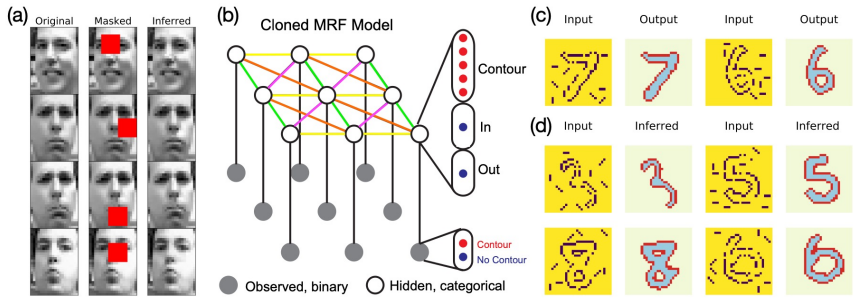
Context and Priming in Recursive Cortical Networks
FINAL PERFORMANCE REPORT
N00014-19-1-2368, 05/01/2019 – 01/31/2022)

Objectives & Relevance

- Develop methods for flexible contextual representations in the Recursive Cortical Network model, and demonstrate its efficacy on problems that require interpreting evidence in context.
- Robustness of visual and spatial perception and interpretation depends the above ability. Eg., without this, STOP signs drawn on the sides of a building will confuse a self-driving car.



Technical Approach

- We investigate the computational underpinnings of neuroscience observations
- In this work, we discovered a potentially important computational role for clonal neurons in a cortical column.
- We show that clonal representations lead to efficient representations of higher-order context.
- Applying this idea to sequential inputs led to a general model for cognitive maps of the hippocampus.
- A 2D extension led to flexibile border ownership representations with top-down binding.

Accomplishments/Impact/Transitions

- This research led to the development of a unified model for cognitive maps in the hippocampus. This was published in Nature communications, and several researchers have found the model to be insightful and useful.
- A new manuscript on with flexible border ownership inference in challenging visual scenes is now ready for submission. A new method for training undirected graphical models was developed and published in AAAI

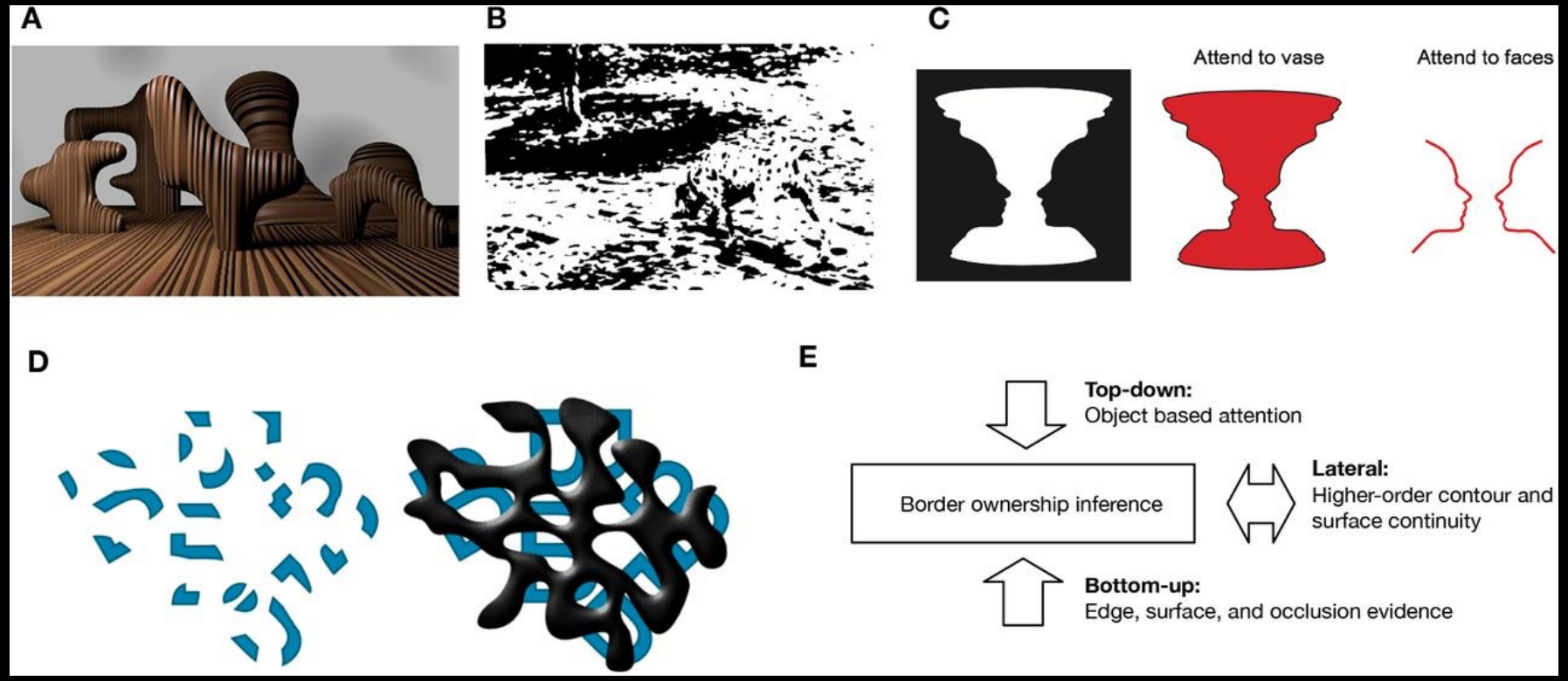
Context and Priming in Recursive Cortical Networks
Program Closeout Meeting

