**Project**

**C.A.M.I.L.A.**

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**Analysis**

* 1. **The Problem**

As of the time of writing this, I have had my interest peaked by phycology for a while now. Specifically, how little organisms with inherently no form of individual intelligence interact as a group to produce somewhat intelligent responses to stimuli. Some have recognised the advantages of implementing this method of problem solving on computers which came with the eventual surge and popularity of Machine Learning in our culture.

Often mistaken for Artificial Intelligence, Machine Learning, a subset of Artificial Intelligence, is just that, a computer learning how to respond to a set of data and that data only. It regurgitates, appends and relays information; It is rigid, and it is extensively limited. Naturally, I was dissatisfied with such a tool that, using prompt to text, can’t even add two numbers together correctly.

Looking through the market, there was no solution to my dissatisfaction; the existence of abiotic neural networks is unheard of. Many Computer Scientists and Phycologists are limited to think that computers are restricted to following logical algorithms and have no way to visualize neural networks. Phycologists are limited to studying only biotic neural networks that have no way to be replicated and visualised while Computer Scientists are bounded to rigid primitive tools that dare call themselves Artificial Intelligence.

I was inspired by Von Neumann’s Artificial Automata, neuroscience and this gap in the market to expand on this sector of Computer Science. Cellular Automata Morphogenesis Intelligence, Layered Algorithm: C.A.M.I.L.A. is composed of two 2-Dimensional layers of Cellular Automata regulated by a reward system. The first layer, Structure Layer, acts as a railroad of sorts with stations, formed through morphogenesis and cellular automata. The second layer, Transmission Layer, depends upon the first layer, it is the train travelling along the railroad, it is simpler but will still be using cellular automata. Both have their own set of rules that determine how the cells interact with each other to determine how the network generates and how the signals are transmitted. The goal is to be able to use it within any program and therefore will be interactable via a service API. This API can be used to produce a user interface to visualise the network and interact with it. This network can be trained with the principles of reward and punishment to produce a desirable response to stimuli in REAL time.

This solution will need efficient management of data and parallel processing capabilities, such as of a GPU. C.A.M.I.L.A. and its API are the main module, with optional and desirable modules like CLI and GUI that are lightweight and allow the visualisation of the network. All of these are amenable to a computational approach.

This solution will need efficient management of data and multiprocessing capabilities, such as of a GPU. It will also have to provide an optional lightweight GIU and visualisation of the network. All amenable to a computational approach.

**1.2 Stakeholders**

My main target demographic is computer scientists and students of phycology. For this I have gathered two phycology students, one computer scientist and one phycology students with involvement in computer science.

The phycology students would greatly benefit from a more in depth and real time visualization of how neurons work together, grow and form networks. They will be mostly interacting with the visualiser and the tools that come with it.

On the other hand, computer scientists can benefit from the tools that can produce organic neural networks to aid in their own algorithms, solve solutions and gain a greater understanding of the field of artificial intelligence as well. They will be mostly interacting with the API but will occasionally venture with the visualiser to check on the ‘health’ of the network.

Other stakeholders may include anyone interested in learning about neurons and users that want to produce visualisations of neurons.

My stakeholders include Marta (year 13 Phycology and Computer Science student), Ana Astoria (year12 phycology student), Syima (Year 13 phycology student) and Ashton Pitcher (Year 12 Computer Science Student).

**1.2.1 Interviewing Stakeholders**

As this project’s aim is to better people and involves a GUI; an interview with the previously mentioned stakeholders seems appropriate. These series of questions will try to return useful feedback in terms of what features are needed or beneficial and try to find out how all of this is suitable to each type of person. These questions (and its respective clients) will be referred back to all throughout the development process.

Questions include but are not limited to:

1. Tell me about yourself
2. Where do you get your understanding of neurons/ neural networks?
3. Do you use any websites, videos or any computer resources to expand and enhance your understanding of neurons?
4. What are the drawbacks and benefits of such methods of learning?
5. How would an interactable model for learning about neurons change the efficiency of your retrieval?
6. For an interactable mode/ sandbox for neurons, what key features are needed?
7. What other features would be nice quality of life additions?
8. What are your thoughts on a sandbox interactable model that grows to produce a response to stimulus?
9. Any other comments or questions?

