Investigating behaviour change in action selection of embodied and situated agents in a dynamic environment.

1. Background and Motivation

The research of intelligent behavior has been dominated by computationalism that emphasises internal models, explicit representations and rule-based processing. With the development of Post-cognitivism approaches, an alternative perspective has gained traction, suggesting that complex behaviors can emerge from simple sensorimotor connections without requiring sophisticated internal models or explicit representations (Hotton & Yoshimi, 2024). This perspective aligns with embodied and situated cognition theories, which posit that cognition is fundamentally grounded in an agent's physical interactions with its environment rather than residing solely in abstract mental processes.

Valentino Braitenberg's groundbreaking work "Vehicles: Experiments in Synthetic Psychology" (1984) introduced a powerful conceptual framework for understanding how simple sensorimotor connections can give rise to seemingly complex behaviors. His thought experiments involved creating increasingly sophisticated "vehicles" with direct connections between sensors and motors, demonstrating how behaviors that appear intentional, emotional, or intelligent could emerge from these minimal architectures.

Building on Braitenberg's foundations, Seth (1998) demonstrated that complex action selection and selective attention phenomena could evolve in minimal animat architectures without requiring explicit internal representations of actions or selection mechanisms. In his groundbreaking paper "Evolving Action Selection and Selective Attention Without Actions, Attention or Selection," Seth showed that a set of autonomous, continuously active sensorimotor links, without any interconnections, could support a full range of action selection behaviors when shaped by genetic algorithms. His animats successfully navigated environments containing food, water, and hazards, exhibiting prioritization, opportunism, and appropriate interruption of behaviors without any centralized decision-making mechanism. Seth's work challenged traditional approaches to action selection that assume internal arbitration between competing behaviors. Instead, he demonstrated that coherence between multiple sensorimotor processes could produce adaptive behavior without requiring higher-level representations. This perspective views behavior not as the product of internal deliberation but as emerging from the ongoing interactions between an agent, its environment, and an observer's interpretation of these interactions.

Our project maintains Seth's minimalist sensorimotor architecture but extends the scope to multi-agent environments, where genetic algorithms will be used to shape behavior selection strategies rather than the sensorimotor connections themselves. By introducing sensors capable of detecting other agents, we enable potential social interactions while preserving the simplicity of the underlying architecture. This approach allows us to investigate whether complex social behaviors like cooperation, competition, stress responses, and aggression can emerge from the evolutionary shaping of behavior selection in minimalist agents.

Hotton and Yoshimi (2024) have recently explored the open dynamics of Braitenberg vehicles, emphasizing how these systems can demonstrate complex behaviors through their coupling with environmental features. They argue that analyzing the dynamical systems properties of agent-environment interactions can provide insights into emergent behaviors that might otherwise be attributed to complex internal cognitive processes. Their work provides theoretical grounding for our approach, suggesting that social behaviors might similarly emerge from the dynamics of agent-agent-environment coupling rather than from sophisticated internal models of social interaction.

The relevance of multi-agent dynamics to evolutionary processes is illustrated in Primer's educational video (2019), which simulates how different survival strategies (labeled as "Hawk" and "Dove" behaviors) influence population dynamics and evolutionary outcomes. The video demonstrates how game-theoretical principles can shape biological evolution when different behavioral strategies compete within a shared environment. Similarly, our project aims to uncover how genetic algorithms might shape behavior selection strategies when agents must navigate environments containing not only resources and hazards but also other agents with potentially competing interests.

By focusing on genetic algorithms for behavior selection, our project aims to identify what strategies emerge when minimalist agents must compete or cooperate for resources. This could provide insights into how complex social behaviors might evolve in simple organisms without requiring sophisticated internal models of social interaction. If successful, our project will demonstrate that behaviors typically considered to require advanced cognitive capabilities can emerge from the evolutionary shaping of behavior selection by embodied and situated agents in a dynamic environment.