Dr. Dileep George
Vicarious AI
Feb 17 2022

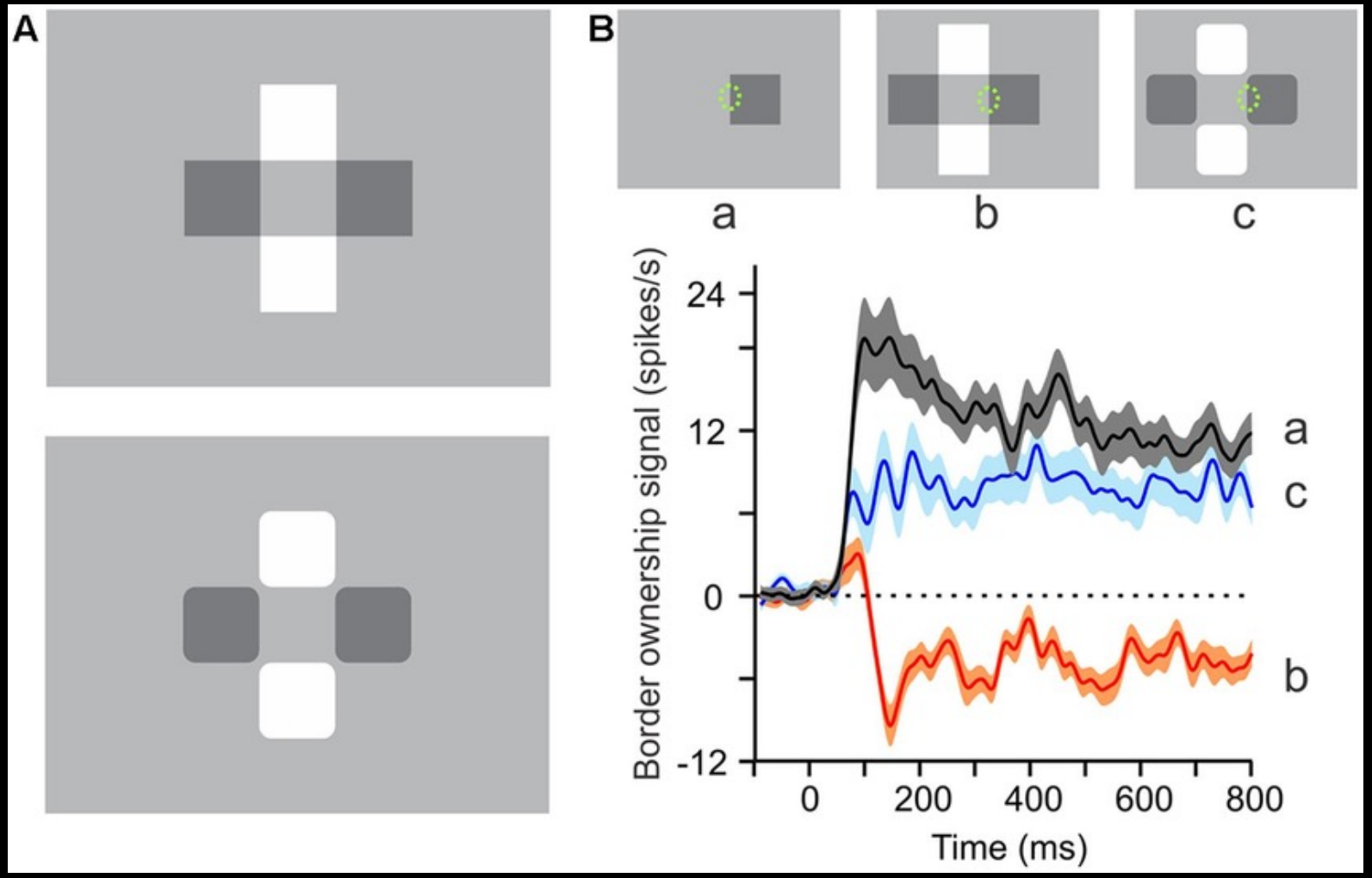
Background & Objective

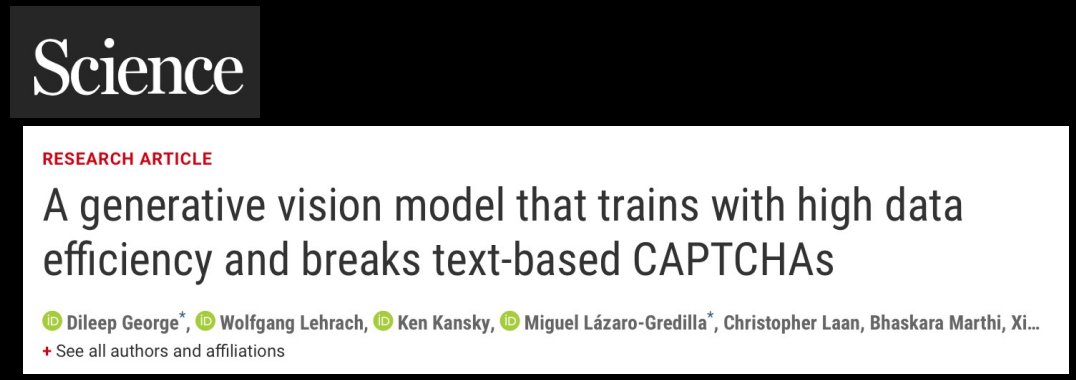
- Background
  - Humans use context to disambiguate perceptual evidence, and can interpret evidence based on priming. These dynamic capabilities are still lacking in current deep learning models.
- Objective
  - Investigate structural scaffoldings, learning, and inference mechanisms for dynamic contextual inference and priming in Recursive Cortical Networks and related models.

Motivating examples of context and priming in perception/cognition



Motivating examples of context and priming in perception/cognition





Our starting point model had some good properties for context and priming

m!!

coungk

Explaining-away local evidence helps to find the globally best solution

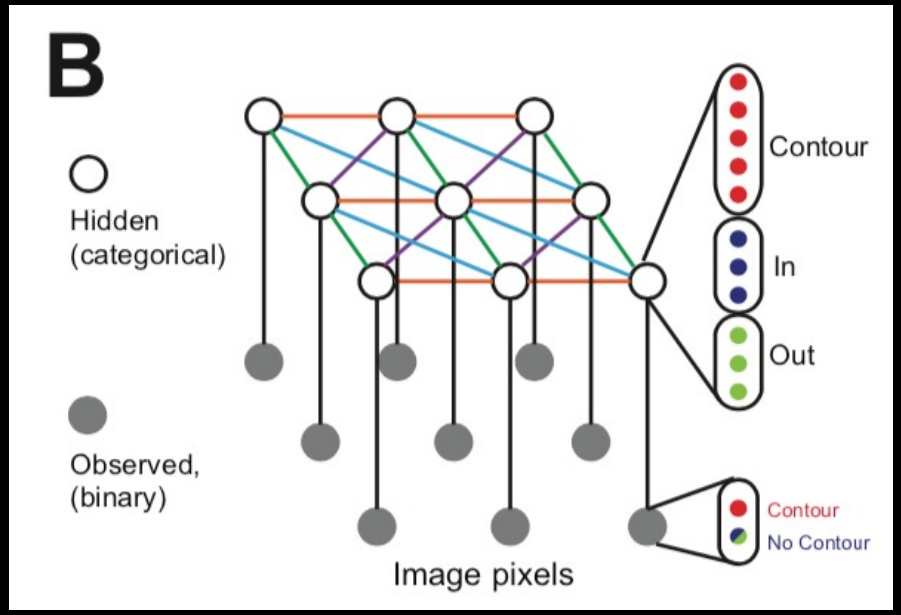
For flexible contextual inference, the model needed the following

