Proposal for Project #16 of INCF at GSoC'20: Contextual Neurodevelopmental Dynamics

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Table of Contents

1. Abstract

The thought experiments that lead to the creation of Braitenberg Vehicles (BVs) have helped us to create a computational analog of the nervous system. BVs also provide us with embodied nervous systems that perform interesting behaviors such as

- Spatial Navigation
- Multi-Sensory Integration
- Co-ordinated Emergence

But Braitenberg Vehicles are representation free to the extent that they remain, mere connectivity-driven behavioral models. In a sense, the BV brain is limited to input data from the environment to extract emergent behavior. Adding a representational structure on top of the BV's basic topology of the internal neural network may result in the development of more sophisticated intelligent nervous system architecture that we are trying to build.

2. The Project Details

2.1. What is this project about?

This project is a blend of the Google Summer of Code project ideas of the past couple of years i.e. **Developmental Braitenberg Vehicles [GSoC'19]** and **Contextual Geometric Structures [GSoC'18]**. These are two artificial intelligence paradigms, which are to be combined together and integrating elements of these two initiatives into something called ***Contextual Neurodevelopmental Dynamics.***

2.2. Why is the aim of the project?

The aim is **to build an artificial nervous system** with neurons and connections (i.e. Node and Links in equivalent simulation) and thereby creating a robust representational system. This would result in simulating an intelligent artificial organism exhibiting complex behaviors. The system, also termed as Contextual Connection Machines, would be a hybrid model that captures multiple aspects of intelligent behavior and scales of the brain. It would appear as if the agents of the environment are 'thinking' to make decisions.

3. The Project Plan

I submitted a proposal to this organization last year that argued integrating the BV simulation platform with a deep learning model. Following that, I worked on making a robust platform suited for agent-based simulation and did implement some portion of the original proposal plan, during my last semester.

The idea this year is to build upon the already existing environment with agents and stimuli. In the developed simulation as of now, the vehicle (BV) has the following properties,

- It's an agent with a pair of sensors and effectors
- It moves autonomously with the help of effectors(wheels) based on its sensor inputs
- It exhibits different behaviors depending on how sensors and effectors are connected
- It appears to strive to achieve certain situations as various parameters are tweaked

But as the current project demands to add a representational structure on top of the BV's basic topology of the internal neural network, I have planned to amend the platform as explained below that meets the project requirements. However, it remains to be an agent-based simulation.

3.1. Implementation - How will you handle the Project?

The core idea here is to introduce multiple stimuli into the environment, apply the CGS (Contextual Geometric Structure) classifier algorithm on the stimuli to partially label them and closely observe the development of the swarm of agent behavior over time. The emphasis would also be on how a single agent is making sense of the environment considering how they acting upon the overall representational structure of stimuli present.

At first, I plan to build rules of classification of elementary behaviors such as cowardness/aggression, love/exploration. Depending upon the time available I would try to incorporate more complex behaviors such as '*showing special taste*', logic, and more complex behaviors described in the book by Valentino Braitenberg.

