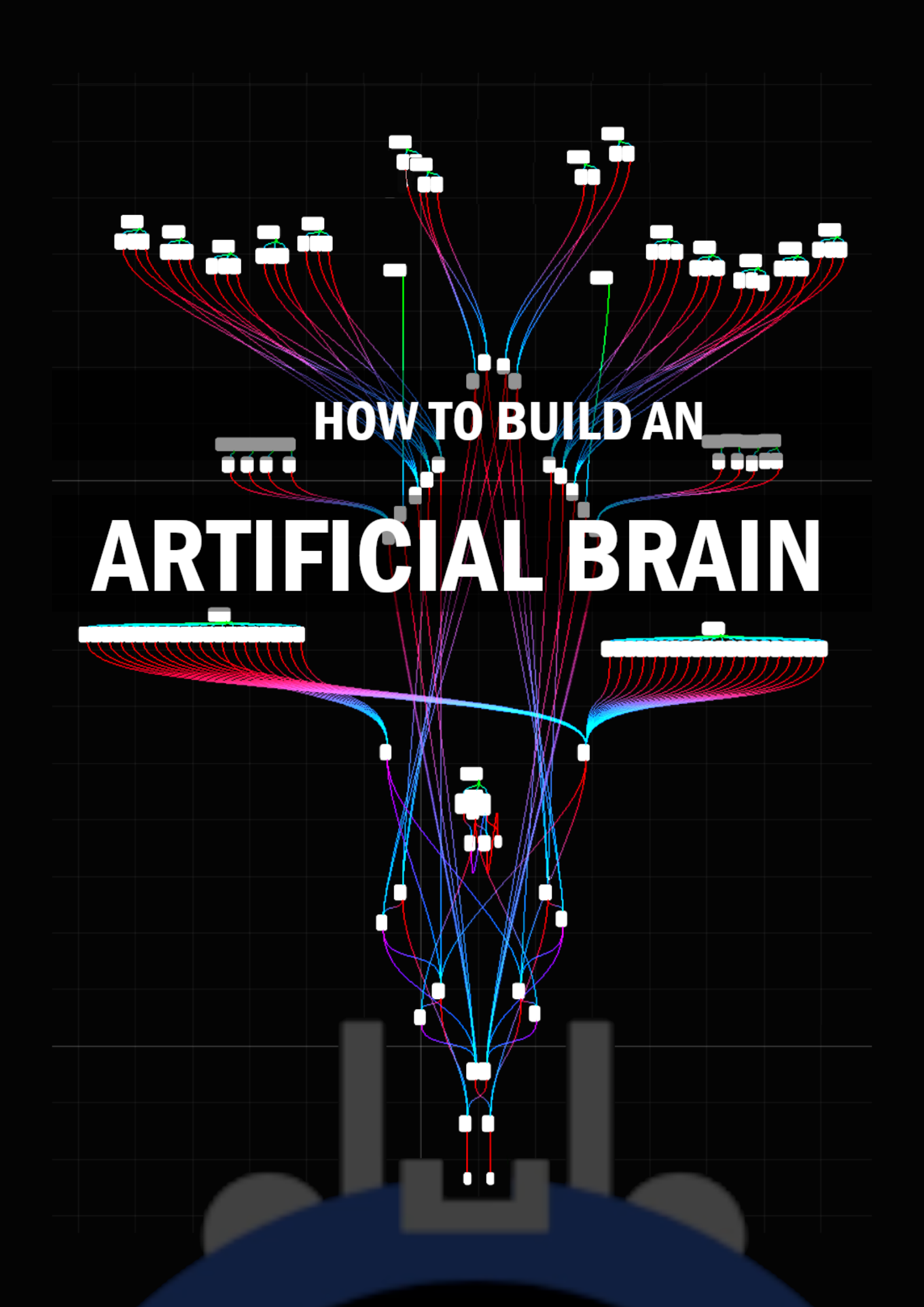
HOW TO BUILD AN
ARTIFICIAL BRAIN

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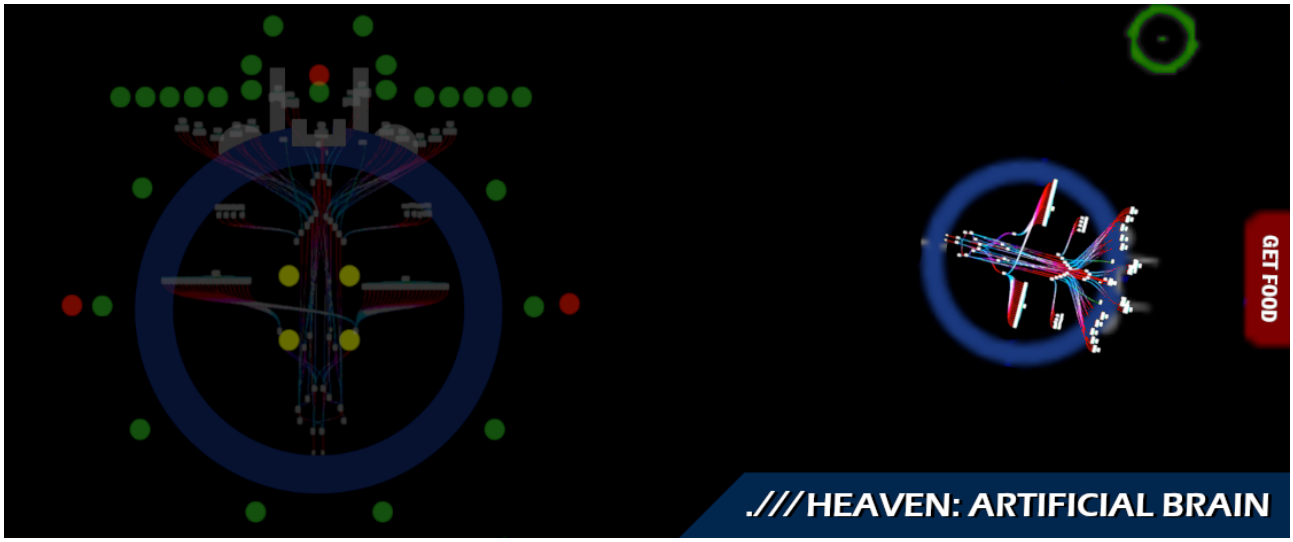
Title: **How to build an Artificial Brain with a hybrid of the spiking neurons (1st edition)**



Abstract:

This paper describes the first part of an experimental research, that focused on the creating of complete artificial life model. The nervous system itself was built of proposed spiking neurons hybrids, and symbiotically interconnected with a simple body of a generalized organism, which allows it to exist and learn as the physical object in a two-dimensional space.

Talking about what is the artificial brain itself, i assume it to be a network of logically connected computational nodes, topology and mechanics of which would mimic the biological system in reasonable manner. That includes:

- A perception of the sensory information from all around the body;
- Parallel processing by a number of neuromorphic mechanics and architectures;
- Following motoric response, which is directed for satisfying of creature's internal needs.

Most of the general ideas has been developed through various experiments and ongoing research, during a non-public stage of the project, which has been conducted in a period from 2014 to 2024 at The .///HEAVEN project's lab. The goal was to discover a new opportunities, provided by the mechanics of the natural neurons, recreated within the controlled environment.

The need for a hybrid development emerged as the way of bypassing limitations of natural mechanisms in biological cells, adapted primarily to physical space. As a consequence, it allowed to increase the overall efficiency and now offers a new methods for agents.

Sometimes I will use 'open cyberspace' as the term that highlights a difference between the environmental natures, especially referring to a samples where the laws could be much differ from which can be found in a three-dimensional one.

The artificial nervous systems presented here contains fewer than 200 neurons, yet it is still capable of perception, simple learning, and exhibiting motivated motor behavior in response to incoming stimuli from both internal and external environments.

The most advanced system (of presented) solves a range of 'survival' challenges, including hunting, avoidance, obstacle navigation, homeostatic behavior: searching, hunting, or pressing a button to receive the food directly.

Additionally, a special software will be reviewed, which is designed specifically to implement the model in practice, but in a form of constructor. It allows the reader to open or reproduce described models on their computers, and gain hands-on experience on how to build a new neuromorphic applications based on the proposed methods.

The software was named ".///HEAVEN: Sandbox". Based on this research, it has been created with the open game engine GODOT 3.5.1 as the supplementary IDE for private research use, and now is will be distributed as opensource project under GPL3

Keywords:

Artificial brain, artificial neurons, artificial nervous systems, artificial life, aLife, aCNS, Artificial intelligence.

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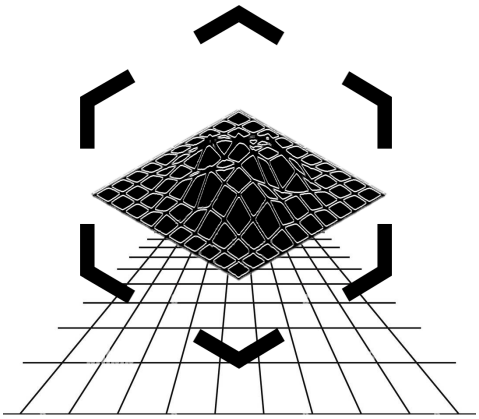
Introduction

2025 – New AI Summer



At this exact moment a computer science that studying an artificial intelligence is experiencing a true renaissance: after a long period that known as "AI winter", now it has become increasingly noticeable that there is a continuous return of the interest among growing number of researchers around the world towards this topic.

The "freeze" most probably was caused by theoretical foundation which significantly overcome technical capabilities of its time,
in 21st century this recent and rapid progress has been fueled by "the open knowledge" culture, accessibility of computational powers for the consumers, and many other reasons, which I personally consider as great.

As new approaches and projects emerge daily, along with cutting-edge architectures and techniques, it's hard not to believe that in 2025 we reach the point of a new "AI summer"!

It seems most likely, that the next wave is driven by breakthroughs in areas like transformers, LLMs and chatbots, which now bringing even first workable agents that already giving significant results.

Nevertheless, over the past decade, my personal interest has been consistently focused on developing a new kind of neuromorphic aCNS agents, whose architecture and properties are at least comparable to the same from the biological systems.

[?] aCNS – artificial central nervous system

What is «artificial brain»?

I am publishing this work during a historical period of intense competition among multiple companies which striving for a leadership in developing of the most efficient architectures, aiming the goal of Artificial General Intelligence (AGI+).

When this will be finished at the level of autonomous agent which is capable of generating and satisfying its internal needs, I believe it's going to be eligible to say that a fundamentally new, novel architecture of the brain has been invented, one that is able to effectively store, process, and utilize an enormous amount of information in a manner which is much superior to a human beings – most valuable players, known at the moment.

However, when we talk about such phenomena as neural networks, traditionally we assume those algorithms do not inherit too much from the mechanics of biological neurons. Usually, we mean some of the 'inspired by the biology' mathematical models that solve tasks such as classification, high-order statistics extraction, prediction, and numerous other separate problems that a biological brain can solve as well, but doing that on a much higher level of efficiency.

» ***The Question:*** Why do we need a progress in neuromorphic systems, when innovative methods of AI giving *such* results?

