Decoding latent decision subspaces through hidden Markov models

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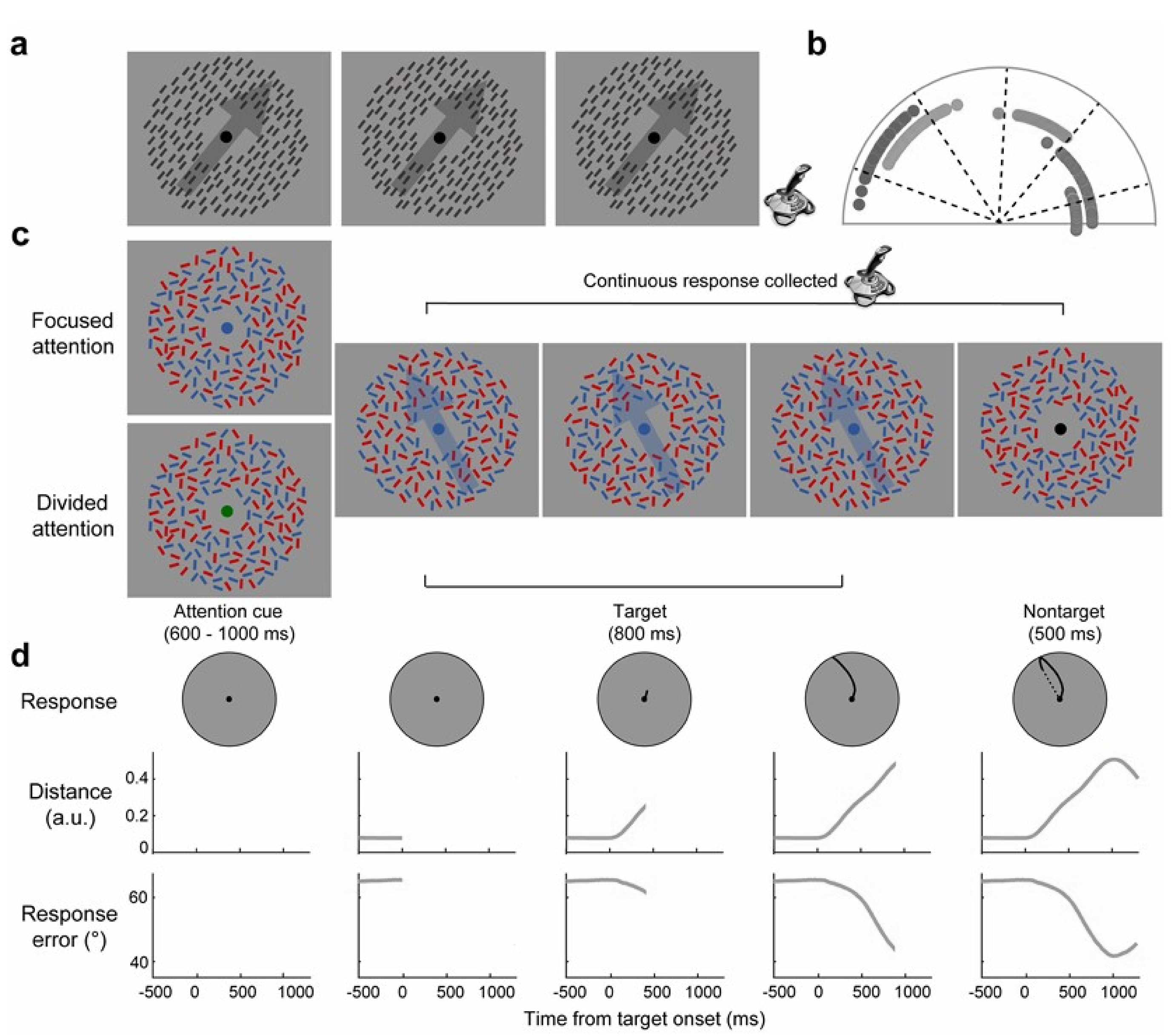
Abstract