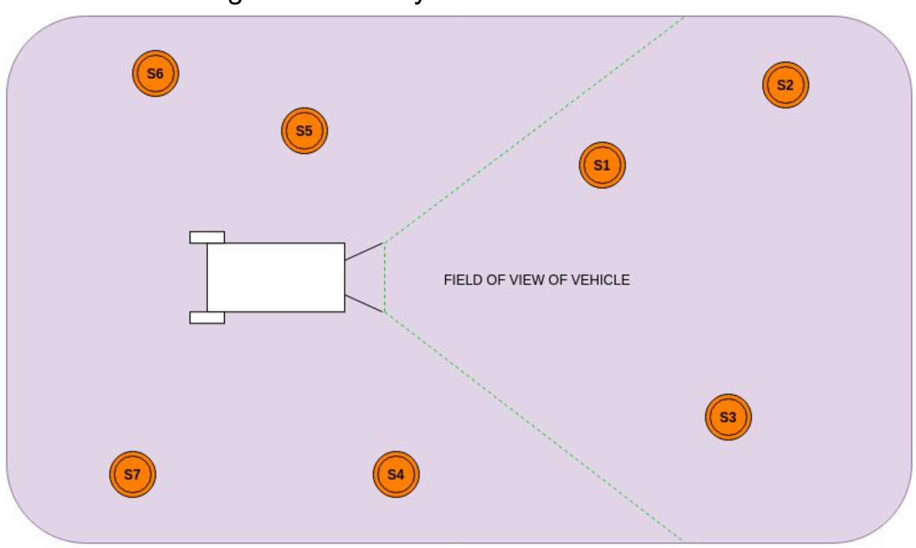
The agent's neuronal network responds to the classified stimulus and results in the agent's actions as per the label's provocations. Note that a particular stimulus is classified as per the range of behaviors considered for labeling. For example, a particular stimulus may be classified and hence partially labeled as 55% Aggression provoking - 30% Cowardness provoking - 10% Love provoking.

3.2. Detailed Description

The key components of the simulation are how the environment, the classification algorithm, and multisensory integration, is handled. As far as the building up of the environment is concerned, I would use the already established platform that I have for current simulations i.e. using *Processing.py*. However, I have made some key changes in the simulation plan as compared to the existing one. They are described as below.

3.2.1. The Environment Characteristics

- **Stimulus Properties**
  - The stimuli are introduced to the atmosphere as they go through *CGS classification* and as a result bear labels that provoke a variety of behaviors in the surrounding agents.
  - There may be multiple stimuli roaming around in the environment as per the *boid's algorithms* preventing them to collide with each other.
  - Each stimulus has multiple features too by which it is identified. Note that the features may be visual or auditory. But for the sake of simplicity, we would currently focus on mere visual stimuli.
  - To make the simulation match real-world scenarios, some concepts may also be introduced such as there won't be any activation due to visual features if the stimulus doesn't directly come under the field of view of the agent which changes its orientation as per the environmental constraints. For example, in the following scenario, the vehicle would be influenced by the stimuli S1, S2, S3, while being unaffected by the rest of the stimuli.

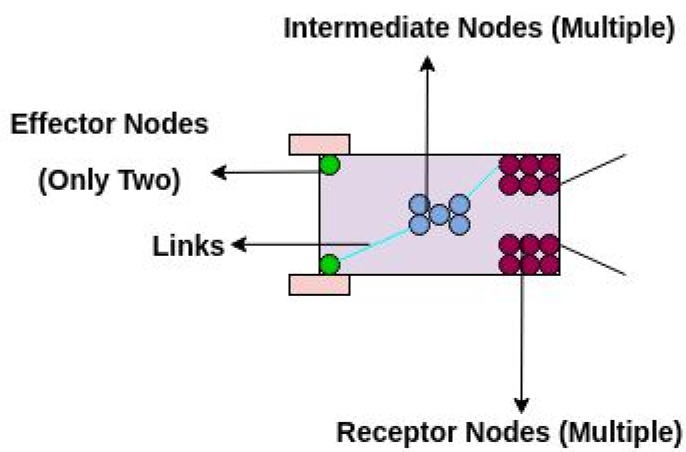


- **Vehicles / Agents Properties**

- The essential parts of the vehicle consist of the sensors, effectors/wheels and the vehicle brain/body (the seat of internal neural wiring where information processing takes place leading to decision-making).
- The sensors are equipped with multisensory receptors to receive activation produced by every kind of sensory feature present in the stimuli i.e. visual and auditory.
- The effectors (wheels) are mere help to exhibit actions as per instructions received from internal neural wiring.
- The most important part i.e. the internal neural wiring consists of neurons and connections. More suitably they may be called nodes and links in the context of a virtual simulation.