In my opinion, the researchers in a different fields of the machine learning has made an absolutely remarkable breakthrough, demonstrating truly impressive results, but since popular models does not inherit natural neurons at the moment, they giving results that critically different from us. Not only in a terms of the information processing methods, but also in sense of the very nature of itself, and as consequently – it giving a much differ results of its operation.

Despite the progress were made, we have not yet been able to develop an architecture of an agent that can desire something or to be afraid; experience emotions, such as attachment to something or to someone; AI is lack of the conscience in a form that we understand: it still can't really precept, think or act as autonomous individual.

In my opinion, the solutions to these problems is on the surface: we need to explore and replicate what already works — the brain itself.

As a result, the novel class of motivated agents will emerge, which then could be upgraded or united with the other approaches, to achieve the system with biological properties and machine learning efficiency "in a same jar".

In theory, with neuromorphic approach it is possible to achieve unique properties that are known only for organic life, among which:

- **Perception**
  - As the agent's ability to collect and classify information from the space surrounding its body.
- **Reflectory response**
  - … to produce, consolidate and modify a motor response based on spike mechanics.
- **Neural Plasticity**
  - … to change the structure of its own network, for adaptation or even regeneration.
- **Real-time learning**
  - … to instantly making processed information as part of its "world picture", without hyper-extension problem.
- **Autonomy**
  - … to maintain its own homeostasis independently, self-adapting to external conditions.
- **Attention**
  - … to shift focus among objects and tasks which is related to the current needs, and to avoid unrelated.
- **Emotions**
  - … to develop a subjective evaluation of the new events flow based on evaluations from the past.
- **Thinking**
  - … to rationally process incoming information, and make the conclusions about how to cover organism's needs.
- **Needs**
  - … to make a conclusion about what exact criteria must arise in the receptive fields in order to exhibit inner requirements.
- **Motivation**
  - … to perform thinking and output behavior aimed at satisfying its internal needs, both basic and acquired.
- **Consciousness**
  - as a cumulative side effect of the distributed operation of nuclei, in a sufficiently complex nervous system.

Is it really possible to achieve that «in-silico»?

One of the reasons behind this paper is laying in my assumption, that since biological algorithm is going to be moved from it's natural space, the complete replica would be excessive, and therefore – desired properties could be achieved even trough a simplified form of the neurons, where they can also be hybridized to become more lightweight and efficient.

I explain this statement by the fact, that many events performed in the process of information exchange between the neurons are caused by the physical laws of the space in which known biological branch is evolved. Therefore – they are not exactly crucial in the formation of the required properties of CNS directly, but supplementary important for the cell homeostasis itself.

*» **The Question:** If the method is called a neuromorphic,, is it correct to change the source algorithm?*

Since in a physical world a giant amount of computational energy is spending on the metabolism of the cells, which have to take place in a general – by the mechanical way (as everything else, actually), so in digital environment it just have to take less.

For that reason, the focus in my research for a solution to the problem of artificial intelligence has been more on "for what purpose" the brain and its individual components do what they do, rather than "how exactly".

I was looking for the patterns in the structures of the brains between different species of insects, crustaceans, and other animals (especially vertebrates, including humans), and then trying to summarize their commons, finding the logic in the constructs, and their replication in-silico, which I have actually achieved to some extent, and which I'm also intend to demonstrate in this publication.

In other words, in the context of cyberspace, it is possible to replicate only critical techniques, cut off a lot of unnecessary things, add something new and achieve the better result. Or at least, in some way similar to the natural one (which is already not bad!).

Neuromorphic hybrid: how and why?

The original reason behind the hybridization began at the sensors: after I build some of the first spike transmission methods (See *"Interneurons: inhibition and exhibition"*), there become a necessity in a primary source of the data – the sensory organs of the body. Those are special encoders, that preparing impact from external environment into the signal that is comparable with the network.

After experimenting with encoding data as real values at the side of the organ, I became interested in injection of not encoded packets, to mix it with potentials flow. Which I did, in such way obtained a network that uses neuromorphic mechanics of accumulation and transmission of action potentials as the root transmission mechanism for any arbitrary data.

Another reason arise from the motor system: within the physical space, the only available option for the nervous system to interact with the external environment was also a purely physical one (a direct mechanical impact on it), when in the cyberspace – such concept as physical laws is applicable only if they have been clearly defined at the level of an engine.

After that, my interest in hybridization was additionally fueled by the question of what creature's body could look like, as it will become adapted to operate within the space with no physical limitations.

» Why it has been decided to conduct the research of this exact AI approach

A researcher's pursuit to create a fully functional artificial brain, which would work (at least) similarly to a biological - goes deep into history, and until some while ago I thought myself that was the reason why such field of science as the AI is existed at all.

This may have been that way in the past, but now the leading role is rightfully occupied by innovative machine learning systems, which are already significantly superior to the biological brain in solving of specific tasks, that the brain is capable in general and separately.

High efficiency, impressive and useful results, as well as relatively low cost of computation allowed to commercialize such models, which greatly assisted in their further industrial success.

And although research of neuromorphic systems in one way or another is still being carried out by the some major players in tech (apparently), for some reason inside of the community there is an opinion I heard, like there is little of sense in all of this – as if we're trying to build an airplane with flapping wings, as it was at the beginning of aircraft industry: today we know much more optimal ways.

Somebody will even say that there is an optimal ways has been found already, if we compare AI and aircraft.

Despite all this, I still believe that the potential of the neuromorphic approach is significantly underestimated, due to the complexity of practical application and still some controversy and issues (ethical?) in understanding of how does the brain work.

As a result, I believe there is still a significant gap in this knowledge, which I will at least try to fill, inviting a new community members to join this project, so we could find new solutions, designs and applications together.

» How this technology can potentially turn out to be useful

The promotion of this method for intelligent machines is may help to open a new paradigm in AI, were advantages of the biological brain is achieved within the energy-efficient, small and autonomous agent.

I do not claim to have an exact understanding of the brain function, and with this paper I only wish to demonstrate what progress do I personally accomplished with this, what did I discover, and which conclusions did I made about this technology perspectives.

But honestly, I believe it just take a closer look for discovering a new surprising opportunities that (theoretically) can be achieved in the future using the neuromorphic approach.

And these are just some of the areas in which it could be potentially useful, or to make a contribution for their development:

- Brain-computer direct interface
- Neural engineering
- Systems of the reflectory automation
- Motivated agents
- Augmented limbs
- Explanation of the brain
- Medicine
- Agentic AI
- Military supply
- Other AI models modification

… And many others, still to be discovered in the future!

Methods

- The project was founded as an automation tool for a wide range of the tasks.
- After several experiments and personal insights, my goal has become to create a flexible model of an artificial brain in a cyberspace, as it seem it has all the properties required for universal tool that capable for adaptation.
- The necessary amount of information about the brain function in humans and other living beings was collected from available sources in order to replicate the principles of their structure.
- On the ground of conducted work there was formed the idea of the brain, as a system of logically interconnected nuclei, which built on the computing nodes, that capable of data transmission trough the “spiking mechaniks”, and in addition, which would be composed in interrelations with sensory and motor system of an organism, for the purpose of inhibition of internal needs and further survival.
- Multiple theoretical constructs and mechanics were tested on paper, eventually showing promising results.
- Once a minimal theoretical model was compiled using the free Godot 3.5.1 game engine, special software was created for automated testing and improvement in the model and the neurons themselves.
- For the beginning, 4 basic neurons were isolated and implemented into software:
    - **sensory**
    - **motor**
    - **inhibitory**
    - **exhibitory**
- That was enough to build a simple polysynthetic chains
- Next to the neuroconstructor, it was decided to realize possibilities for bidirectional integration of the constructed networks with a variety of bodies and simulations.
- For this purpose, a biomorphic body and a two-dimensional environment with local physical laws were created.
- To model the relationship between the body and the brain, additional research was conducted on biological organisms: was overlooked the body's ability to convert external and internal influences into an internal format using sensory systems, as well as the reverse conversion of internal information from the nervous system into mechanical work using the muscles.
- A protocol and a universal format for two-way communication called BRIDGES was developed to scale the structure of the connected body, and hence the brain in its peripheral regions.

*[*]* Further stages of the particular work I consider to be a kind of the initial results.

Results

» In general

During experiments with developed software it was possible to discover some interesting properties of the polysynaptic chains, reflexes and nuclei, that made of neurons run by a spiking mechanics (in a hybridized form). Moreover, a few complete nervous systems* were build and described along the paper, which is subjectively enough to understand the natural brain a quite better.

* as the models of organized conditional reflexes, regulated by the needs and functional logic.

Jumping a little ahead, it was possible to create a systems capable of simple perception, attention, inner processing of reflected surrounding space, memory and as the result – a certain degree of motivated behavior, aimed at solving a number of complex problems that ensure the maintenance of internal homeostasis. That make me consider those as the first significant proves of the project value.

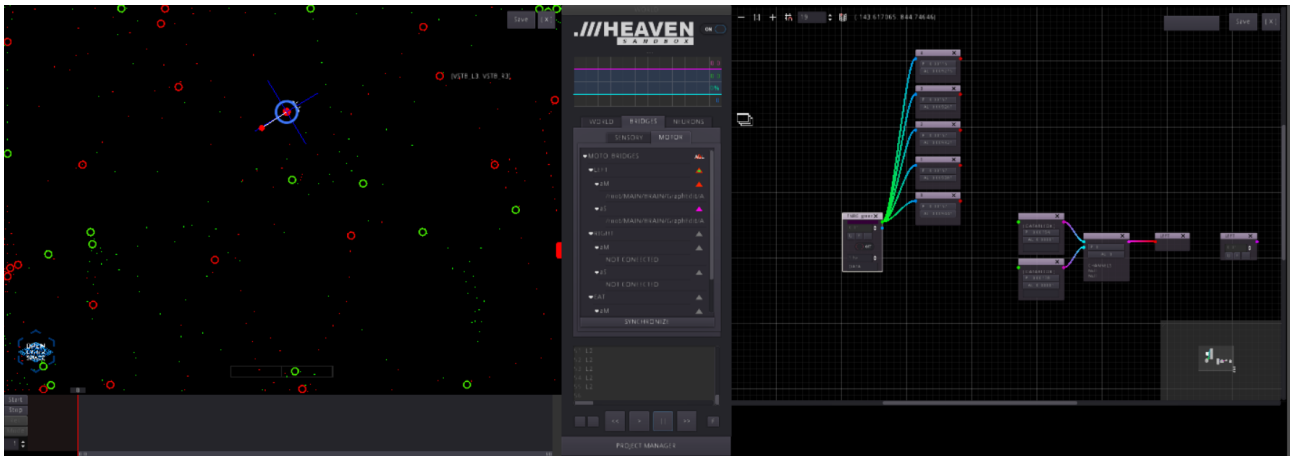
Here are some of the notable features of the ADAM:S1E1 agent behavior, the implementation of which required ~165 neurons:

- avoiding obstacles
- object classification
- search behavior
- pressing a button to get food
- state of hunt
- state of rest
- basic attention
- basic memory
- basic learning
- tactile reflexes

In general, the initial goals of this stage have been achieved:

- **simple biomorphic organism** has been created;
- **logic and methods** for building such systems has been found;
- **opportunities and limitations** of this approach has been defined;
- **neuroengeneering software** was built, and cleaned for a public release.