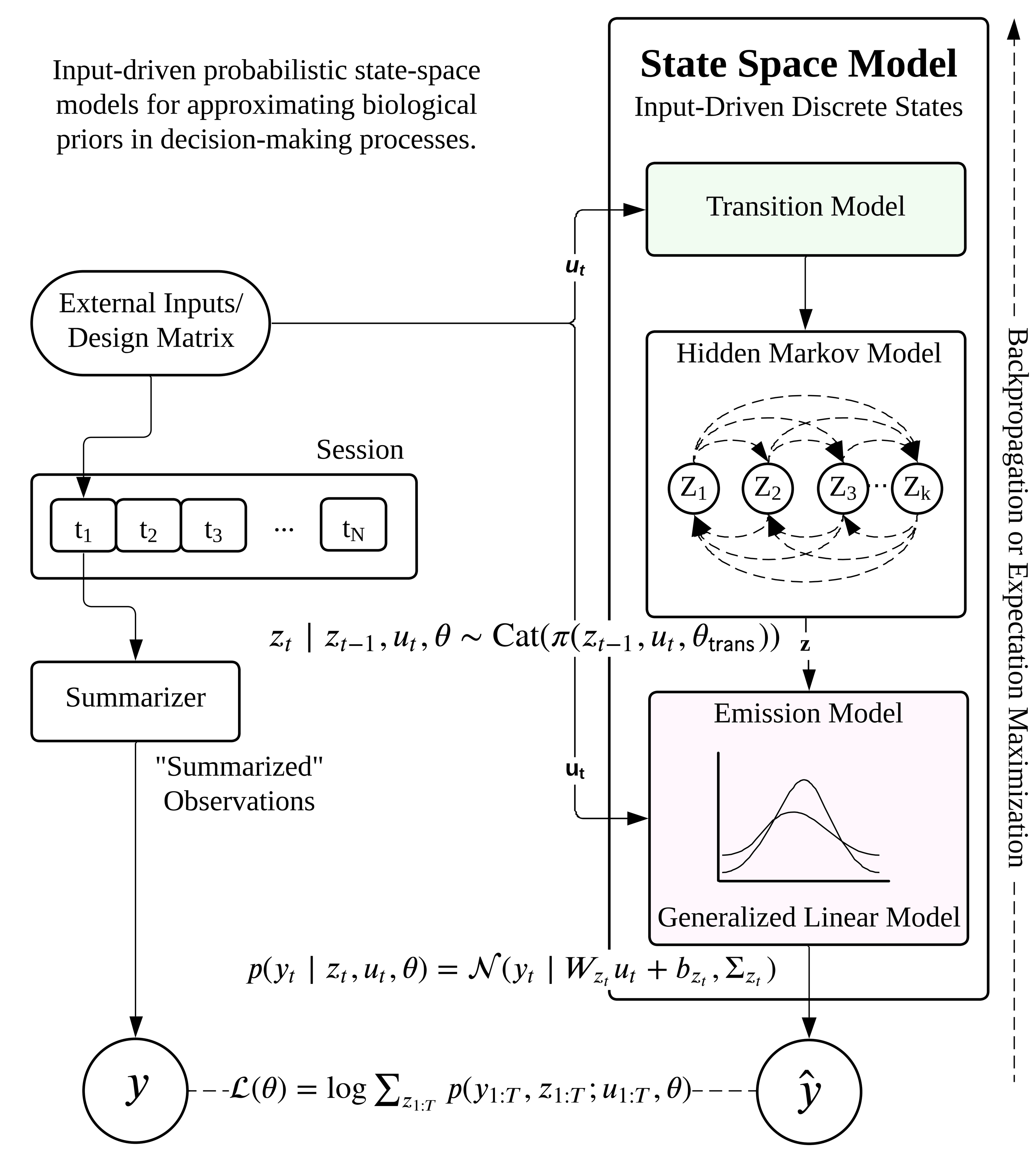
This research introduces a novel framework for decoding latent decision subspaces in perceptual decision-making using hidden Markov models (HMMs). The approach leverages top-down and bottom-up cognitive manipulations as external drivers of discrete state transitions, aiming to reflect the structural dynamics of hidden cognitive processes. We apply this framework to model perceptual decision-making as a series of continuous observations across multiple dimensions. Our method captures the underlying cognitive states that drive decision-making, providing a robust tool for inferring hidden states and dynamics that are not directly observable in human cognition.