Interviewing Asthon

1. Asthon: My name is Ashton Pitcher; I am a student at Doncaster UTC. I do Computer Science, Business, Math and Further Math. I do taekwondo and play drums. I am extremely interested in neural networks, which is why I took this Interview.

Me: What do you know about neural networks?

Asthon: I don’t know much; I have a lukewarm understanding of neural networks. I once witnessed brain scans in person which intrigued me to pursuit more knowledge on neural networks.

1. Asthon: I get my understanding from sources such as Wikipedia and word of mouth, but apart from that, I lack any major knowledge in neural networks and the field of Physics.
2. & 4 Me: The question doesn’t apply to you, but if you were to start learning about it, what resources would you use? What are some benefits and drawbacks of such methods?

Asthon: I would invest in university courses. However, they are expensive to join, and it would take a rather large chunk of time out of my busy day. The benefits of a university course is that its very in depth and provides a formal qualification.

I could also speak to a family friend who is a neuroscientist. They have a lot of field experience that they can share, therefore they are extremely qualified. However, they might have trouble explaining and simplifying the information down to make it easy to understand.

1. Ashton: A sandbox isn’t complicated for a person like me to understand which will let me understand networks through exploration in my own way and understand how the neural networks interact.
2. Ashton: The most important feature would be simple interactive UI, this is to make it accessible to all age groups and all ranges of intelligence.

Me: Anything important to navigate the UI?

Ashton: Colour coded interactions that have keys that explain it. I want to interact with the neural network via cutting and adding neurons.

1. Ashton: A qualify of life feature that I would find very helpful is being resourceful light; taking less that a whole gigabyte of ram and not cause any memory leaks. Easy tools for manipulation of neurons.
2. Ashton: Will it be accessible?

Me: Accessible in terms of what?

Ashton: What other platforms is this available on?

Me: The plan is to make it accessible on the computer first and then if it works out make it accessible on mobile devices for greater accessibility of knowledge. Any other questions?

Ashton: No, thank you.

Interviewing Ana Astoria:

1. Ana: I’m Ana and I am a student at Hall cross, I go to 6th form, and I do sociology, phycology and law. I plan on going London to get a law degree and become a Barrister. I really like music and I’m pretty much into a bit of everything, but my favourite band is Radiohead.
2. Ana: Well, I learn about neurons in bio-phycology and when I revise a topic, I usually go on the resources given by my teachers on google classrooms.
3. Ana: I usually just search up videos about the particular topic I want to revise on YouTube and Safari, I usually use Quizlet.
4. Ana: I’d say that some benefits is that its really accessible and easy to find resources, and there’s a wide variety of content. I’d say that a drawback would be that it is a lot easier to get distracted when revising.
5. Ana: For learning it wouldn’t help memorise any new information, it is a lot easier for me to just revise by watching videos and answering exam questions however yes, with retrieval it would have a positive improvement, and it would improve my understanding of neurons.
6. Ana: Maybe give a clue to the user when they are unsure or give a definition of terms when you hover on it to guide you.
7. Ana: Keep it easy to use, accessible, to make it free if possible, and maybe make it an app as well that is available on both laptops and phones.

Interviewing Marta:

1. I’m 18 years old, I was originally born in Lithuania, but I moved to the UK when I was 14. I do Maths, Phycology and Computer Science for A levels. My hobby is music, and I enjoy skincare too.
2. Mostly from Phycology lessons and Research on the internet.
3. Mostly Google and YouTube.
4. Yes, that would be helpful to retrieve information.

Me: How much? You believe there’s a lack of it in your methodologies when studying phycology and how would it improve it?

Marta: I feel like it would have a significant difference. Studying phycology is mostly theory and there isn’t much practical element to it. I would also include more practical and real-life research to make it more personal and easier to remember.