- Need a representational scaffolding that is more flexible
- Need a mechanism to learn that representation from data
- Need a flexible inferencing method
- Should be compatible with the RCN hierarchy

For flexible contextual inference, the model needed the following

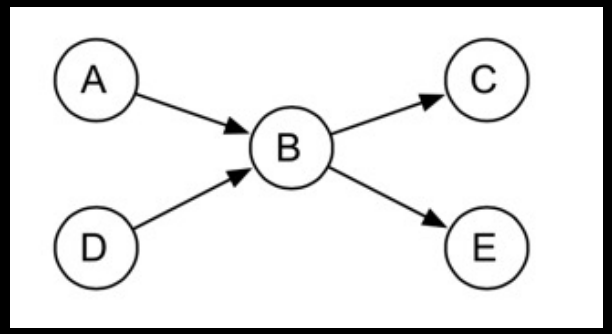
- Need a representational scaffolding that is more flexible
  - **Clone-structured models**
- Need a mechanism to learn that representation from data
  - Query Training / Expectation Maximization/ Gradient Descent
- Need a flexible inferencing method
  - Loopy BP with novel schedules
- Should be compatible with the RCN hierarchy

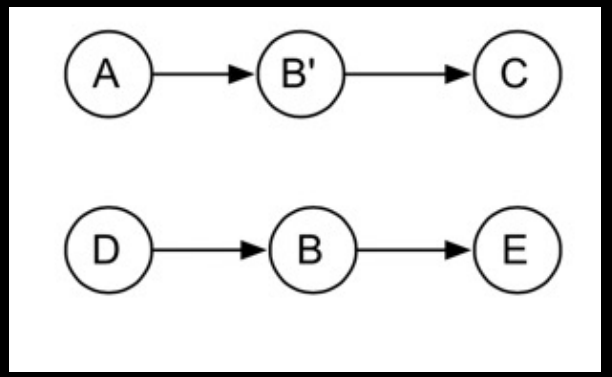
Representational Scaffolding: The cloned MRF model