Decision-Making Task

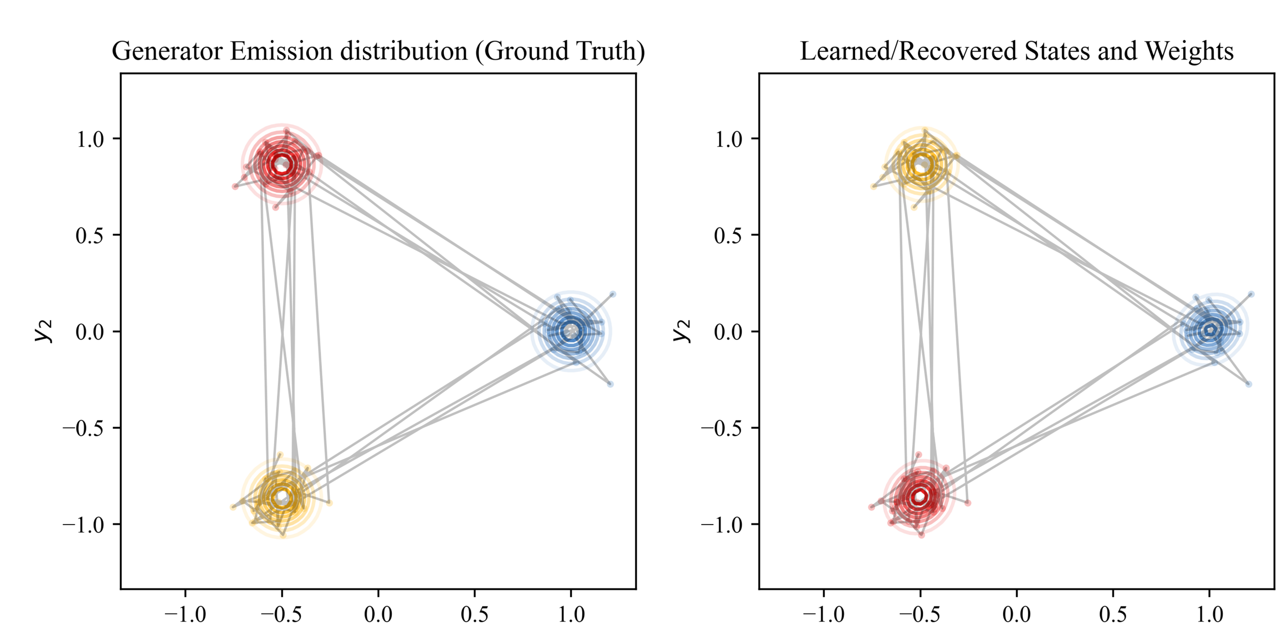


a. The calibration block On each trial, participants saw flickering black bars and were instructed to report the coherent orientation of these bars by moving a 360 deg flight simulator joystick. **b.** Stimulus space. There were 5 possible orientations from 15 to 159 with 36 degree increment. Solid circles are responses from one sample participant from a calibration block corresponding to each of the five target orientations. **c.** The main experimental task. Each trial began with a fixation point (400 to 800 ms) and was followed by an attention cue (600 to 1000ms) to indicate color of the bars that would represent coherent orientation (target) A red(blue) attention cue indicated that coherent orientation would be represented with red(blue) bars (focused attention condition). A green attention cue indicated that coherent orientation would be represented with either red or blue dots, i.e., the participant had to discern which color of bars were in coherent orientation (divided attention). Coherent orientation was presented for 800 ms during which the participant starts beginning to make a response by moving the joystick in the direction that matched the perceived coherent orientation. Responses were collected until the non target presentation which lasted 500 ms.

