Modeling Human Eye Movements with Neural Networks in a Maze-Solving Task

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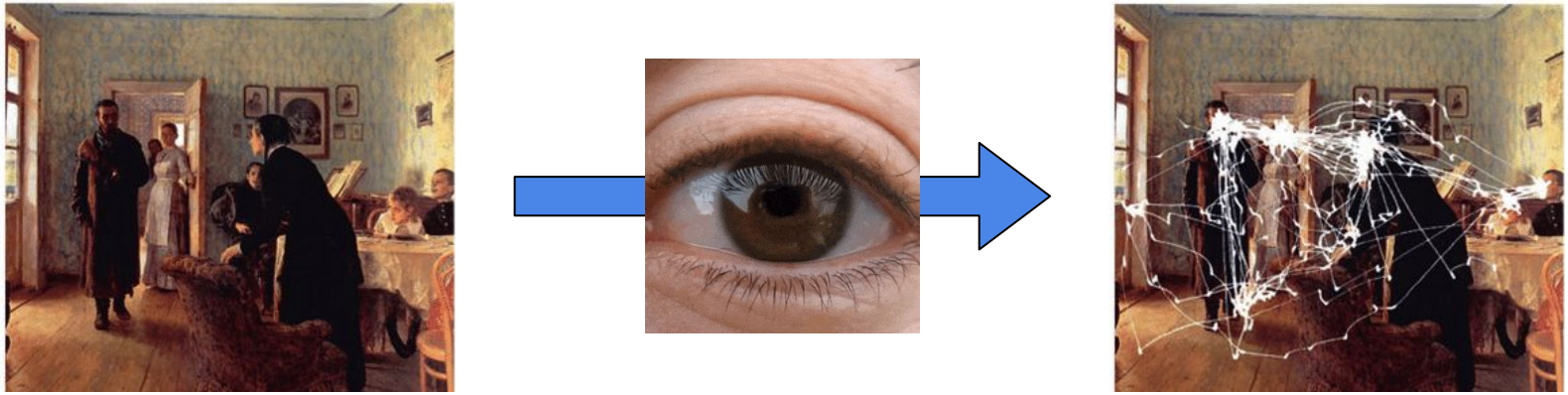
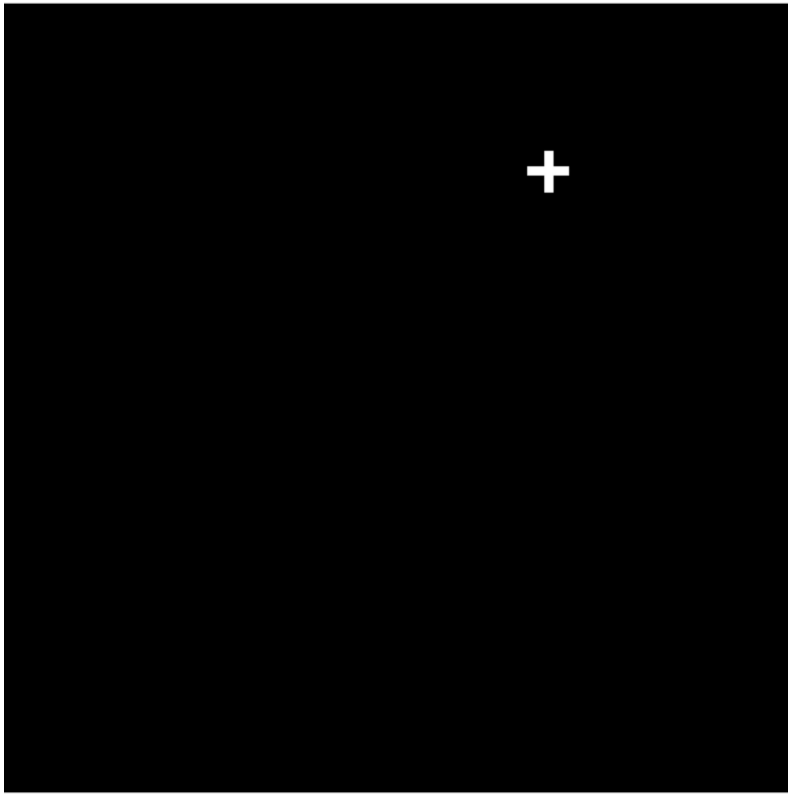