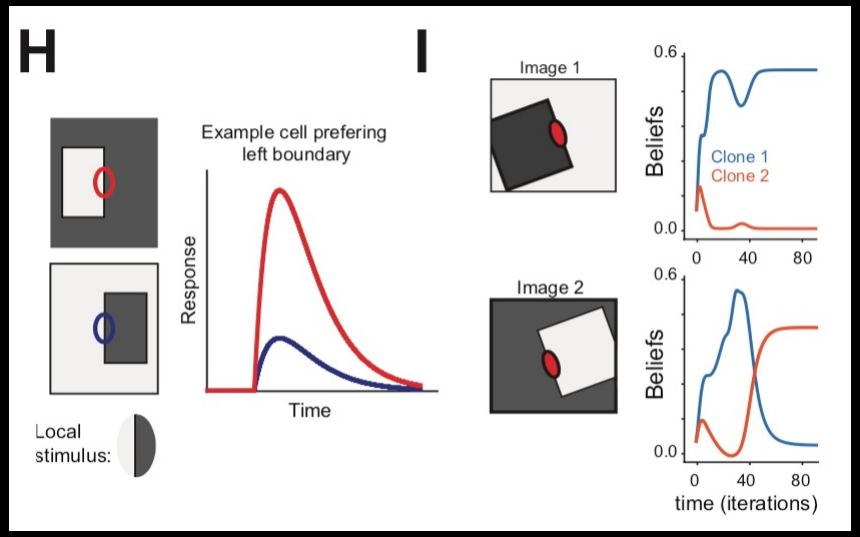


Core idea: Different clones for different contexts

Clone trick: storing higher-order models



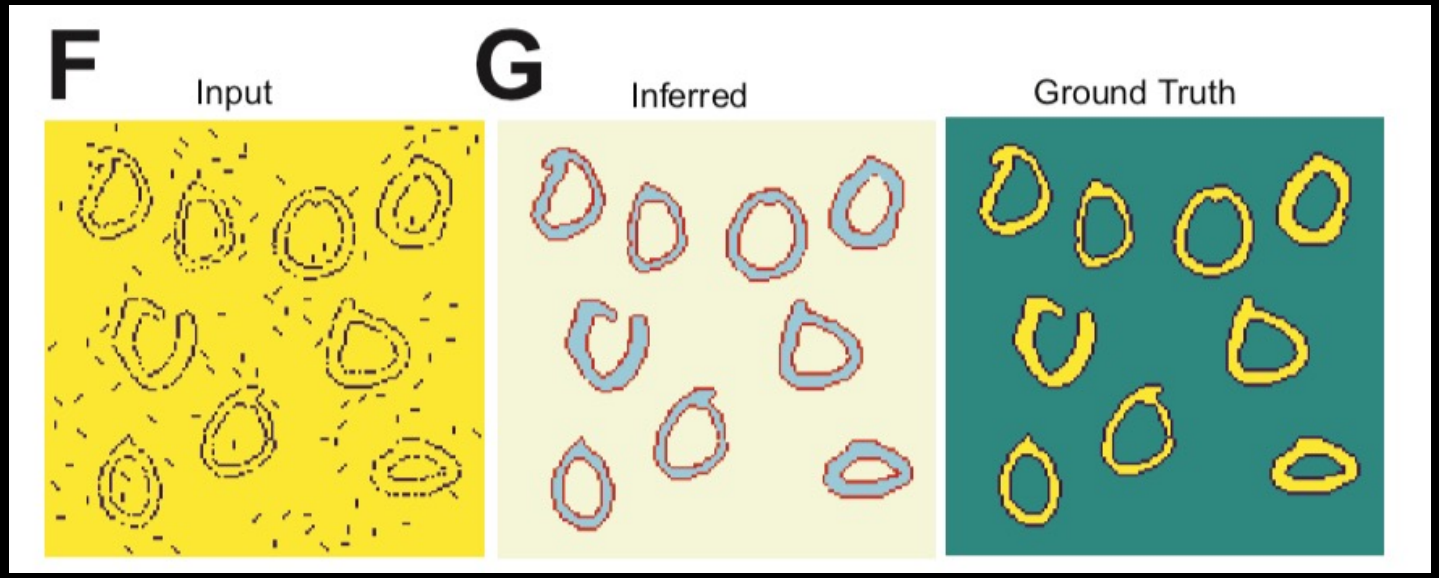




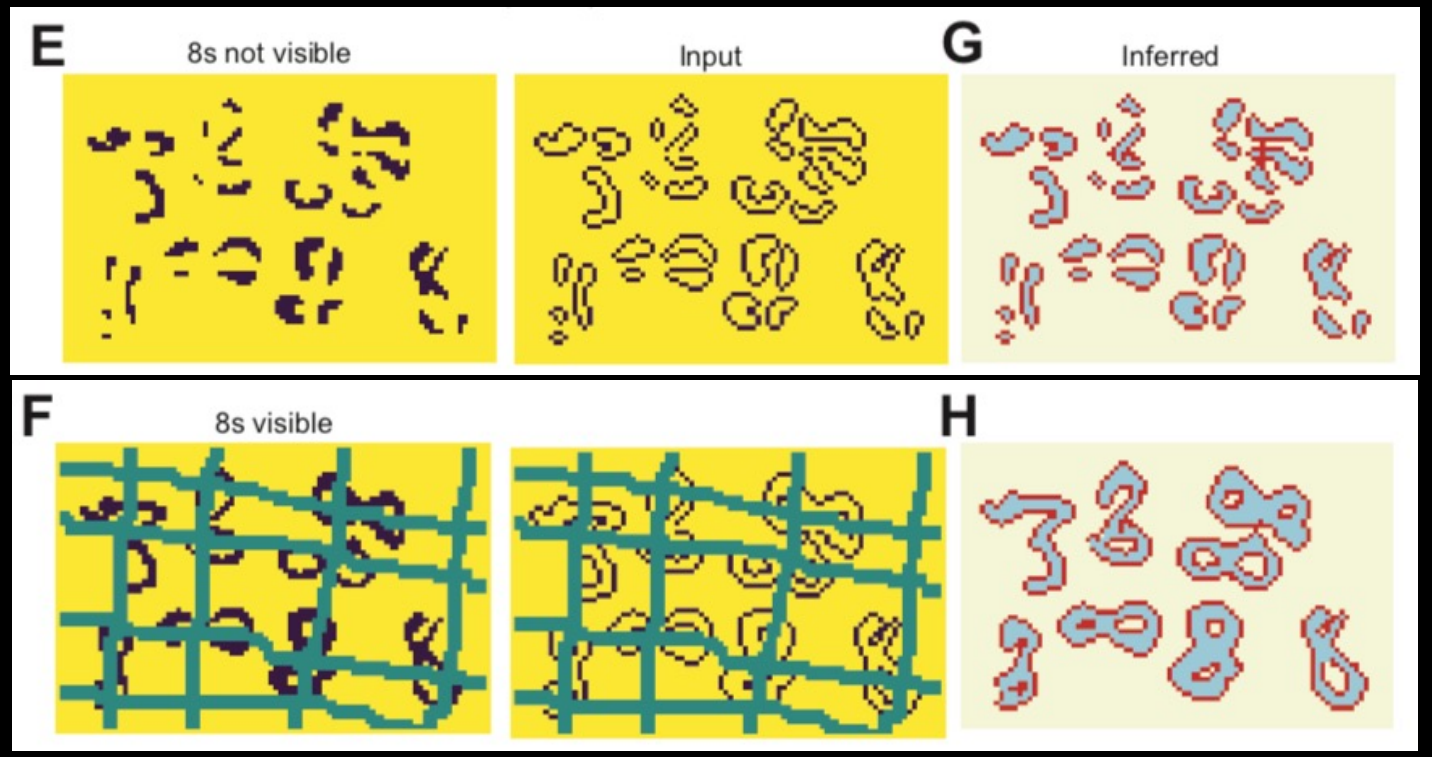
- Different clones learn to represent different border ownerships.
- The correct border ownership is assigned during inference.