Understanding complex behaviours like stress, aggression or other social responses has long been a challenge in both cognitive sciences and psychology. It is a really interesting topic to tackle as we commonly associate such behaviour with intelligent life, and if we are able to simulate these behaviours using very simple weights between a sensor and a motor; no neurons, this would be some evidence that cognition or at least these behaviours are closely linked to the environment, body and time rather than just solely in the brain.

Traditional computational models often rely on explicit representations to model the “mind” however in this project we aim for a more post-cognitivist/anti-computationalist approach where instead of us, the human designers, pick out the important relationships into the animat’s model, we instead let it figure it out itself, using genetic algorithms to train the sensorimotor systems.

Building on the foundational work of Seth (1998), who demonstrated the mechanisms for action selection and selective attention could evolve without requiring explicit

representations of actions, attention or selection. We wish to explore whether complex social and affective behaviours like stress or cooperation can emerge in minimal models.
We want to specifically use Seth's model and by introducing more dynamic interactions within a shared environment to monitor the that it will produce between the robots.

The main motivation for this project is to investigate whether behaviours typically considered to be emotionally or socially grounded like stress and aggression, can arise purely from the evolved dynamics of a simple sensorimotor system in a multi-agent environment. With the power of genetic algorithms, our approach allows us to explore how cognitive behaviors may change under different environmental pressure. By comparing behavioral patterns across environments, we can examine whether emergent action selection adapts differently to various forms of environmental complexity, potentially revealing insights about opportunistic behavior, risk taking or resource prioritisation without explicitly programming these capabilities. If successful, this would challenge the necessity of high-level representations in the modeling of behaviour and offer new insights to how minimal architectures can give rise to such rich and emergent phenomena.

2. Statement of Research Intent

This project aims to investigate whether, in dynamic and multi-agent environments, extremely minimal animat architectures can also exhibit behaviors similar to "stress" or "emotional adaptability" through evolutionary processes. Based on the research of Seth (1998), we further extend the model and the environment. Animats are equipped with two separate batteries, which manage energy for food and water respectively, thus introducing competing physiological needs. The environment contains food resources of different sizes, with differences in value and accessibility. At the same time, the number of agents is increased to intensify competition and resource scarcity.

Our core research question is: In such minimal systems, when facing deceptive resource cues, a highly scarce environment, and other competitors, can behaviors similar to "stress" or "urgency" still evolve? We use genetic algorithms to evolve strategies in both standard and manipulated environments, comparing differences in survival rates, movement patterns, and behavioral changes. Special attention is paid to how strategies adapt under agent competition and conflicting needs (such as survival competition). The significance of this project lies in further challenging the traditional embodied view that "life consciousness is a dynamic behavior emerging from the interaction between elements within an organization and other internal and external elements."

3. An evaluation plan

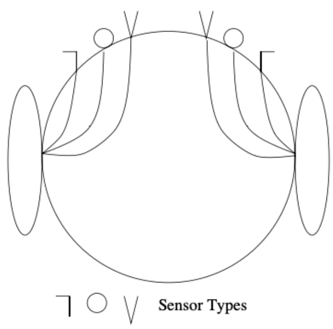
We will evaluate this project by comparing how robots behave in normal and stressful environments. We will measure how often robots make mistakes, how fast or urgent they move, and how long they survive from the last generation, also we will track how their behaviour changes over generations. If animat is exposed to a dynamic environment, it may start to act differently, such as moving more cautiously or urgently and these adaptations lead to improved survival. We will consider this as the emergence of social-like behaviour; how it acts in relation to other robots. In addition, monitoring failure timing can help us assess whether urgency correlates with perceived stress. If we see clear patterns that enhance robots' survival time, it indicates our project is successful, otherwise it suggests a more complex system is required. Essentially we are monitoring the change in the robot's behaviour compared to Seth's base robot when a change in the environment has been enacted.