» Quick overview of the .///HEAVEN:Sandbox v1.0.0+



** Workspace of the .///HEAVEN:Sandbox, unfolded mode.*

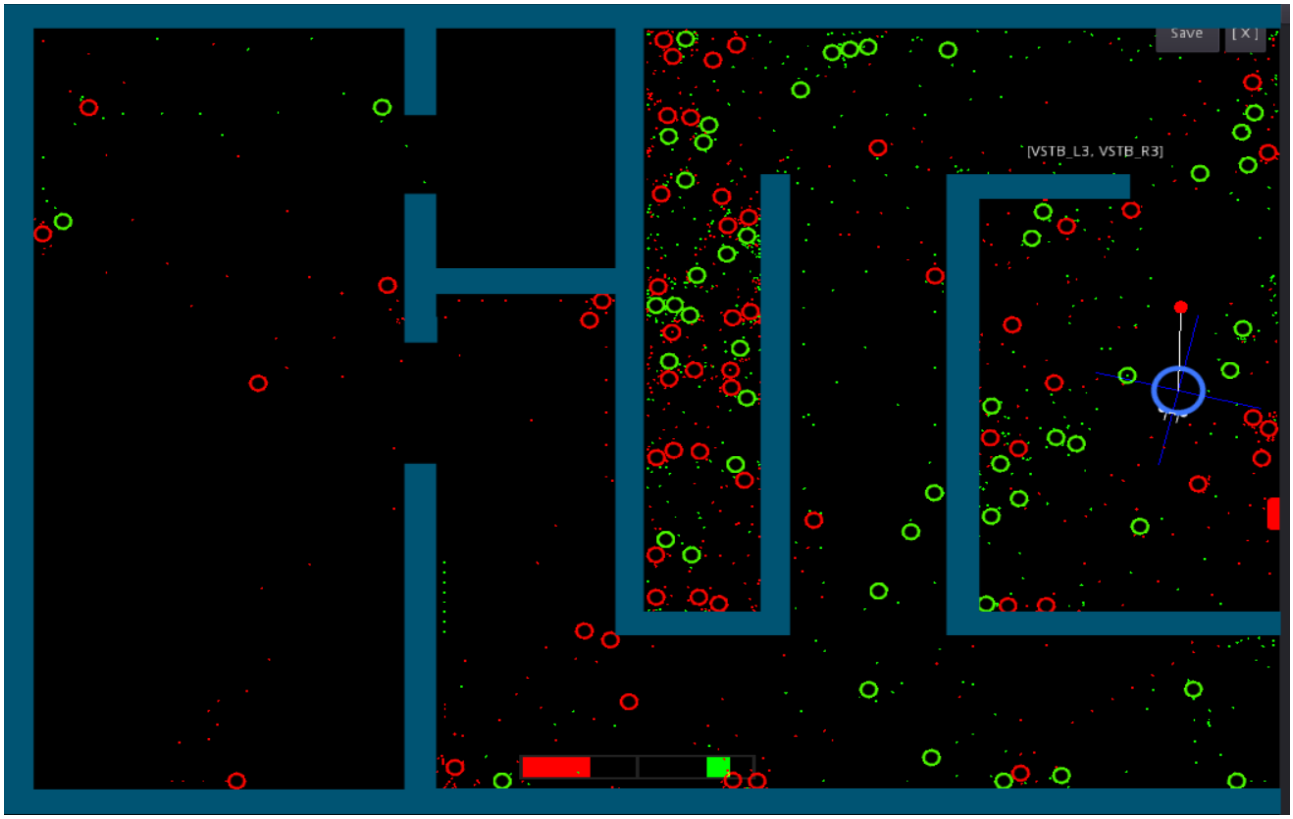
In total, in this version of the program (v.1.0.0), the following functionality is implemented:

- Interface for constructing of the nerve circuits, and even a whole systems.
- Simulation of the external environment and/or body can run within the software
- Primary tools for the project management and analysis

Using the features developed in software, users can freely build and experiment with neuromorphic systems, easily connecting them to a prepared cyberspatial environments through the BRIDGES protocol, and perform a simple analysis in real time.

» Cyberspatial environment

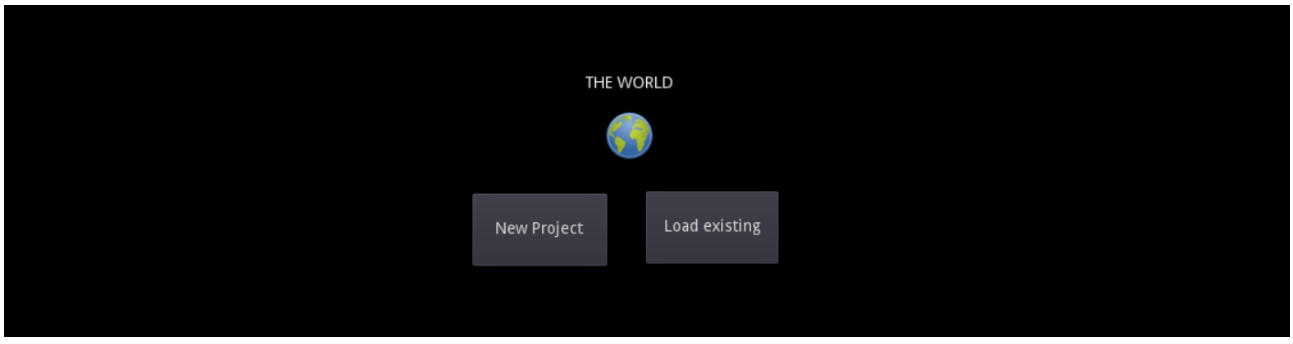
To ensure system's learning process in its most organic manner, an external environment was designed to allow the network to interact with it's ecosystem as physical biomorphic organism. The environment itself is now consist of:



- Physics in a two-dimensional space.
- Spatial borders
- Biomorphic body ADAM:S1E1, connection-ready.
- Interactive objects
  - Nutrient and toxic "microorganisms"
  - A button that triggers food
  - (optional) Labyrinth borders

» ***How To Launch A Default World***

When a new session of the program is loaded, you will be offered to launch a new (default) world that contain the ADAM body:



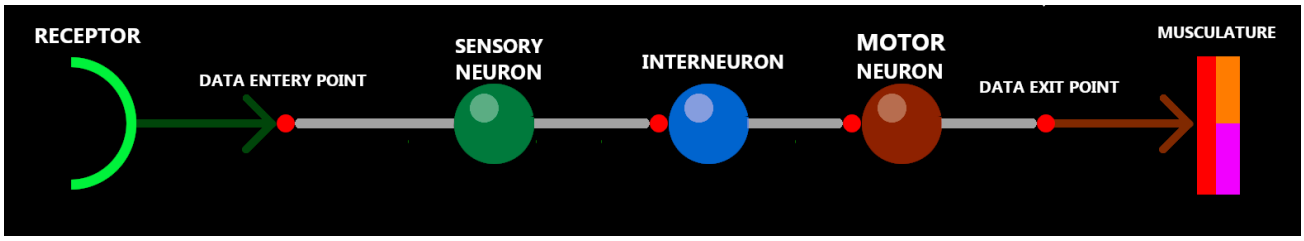
» Q: Can I Connect My Own Simulation?

You don't have to limit yourself to the standard simulation, because the demonstrated project is just an example of the features offered, and the software itself has been designed to be easily extensible. If the bridges protocol for the body is followed within the space that you are creating, they will be automatically determined by the software, which will propose connections to all available bridges, the same as this occurs with default world example.

*[*]* The procedure for adding a new environments is discussed in the "**Project Management**" section.

» Neural chains: a master key to the neuromorphic approach

The core component of proposed model that lay behind its operation is a chain of the neurons. It is biologically inspired construction, that provides transmission from the sensory organ to the contractile fibers of the muscle, through two or more neurons:



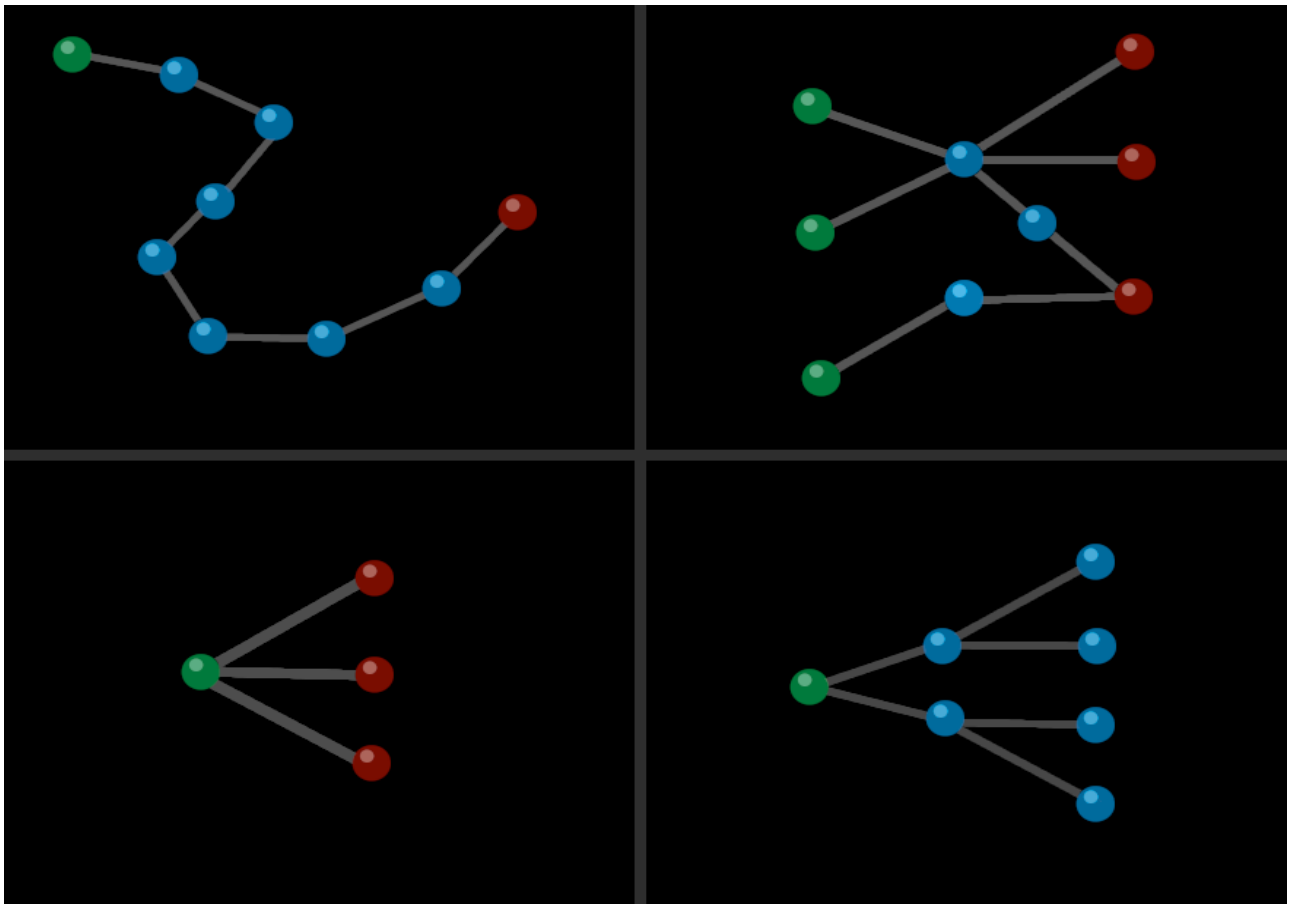
In general, there are two primary types of neural chains is classified:

- **Monosynaptic chain**
  - Sensory neuron → Motor neuron
- **Polysynaptic chain**
  - Sensory neuron → Internal neuron → Motor neuron

[*] A more complex form of chain is called the reflex, which can be both mono or polysynaptic. However it is typically involves sensory feedback - data from specialized sensors within the muscles, that can affect the flow of the data within the chain and change it's output.