Input to CMRF
Output of CMRF

Works with completely novel categories. “0” category is not seen during training at all



Occlusion reasoning with flexible lateral connections

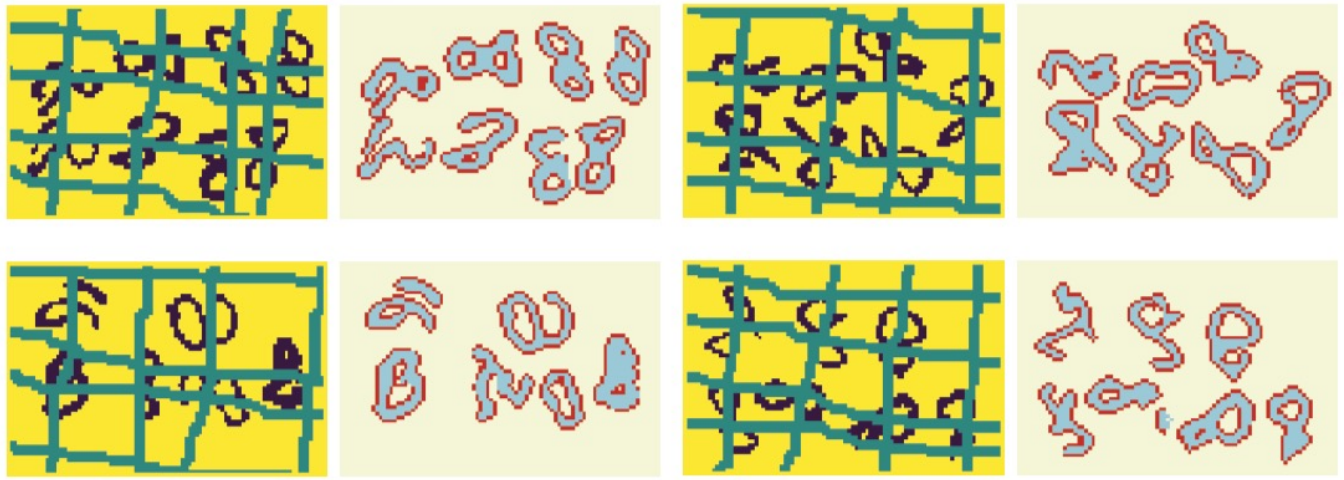


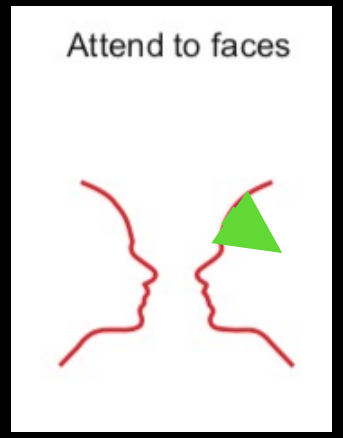
Note that the category “8” is completely novel. No “8”’s in the training set.