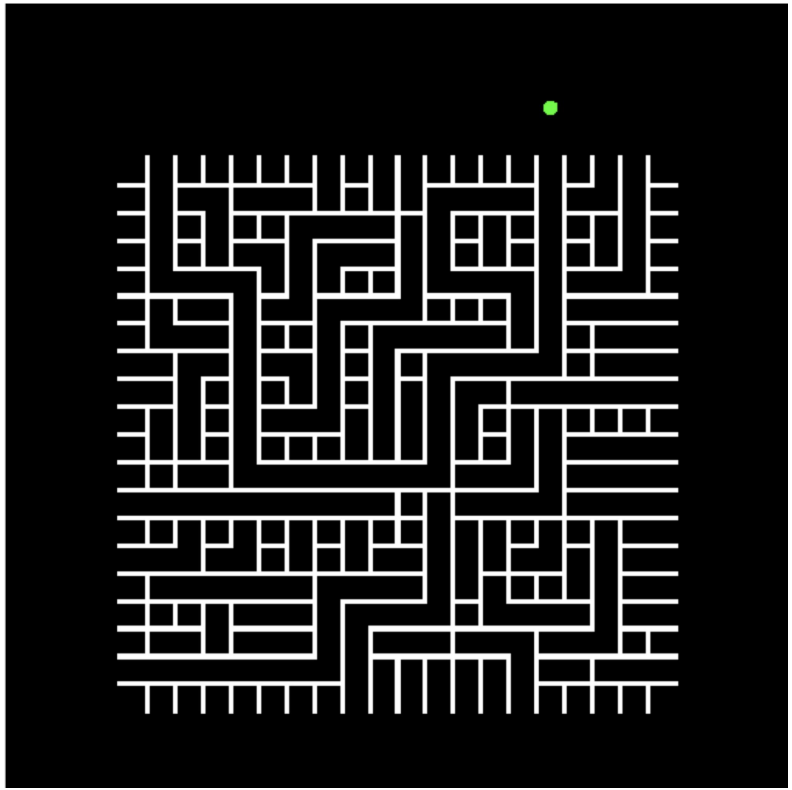
(Yarbus, 1967)

Goal: Build a **generative model of eye movements** that incorporates features of human vision like a fovea and discrete saccades.