- **The reflex scenario is usually made of those:**
  - Step 1: Sensory neuron → (optional) Internal neuron → Motor neuron;
  - Step 2: External impact on the motor executor and subsequent activation of proprioceptive sensor;
  - Step 3: Proprio-sensory neuron → (variable) Motor neuron **/** Internal neuron / Deep areas of the network;

Due to their connective design, the chains can grow in length and wide, contain different types of intermediate neurons, making relations with other circuits and forming entire webs of reflexes and logic, in which events from one part of the network can influence processes in another.



* Variations of the neural combinations that forming a mono- and poly synaptic chains

» Hypotheses: what purpose does the neural circuits serve

- **Data unification**
  - The first thing that becomes obvious when taking a closer look at monosynaptic chain, is that design solves the problem of consolidating information from two different systems (sensory and motor) to internal, unified format.

- **Data transmission**
  - Communication between the neurons is possible, which includes transmission of certain amount of data from one neuron to another, using spikes and making an impact which is depending on a type of the chain:

    - ***Mono-synaptic —*** transforming sensory stimuli into a motor activity by the shortest route.
    - ***Poly-synaptic —*** allows for intermediate nodes to define additional logic and conditions.

- **Transmission mechanics**
  - Transmission is ensured by a set of compatible mechanics inside the neurons between which the information flow passes.

    - ***Polarization —*** As incoming information is received, an increase in the level of polarization occurs around the neuron—in other words, an increase in the total charge.

    - ***Activation threshold*** — this is a special dynamic parameter that determines the sum of incoming spikes, required to generate an outgoing spike, or even a series of them.

    - ***Spike*** — it is a phenomenon accompanied by depolarization of a neuron after sum of data exceeding its activation threshold.

      A transmission of information packets travel to child neurons via axon, and once entering the target synapse, it instructs them about the metabolic changes it needs to take, such as: increasing or decreasing its own polarization level, changing the parameters of membrane elements, and so on..

      * ***The elements of a membrane –*** *is a mechanics that ensures physical exchange between the internal part of the cell and its environment. It is meant to maintain the neuron stable in a state of the rest, and to be changed with parental instructions.*

- **Timing control**

  - A transmission mechanics in polysynaptic chains establishes the logic of data flow by determining the amount of stimulus required to activate the spike on the level of each link, which allows these effects to occur as result:

    - **Delay** — is determined by a higher activation threshold, and therefore requires more time before activation;

    - **Acceleration** — in turn the level is lowered and therefore the signals go forward in a shorter time and higher frequency;

  - Exactly the work with time is one of the key reasons why the mechanics of nervous systems are formed in such manner. However, it is quite reasonable, since time is one of the key properties of physical space, relative to which biological life has to evolve.
  - Any movement – whether it is an attempt to escape, to wait for food during a hunt, to dance, to play the piano, or even to give a simple thumbs up gesture – each of these motor skills requires a time-related sequence of muscle activations. And even before that, the brain is constantly have to make a lot of rapid, or measured decisions, where time is having a critical role.

- **Noice compensation and self-tuning**

    - Changes that caused by the action potentials can reach a large number of child neurons, that can be located at different distances from the parent, and therefore – noise and losses can occur during data transmission.
    - In order to compensate this, neurons have developed following mechanics:

        - **Growth —** since the transmission of data through a neuron is not only its functional task in a terms of intelligence, but also an integral part of its metabolic processes, so i believe that during active usage there is changes in the volume of the neuron occur.

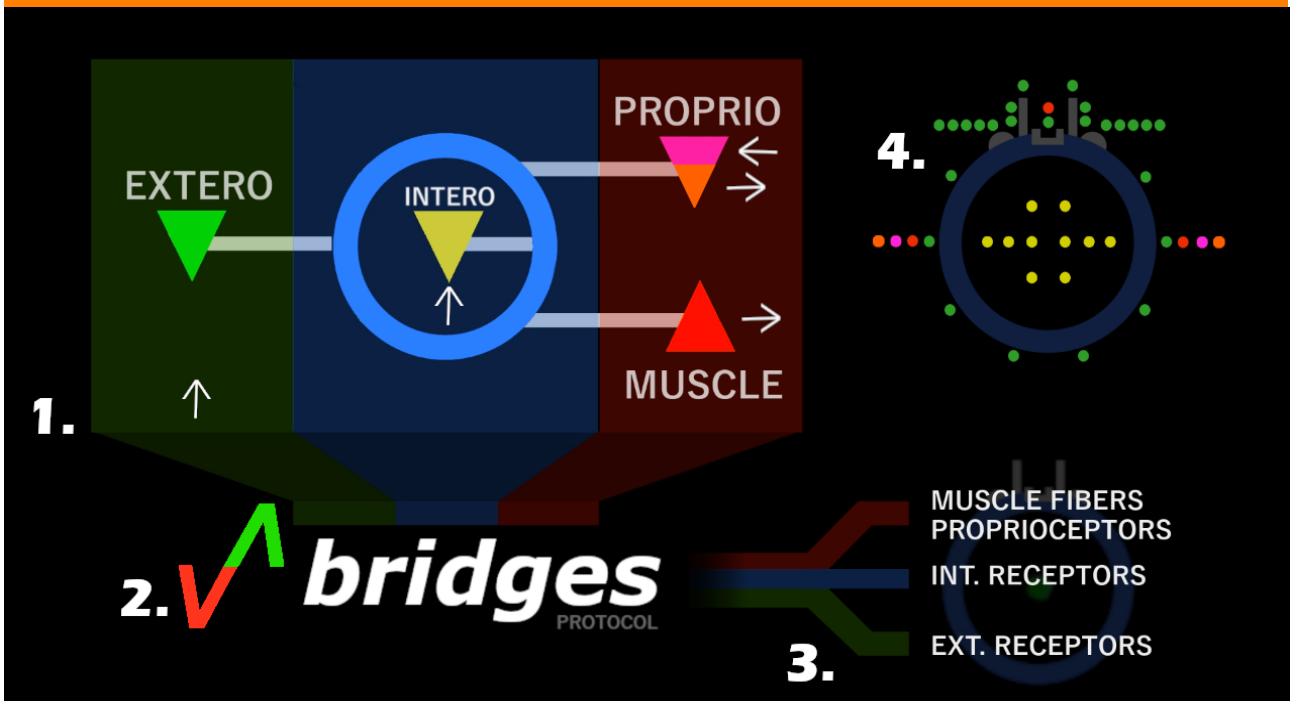
        - **Myelinization** — in biology it is the process of building up segments of a special substance around the axon with the help of special supporting cells traveling along and layering this material on, like a roulette.
            - This process leads to additional acceleration and other changes in signal transmission, which solves the problem of traveling long distances without excessive increase in the size of the original cell or signal distortion.
            - In my opinion, in addition to the genetic factor, this effect is associated with repair processes in axons damaged by excessive loads, thus increasing the speed of passage.
                - [*] Under development, (See **Discussion**)

        - **Degradation** — is the process of natural aging of a neuron due to the fact that it has not been used, or simply loss of its functional specification, which may lead to its elimination from the network.

- **Local memory**
    - Each neuron plays its own role in the correct operation of entire network, because its stores a fine and local settings that lead to changes in the outgoing signal, which then can make a serious changes in other areas of the brain. These parameters can change over time, during metabolic processes or external influences, which can eventually lead to changes in the final motor response.

*[*]* Under the condition of an acceptable level of replication within artificial nodes, this can be used to build a sufficiently flexible and damage-resistant (to some extent) artificial nervous system, capable of regeneration, learning, plasticity, and other desired effects to ensure the operation of an autonomous organism unit

» Architecture of embodied aCNS agent



* A general template of the ADAM nervous system, and distribution of the BRIDGE entry points within the body, with arrows is shown direction of data flow.

1. **Simplified diagram of the nervous system**

   EXTERO – external sensory inputs (e.g. eyes, skin, etc)
   INTERO – internal sensory inputs (e.g. chemo receptors, vestibular system)
   MUSCLE – motor outputs
   PROPRIO – proprioceptive systems

   * ***Blue circle*** *indicates the neural construction that integrates all other elements as unified system.*

2. **Two-way communication protocol BRIDGES:**

   [?] A system protocol that establishes a connection between the aCNS network and the body's components

   - **^ Ascending Bridges**
     - **EXTERO** the channel carries information from ***external transducers***
     - **INTERO** ... from ***internal transducers***

   - **V Descending Bridges**
     - **MUSCLE** - *connects* ***motor output*** *and* ***muscle function***
     - **PROPRIO** - *connects the proprioceptive complex to the network*
       - **PROP-SENSE** – *entry point for proprio-sensory information*
       - **PROP_MOTO** – *connects* ***Prop_moto output*** *and* ***Prop_muscle function***

3. **Types of possible connections**

   [?] A set of body elements that provide the network with information and methods of interaction within the space.