Model Architecture



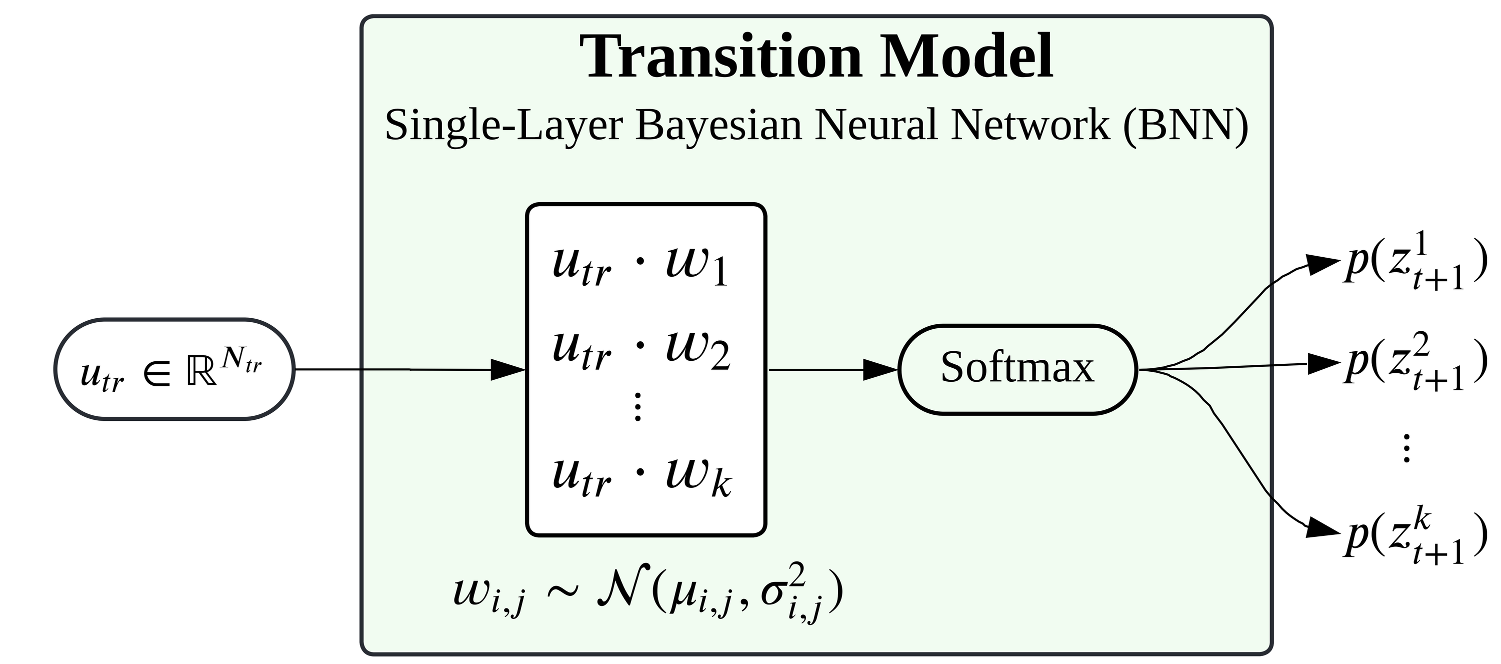
Experiment 1 (Synthetic)