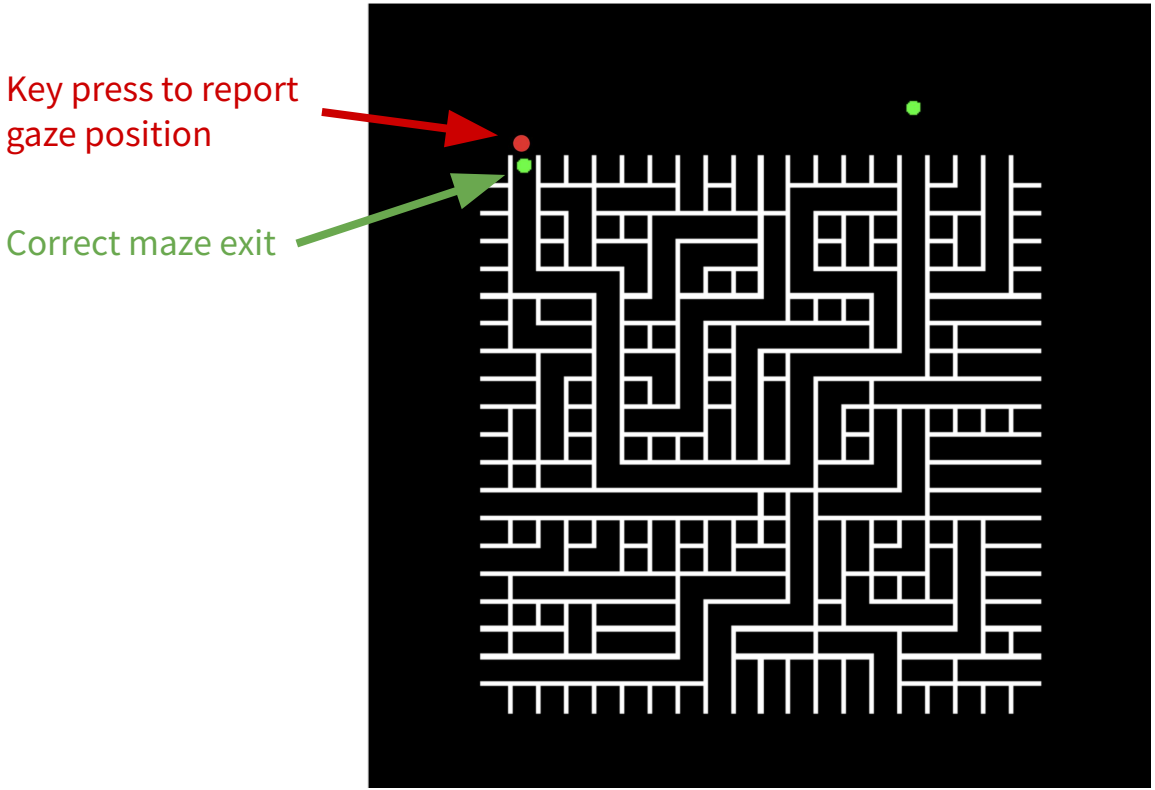
Maze task: Fixation at Entrance



Maze task: Maze Presentation

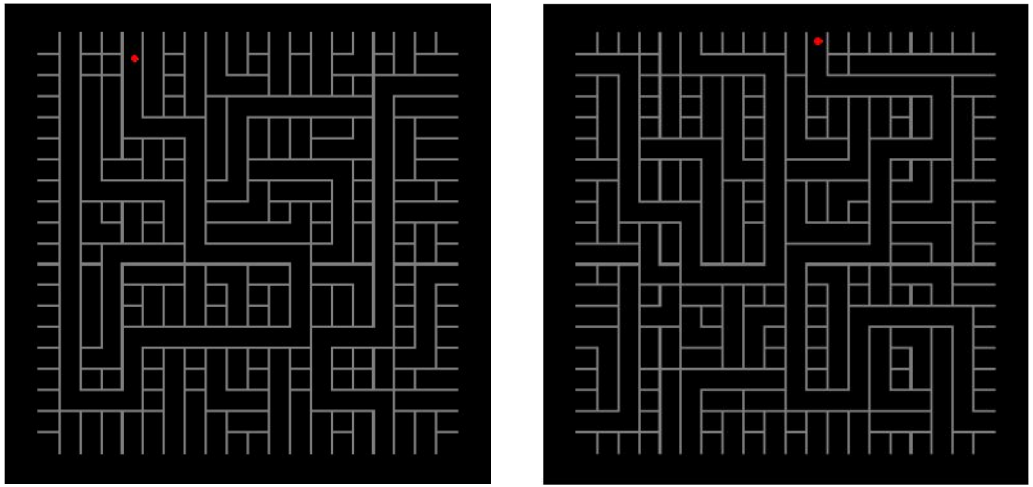


Maze task: Saccade to the Exit



Maze task

- Rich variety of spatial plans allows study of task-driven saccade sequences
- Eye movements are largely consistent across humans
- Allows us to test mental simulation as a strategy guiding eye movements



(videos shown 30% full speed)