1. Marta: Easily accessible features, clear instructions, understandable signs and markings.
2. Marta: Maybe include some visualizations to give the user a better representation?

Me: What would be a reasonable and achievable task for such a neural network?

Marta: Train the neural Network using the training dataset and see how it associates images with its corresponding labels.

Interviewing Siyma:

1. I’m a 19-year-old student currently studying A levels and hopefully moving onto medical school at Cambridge, outside of education I play tennis competitively, compete in 100m sprints and play violin in me free time
2. My understanding of phycology and neurons comes from my usual studies at A-Level, but also further research like books and articles covering many phycological topics. My knowledge also comes from medical studies, as much of medicine stems from neurons and treating phycological illnesses interlink with medicine massively. Research papers are also hugely beneficial to me as they encompass the fundamental principles of much psychological research, allowing me insight into various aspects of phycology and the neurological process of the human mind.
3. Personally, the benefits of these learning methods I believe offer an in-depth analysis, comprehensive coverage and also valuable insight into the wide array of psychological research that help strengthen my understanding of psychology through an academical lens. Being able to see research from esteemed and knowledgeable professionals really opens up your eyes to certain aspects of Psychology, for example Mary Ainsworth research of attachment styles in infants. This experiment revolutionised the understanding of attachment theory and had a profound impact on developmental psychology, parenting practice and helped create healthy attachment relationships in infants.

However, the limitations of such methods could be due to articles and research papers may reflect researcher bias and may not be a true and accurate representation of Psychology or the researching topic. The assess ability of such research can also vary, many articles and papers are hidden behind restricted access or paywalls, limiting their availability to the wider audience. The pace of academic publishing may also be outdated and may not keep up with how society is changing and evolving psychologically.

1. I believe an interactable model for learning about neurons could potentially enhance my efficiency of retrieving informational as it would provide visual representation of complex neurological processes, making abstract concepts significantly more tangible and easier to comprehend. Visual aid from a psychological perspective can also aid in memory retrieval by proving mental cues or triggers prompting the recall of information. Further to this, I believe interactive models can be customised to cater to the many individual learning styles and preferences. Users are able to explore this model at their own pace, focusing on areas of difficulty or of interest, optimising the efficiency of the retrieval of knowledge by targeting the specific areas of need. Interactive models are able to also stimulate neural processes, allowing users to be able to conduct visual experiments thus proving a hands-on experience without the need for physical resources. Interactive models are able to my knowledge offer immediate feedback to users, aiding them to correct misconceptions and reinforce an accurate understanding. This again can facilitate in the consolidation of knowledge and help improve users retention, ultimately improving the efficient of the retrieval of their already present knowledge.
2. Several key features I believe are essential to an engaging and educational experience would be visual representation, the model should offer a visually appealing and accurate representation of neurons and neural networks. I believe being able to create a model where the user is able to observe the structure and function of neurons including dendrites, axons, neurotransmitters etc would be beneficial and provide in depth learning and analysis. The model could also have an interactivity feature, being able to manipulate elements of the model like removing or adding neurons or adjusting the synaptic strength will also aid users massively. If the model was able to provide real life stimulation, a reflection of the true stimulation of neural processes and allow users to be able to observe how changes in parameters affect neuronal activity enables experimentation and rhetorical exploration of different scenarios for the user. Being able to see visual data relating to neural activity such as spike trains or membrane activity can help further understanding of the neurological process. Visualisation tools will help enhance understanding and facilitate the interpretation of complex neural dynamics.

Finally, if the model is able to include educational guidance throughout explanations of the neurological process to support people in understanding the complexity of neurons will be hugely beneficial. This could include features such as tutorials that are interactive, pop-up explanations or guided exercises will aid users that may be struggling, thus the model will be able to tailor to the wider population, no matter what degree of academical understanding a person currently has on neurons.

**1.3 Problem Research**

As this is quite a niche problem, the research will mostly focus on

different technologies that could aid in the development and implementation of this glorious idea.

