Computational Modeling of Odor-Associated Avoidance in Fruit Flies Using Cybernetic Automata

Thu Rein Linn, Dr. Brian Stuart
Drexel University, College of Computing & Informatics

ST★R SCHOLARS

DREXEL UNIVERSITY
Undergraduate Research & Enrichment Programs
Pennoni Honors College

Introduction

- In neuroscience, many experimental studies explore how fruit flies (*Drosophila melanogaster*) form these associations for studying learning behavior due to its simplicity, 60% genetic similarity to humans.
- Replicating these protocols computationally provides an alternative way to test hypotheses about learning, reduces reliance on live animal testing, and enables systematic manipulation of parameters.
- This project validates how much a cybernetic automaton model,a mathematical system that adapts through feedback, simulating natural intelligence based on cognitive science, can replicate first-order and second-order conditioning in fruit flies' learning behaviors, bridging computer science, cognitive science, and neuroscience to uncover brain mechanisms.

Methods

Three Different Protocols

- Paired-Paired(P-P): paired electric shock with the first odor in delayed conditioning 12 times in 3 batches and presented the second odor, and linked the second odor with the first odor 12 times in 3 batches simultaneously.
- Paired-Unpaired(P-U): connected shock with the first odor in delayed conditioning, but dissociated the second odor from the first odor 12 times in 3batches.
- Unpaired-Paired (U-P): dissociated the shock with the first odor, but presented the second odor alone for 7 seconds and later paired the second odor with the first simultaneously 12 times in 3 batches.
- Trained first 50 and second 50 groups with both first- and second-order conditioning. Presented the first odor to the first group and the second odor to the second group.
- Counted the number of learning responses from both groups and converted them into percentage values to calculate performance index values(PI).
- The PI quantifies learning rate, measuring the proportion of flies avoiding both odors.
- A PI of 100 indicates complete avoidance, while a PI of 0 indicates a 50:50 distribution (no preference, i.e., no learning).

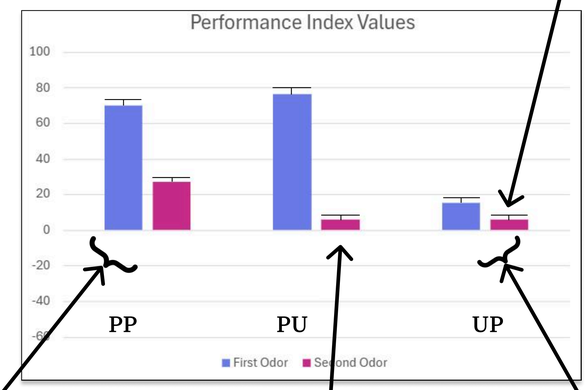
PI = (Percentage of flies avoiding CS- 50) ×2

CS: Conditional Stimulus | UCS: Unconditional Stimulus

Results

Second-Order Conditioning

Biological Experimeent

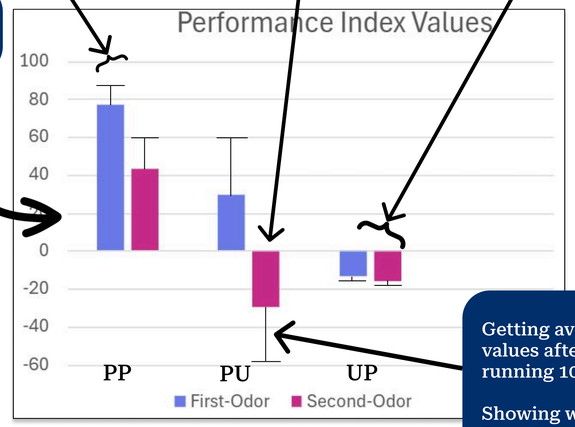


Similar (PP) PI Values

Differences in (PU) PI Values for 2nd odor Conditioning

Minor Differences in (UP) PI Values

First-Order Conditioning



Getting average values after running 10 trials

Showing with Error Bar

Computational Experiment

Protocols	First-Order Conditioning	Second-Order Conditioning
Paired-Paired (PP)	Electric Shock + First odor	First odor + Second odor
Paired-Unpaired(PU)	Electric Shock + First odor	First odor + Second odor
Unpaired-Paired(UP)	Electric Shock + First odor	First odor + Second odor
Stimulus	Electric Shock / First odor	First odor / Second odor

Conclusion

- Demonstrates that a cybernetic automaton can effectively replicate first-order and second-order conditioning in fruit flies, with the P-P protocol achieving the strongest conditioning (PI=76 for FOC and PI=32 for SOC).
- Reproduced key behavioral signatures: direct avoidance of a conditioned odor (CS1) and indirect avoidance of a second odor (CS2) through associative transfer.
- Suggests that computational models can serve as powerful tools for validating theories of learning and validates the model's ability to mimic biological learning processes.
- Reveals how temporal associations drive memory, offering a scalable alternative to lab experiments.
- By bridging computer science and neuroscience, this work provides insights into neural circuit dynamics, with potential applications in understanding memory disorders and developing ethical AI learning models.

References

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Future Work

- Examine why PI values in PU and UP protocols differ from those observed in biological experiments.
- Investigate why the model produces larger negative PI values compared to experimental results.
- Explore why UP protocols yield negative PI values rather than small positive ones seen in biology.

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