Maze task

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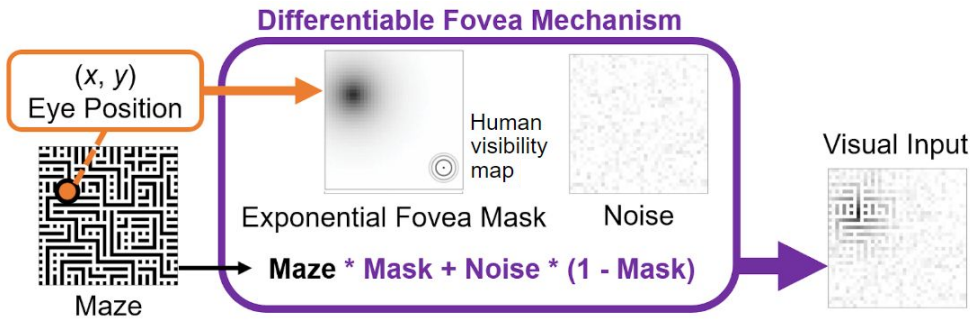
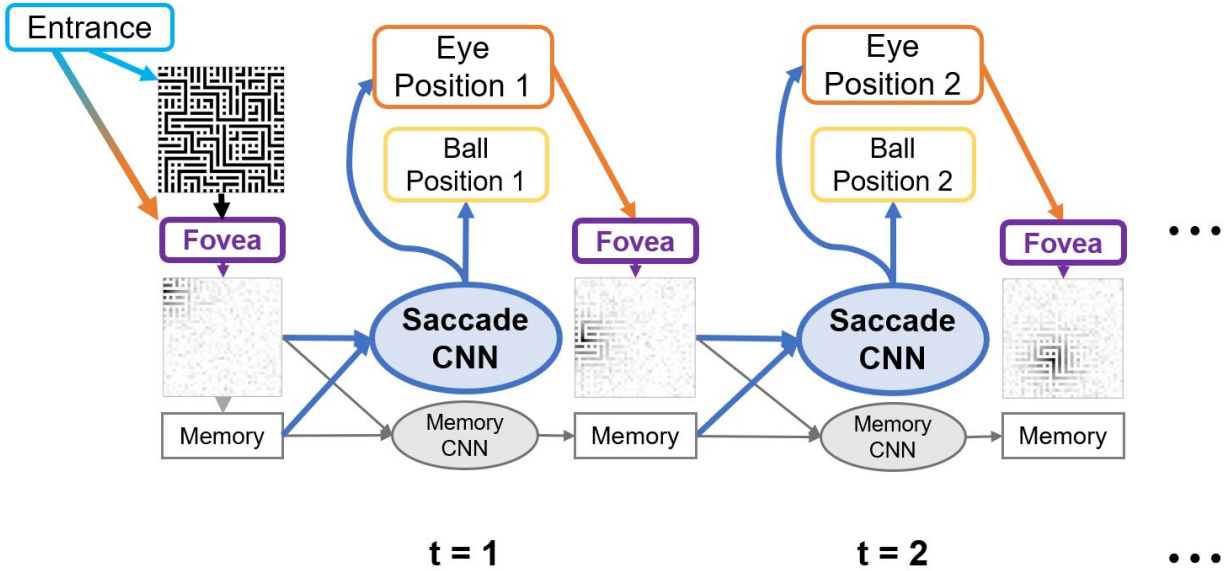
Human data collection

- 14 human volunteers
- Each subject completed ~400 trials
- Saccades extracted by filtering and thresholding eye velocity

Gaze RNN Models

- Novel differentiable fovea mechanism allows end-to-end training
- ConvRNN architecture unrolls through time for any number of saccades





3 Gaze RNN Variations

- **EXIT**: Reach exit in as few saccades as possible

Minimize $L_{\text{EXIT}} = \frac{1}{n}\sum_{i=1}^{n}(\hat{p}_i^{\text{eye}} - p^{\text{exit}})^2$

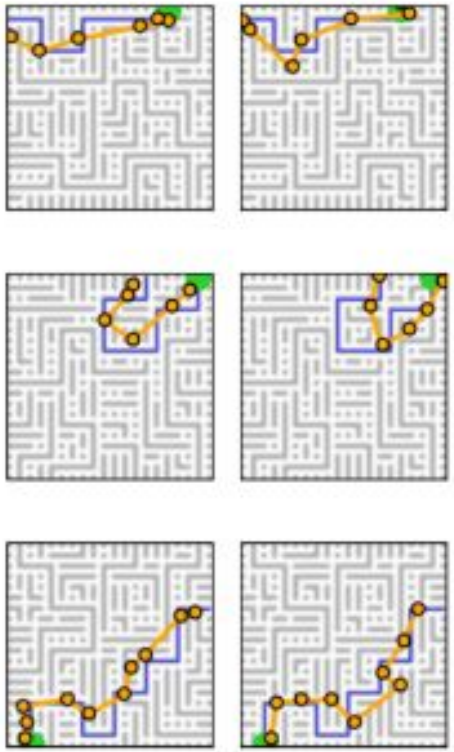
- **SIM**: Track an imaginary “ball” moving through the maze