Additional Examples: 8s visible with the occluder

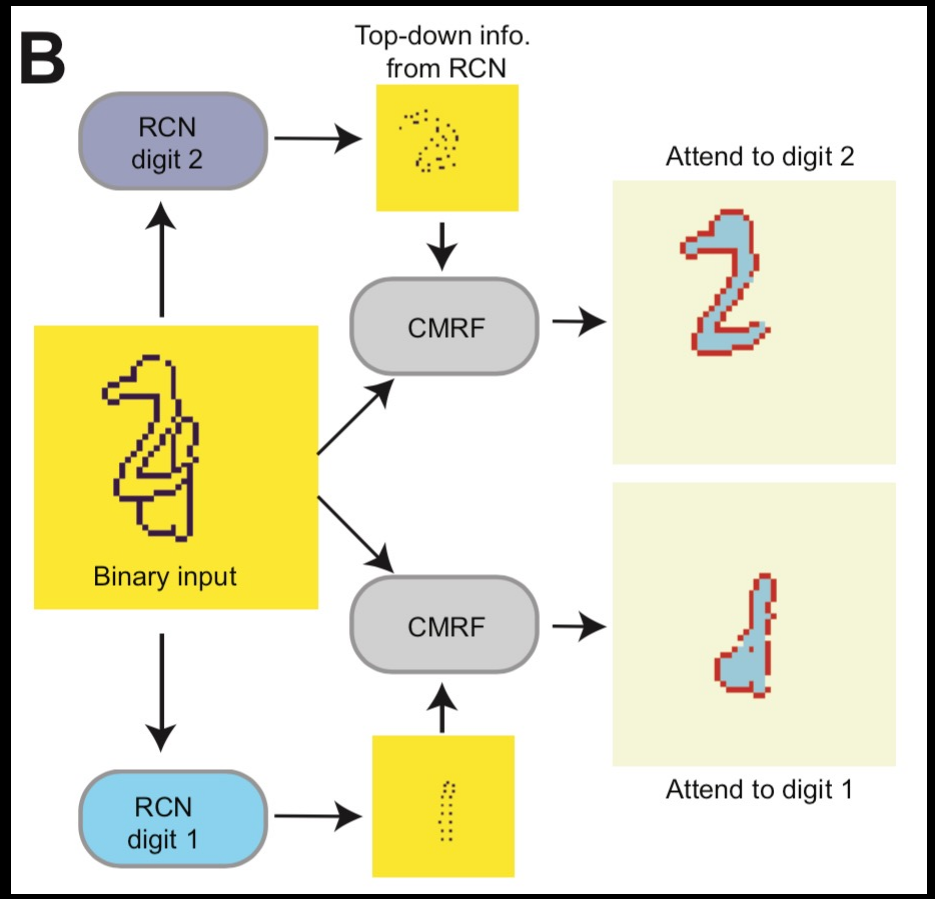
Input to CMRF

Output of CMRF

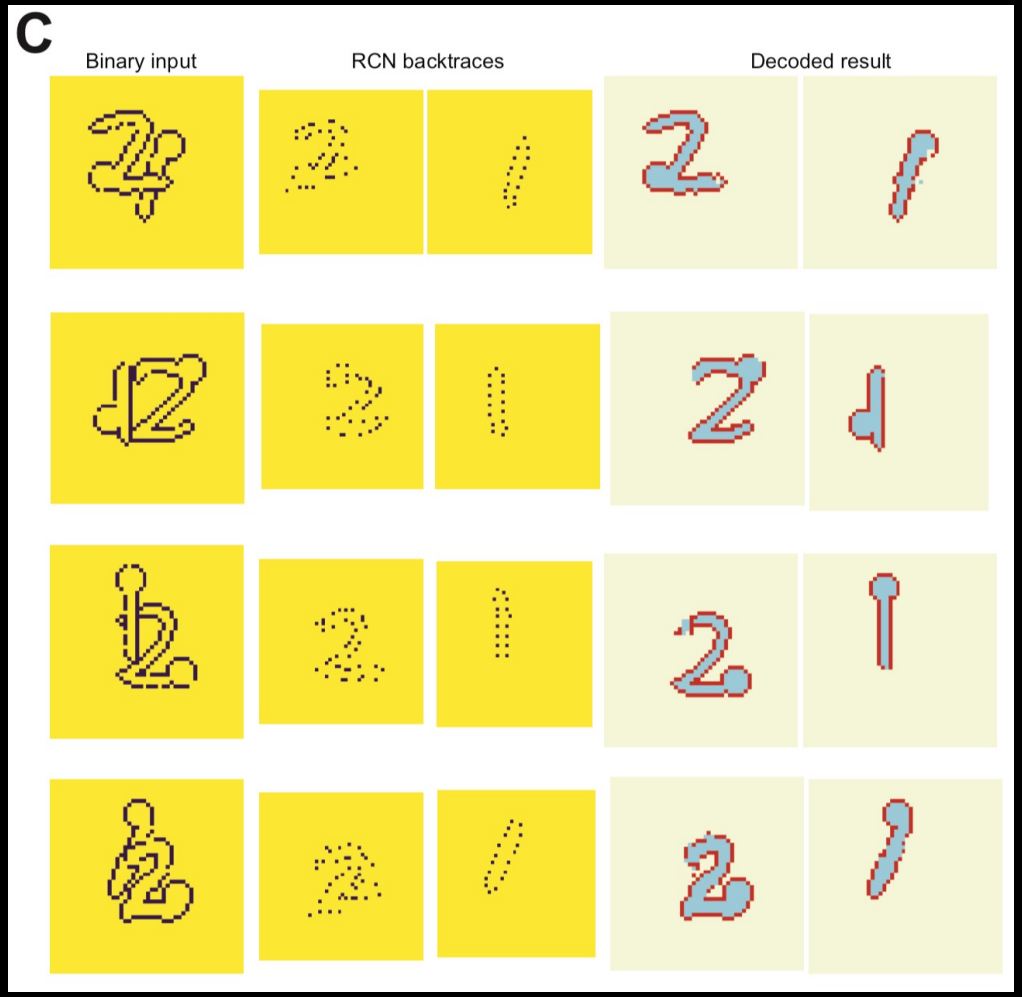




Border ownership assignment based on top-down context

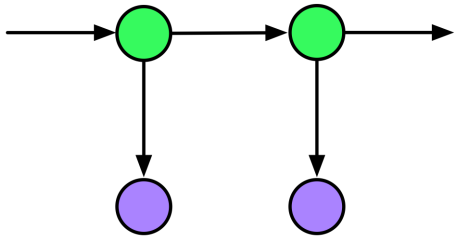


Note that these digits have “tumors”