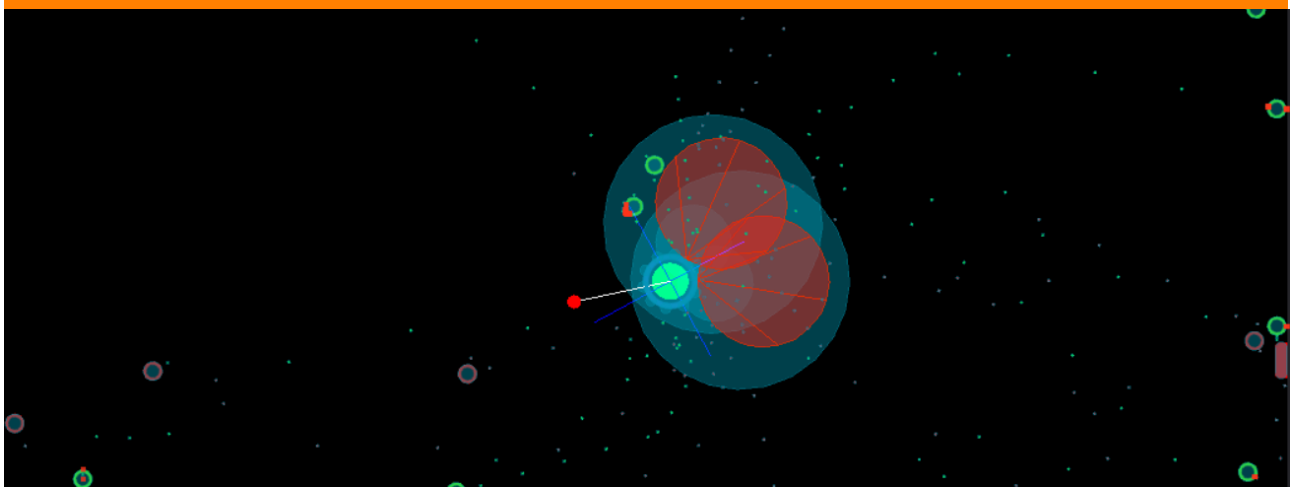
   - **External** sensory transducers
   - **Internal** sensory transducers
   - **Musculatory** functions
   - **Proprioceptopy** functions

4. **Anatomical map of the body ADAM:S1E1**

   [?] Distribution of components in the body, the type is highlighted in color:

   green – indicates external sensory systems
   yellow – ... inner sensory systems
   red – ... «extrafusal» motor functions
   purple – sensory part of the proprioceptive complex
   orange — motor part of the proprioceptive complex

» Sensory systems

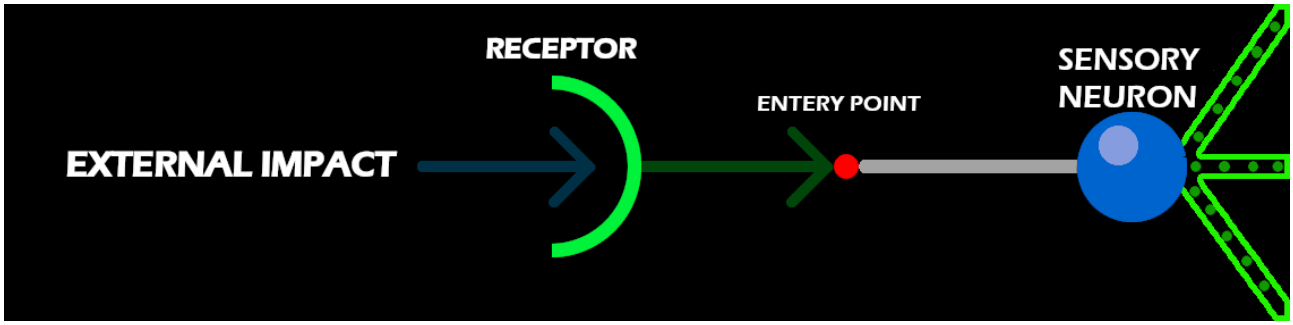


The body was designed in the way to mimic the structure and internal processes of some generalized, and very simplified organism with a number of sensory systems, that will provide the network with information about the surrounding space.

» Common Principles Of The Sensory Data Transmission

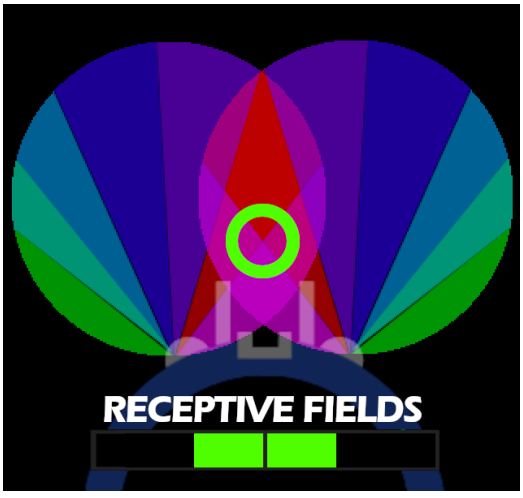
Artificial receptors – is a set of elements that placed inside of the physical body as its own part, and which is converting specific impacts from the external environment, preparing it for encoding into inner data format of the network – the action potentials. To achieve that, prepared signal is sent via its BRIDGE directly to a connected sensory neuron, located inside the constructor session.

Although there is a large variety of sensory systems in nature, I think it is acceptable to reduce it to a simple diagram:



** If the protocol is followed, any source capable of transmitting prepared data can be connected in the same way.*

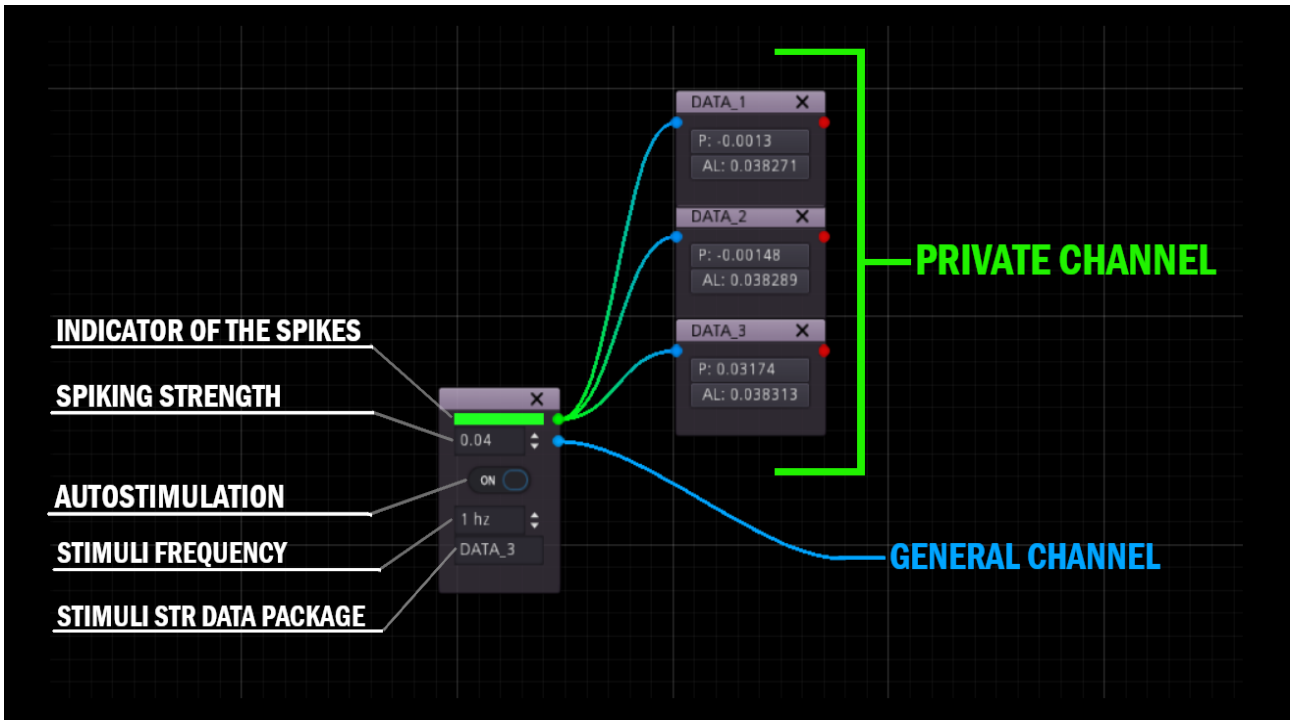
» An Example Of The Sensory System.



In order to better understand the nature of this process, lets take the creature's visual system as an example:

- **Exposure** — in this case, it is the fact which is telling that object "green food" appears in the receptive field of the visual system. They have its own color parameter, which the receptor is "sensitive" to.
- **Receptive field —** it is a group of receptors, representing the areas in which the stimulus could affects the receptors, visual fields in this case.
- **Entry point —** provides connection via an ascending bridge, to which a receptor addresses in order to transmit prepared data
- **Sensory neuron —**is a specialized computational node that provides correct information arrival to the network, its primary processing, encoding and forwarding.

» **Anatomy of the sensory input node**



Sensory inputs — represent computational nodes that play a role of the entry points, where information gets in.

It can work on its own as a signal generator for testing and research, but in the practical applications it is used to build ascending bridges between the body's receptors and the neural engine, providing the network with a constant flow of important data.

The neuron object is located in the res://NEURONS/SENSOR_adr+ v1.0.0 directory, appearing in the constructor after installing the bridge, but can be called (temporarily) trough the right-clicking on the workspace » SENSORY

A node design has the minimalistic interface for monitoring and manual control:

- **Spike indicator** — is an element that visually signals the transmission activity of a sensory neuron.
- **Spike strength** — the field whose activation will cause the strength of the output signal to be replaced by this value.
  - Inactive by default, to activate: Mouse button on the neuron → VALUES
- **Autostimulation —** is a mode that activates a generation of the sensory signals by the neuron itself
- **Stimulus frequency** — is a setting in the auto stimulation mode that determines the frequency of the signal generator.
- **Stimulus data** — is a packet of STR-type information transmitted by a neuron

Also, there is 2 axonal channels for the output of information and its further transmission to the child neurons.

- **Private channel** :
  - Sensory neuron is able to provoke the appearance of child interneurons of excitatory type (+) , in the form of which the long-term memory about the varieties of sensory signals is stored.
  - Recognizing the incoming signal as being stored in a private channel, the neuron routes it to the appropriate interneuron.

- **General channel :**
  - Transmits the full range of information entering the neuron in a solid stream.
  - Has priority in processing, to increase the common speed of information getting deep into the network.
  - Can be used with experimental nodes, such as CGN+ (see "**Discussion**")

[!] By default, if the general channel is connected - the neuron stops the appearance of child neurons in the private one

» The ascending bridge: a communication protocol between receptor and the neuron

```
############ BRIDGES PROTOCOL #################

#SENSORY BRIDGES ^^^
onready var BRIDGES_UP = {

    # Interoreceptors of the CORE block
    "ENRG_green": null,
    "ENRG_green_incr": null,
    "ENRG_red": null,
    "ENRG_red_decr": null,

    # Facial exteroreceptors
    "MOUNTH": null,
    "RS": null,
    "LS": null,
    "RS_big": null,
    "LS_big": null,
    "FIB_L": null,
    "FIB_R": null,
```

* Format for declaring ascending bridges within the body script – each item opens a cell for the associated node to be inserted .

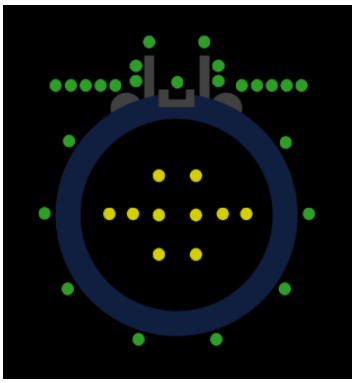
To interact with the software, a special object must be located inside the creature's body, which defines a map of sensory bridges.

```
onready var BRIDGES_UP = {
        #Comment that is describing a purpose of the sensory group
        "Bridge_name_1" : null,
        "Bridge_name_2" : null
        ...
        }
```

- After connecting to the bridge, instead of null, the cell will be set to a link to the network's sensor input
- When the receptor generates a signal, it goes through this record → to the bridges → and then to the neuron
- After bridge is built, the link to a neuron will be fixed as the parameter of a sensory organ

» Two main types of the receptors

Since the ADAM:S1E1 body is implemented as a physical one, I will use such notations for sensory systems in the context of this work:



- **EXTERO receptors** — gather information outside the body.
  - Tactile, gustatory, visual, olfactory, etc.