Minimize $L_{\text{SIM}} = \frac{1}{n}\sum_{i=1}^{n}(\hat{p}_i^{\text{ball}} - p_i^{\text{ball}})^2$

- **HYBRID**: Weighted sum of the two loss terms

Minimize $L_{\text{HYBRID}} = \beta \cdot L_{\text{EXIT}} + (1-\beta) \cdot L_{\text{SIM}}$

Results: Qualitative Behavior



Human 1 Human 2

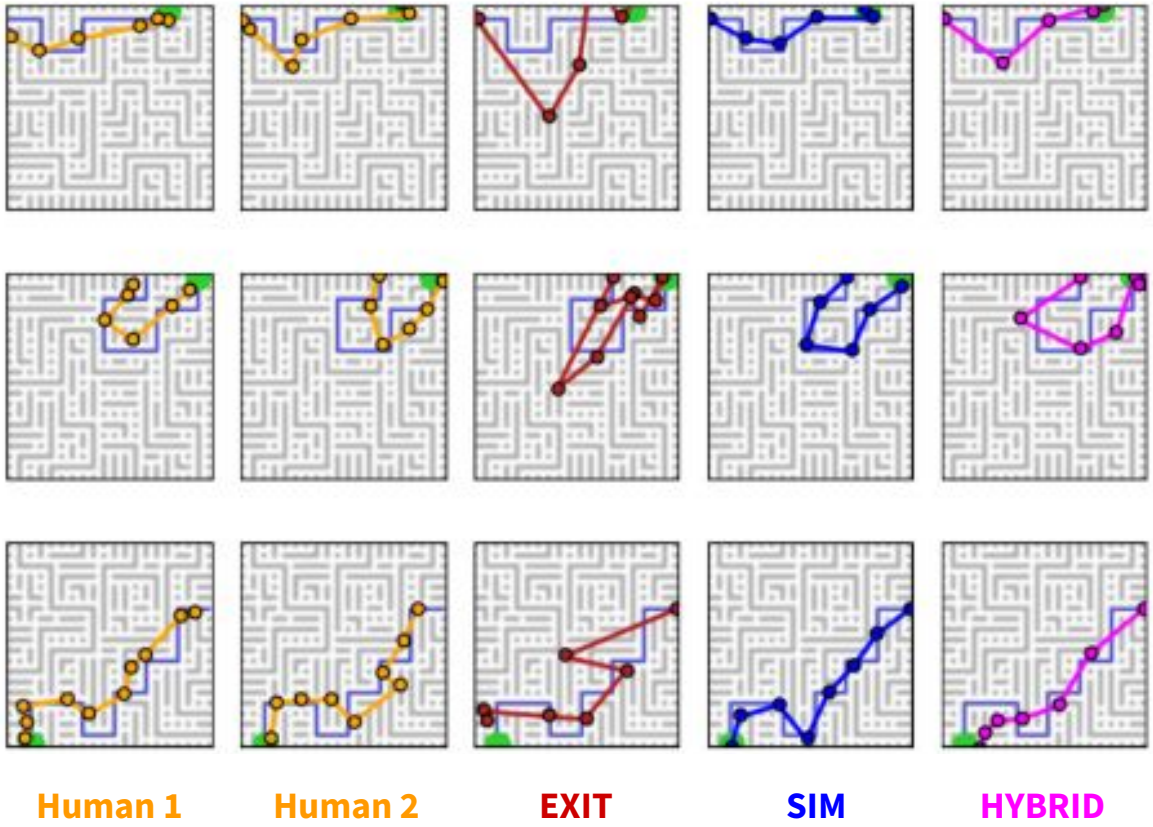
Exit

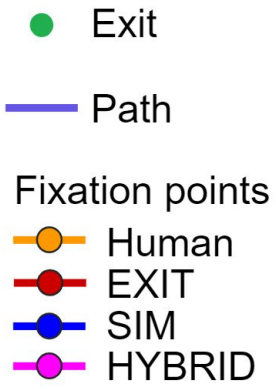
Path

Fixation points

Human

Results: Qualitative Behavior

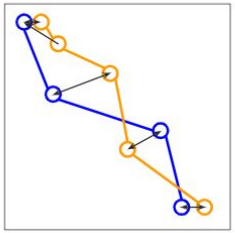




Results: Quantitative Metrics

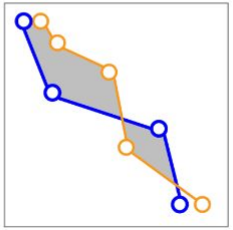
Nearest Neighbors Distance

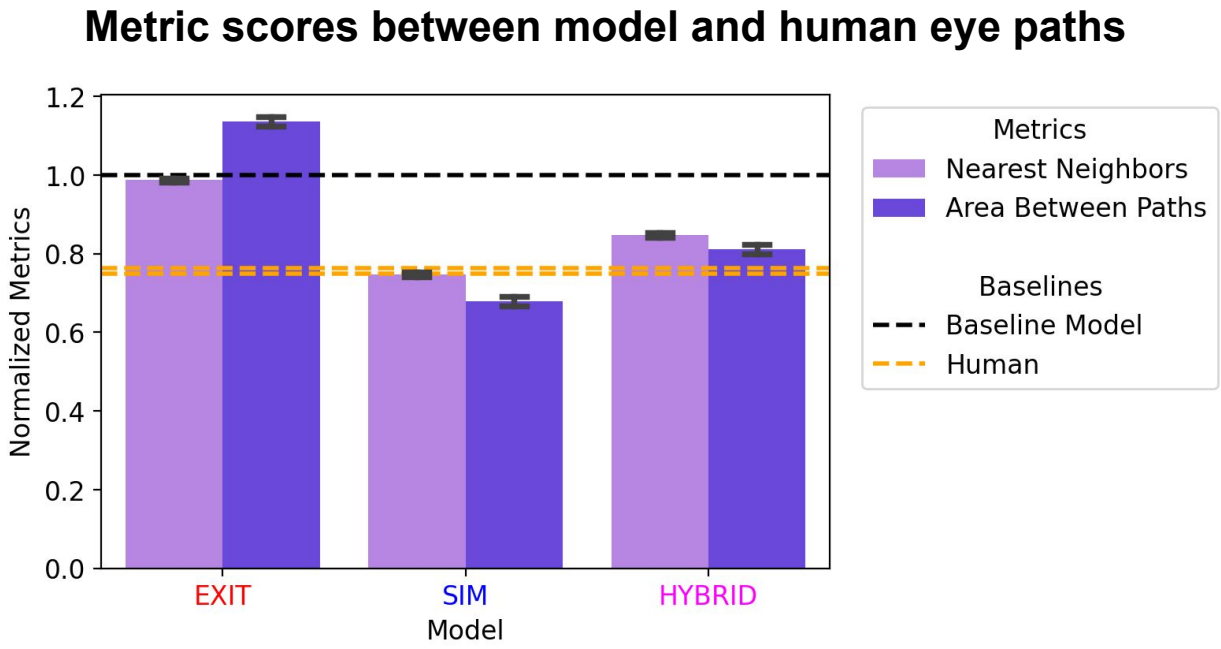
Mean of the nearest point in path **A**
to every point in path **B** and vice versa



Area Between Paths

Total plane area of the polygon(s)
formed between paths **A** and **B**





Conclusions & Future Work

- In the maze-solving task, a gaze RNN trained to run an internal simulation of a ball moving through the maze generates more human-like eye movements than a model trained to solve the task optimally
- Humans may employ a similar mental simulation when solving this task
- Future work may address:
  - Biological accuracy of model fovea hyperparameters
  - Introducing non-constant simulation speed
  - Allow gaze RNN to control fixation durations
  - Apply gaze RNNs to other task domains

Acknowledgements

Thank you!