Simulating Multimodal Communication in Vervet Monkeys with Braitenberg Vehicles

1. Summary of the Proposal

The thought experiments by Valentino Braitenberg that lead to the creation of Braitenberg Vehicles (BVs) help us in very robust modeling of basic emotions emerging from simple neuronal wiring. These emotional responses can be utilized in modeling predator-prey behavior in an ecological setup. Here I propose simulating vervet monkeys' behavioral aspects (Cercopithecus aethiops), especially how they deal with predators in an ecological setting. Vervet monkeys give acoustically different alarm calls to different predators and hence show signs of semantic communication. I will use my already developed agent-based BV simulation platform in developing this simulation, primarily focusing on the communication aspects in vervets.

2. Background

2.1. The Existing Simulation

The work by Dwight and Francis Steen (2008): “Reducing Uncertainty in Costly Information Gathering: An Agent-Based Model of Vervet Monkey Warning Cries” explores representational communication’s evolution based on vervets’ documented behavior in the wild (Seyfarth, Cheney, & Marler, 1980). Vervets use distinct alarm calls for three types of predators: leopards, snakes, and hawks. While there is no location in the vervets’ habitat where they can seek adequate shelter from all three predator types, they seek out bushes to conceal themselves from hawks, trees to escape from leopards, and stoney ground to stay safe from snakes.

2.2. Needs for extending the model

The existing model explores how the vervets act and communicate under the threat of these three predators. Further development is needed to address the following questions,

- How can it be extended to add further factors?
- What could we add to the environment to add another variable that affects the vervets' actions?
- What inter-vervet behavior besides flocking might we add?
- What if we let the predators learn from their encounters? What might the effects be?

2.3. What am I going to address?

- How are the predator-specific alarm calls utilized by the vervets focusing on the net benefits of communication?
- Apart from the specific predator hideouts in the already existing simulation, I propose to introduce non-uniform distribution of resources in the foraging area.
- I also propose introducing probabilistic attention towards stimulus (vigilance) in the vervets based on their previous experiences.
- After this, I also plan to consider multiple types of stimuli (apart from the visual stimulus) from the predators, e.g., auditory and olfactory stimuli, being received by the vervets.
- If time permits, I may also attempt to add the inter-vervet behavior described in *Meaning and Mind in Monkeys* (Seyfarth & Cheney, 1992).

3. Goal and Objectives

- Verifying the significance of the vervet alarm calls
- Observing the ecological balance as we tweak the environmental parameters
- Observing the evolution of multimodal communication
- Observe the collective intelligence as vervets collaborate to avoid predators
- Saving the simulation parameter for analysis data and drawing inferences

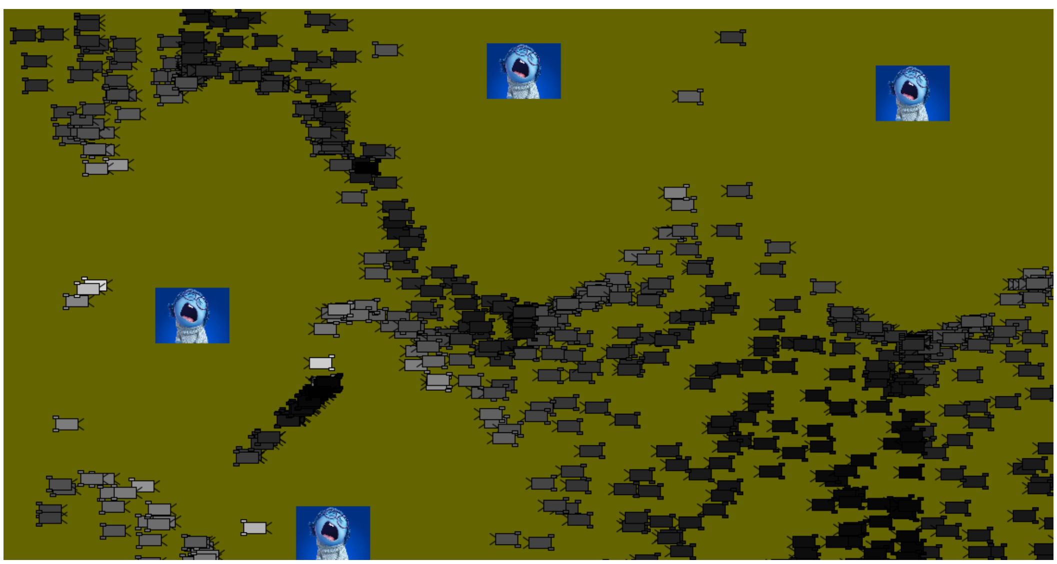
4. Minimum Deliverables and Implementation Methods