**1.3.1 Cellular Automata**

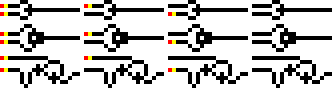
Cellular Automata: What are they?

A complex system of many simple agents where when they work together, they exhibit complex intelligent behavior. They act upon a grid defined by some rules.

Properties of a cellular automatons:

* It has a grid of cells; this can be any dimension and any shape.
* Each individual cell has states defined in code and its state is defined as a function of its neighborhood (von Neuman, Moore’s)
* CA can be classified into four classes:
  + Class 1: evolve into stable, homogeneous state
  + Class 2: Almost all initial patterns transform into stable or oscillating pattern
  + Class 3: All initial patterns transform in a chaotic or pseudo-random pattern
  + Class 4: All initial patterns transform into complex structures that interact with each other
* The state of each cell can not only be a function of its previous generation’s neighborhood, but also as a function of many previous generations.
* The states can be continuous floats rather than distinct states.
* The state outcomes could be tied to probabilistic functions.

Wireworld (logic circuit simulator, cellular automaton example):



A green and black pixelated object

Description automatically generated with medium confidence  
Wireworld is a cellular automaton in its simplest form (previously investigated). It was first proposed by Brian Silverman in 1987, as part of his program Phantom Fish Tank. The principle of this program is to emulate how signals would propagate along a wire, with each cycle/generation, the position of the charge updates. This automaton allows for logic gates and therefore complex circuits (such as shown above).

The rules of this Cellular Automaton are as follows:

A wire world cell can be in one of four different states, numbered from 0-3 in its code.

0 – empty

1 – electron head

2 – electron tail

3 – conductor

Time proceeds in discrete steps called generations. Cells behave as follows:

* Empty will remain Empty
* An electron head will turn into an electron tail
* An electron tail will turn back into a conductor
* Conductor will become an electron head if one (or two) of the neighbouring cells are electron heads

Furthermore, this cellular automaton uses “Moore’s neighbourhood”. Where all 8 cells surrounding a central cell in a two-dimensional grid are considered.

A website providing an interactable simulator is <https://xvlv.io/WireWorld/>.

It has a defined grid and colour coded components that make up the cellular automaton. Furthermore, a range of options to control the automaton and clearly explained.

A screen shot of a computer

Description automatically generatedThis provides a great foundation for the structure of my cellular automaton in terms of signal transmission, however, it is very static in its structure which is not viable when trying to imitate an organic process.

In terms of design, it is well structured with clear distinct cells and colour coded. This eliminates any confusion when trying to understand the system which is a nice a nice ease of use features. As the design is minimal, I cannot point to any flaws.

Conway’s game of life (2D Cellular Automaton):

Conway’s game of life is the most well-known Cellular Automaton out there. It was devised by British Mathematician John Horton Conway in 1970. The player can create an initial configuration of live cells and let the grid take its course through generations.

A black and white image of a black and white image of a black and white image of a black and white image of a black and white image of a black and white image of a black and

Description automatically generatedConway it in the fabrication of this CA, was trying to exhibit the properties of biological reproduction using simple rules. Therefore, the growth pattern cannot be predicted from its initial pattern.

The rules of this Cellular Automaton are as follows:

The cell can have two possible states, live or dead. This too follows “Moore’s neighbourhood”, as it interacts with its 8 cells.

In each generation, the state of the cells is determined by:

1. If the cell has less than two live adjacent cells, it dies (underpopulation)
2. If the cell has two or three live adjacent cells, it lives
3. If the cell has more than three live adjacent cells, it dies (overpopulation)
4. If a dead cell has three live adjacent cells, it turns alive (reproduction).

The rules applied to all cells, represented by a two-dimensional array, simultaneously in each generation.

A website providing a sandbox of this Cellular Automaton is: <https://conwaylife.com>.

