Modeling Spatial Memory in Mice

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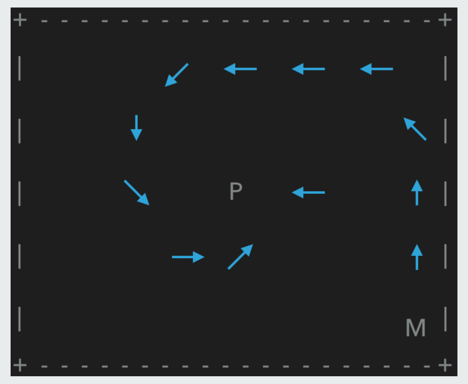
Introduction

This work seeks to model mouse performance on a spatial memory test, the Morris water maze test, described in Morris (1981). Spatial memory is the ability to remember spatial information. In the Morris water maze test, mice seek to find a hidden platform placed slightly below the surface of water, in a water tank where the water is opaque. Q-learning with a softmax, a reinforcement learning process, is used to model mice performance on the task.

Model Components



- Q-learning: Assigning utilities to states

$$Q(s,a) = Q(s,a) + \alpha[r + \gamma \max_{a'} Q(s',a') - Q(s,a)]$$

  - Q(s, a) is the q-value of the current state
  - α is the learning rate; $0 < \alpha < 1$
  - r is the reward for transitioning from state-to-state
    - This variable can be ignored
  - γ is the discount factor; $0 < \gamma < 1$
  - $\max_{a'} Q(s', a')$ is the largest q-value in an adjacent state to the current state

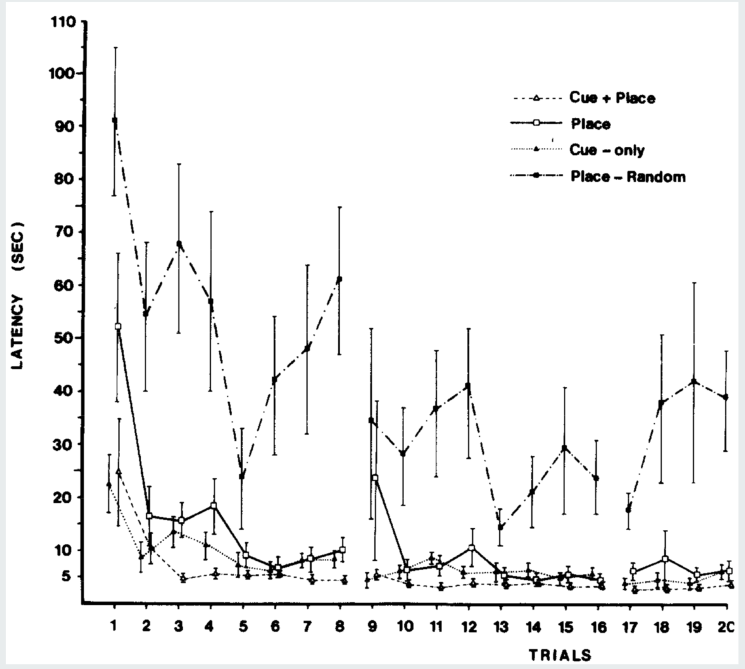
- Softmax: Assigning probabilities to moving to states

$$P(a_i) = \frac{e^{Q(a_i)/T}}{\sum_k e^{Q(a_k)/T}}$$

  - $P(a_i)$ represents the probability of moving to an adjacent state, a possible choice
  - $Q(a_i)$ represents the adjacent state's q-value
  - T represents the computational temperature
    - $T \to \infty$, the model favors exploration
    - $T \to 0$, the model favors exploitation
  - Start T large and after each trial, decrement T by parameter, MOD_T

- Forgetting a spatial bias
  - For the model to forget a spatial bias, the model needs to have made a certain number of moves after being trained on a constant platform location for a certain number of trials
  - Reset the computational temperature to its initial value
  - Set the new platform's location to have a q-value that is twice as large as the q-value of the old platform location

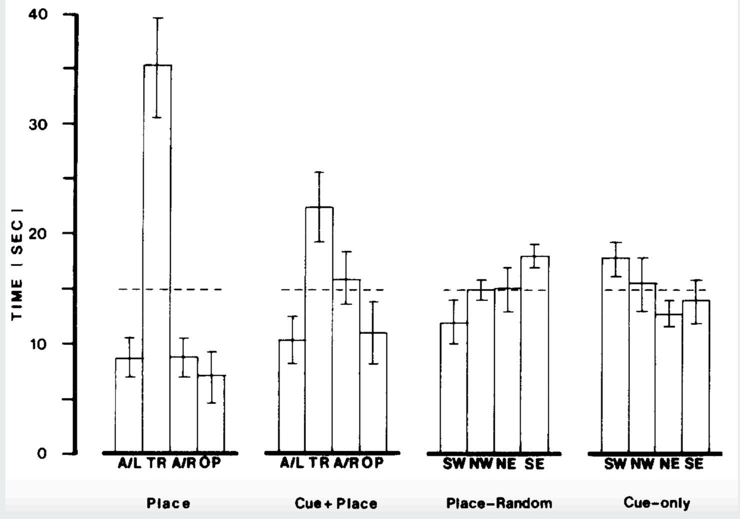
Establishing a Spatial Bias
Morris (1981):