3.2.2. Internal Neural Wiring Details

- **Nodes** are pivotal as they possess the context for the information flow across the network. I have defined three types of nodes for our model, i.e., *receptor, intermediate* and *effector* nodes.



Receptor Nodes are those who are directly connected to sensory receptors. There exists a receptor node in the vehicle corresponding to each labeled stimuli's sensory feature present in the environment. Thus, the number of receptor nodes equals the summation of the number of features in each stimulus.

Effector Nodes are those which are directly connected to the vehicle effectors(wheels). There are just two of these as BV can have a maximum of two wheels.

Intermediate Nodes are those in-between connecting the other two types of nodes. Note that they might be absent in case of the simplest of neural provocations.

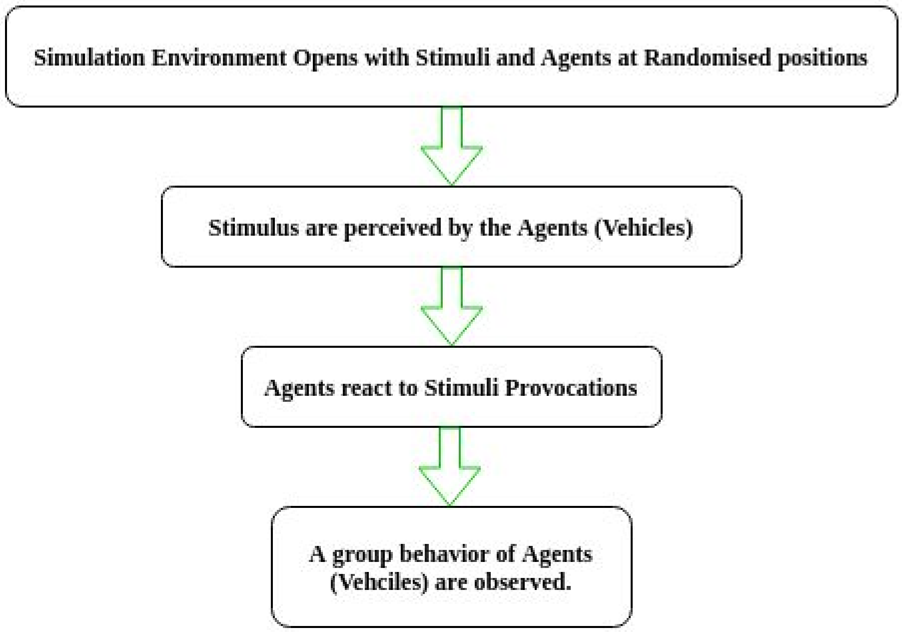
- **Links** connect any two nodes of the neural wiring. These links are a result of neural provocation by present stimuli in the environment, leading to the neuronal network. Also, each link can be assigned to have a *transmission function* taking care of the type of transmission.
- Each labeled stimuli as per the CGS classification provokes a particular linking between the nodes resulting in a neuronal network that helps in sending the appropriate instructions to the effector.
- Note that an agent would exhibit a mixed type of behavior towards a stimulus as per it's resultant labeling e.g. 55% Aggression provoking - 30% Cowardness provoking - 10% Love provoking.

3.2.3. CGS Classification and Simulation Details

- The Contextual Geometric Structure (CGS) approach allows for the bridging of dynamical cognitive models with the larger-scale process of population-wide cultural evolution. It is useful in our case as it would help us to classify the stimuli not necessarily giving discrete results with some percentage errors, unlike a deep learning model. But it presents a more ambiguous version of the subject under consideration, giving partial weights to all the outcomes possible. An example would be, taking a convex quadrilateral, a deep learning model may predict it to be a quadrilateral with a certain degree of error but a CGS classification may declare it to be 40% triangle and 60% quadrilateral.