A screenshot of a computer

Description automatically generated

It provides many great ease of life features such as playback speeds for advancing through the generations, zoom, draw, etc. Making it very nice to use. However, the design is very harsh to eyes and is borderline uncomfortable to use.

Growing Neural Cellular Automata: An upgrade from the simple CA

Morphogenesis is the process through which organism’s shape development of their systems. The aim of this project is to be able to produce a growing, reproducing and interacting network of neurons, making this example where morphogenesis is done through CA fundamental to the project’s development.

A green lizard and a lizard

Description automatically generated

Tissue, Organs, Organ systems, they are made of billion of individual cells, they communicate with each other through processes out of scope for our cause but nevertheless produce these robust systems reliably. We aim to imitate this process as closely as possible with as little resources as possible.

The update rule is made of two steps:

1.Convulution

This is the cellular automata part of the algorithm. It is where each cell looks at its neighbours to determine its next state. A filter is applied to its neighbourhood and the state of the cell is determine by the sum of products of the cells with the filter value. If filters reach the edge of the grid matrix, it wraps around to the other side.

2.Activation

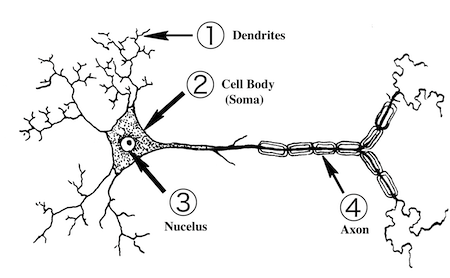
The activation function is a mathematical function that is applied to each cell. It uses the value obtained from the convolution step, performs some logic with the value and returns that value. In the end, this is the value that is display as a pixel on the grid. The end value is a float value; therefore, this can be though as a mathematical function.

The activation function will hopefully be a simple neural network that will allow these cells to communicate with each other to produce these complex systems. In this case, a neuron.

This is an emerging technology that is used by “AI” to produce generative images and text. However, we can use this to produce our systems, the neurons, to further produce complex structures of neurons.

What are neurons? summary:

They are specialised cells for transmitting and receiving information, they communicate with each other and other cells. There are about 86 billion neurons in a typical human brain. So, they have to work efficiently and in harmony.



There are about 1000 types of neurons, but they all have these general components.

Neuron communication:

* They use electrical and chemical signals.
* They main type of electrical signals are called action potentials. They are created when ions flow into neurons and generate an impulse that can travel from one end to another in a neuron.
* An action potential can cause the release of chemical signals called neurotransmitters, which travel from one neuron to another, this can either cause a response or inhibit a response in the next response.

Parts of neurons:

* There are branches of extensions from the cell body called dendrites. They are the parts of the neurons that typically receives neurotransmitters from other neurons at special proteins called receptors.
* The cell body is called a soma, it is the metabolic centre of the cells.
* Axon hillock, when information is released to the dendrites, it causes changes in the electrical properties of the cell, at the axon hillocks, this is where the signals are integrated. This determines if it is enough to produce its own action potential.
* The act on integrating potentials is called summation.
* Axons are covered in insulator material called myelin. It helps to improve the propagation of electrical signals down the axon and prevents current from leaking out.
* The node of Ranvier, at these gaps there’s channels that let positively charged sodium ions to flow into the neurons, this influx of ions helps regenerate the action potential along the axon.
* At the end of the axon, it ends at terminals called axon terminals or synaptic boutons. Situated close to other neurons dendrites, they communicate using synapses.
* Synapses, the space is called a synaptic cleft, pre-synaptic is the one that ends at the axon while the neurons on the other side of the synaptic cleft is called the post-synaptic neuron.
* When an action potential reaches an axon terminal, it can cause the release of neurotransmitters. The neurotransmitters can bind or attach to the receptors in the post-synaptic neuron, which can increase the likelihood or even decrease the likelihood that the post-synaptic neuron will release its own active potential.