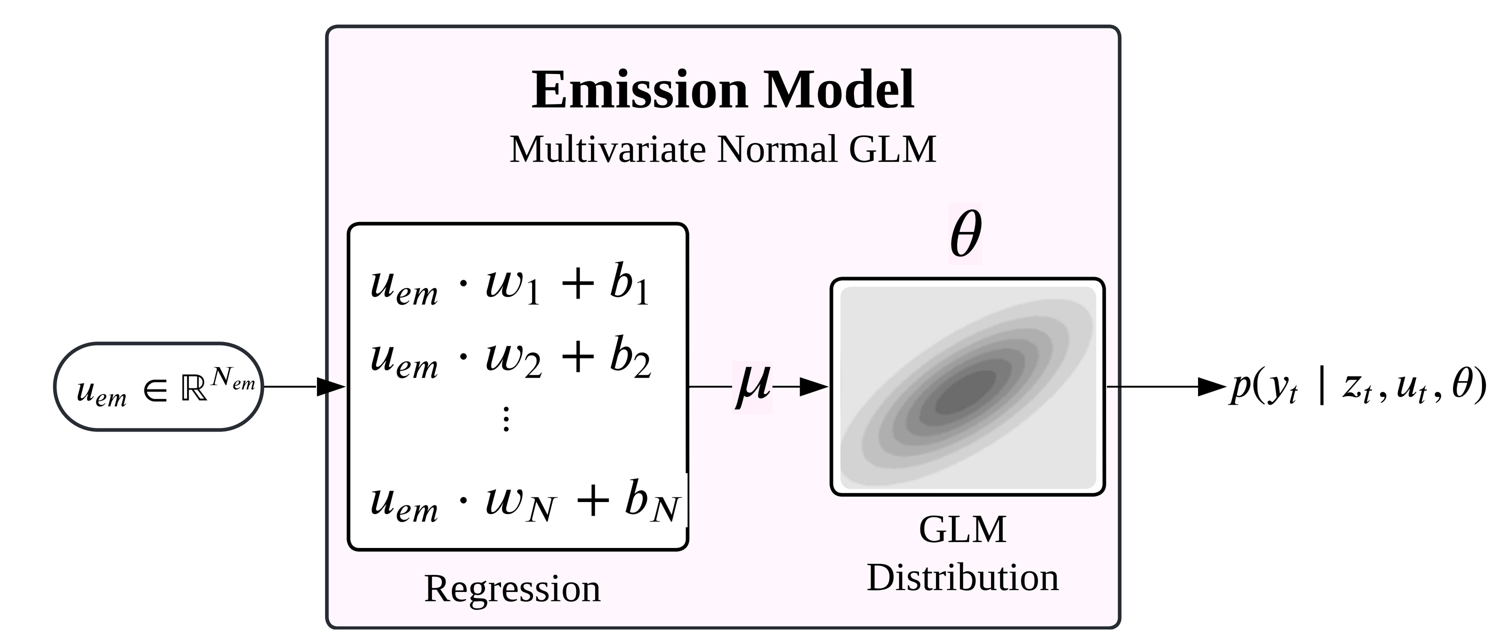
Conclusions

- Architecture successfully recovers discrete latent states from generator.
- Latent states can be characterized by interpreting probabilistic weights
- Input-driven emissions & transitions converge faster than ablations.
- We can successfully infer potential hidden states in decision-making.

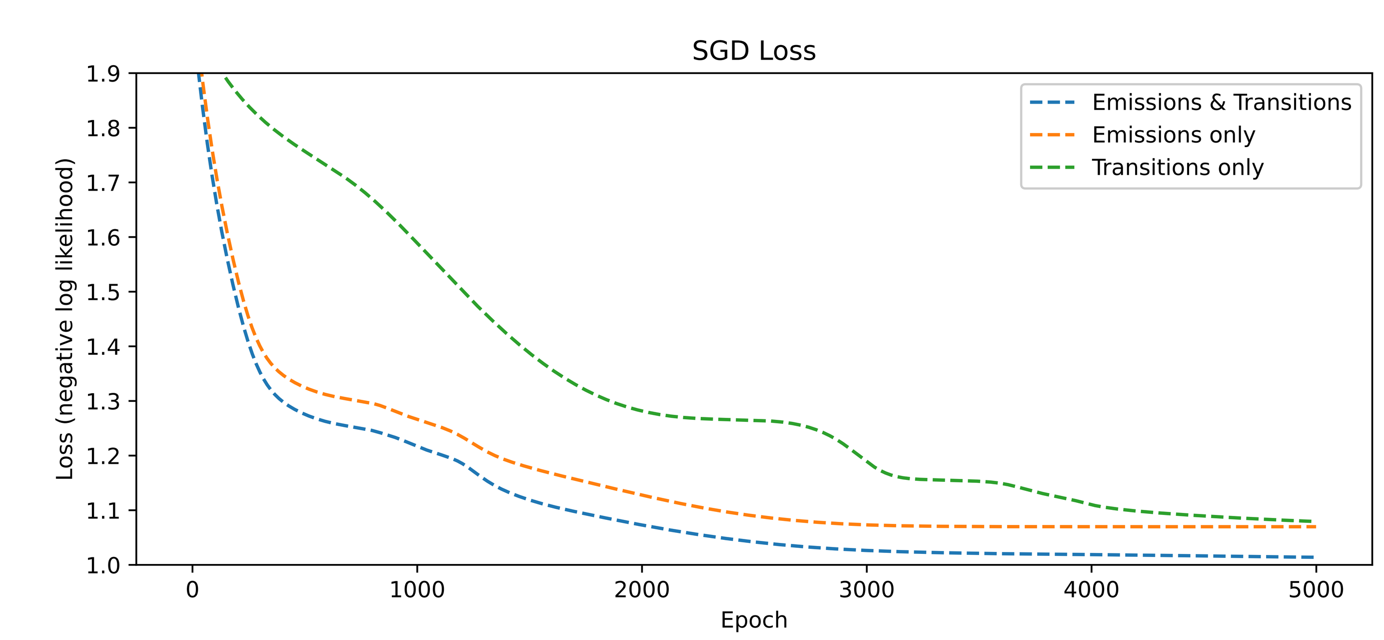
Transition Probabilities



Emission Probabilities



Experiment 2 (Human)



References & Acknowledgements

- Rungratsameetaweemana, N. (2020) *Ph.D. Dissertation, UCSD.*
- Ashwood et al. (2022). *Nat Neurosci.*
- Calhoun et al. (2019). *Nat Neurosci.*
- Beron et al. (2022). *PNAS.*
- Roy et al. (2021). *Neuron.*
- Linderman et al. (2015). *NeurIPS.*

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