- Considering visual features like shape and/or color, they are made to go through the CGS classification and get partial labels. In the simulation, different features of even the same stimuli seem to affect the agents with different levels of activation. However, the provocation of a particular type of internal neural wiring in the agents remains the same due to one particular stimulus. For example, say if we take the stimulus as a purple hexagon, based on the labels assigned to the overall stimulus it is going to provoke activation of the same neuronal network in the agents but its different features i.e. shape and color have different levels of activation in the surrounding agents. This would create an influence bias between different stimulus features which may seem like preference perception for some feature over others. Talking about this specific example, the agents may be made to be more sensitive (stronger activation function) to the shape feature over color.

3.3. Flow Chart for Working of Simulation



3.4. Communication With Mentor

I will keep in contact with my mentor with Saturday Morning NeuroSim meetings. We can discuss the progress of the project on in person as well (in the buffer weeks) if the situation demands. The frequency of personal Skype/Zoom/Meet calls may increase as per necessity.

I would push the work that I will regularly be doing in my GitHub repository. I would be sharing the new developments with my mentor and Neursostars community regularly. Also, I will be writing blogs regularly describing the progress in the project and experiences, to let my mentor keep track of the work done. Besides this, I would stay active on Slack where I can interact with fellow developers and would be sharing the new developments regularly.

4. Timeline

I have planned to work on the project in 3 phases, the time allotted to them is as below,

- Phase 1: Week 1 - Week 5 [Enhancing the existing platform]
- Phase 2: Week 7 - Week 10 [Implementing CGS classification]
- Phase 3: Week 11 - Week 12 [Integrating the two paradigms together into the environment]

4.2. Approximate Timeline

Proposal Review Period (9 April- 5 May)

- Be involved in the Saturday Morning NeuroSim meeting.
- Write a blogpost on takeaways and inspirations from the book "Vehicles: Experiments in Synthetic Psychology" by Valentino Braitenberg.

Community Bonding Period (6-26 May)

- Review the existing literature leading to the fabrication of this project.
- Review the simulation plan again and discuss any changes which may be more appropriate as far as project goals are concerned.

Week 1-2 (June 1-14)

- Start of enhancing the platform to make it more suited for this year's simulation plan.
- Import previous year code and mend the code architecture to meet the requirement for this year's simulation plan, especially in terms of dealing with nodes and links for neuronal processing of the vehicle.
- Introducing already labeled multiple stimuli into the environment to work on simulation features and monitor agent behavior.
- Write tests as well as the documentation of the newly implemented functionalities.

Week 3 (June 15-21)

- Write code to prevent intercollision of stimulus and vehicles as to define interaction rule between themselves.
- Might use the well known Boids Algorithms for this purpose.
- Write tests as well as the documentation of the newly implemented functionalities.

Week 4 (June 22-28)

- Write code to let the vehicle align itself in the direction of its instantaneous velocity.

- Define the field of view of the vehicle, restricting the responsiveness of agents due to visual stimuli lying outside the field of view of the vehicle.
- Write tests as well as the documentation of the newly implemented functionalities.

Week 5 (June 29- July 5)

- Write and amend code to run the simulation among stimuli with mixed/partial labeling i.e. that expected after the CGS classification of the stimulus.
- Write tests as well as the documentation of the newly implemented functionalities.

First Evaluations (June 29 - July 3)

Week 6 (July 6-12)

- This is a mid-project buffer week.
- Anything lagging in terms of writing code/documentation/blog would be accomplished.
- If everything is on time, the planning for CGS architecture implementation can be started.

Week 7 (July 13-19)

- Build rules (or conditions) for the CGS classifier considering the appropriate number of behavior in the sample space.
- Create a dataset, or build a model of the intermediate continuum, if the situation demands.
- Write the documentation of the newly implemented developments.

Week 8-10 (July 20- August 9)

- Write code for the CGS classifier considering the rules created in the past week.
- Do enough trials to ensure it works accurately when integrated with the environment.
- Write tests as well as the documentation concerning the CGS classifier.