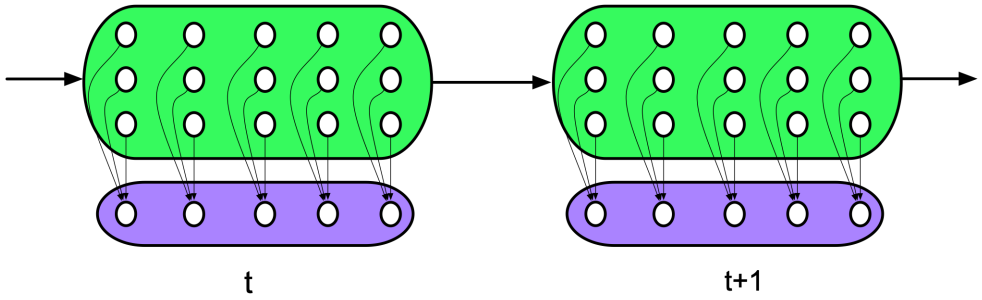

C
Binary input
RCN backtraces
Decoded result

Bonus: We found that the same clone-structured idea works in the hippocampus to learn cognitive maps

Formulate as a restricted hidden Markov model (HMM) and learn with EM



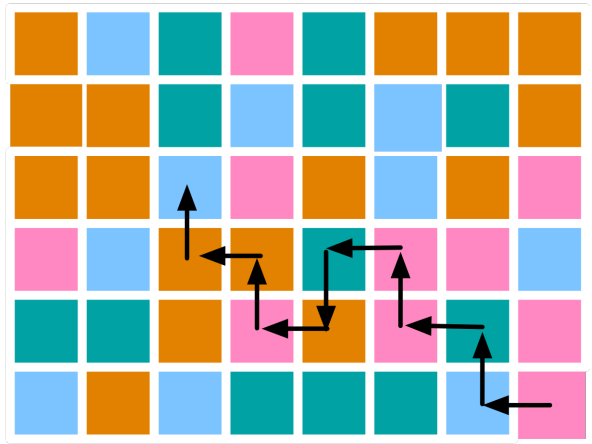
standard HMM structure

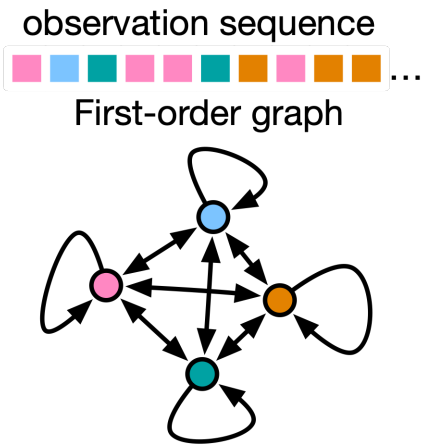


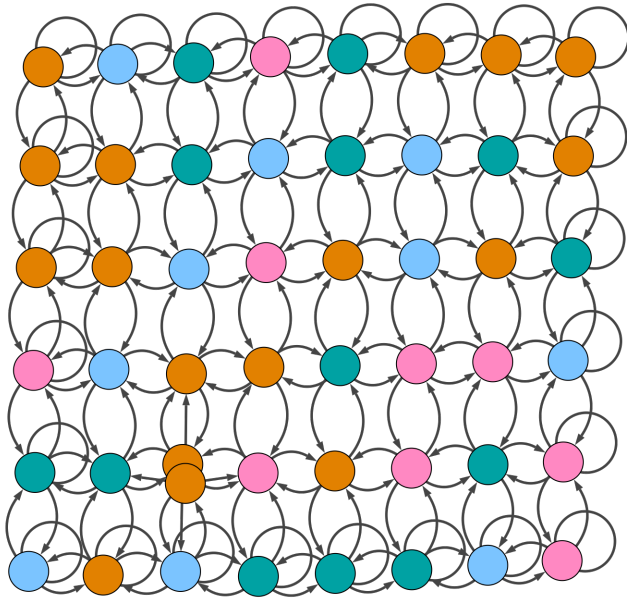
“cloned” HMM structure

Better learning, creates capacity bottleneck, introduces generalization

Only four distinct observations in the room

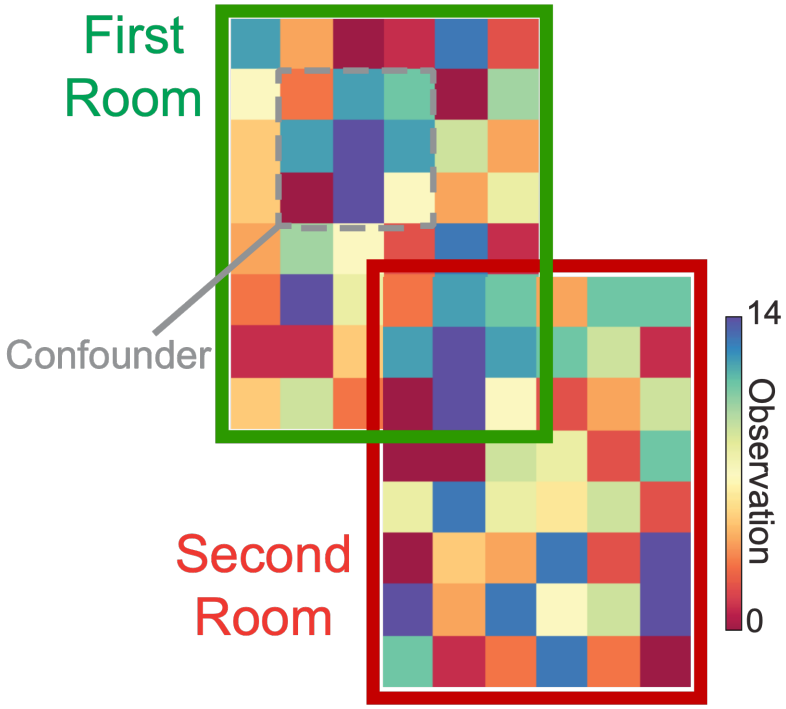




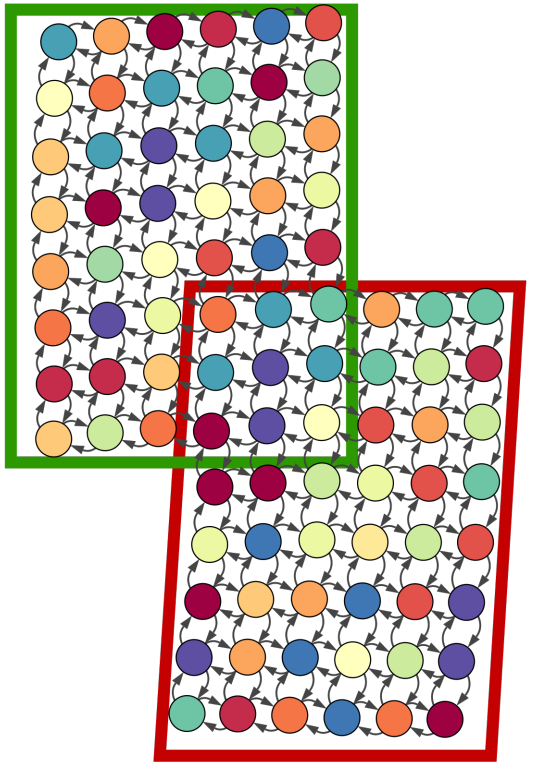


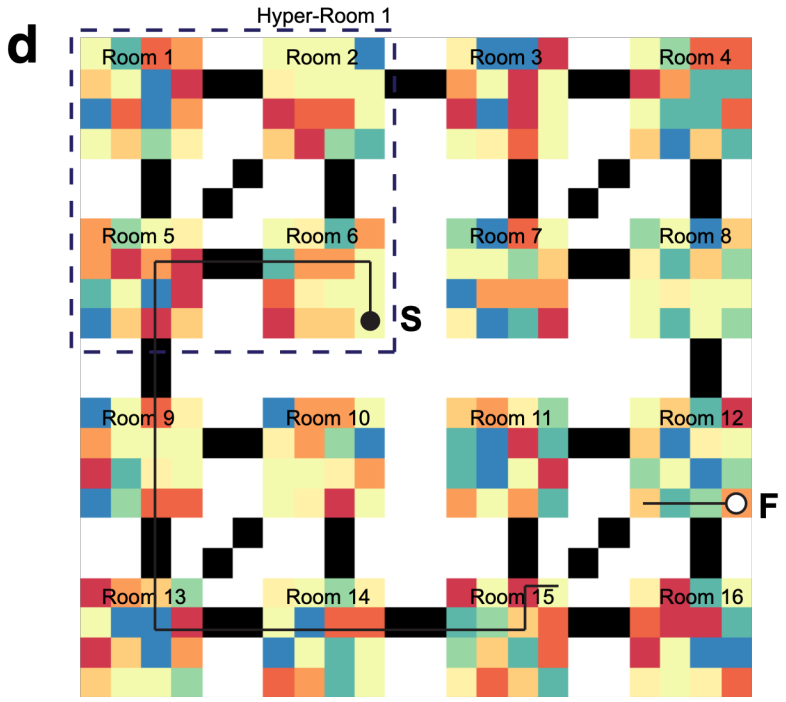
Cognitive map from pure sequential data
No Euclidean assumptions