(Morris, 1981, p. 246)

- Data of Interest: group Place
- Training results

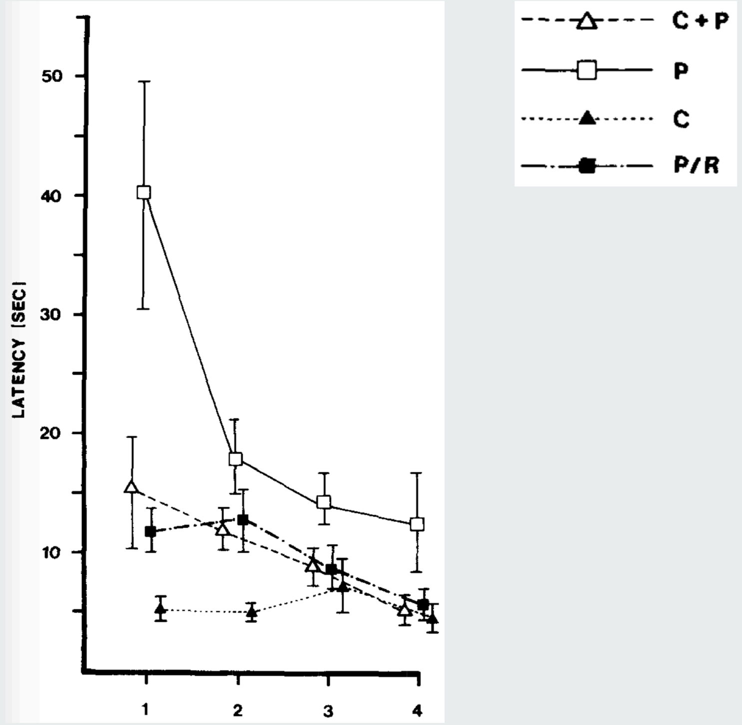
The Severity of the Spatial Bias
Morris (1981):



(Morris, 1981, p. 250)

- Data of Interest: group Place
- After training, the platform is removed from the water maze
- Mouse is given 60 seconds to move in the water maze

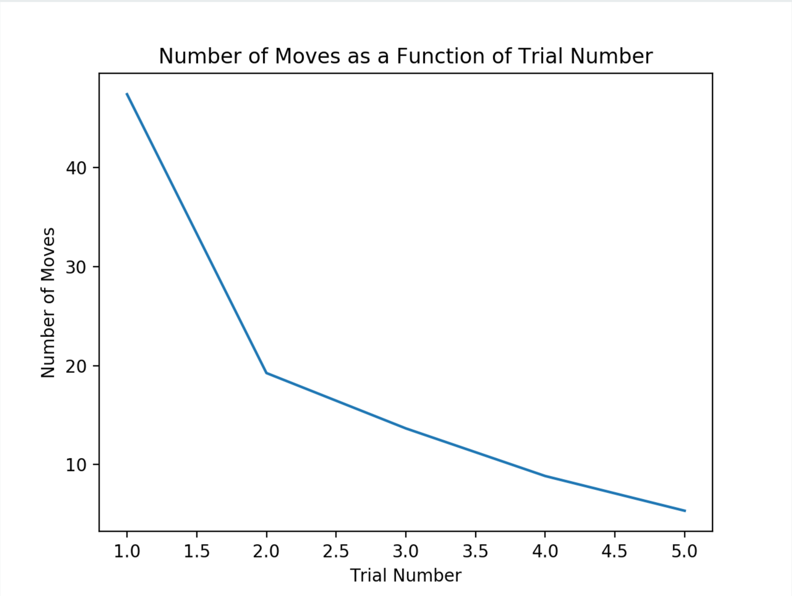
Forgetting a Spatial Bias
Morris (1981):



(Morris, 1981, p. 251)

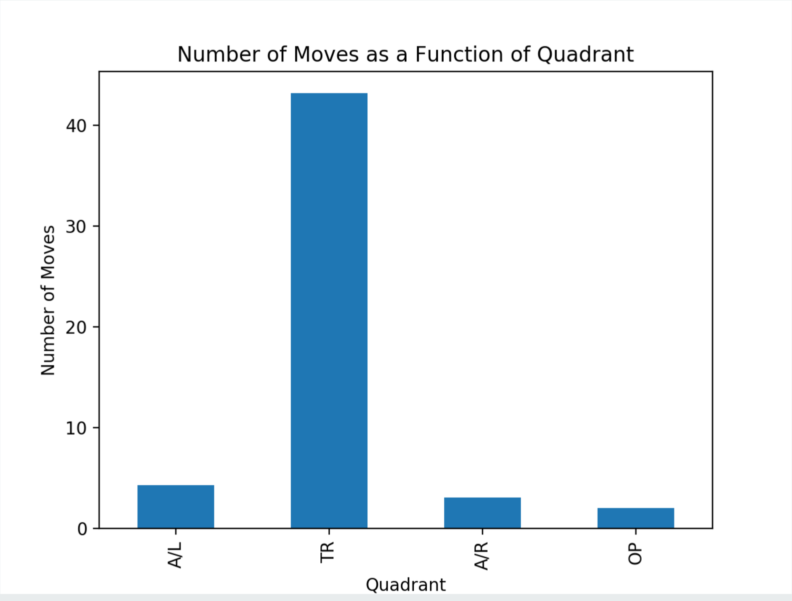
- Data of Interest: group Place
- After training, the platform is moved to a new location