Second Evaluations (July 27-31)

Week 11-12 (August 10-23)

- Integrate the CGS code to the BV platform.
- Analyze the pattern of agent swarms and draw inferences from it.
- Change activation functions for different features of the stimulus and observe agent behavior.

- Write the documentation of the newly implemented developments.

Buffer Week (August 24 - 31)

- Anything lagging in terms of writing code/documentation/blog would be accomplished in this period.
- If everything is on time, write a detailed blog on your journey with Braitenberg Vehicles and what you experienced in terms of simulation developed over this summer.

Final Evaluations (August 24 - 31)

4.3. Minimal Set of Deliverable

- Further developing the environment considering up to vehicle 3 as part of the simulation.
- Implement the CGS classifier.
- Integrate the two paradigms and make the agents respond to stimuli as originally planned.

4.4. If Time Permits

- Do some tweaks with the vehicle's neuronal network to include the aspect of development in the simulation.
- Include more vehicle's behavior types and incorporate them into the environment through CGS classification.

4.5. Future Developments

- Include sound also as a stimulus and applying CGS classification to give them meanings and hence integrate them into the environment as well.
- Include more types of vehicle behavior provocations due to environmental stimuli.
- Make an API with the existing code and make it a user-friendly and customizable platform to run the behavioral simulations.
- Document the inferences and observations of the simulations and submit them to an appropriate journal.

5. About Me

5.1. The Student

Full name: Ankit Gupta
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Location (Country and City): Kharagpur, India
Portfolio: ankiitgupta7@LinkedIn, ResearchGate Profile Link
Hangouts ID: ankiitgupta7
Skype ID: dchampankit

Github: [ankiitgupta7]
CV: [Link]

5.2. The Institute

University: Indian Institute of Technology Kharagpur ([IIT KGP])
Major & Year: Mining Engineering, Fourth(Pre-Final) Year Undergraduate
Degree: Bachelor & Master of Technology (Dual Degree)

6. Candidate Details

6.1. Motivation - Why do you want to do this Project?

Last year after continuing to work on my proposal idea, as expected I was overwhelmed with the simulation results and since then I have been a fan of Braitenberg Vehicles as it provides a plethora of possibilities that can be derived out of it. I got introduced to the concept of swarm intelligence as after I introduced multiple vehicles into the environment, the agents seemed like exhibiting collective intelligence.

I believe this year's project would entertain my curiosity further to remain associated with BVs and also as we are merging another AI paradigm with it, I am super excited to work on this project as something novel might just come out of it. Also, as a result of working with BVs since last year, I have been developed an inclination towards Biologically-inspired Robot Collectives and Self-organizing Systems. And I feel working on this year's project would help me get more insights about working in this field in the long run.

6.2. Match - Tell us something that will make you a good candidate for this project.

I have been associated with Braitenberg Vehicles simulation making for the past one year. I have presented several times in our weekly meetings about the developments. I have been an integral part of our paper "Braitenberg Vehicles as Developmental Neurosimulation" whose preprint is already live on arXiv and Researchgate. Also, we took this idea of Braitenberg Vehicle simulation to an online conference called OHBMx which happened on Twitter on the 20th March 2020.

I feel very passionate about working on an intelligent system design simulation as I have been thinking of pursuing my higher education in this field too. And as I find myself in a position to make such simulation with ease and interest, I guess it would be a win-win situation if I get to do this project under this year’s Google Summer of Code.

6.3. Programming and Development Experience

I have been very much experienced with open source development as I have been doing it since the start of my sophomore year. Thanks to the various projects I have been associated with I have also gained expertise in Data Structures and Algorithms, GUI Development, Web Scraping, Web Development. Also, over the years, I have developed proficiency in programming languages and tools such as C, C++, Python, Java, JavaScript, MATLAB, Processing.py, Turtle, Tableau, GNU Octave, Node.js.