- **INTERO receptors** — gather information inside of the body.
  - Energy balance, proprioception,

[*] Although in many respects the difference between them is often just nominal, within the context of the biomorphic model of the body, this separation serves as a marker defining the functional, and topological purpose of this source of the sensory information.

[*] Creation of the receptors is an important and even creative part of the neural engineering, as it often necessary to convert external data into format that is comparable with the network's. In the future, I want to automate this process somehow.

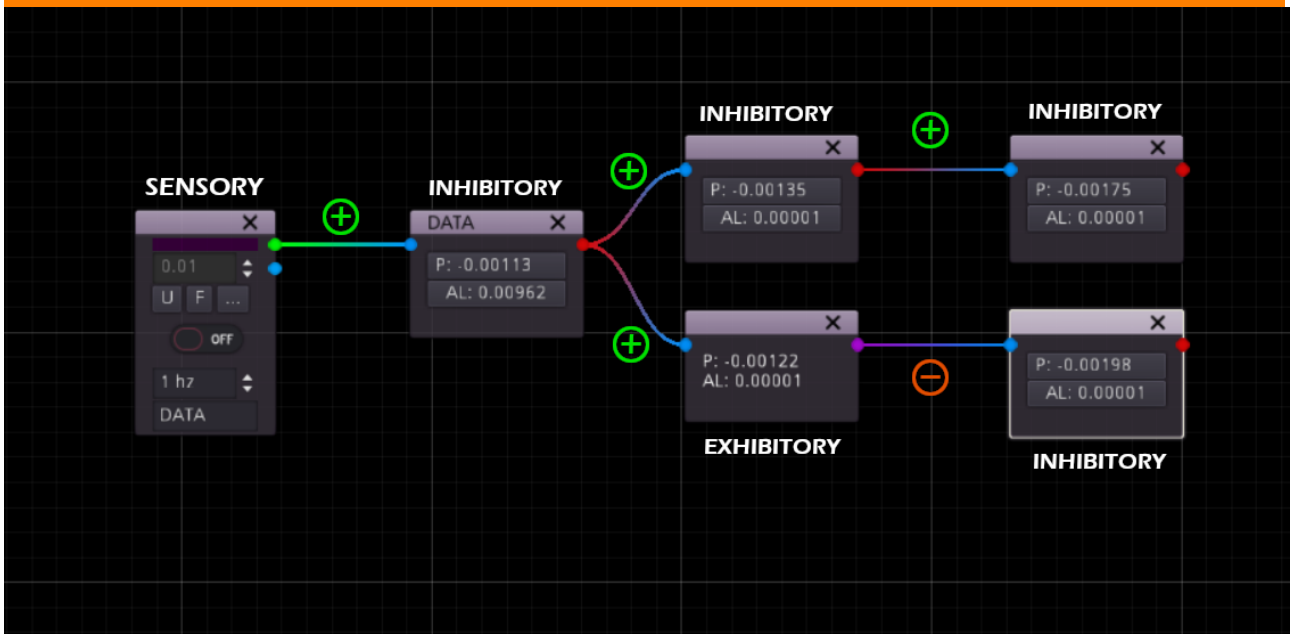
» ADAM:S1E1 External Sensory Systems List

1. **» Facial exteroceptors**
    1. **MOUTH**
        - "Taste buds" of the mouth
    2. **RS**
        - Right olfactory receptor of the near spectrum
    3. **LS**
        - Left olfactory receptor of the near spectrum
    4. **RS_big**
        - Right olfactory receptor of the far spectrum
    5. **LS_big**
        - Left olfactory receptor of the far spectrum
    6. **FIB_L**
        - Left facial vibrissa
    7. **FIB_R**
        - Right facial vibrissa
2. **» Skin exteroceptors**
    1. **LEFT_1**
        - Left anterior tactile receptor of skin sensitivity
    2. **LEFT_2**
        - Left mid-anterior tactile receptor of skin sensitivity
    3. **LEFT_3**
        - Left mid-posterior tactile receptor of skin sensitivity
    4. **LEFT_4**
        - Left posterior tactile receptor of skin sensitivity
    5. **RIGHT_1**
        - Right anterior tactile receptor of skin sensitivity
    6. **RIGHT_2**
        - Right mid-anterior tactile receptor of skin sensitivity
    7. **RIGHT_3**
        - Right mid-posterior tactile receptor of skin sensitivity
    8. **RIGHT_4**
        - Right posterior tactile receptor of skin sensitivity
3. **» Visual exteroceptors**
    1. **L_RET1**
        - Left optical sensor (first from center)
    2. **L_RET2**
        - Left optical sensor (second from center)
    3. **L_RET3**
        - Left optical sensor (third from center)
    4. **L_RET4**
        - Left optical sensor (fourth from center)
    5. **L_RET5**
        - Left optical sensor (fifth from center)
    6. **R_RET1**
        - Right optical sensor (first from center)
    7. **R_RET2**
        - Right optical sensor (second from center)
    8. **R_RET3**
        - Right optical sensor (third from center)
    9. **R_RET4**
        - Right optical sensor (fourth from center)
    10. **R_RET5**
        - Right optical sensor (fifth from center)

» List of ADAM:S1E1 Internal Sensory Systems

1. **» Energy balance**
    1. **ENRG_green**
        - Signals the current energy level if it exceeds zero to +20
    2. **ENRG_green_incr**
        - Signals of variants in energy level increasing peaks.
    3. **ENRG_red**
        - Signals the current energy level if it is below zero to -20
    4. **ENRG_red_decr**
        - Signals of variants in energy level decreasing peaks.
2. **» Vestibular apparatus**
    1. **VSTB_L1**
        - Vestibular field: left anterior
    2. **VSTB_L2**
        - Vestibular field: left middle one
    3. **VSTB_L3**
        - Vestibular field: left posterior
    4. **VSTB_R1**
        - Vestibular field: right anteriorly
    5. **VSTB_R2**
        - Vestibular field: right middle one
    6. **VSTB_R3**
        - Vestibular field: right posterior

» Interneurons: inhibition & exhibition



* Demonstration of a simple branched polysynaptic chain in which one inhibitory signal takes the form of two different polarities at the output.

In a polysynaptic chain, there is optionally could be one, or even more of the interneurons that follow the sensory one. These are the special computing nodes, that provide additional logic during the passage of signals along the chain they belong.
As the output, internal nodes can switch the polarity of the flow, playing supplementary or even crucial role in a tasks the chain involved.

- **INHIBITORY**
  - Accumulates incoming spikes, and when the current activation threshold is exceeded, it generates excitatory spikes.
- **EXHIBITORY**
  - With the same conditions it sends an exhibitory.

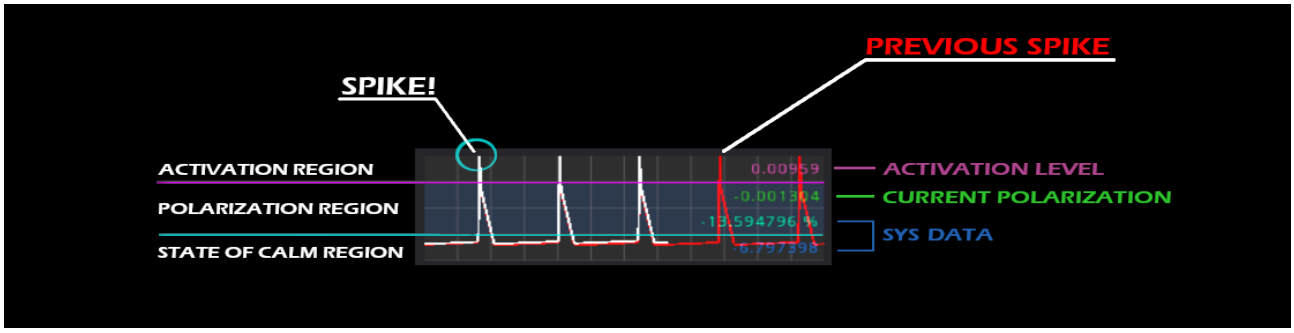
And of course, there are many of communication methods between neurons, but majority of them could be categorized into these two..

All of this exposing a root principle that is used all around the nervous system, and which is one of the most important ones:

» The ability of "parent neurons" to make an impact on the inner state of their "children neurons" trough communication «

Here, I call a neuron «parental», if it is being a source of signals for its «childrens», i.e. those to which dendrites parent axon synapse on.

» What is "the spike" of a neuron?



1. The signal delivered by the receptor enters through the sensory input node, from where is then routed deep into the network.
2. There it enters the interneurons in which it triggers a number of inner processes:
   - **Polarization —** is a process of accumulating the sum of incoming instructions from the parent neurons.
     - Instructions in a form of a stimuli can both increase (inhibit) the level of polarization, or decrease it (exhibit).
   - **Activation threshold —** is a special parameter that determines the amount of stimuli needed to generate a spike.
     - this number is not constant and may vary due to internal or external circumstances.
   - **Spike** — is the a moment of transferring data from one neuron to another, where threshold was breaked.
     - If the sum of potentials was enough, it generates a data packet with instructions, and then sends it forward.

» Why is the exchange of “spikes” between neurons are necessary?

By generating spikes of a certain “polarity”, the interneuron instructing its children that their polarization level should be increased, or decreased – in such way provoking, distancing or even blocking their activation. Such instructions would be transferred along the axon, followed by the package of: **[spike_strenght, spike_data]**, which may have an important role at each connection

[!] The network is based on spike neurons, which is my own practical model describing the mechanics of data appearance and transmission in biological cells. When developing the model, I did not orient on any existing works specifically on the topic of spike models, consciously ignoring their possible existence, because in the process of work on replication of neurons I focused solely on the learned knowledge of neuroscience, so that my mind could create an artificial model by its own.

And although it is difficult to call this method a good idea, it is preferable for me due to a number of circumstances.

However, some time after completing the fundamental part of my work, I discovered that other models of spike neurons do exist, and perhaps some of them may be more optimal (See Discussion section). My goal is only to show what (in my opinion and based on the results) can be achieved by using spike mechanics in the construction of artificial nervous system models, as well as how their capabilities can be extended.

