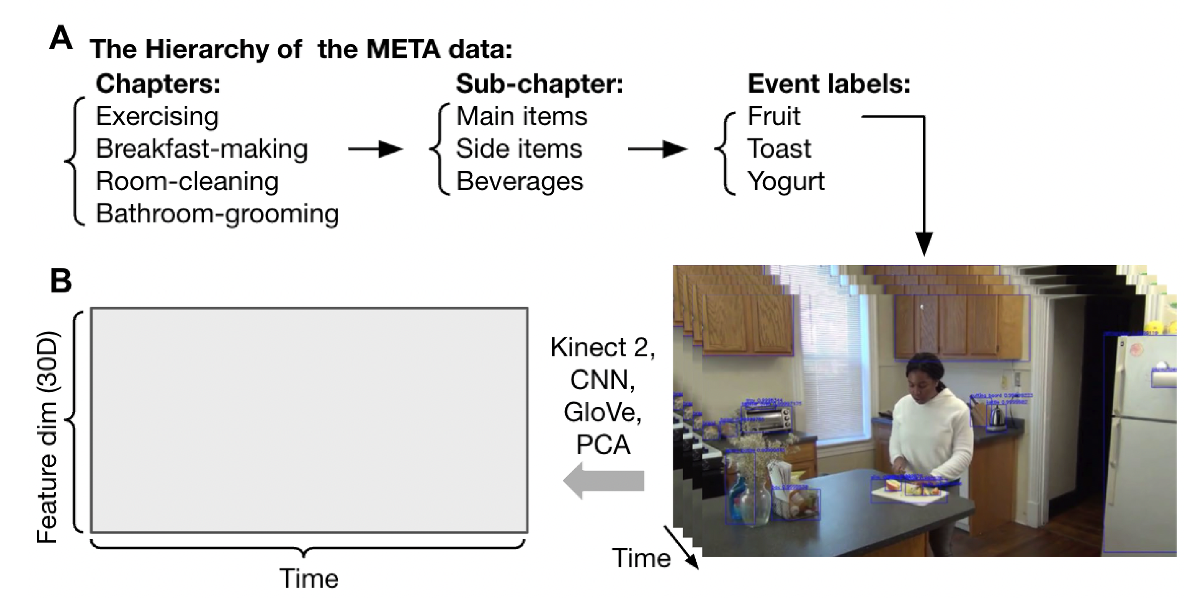

Figure 6:A) The hierarchical structure and B) preprocessing steps for the META dataset (Bezdek et al. 2022a), which consists of more than 100 hours of daily activities.

We trained a recurrent LCNet on a pre-processed naturalistic video dataset – META (Bezdek et al. 2022a) to predict the upcoming frame of the video (Figure 6). We found that ...

- the way our model segment events captured the human event boundaries data (Figure 7 A,B,C) and the ground truth event structure (Figure 7D), even though the model was only trained to predict upcoming frame of the video, which is similar to SEM2.0 (Bezdek et al. 2022b).

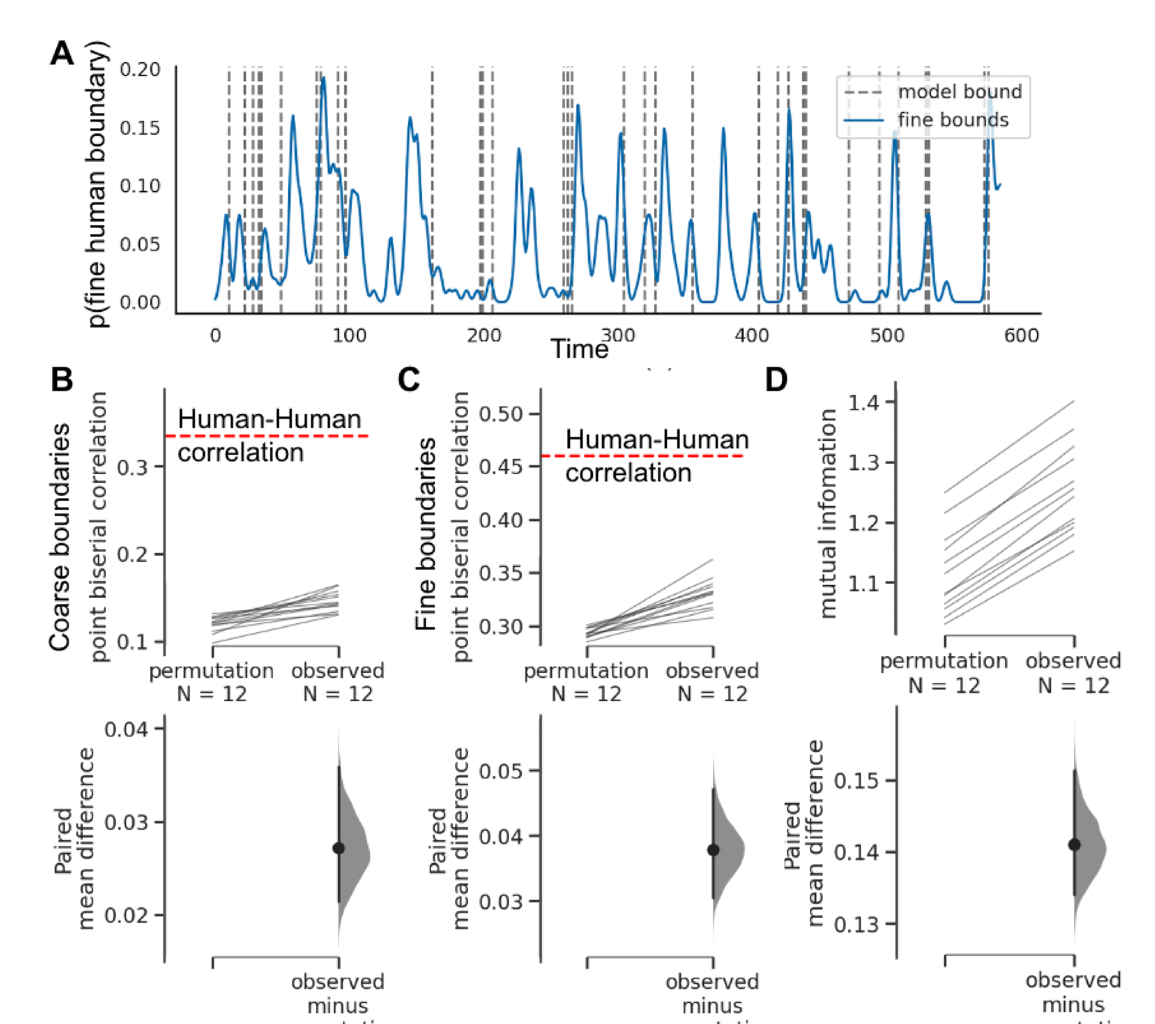

Figure 7:A) Model boundaries vs human boundaries for an example video. B, C) The event boundaries extracted from the models are significantly correlated with human coarse/fine boundaries. D) The LCs inferred by the model and the ground truth event labels shared significant mutual information.

References & Links

1. Franklin, et al. Psych Review 2020
2. Beukers, et al. PsyArXiv 2023
3. Bezdek et al. Behav Res Methods 2022a
4. Bezdek et al. PsyArXiv 2022b

Acknowledgement: This work was supported by a Multi-University Research Initiative grant to KAN, JMZ, SJG and UH (ONR/DoD N00014-17-1-2961).

Contact: `qlu@princeton.edu`