To replicate a network of neurons, we must understand its structures, components and how this work together to transmit information and therefore produce intelligent behaviour. However, a simplification is necessary, otherwise it would be unachievable with modern technology. For example, a project that mapped a small sample of neurons, about 5000 slices, took about 1.4 petabytes. So simplification is only smart.

Rust? What’s that?

Rust was made to replace C/C++. It has amazing performance. Being a fast, memory efficient programming language. It is compiled programming language with runtime or garbage collector. Therefore, allowing for low level control with high level features.

It is also a very safe and reliable programming language. It is a memory safe and thread safe programming language. This eliminates many possible bugs that could of come up trough compile-time.

I believe that Rust is the most suitable programming language for this project. It provides great documentation; it is fast and reliable. All needed for such a complex project. However, it is not the most known programming language, so there might be issues with interpretation from outside sources.

Key features of the solution

From the interviews and research, this is what I concluded the key features should be:

* The sandbox should be available on both phones and computers. However not as a web application, as this limits the scope of the application.
* A GUI should be present that allows the presentation of a grid matrix. This should be simple, colour coded and provided suitable information for further learning.
* Tools should be provided to interact with this grid matrix of cells and the network of neurons within it.
* CLI tools should be provided such that the neuron network can be interacted within such a way that it produces intelligent behaviour. Features such as inputs and output management are a must.
* An algorithm should be provided that produces a structure of neurons. This will have two layers, the structure itself and the action potential.

Limitations

Many of the clients suggested an app on the web or phone, however, there’s limitations.

* The sandbox (and therefore the program itself) will be very resource intensive. This means that a web version is almost impractical and would also require an external server, therefore greatly increasing the complexity of this program. A phone version of this program would struggle to compute the different generations. A GPU with many cores is a necessity due to the many parallel calculations being done each second.
* Furthermore, a web or phone version of this program will not allow automation and interaction of the network of neurons through a CLI, and programming as intended. One might point to an API as a solution. However, this would put too much strain on the server as they would have to process many a request every second, making this impractical.

System requirements

Hardware requirements

|  |  |  |
| --- | --- | --- |
| Hardware | Minimum | Recommended |
| CPU | Intel i3, Ryzen 3 | Intel I5, Ryzen 5 |
| GPU | Dedicated GPU | GTX 1050 |
| RAM | 8 GB | 16 GB |
| Storage | 500 MB | 500 MB |

Software Requirements

A modern windows device that contains modern graphic packages and the GODOT game engine for rendering.

Essential success criteria

* Standalone app:
  + Should be independent of any other software or web services
* GUI:
  + Project selection screen
  + Main windows/area displaying sandbox
  + Side window/area with a toolbox
* Sandbox:
  + 2-Dimensional grid matrix of cells that wraps around in all directions
  + Two acting layers:
    - Structure layer that defines how the neuron form and interact with each other to form a network
    - Transmission layer that decides how activation potentials are transmitted along the structure layer
  + Input nodes and output nodes that directly link to the CLI toolset
* CLI toolset:
  + Able to manipulate sandbox
  + Able to provide input sets and receive output sets

Desirable success criteria:

* GUI:
  + Colour coded
  + Easy to the eyes
  + Provides further information about toolboxes and features (educational)
  + Provide additional information on the neural network. Such as activity graphs, etc.
  + Documentation
* CLI:
  + Monitor the sandbox
  + Documentation
* Sandbox:
  + Save snapshots of the state of neural network

Resources:

https://www.youtube.com/watch?v=3H79ZcBuw4M

Partial differential equation:

https://www.youtube.com/watch?v=ly4S0oi3Yz8

<https://mathworld.wolfram.com/ElementaryCellularAutomaton.html>

<https://mathworld.wolfram.com/WireWorld.html>

<https://www.techtarget.com/searchenterprisedesktop/definition/cellular-automaton#:~:text=A%20cellular%20automaton%20(CA)%20is,the%20states%20of%20neighboring%20cells>.

<https://neuralpatterns.io>

<https://distill.pub/2020/growing-ca/>

7.3, 7.2, 7.1 - The coding Train