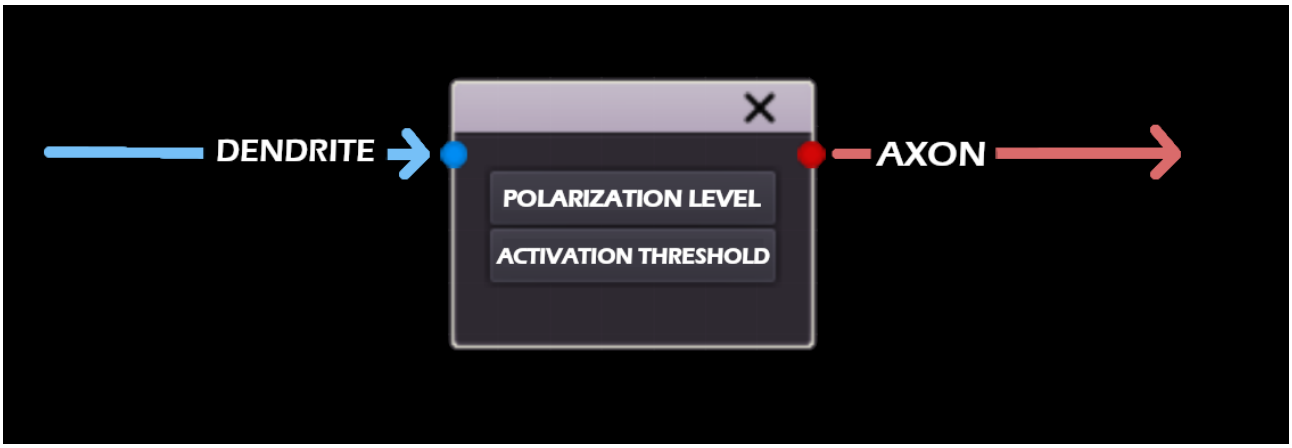
» Metabolic processes in interneurons

The state of a neuron is affected by internal changes over time:

- **Stabilization** — is a process inspired by the mechanics of cell membrane potassium-sodium pumps.
  - The task of this mechanism is to gradually restore the level of polarization of the neuron to the resting state.
- **Growth** — is the process of gradually increasing the level of the sum of signals required for spiking.
  - Each time the activation threshold is exceeded, its value is transmitted and the level increases.
- **Degradation** — it's a process of gradually decreasing the level of the right amount of signals.
  - The purpose of this mechanism is to gradually move unused information out of the network.

» <u>Anatomy of the standard (+ / -) interneurons</u>

[!] The ./// HEAVEN software is constantly being improved, so in new versions the look of the neurons may be changed



An intermediate neuron design is made very simple at the moment:

- **Dendrite** — This is a channel for incoming information.
  - Compatible with other interneurons of both types (+ and -)
- **Polarization level** — indicator that reports the polarization value.
  - when pressed, opens a menu for manual input of current potential level
- **Activation threshold** —indicator that reports the polarization value.
  - when pressed, opens a menu for manual input of current activation threshold level
- **Axon —** This is a channel for outgoing information
  - Compatible with A-motor neuron and NSA (node containing argument)

» Motor system

» All shapes and sizes: An optimal way to achieve a diversity among the bodies

As it was mentioned previously, biological life was naturally evolved relatively due to the laws of the physics, which is reflected in every aspect of that phenomena: from to the internal cell mechanics of to a complete organism construction. For example, I guess that is the reason why a motor elements that ensure a process of locomotion are usually built in a form of deformable mechanical constructions, which is made of the bones, ligaments, joints and muscles under the nervous system control.

» Biological Musculature Complex: The Structure And Purpose

Skeletal muscles, perhaps, are the most interest element for our purposes:

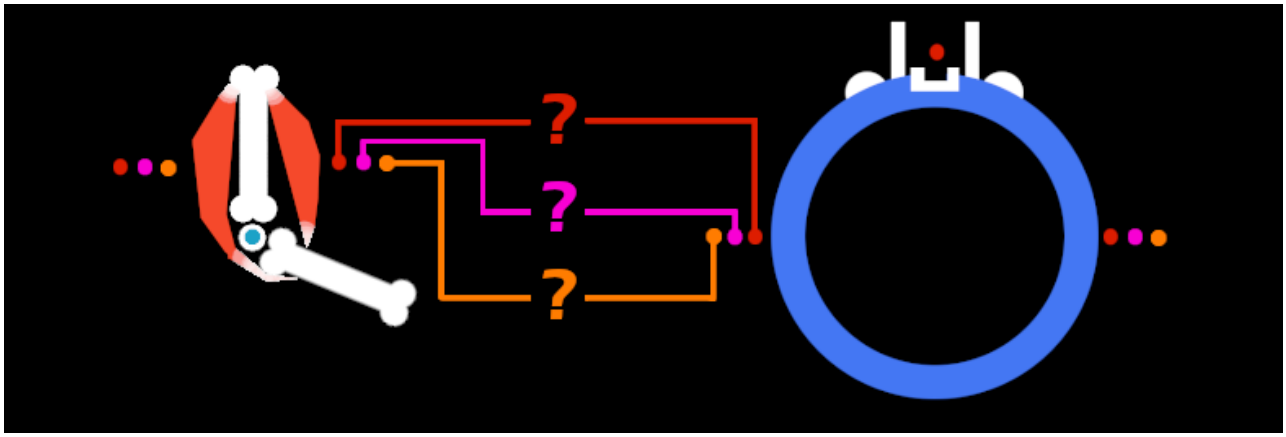
- **The musculature** – is a natural method that allows for a quick and almost direct transformation of the aCNS final outputs, from the form of action potentials into mechanical work.

This means, that essentially the same method, that taking a various parameters and forms is used all around the bodies: for the limbs, for the voice production, and even for the internal metabolic mechanisms. For me, it is seem to be an optimal and flexible method which allows evolutionary mechanism to find a completely different forms and solutions in the process of adaptation.

This hypothesis is confirmed by the stereotypical structure of the spinal cord along its entire length, For me personally it indicates that all of the motor elements are fundamentally the same, no matter what shape or size they take. Therefore, in the case of the model in cyberspace, it will make possible to adapt any function to the organism, and to use the same control construct all around the body.

[!] Note: the following chapter tells about the motor approach, which is used in ADAM:S1E1 just partially: in order to simplify the introduction projects, and since some of the components is under developmenet the model uses direct motor output without arguments or the feedback. However, it is still recommended to read this section to get a general idea of the motor systems, as well as the basics of building aCNS agents in a different kinds of space.

» A New Type Of The Space = New Opportunities!



I guess that the previous assumptions allows me to make an another one:

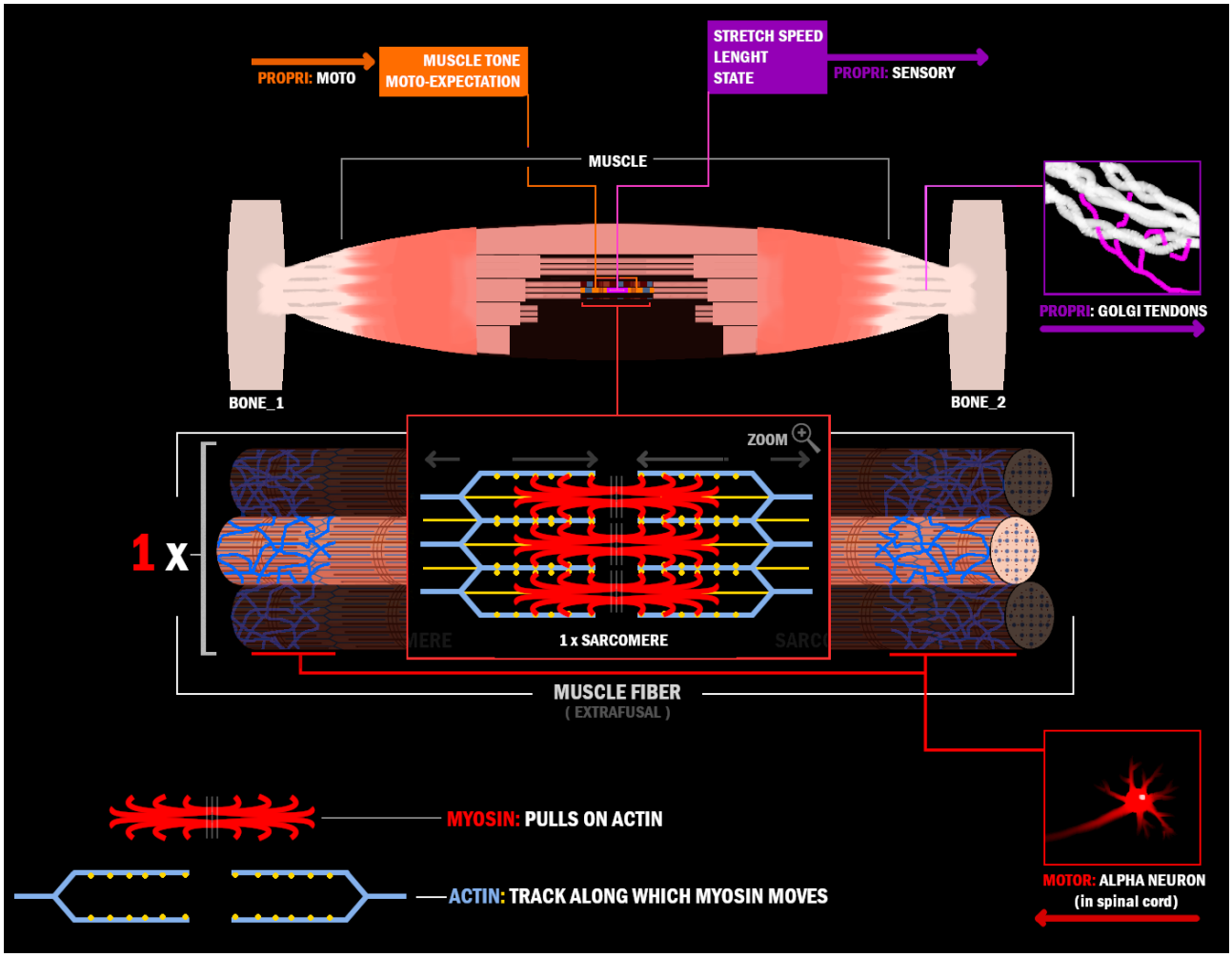
,

- In order to adapt a biological model to the form of space that is lack of the physical laws limitations, we have to compose a model of the motor complex in-silico, as well as the nervous periphiral constructions which controlling it.

- Once the model would be achieved, it could be used to build a new, hybridized motor complex from the scratch, which is stll preserving compatibility with natural neurons, but at the same time going beyond the only contraction function.

In order to do that, we should first pay attention to the two main groups of which it consists.

» **A Two General Types of Muscle Fibers**



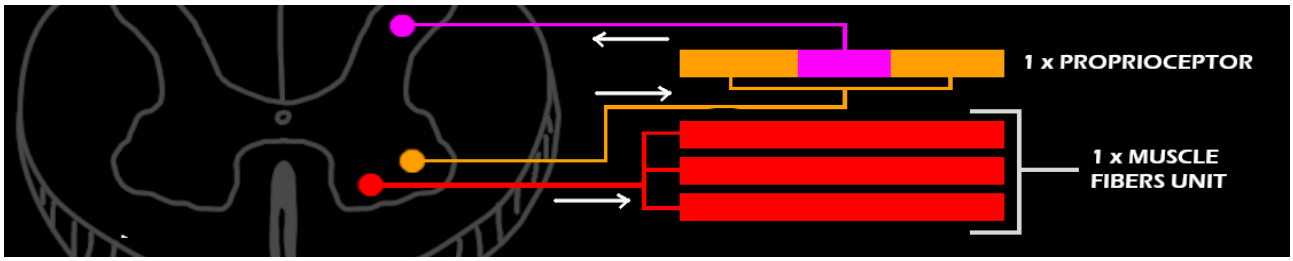
*** The structure of natural muscle complex in humans: inputs, outputs, inner mechanics of the muscle fibers contraction.**

CONTRACTIOIN
(EXTRAFUSAL FIBERS)

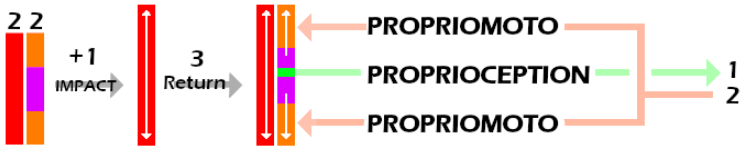
PROPRIOCEPTION
(INTRAFUSAL FIBERS)

- ***Extrafusal*** – is a type of the fibers, that defines a **function of muscle**, i.e. the work it performs;
  - One-way descending component, which produce contraction, in a response to signals from the A-motor neuron

- ***Intrafusal*** – is another fiber type, that designed to provide the brain with **proprioceptive information**.
  - It is a two-directional complex of components:
    - Descending – peripheral, which able to contract, but have no crucial role in generating of the muscle force.
    - Ascending – sensitive centers of different type, that is able to stretch and generate various info about that.