4. Analysis and Design Documentation

Our project extends Seth's (1998) framework on action selection of an animat by investigating how more dynamic environments affect cognitive behavior. We'll employ the following techniques:

Sensorimotor Architecture & Genetic Algorithms (GA): We'll maintain Seth's minimal architecture of direct sensorimotor links without modifications, preserving the original.

Seth's animat architecture



We'll use the same GA approach as Seth, with a population size of 100, crossover rate of 0.5, and mutation rate of 0.04. Each genotype will consist of 83 integers (0-99) encoding the 9 sensorimotor links and wheel threshold values. Each 9 sensory motor links consists of each of these values:

- Initial offset
- Gradient 1
- Threshold 1
- Gradient 2
- Threshold 2
- Slope modulation & Offset modulation (Battery influence in function)
- Battery number (right or left)

Research experiment details

- **Fixed Variable:** The animat, water, food, trap
- **Independent variable:** The environment
    i. Switching the food source to fake food source which reward no battery
    ii. Variable food reward (different sizes)
    iii. Introducing more agents (competitors)
    iv. All of the above
- **Dependent variable:**
    i. Change in speed vs Battery level
    ii. Parameter of fittest/least fit individual
    iii. Distance between close food source and its activation function

Technology

- We will use python to simulate Seth's system

Technical Implementation Plan

1. **Phase 1: Baseline Implementation** (Days 1-3)
    - Recreate Seth's original model with the 3-sensor system
    - Implement the basic environment with food, water, and traps
2. **Phase 2: Environmental Extensions** (Days 4-7)
    - Implement fake food/water resources
    - Implement variable food rewards
    - Implement multi agent environment
    - Develop an environment integrating both
    - Develop metrics for measuring behavioral changes across environments
3. **Phase 3: Experimentation and Analysis** (Days 8-12)
    - Run evolution in all four environmental conditions
    - Collect data on speed profiles, opportunistic behavior, and evolved parameters
    - Compare behavioral adaptations across different dynamic environments
4. **Phase 4: Reporting** (Days 13-14)
    - Create comparative visualizations of behavioral patterns
    - Document findings and prepare presentation
    - Analyze findings for implications on cognitive behavior and action selection

Division of Labor

- **Brendan**: Technical architecture documentation
- **Vince**: Environmental design, variable resource implementation
- **Logan**: Multiagent implementation, animat set up
- **Chris Dai**: Data visualization tools
- **Shuo**: Data Analysis

All team members will participate in the experimental runs and report writing.

Scope Appropriateness

This project is feasible within a 2-week timeframe because:

1. **Focused Investigation**: We're examining how different environmental dynamics affect behavior without changing Seth's core architecture.

2. **Modular Implementation**: The environmental variations can be implemented independently:
    - Fake resources require minimal modification to the existing environment
    - Variable food resources require minimal modification to the existing environment
    - Multiagent capability can be layered on the existing simulation framework
    - Each component can be tested separately before combination
3. **Scalability**: The project has built-in scaling options:
    - Core deliverable: Implementation of one additional environmental condition
    - Standard goal: Comparative analysis across multiple environmental conditions
    - Optional: Detailed analysis of evolved activation functions, introduce a more challenging environment and add extra sensors to the animat.
4. **Contingency Plan**: If multiagent implementation proves too challenging, we can focus exclusively on a multiagent system which does not require any other coding apart from following Seth's work.

Reference

Braitenberg, V. (1984). *Vehicles: Experiments in synthetic psychology*. MIT Press.

Hotton, S., & Yoshimi, J. (2024). *The open dynamics of Braitenberg vehicles*. MIT Press.

Primer. (2019). Simulating the Evolution of Aggression

[Video]. YouTube. https://www.youtube.com/watch?v=YNMkADpvO4w

Seth, A. K. (1998). Evolving action selection and selective attention without actions, attention or selection. In R. Pfeifer, B. Blumberg, J.-A. Meyer, & S. W. Wilson (Eds.), *From Animals to Animats 5: Proceedings of the Fifth International Conference on Simulation of Adaptive Behavior* (pp. 157-164). MIT Press.