In the last two of my internships, I have worked in University Research labs, mostly doing the experiment designs using a variety of tools. Also, I have developed a good appetite for reviewing literature in my areas of interest. And working for the Orthogonal Research and Education Laboratory with Bradly, I have developed a deep interest in themes like Swarm Intelligence and have mastered Agent-Based simulations.

6.4. My Association with INCF

I had submitted a proposal to INCF last year on a project named “Modeling Neural Development with Braitenberg Vehicles” and since then have been associated with Orthogonal Research and Education Laboratory lead by Bradly Alicea who is also the mentor of this project as well.

I expressed my interest in the weekly meeting and also on the Neurostars platform, to work on this project just days after it was announced as I wanted to continue my work on BVs. I have been a contributor to the Representational Brains and Phenotypes group and been an active member of the Saturday Morning NeuroSim meetings. And it should be a year of association with Bradly Alicea by now.

6.5. Contributions: Details of Existing Work

6.5.1. Environment Properties

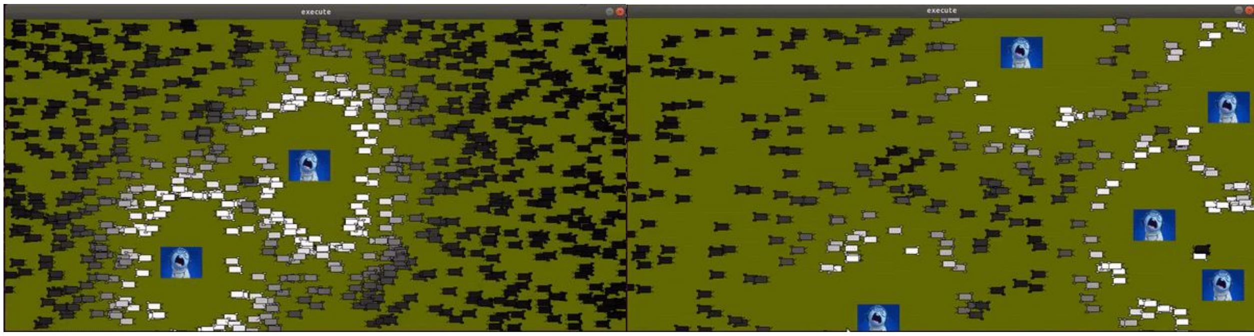
- Agents (Vehicles)
  - Random Population (within a range) in each run
  - Movement dependent on Stimulus
  - Appear at a random location as the simulation starts
  - Light up at high activation
  - Can escape the window
- Stimulus
  - Random Population (within a range) in each run
  - Movement is random with constant velocity in x and y direction, in each run
  - Appear at a random location as the simulation starts
  - Always contained in the window

6.5.2. The Vehicle Kinematics

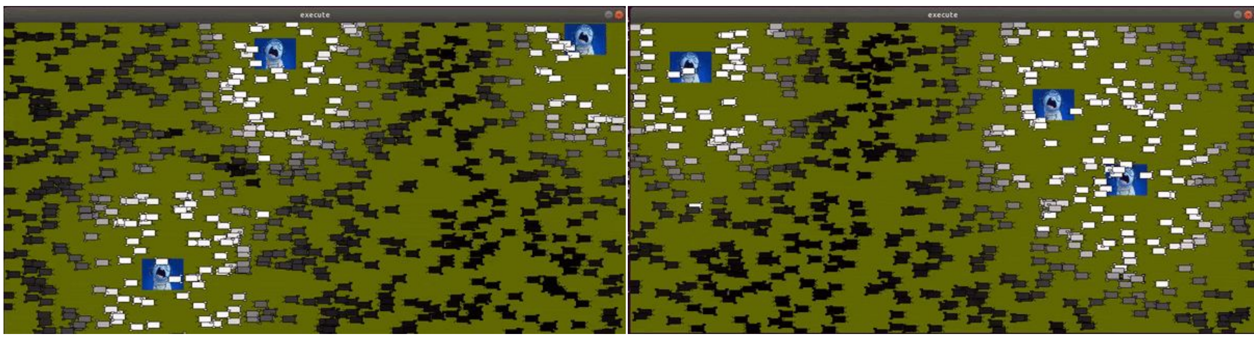
- Movement is the result of the difference of rotation speed of wheels(affectors) of the vehicle
- The rotation speed of wheels depends on sensory activation of motor
- Depended on Activation Function of sensory excitation
- Wiring between sensor and effectors(wheels)