Establishing a Spatial Bias
The Model:



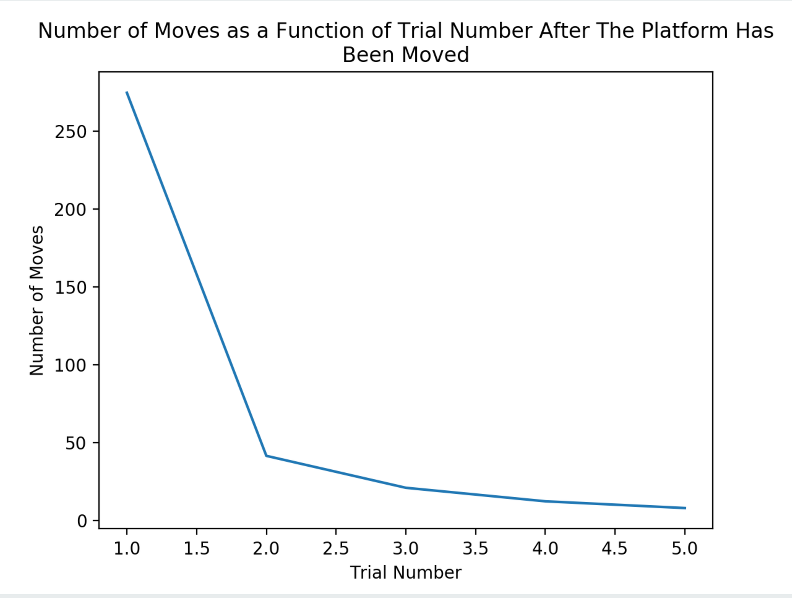
- Total trials: 5
- Total iterations: 1,000
- T: 100.0
- MOD_T: 0.55
- γ: 0.9
- α: 0.9
- The water maze is represented as a 7 x 7 board

The Severity of the Spatial Bias
The Model:



- Total trials: 5
- Total iterations: 1,000
- number of moves allowed: 60
- T: 100.0
- MOD_T: 0.55
- γ: 0.9
- α: 0.9
- The water maze is represented as a 7 x 7 board

Forgetting a Spatial Bias
The Model:



- Total trials: 5
- Total iterations: 1,000
- Total training trials needed to forget a spatial bias: 3
- Total moves needed to reset the spatial bias: 37
- T: 100.0
- MOD_T: 0.55
- γ: 0.9
- α: 0.9
- The water maze is represented as a 7 x 7 board

Discussion

- Generalizing the model
  - The model's performance, on a 7 x 7 board, is comparable to mice performance in Morris (1981)
  - However, this model has been tailored to operate on a 7 x 7 board
  - The model needs to be adjusted to operate in all environments
    - Mnih et al. (2015) built a general learning model to play 49 different Atari games at high performance
    - Mnih et al. (2015) did this by feeding sensory input, pixel data, from Atari games, into neural networks to generate q-values
  - It seems plausible that this same neural network architecture could be used to generate q-values for the model described in this poster
    - The model would, then, be able to perform well on the Morris water maze test in all sorts of environments
  - With this modification to the model, we, now, have a model that could be a cognitive mechanism to explain how mice perform spatial memory tests

- There is a significance to the fact that a reinforcement learning model can model the performance of mice on a spatial memory test
  - A reinforcement learning model can learn all sorts of behaviors
  - It is very possible that the cognitive mechanism a mouse uses to learn to perform any activity well might be the same cognitive mechanism that a mouse uses for spatial memory learning
    - This could mean that mice have one cognitive mechanism for learning

- One might wonder why we are focused on how a mouse's brain functions
  - There is large amounts of data collected from experiments conducted on mice

- Studying how mice perform spatial memory tests informs our understanding of how some brains complete spatial memory tests
  - This studying leads us to consider if it is plausible for other animals' brains to perform the same cognitive tasks in the same manner

References

Mnih, V., Kavukcuoglu, K., Silver, D., Rusu, A.A., Veness, J., Bellemare, M.G., … Hassabis, D. (2015). Human-level control through deep reinforcement learning. *Nature*, *518*(7540), 529-541. doi:10.1038/nature14236

Morris, R.G. (1981). Spatial localization does not require the presence of local cues. *Learning and Motivation*, *12*(2), 239-260. https://doi.org/10.1016/0023-9690(81)90020-5

Appendix

The model can be accessed at https://github.com/bengoebel/WaterMazeTest

Acknowledgements

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