4.1. Setting up the environment

The simulation environment consists of vervets and three types of predators, namely, leopard, hawk, and python, each with some initial population as the simulation starts. The environment has three dedicated hideout areas of vervets corresponding to each predator, while the rest of the area has food resources scattered non-uniformly. The resource density near the hideouts is intentionally tweaked to create tension between vigilance and foraging.

4.2. Modeling of individual behavior of vervets and the predator when they confront each other.

Whenever a predator comes under the vervet's field of view and the vervet becomes vigilant of the predator's presence, the vervet acts cowardly, trying to run away from the predator. The vervet's behavior in such a scenario is analogous to vehicle 2A of the Braitenberg Vehicle (BV), so I will incorporate this into vervets. As the predator aims to chase the vervet, attack them, and then move on to other vervets, this behavior is analogous to vehicle 3B of the BV, so the predator's behavior will be modeled using this. Note that as I have already modeled vehicles 1, 2A, 2B, 3A, 3B for my existing BV simulation environment.



A snip of the agents modeled as vehicle 2A, i.e., coward. For complete project details, please visit the home repository: [https://github.com/ankiitgupta7/Simulations- of-Braitenberg-Vehicles](https://github.com/ankiitgupta7/Simulations-of-Braitenberg-Vehicles)

The predator will be able to attack a vervet if they are successful in reaching into their proximity. The proximal distance may be different for each predator and needs to be decided. Note that the predator won't be able to attack the vervet in their respective hideouts.

4.3. Modeling vervet's predator-specific alarm calls and their response

We know vervets give acoustically different alarm calls to respective predators when they notice a predator(Seyfarth, Cheney, & Marler, 1980). As the sound source can travel in all directions, this will alert all the vervet population present in a circular area (with an appropriate radius) centered around the sound source. As a result of this, vervets run directly towards the hideout, taking cues from the alarm type. In this process, if they notice the predator in their path, they will try to avoid them by acting cowardly, as discussed in section 4.3.

4.4. Modeling population growth of vervets and the predators

The vervet and the predator population are updated after a fixed number of simulation frames (representing the passage of time). A particular fraction of the adult population from the last frame is added to the next frame. This applies to both vervets and the predator. A predator dies only by starvation and old age, while a vervet can die from starvation, old age, and attack from a predator.

4.5. Modeling fitness level and foraging strategy of vervets

Firstly, we need to define some parameters for each vervet before we proceed.

- **A:** Age of the vervet, they die after a certain age
- **E:** Energy level, say between 0-100, decaying over time (frames in the simulation). The only to replenish E is to forage food going out of the hideouts.
- **H:** Hunger level = 100 - E
- **F:** Fear level, proportional to the number of predators spotted by the vervet when it is not confronting a predator. This value is updated with a very high value when the vervet confronts a predator.
- **V:** Vigilance level from predators, having a bell curve dependence on age, proportional to the distance from hideout and also fear level
- **FL:** Foraging loss rate, directly proportional to V as vigilance comes at the cost of foraging productivity
- **FR:** Food reserve at a particular place (represented by pixel in the simulation) in the foraging space

The vervets come out to forage food when the hunger level exceeds the fear level, i.e., H>F. As long as they are not aware of a potential predator nearby, the vervets explore the foraging space by moving in the direction of maximum food reserve (FR) until their energy level reaches maxima, i.e., E = 100. After this, they return to their safest hideout. The vervets die out of starvation if E becomes zero.