6.5.3. The Simulation Snips

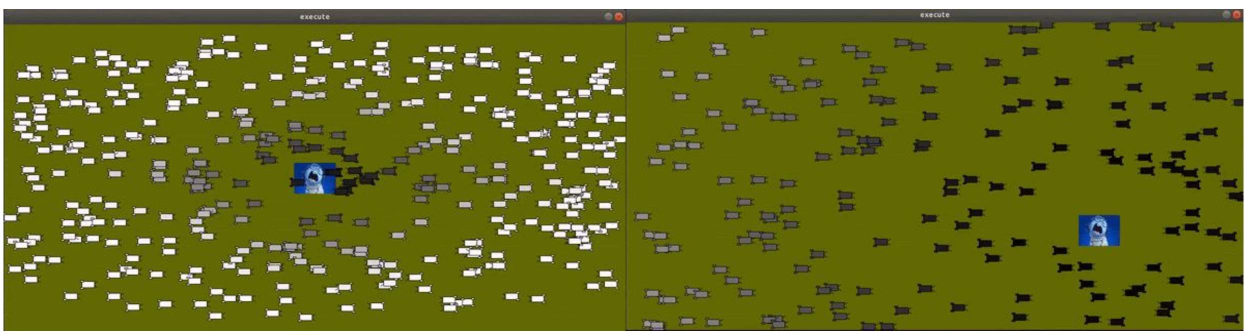
Vehicle 2A [Cowardness]



Vehicle 2B [Aggression]



Vehicle 3A [Love]



For complete code and more information, please visit the home repository: ***https://github.com/ankiitgupta7/Simulations-of-Braitenberg-Vehicles***

6.6. Availability

My summer vacations begin on the 1st of May. The project will be my top priority and I will be committed to it during the specified timeline. My next semester starts in mid-July. The academic pressure is not heavy at the start of the semester; thus I would be able to devote my time in the last few weeks of the coding period as well.

7. References

7.1. My repository on GitHub, on BV's simulation: ankiitgupta7/Simulations-of-Braitenberg-Vehicles: Using Processing.py

7.2. The presentation of last year's work: Braitenberg Vehicles Simulations

7.3. The presentation for the OHBMx conference: OHBMx Presentation

7.4. Link to OHBMx Twitter Conference: https://twitter.com/OHBMequinoX/status/1241012923755102212

7.5. Our preprint of the paper on "Modeling Neural Development with Braitenberg Vehicles": https://arxiv.org/abs/2003.07689, (PDF) Braitenberg Vehicles as Developmental Neurosimulation

7.6. Link to simulation recording snips on figshare: https://figshare.com/articles/Dynamic_demos_of_Braitenberg_Vehicle_collectives/11906847

7.7. Link to the project on Neurostars: GSoC 2020 project idea 16: Contextual Neurodevelopmental Dynamics - GSoC

7.8. Alicea, B. (2012). Contextual Geometric Structures: modeling the fundamental components of cultural behavior. *Proceedings of Artificial Life*, 13, 147-154.

7.9. Alicea, B. (2017). The Emergent Connectome in *Caenorhabditis elegans* Embryogenesis. *BioSystems*, 173, 247-255.

7.10. My profile on the website of Orthogonal Research and Education Laboratory: People - REPRESENTATIONAL BRAINS AND PHENOTYPES