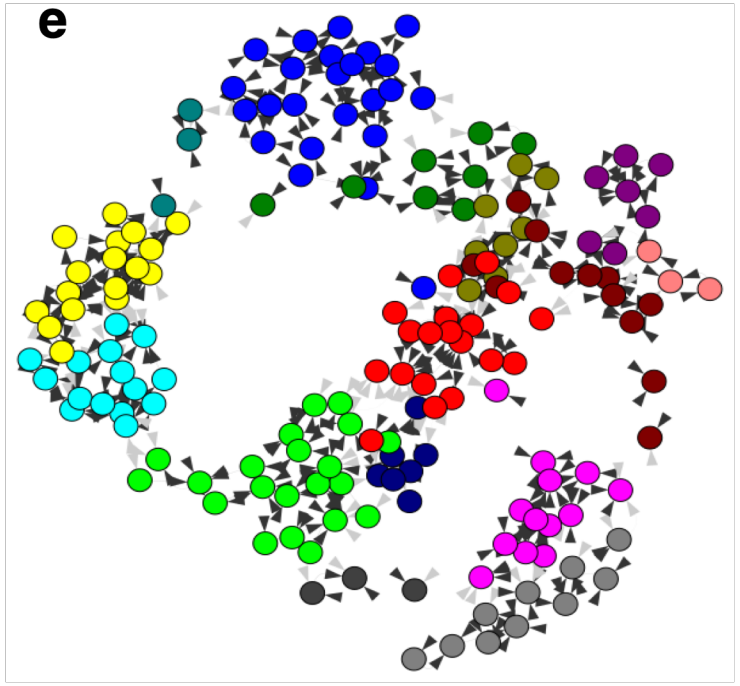
Traverse rooms separately

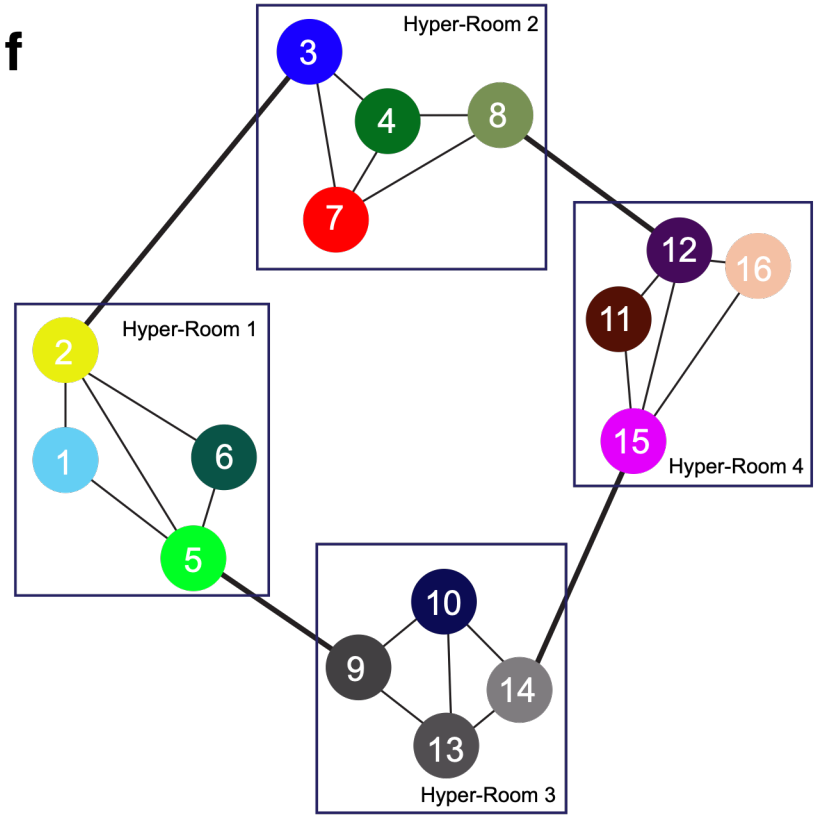


Learned cognitive map









Aliased hierarchical maze

Community detection on the cognitive map

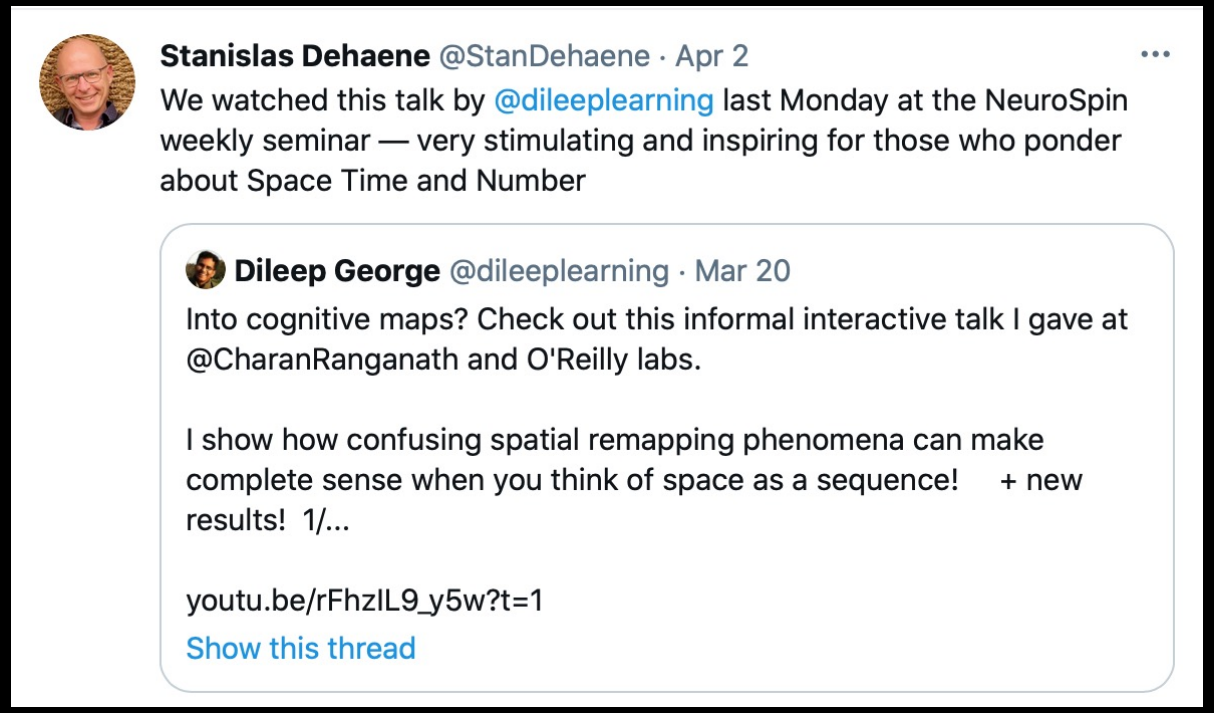
Discovered 3-level hierarchy

nature communications

Article | Open Access | Published: 22 April 2021

Clone-structured graph representations enable flexible learning and vicarious evaluation of cognitive maps

Dileep George ✉, Rajeev V. Rikhye, Nishad Gothoskar, J. Swaroop Guntupalli, Antoine Dedieu & Miguel Lázaro-Gredilla



Also, the CSCG model is featured in a "box" in a recent review paper from Tim Behrens lab. This is despite this being our very first publication on cognitive maps!

Big thanks to ONR!

Papers and Presentations

- Please list all papers and presentations that resulted from this research with full citations

1 paper published in AAAI-2021
1 paper published in Nature Communications 2021
1 paper published in Neurips 2021
2 papers on biorXiv, soon to be submitted to journals
1 paper submitted to ICML this year
1 paper in preparation for first submission to Science/Cell/Neuron

Query Training: Learning a Worse Model to Infer Better Marginals in Undirected Graphical Models with Hidden Variables

Miguel Lázaro-Gredilla, [1] Wolfgang Lehrach, [1] Nishad Gothoskar, [2]
Guangyao Zhou, [1] Antoine Dedieu, [1] Dileep George[1]

AAAI 2021

nature communications

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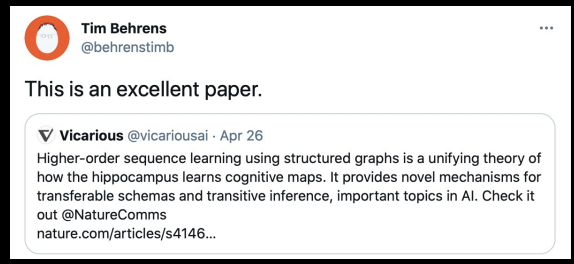

Perturb-and-max-product: Sampling and learning in discrete energy-based models

NeurIPS 2021

Learning attention-controllable border-ownership for objectness inference and binding

Antoine Dedieu, Rajeev V. Rikhye, Miguel Lázaro-Gredilla, Dileep George
doi: https://doi.org/10.1101/2020.12.31.424926

on BiorXiv

New Results

A detailed mathematical theory of thalamic and cortical microcircuits based on inference in a generative vision model

Dileep George, Miguel Lázaro-Gredilla, Wolfgang Lehrach, Antoine Dedieu, Guangyao Zhou
doi: https://doi.org/10.1101/2020.09.09.290601

on BiorXiv

Graphical Models with Attention for Context-Specific Independence and an Application to Perceptual Grouping

Guangyao Zhou, Wolfgang Lehrach, Antoine Dedieu, Miguel Lázaro-Gredilla, Dileep George

Submitted to ICML

Final Thoughts

Very productive project with several publications.

Clone-structured models is likely a general principle that is applicable in multiple domains.

* Also related to clonal neurons in neuroscience.

Our hippocampus/cognitive-maps model is already recognized in reviews as an elegant unifying model.

- Pursuing several follow ups including a potentially Science-level paper.

Context based perceptual grouping models will also grab attention once published.

Big thanks to ONR for the support!

REPORT DOCUMENTATION PAGE

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