4.6. Modeling fitness level and hunting strategy of predators

Predators have equivalent A, E, H parameters like those of vervets. Their energy levels (E) too decay with time, but obviously at a different rate. They too die of old age and starvation, i.e., when E becomes zero. As long as they don't come across a predator, they randomly move across the environment. Once the energy levels of the predator reach maxima they stop preying on vervets and also stop moving.

5. Advanced Implementations

5.1. Parameter plots and saving simulation parameter into files

The vervet and predator parameters can be plotted to show the simulation flow's background information and can also be stored locally to analyze extensive run data. It will give us good insights to understand how communication, specifically the alarm calls, helps produce increased survival rates at a lower net cost.

5.2. Introducing olfactory stimuli for vervets

The vervets may also use their smelling sense to identify the nearby presence of a predator. The smell stimulus can be modeled as a weakening stimulus with time as the predator moves, having the maximum smell around them. A vervet senses the scent of the predator and goes in the direction of receding smell.

5.3. Modeling Intra and Inter-Group Behaviour in Vervets

I will be happy to work on this even after GSoC'21 is over.

6. Tentative Timeline

6.1. Phase 1 (Week 1-2): Setting up the environment and optimize parameter dependencies

6.1.1. Develop the platform to make it more suited for the simulation plan
6.1.2. Discuss and locate the hideouts
6.1.3. Discuss and plan the foraging space resource distribution
6.1.4. Discuss and finalize parameter dependencies
6.1.5. Calibrate the constants of the dependencies

6.1.6. Write tests as well as the documentation of the newly implemented functionalities

6.2. Phase 2 (Week 3): Modelling direct interaction between vervets and predators

6.2.1. Integrate BV behaviors in modeling vervets and predators as vehicle 2A and 3B respectively
6.2.2. Handle proximity issues between the vervets and the predators
6.2.3. Write tests as well as the documentation of the newly implemented functionalities

6.3. Phase 3 (Week 4-7): Restricting interaction and modeling alarm calls

6.3.1. Handle the field of view issue to make visual stimuli interaction more practical
6.3.2. Work on implementing alarm calls and the corresponding response from vervets in the alerted area
6.3.3. Work on vervets' trajectory back to the hideout in case they meet any predator in between
6.3.4. Write tests as well as the documentation of the newly implemented functionalities
6.3.5. Week 7 can work as a buffer week to complete anything lagging in terms of writing code/documentation/blog

6.4. Phase 4 (Week 8-10): Handling population growth across generations

6.4.1. Implement population update as the simulation progresses
6.4.2. Model fitness levels of vervets and each predator
6.4.3. Work on foraging strategy of vervets and each predator
6.4.4. Work on the scenarios when the energy levels are at terminal values
6.4.5. Draw inferences to prove the utility of alarm calls in survival
6.4.6. Write tests as well as the documentation of the newly implemented functionalities
6.4.7. Move on to work on advanced implementations when the minimum set of deliverables are successfully completed.

7. References

- Dvoretskii, S., Gong, Z., Gupta, A., Parent, J., and Alicea, B. (2020). 'Braitenberg Vehicles as Developmental Neurosimulation'. arXiv, Neurons and Cognition (2003.07689)
- Dwight and Francis Steen (2008): "Reducing Uncertainty in Costly Information Gathering: An Agent-Based Model of Vervet Monkey Warning Cries", a simulation created in the UCLA Human Complex Systems Program
- Seyfarth, R.M.; D.L Cheney; Peter Marler (1980). "Vervet Monkey Alarm Calls: Semantic communication in a Free-Ranging Primate". Animal Behaviour. 28 (4): 1070–1094. doi:10.1016/S0003-3472(80)80097-2