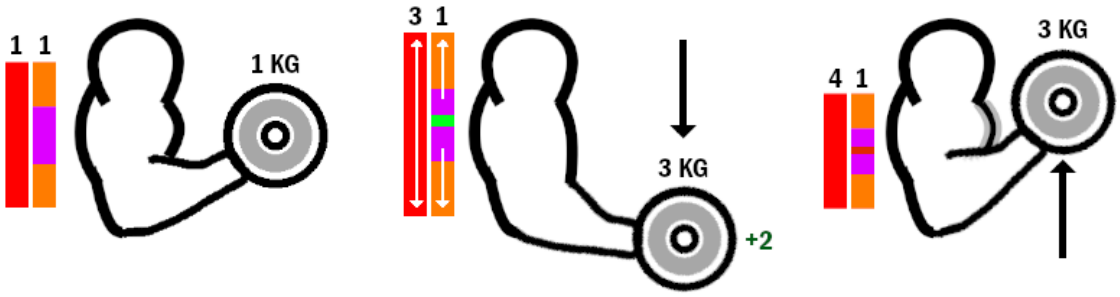
» The Hypothesis About The Role Of Intrafusal fibers In Movement Execution



[*] Demonstration of a general mechanism for generating sensory information by a proprioceptor: an external impact affects a stable muscle in which there is an absolute balance between the extrafusal and intrafusal fibers. When the impact stretches the extrafusal fiber, a new state of the muscle (return) affects the proprioceptor, which at a given tension of the contractile part stretches the central portion, which in turn provokes the generation of a sensory signal about changes in the state of the muscle.

One of the principles that I often notice in the brain's operations – is removing the gap in "expectation" and surrounding "facts", and I assume that the purpose of the intrafusal fibers is driven by the same: before the execution of a motor act, the brain sets the tone for the proprioceptors contractible parts, to set the relative state of the muscle that brain requires to reproduce (e.g., bending the arm)

This creates a conflict between the lengths of the stretched extrafusal, and toned intrafusal fibers. Since in result it's sensory center is being passively deformed and generate information, it also reflect in changes of proprio-sensory signals, which is then used to make adjustments that return the tone back (if possible).



Example: If you hold a 1kg dumbbell, your biceps and the corresponding parts of the nervous system are in a relatively stable state: the signal supplied to the extrafusal fibers is given in exactly the right amount to correspond to the requested goal (holding 1kg).

This ensured by a proprioception, and the striving of the motor system to eliminate the difference between the expectation at the given parameters of reality, where the muscular element is constantly influenced by some stochastic circumstances.

But if the dumbbell are instantly and unexpectedly changes its weight to a 3 kg, your hand will fly down fast, exactly until the nervous system will detect an unexpected changes, and decide to balance the force (reflexively or on the basis of higher processes), but from now – for a new weight of a dumbbell.

This will happen because such a significant change is certainly going to be reflected in the state of the proprioceptors, stretching the sensory center. In turn, it reports the unexpected events to the higher centers, where a motor decision will be found for a balance.

In general case, one of the main tasks of the motor – is to apply such force, as it necessary for the next step of the movement scenario.

*[*]* During my studies, I noticed that the principles of the proprioceptive role are still debated to this day. The proposed logic is just a product of my imagination (as well as almost everything in this paper), but as a result of experimental work I found proposed idea of its operation – is the most logical explanation of that kind of design, and it is also confirmed in practice with the help of software modeling.

» Software modeling of artificial muscle

Now, as the understanding of the muscular components has become clearer, it is possible to make a theoretical model of the muscle, and then implement it into a practice using python. If the hypothesis is correct, we can obtain a functional model that would have muscle properties and functional methods for working with them. If the idea is correct, we could recreate an entire reflex!

First of all, let's define the edges of the muscle in a relaxed state:

muscle_lenght_max = 10 # Max. length
proprio_lenght_max = 10 # Max. length

They denote that both types of muscle fiber, which form the muscle, can be stretched to their maximum value of 10.

And since both types of muscle fiber are initially in a relaxed state as well, the following parameters are set to the same value of maximum length.

muscle_lenght = 10 # Actual length
proprio_lenght = 10 # Actual length

Since there may be some external impact on the muscle, this parameter is also worth specifying in the variable.

external_impact = 0 #Imp

Now we need to determine the entry and exit points, of which there are 3 for the muscle – two descending ones, controlling contraction in both types of the fibers, as well as an ascending one, from the center of the proprioceptor.

muscle_contraction = 0 **# aM — signal from A-motor neuron (to extrafusal contractile fibers)**
proprio_contraction = 0 **# yM —signal from Y-motor neuron (to the contractile part of the intrafusal)**
proprio_sensor = 0 **# yS — signal from the proprioceptional sensory center**

They mimic in and out channels of the muscle components, and within this model are used for calculations of the reflex processes.

- M: [## **muscle_lenght** ##] VAL (+ **external_impact**)
  - aM: **muscle_contraction**

- P: [## **proprio_lenght ##]**
  - yM: **proprio_contraction**
  - yS: **proprio_sensor**

```
[ .///HEAVEN | Muscle proprio FPEV2 | web4plus.github.io]

[ Artificial muscle state ]

   M: [##########] 10 +(0)
     ⌞Imp:0
     ⌞aM:0

   P: [##########] 10 +(0)
     ⌞Imp:0
     ⌞yM:0
     ⌞yS:0

Following command acceptible:
   A - Activate aM neuron (moto)
   Y - Activate yM neuron (proprio)
   W - Apply external impact
   D - Fix the difference

Enter command:
```

The program have a simple interface and allows to interact with the model by entering commands.

- [A] - This command will send the impulces, which will provoke extrafusal (M:) fibers to contract (0 ... 10)
- [Y] - ... will provoke the contraction of proprioceptory peripheral portion (0 ... 10)
- [W] - This will imitate some external impact on the muscle (0 ... 10)
- [D] - This one will calculate the state of a muscle model, depending on its current properties and parameters.

» An example reflex

can be reproduced with the following set of commands:

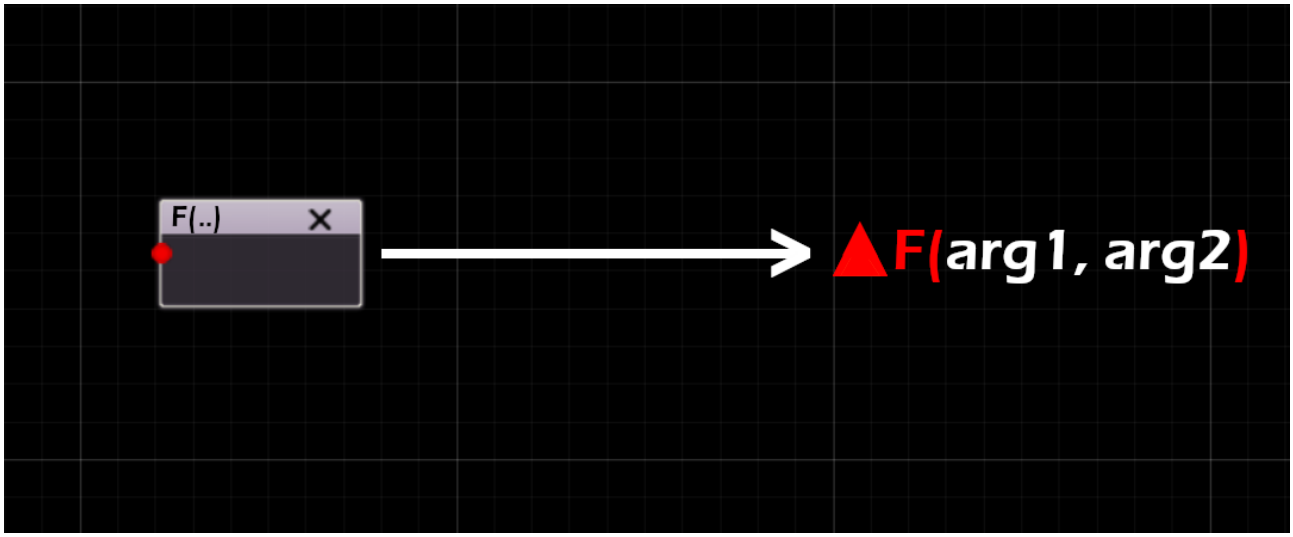
- Enter **[Y]** to set the signal strength to the contractile part of the proprioceptor by value of 6 (six)
  - This will not change the length of the muscle directly, but will trigger the generation of the center, simulating its stretching:
    - **[yS:0 → yS:6; П:10 → П:4]**
- Enter **[D]** to balance the force applied to the extrafusal fiber.
  - This will change the length of the muscle and balance it by activating the A-motor neuron to the proper degree.
    - **[aM:0 → aM:6; yS:6 → yS:0]**
- Enter **[W]** to set the external force to the muscle, by the value of 2 (two).
  - This simulates the occurrence of an external event, such as an increase in the weight now held by the muscle.
    - **[M:4 → M:6; yS:0 → yS:2]**

- Enter [D] to balance the force applied to the extrafusal fiber one more time.
  - A reflex is triggered, leading to a sharp (compensatory) contraction
    - **[M:6 → M:2; yS:2 → yS:-2]**
- Re-enter [D] to balance the force applied to the extrafusal fiber.
  - This will balance and bring the muscle to the state set by the proprioceptor, accordingly the external influence.
    - **[M:2 → M:4; yS:-2 → yS:]**

» <u>A simple motor output from the network: the first solutions</u>

Since the model above is generally confirms a stated hypotheses about the role of individual components in biological muscle, it could serve as the example for creating a more universal motor unit, capable of handling any prepared body functions.

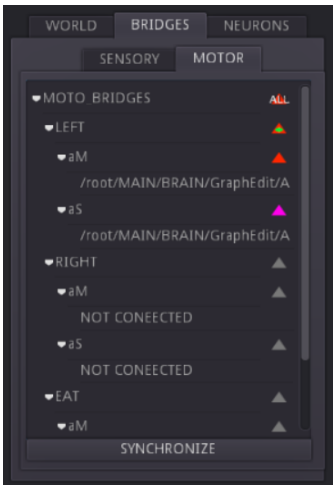
At first, a special object was created for this purpose - an output node **AMOTO**:



* Direct motor output – addresses an attached function when activated, no proprioception is involved

A main difference between the output node and the A-motor neuron is that it does not contain the mechanics of the activation threshold, but serves only as an exit points, through which the action potentials is routed directly to a motor function. If compare that to a biology, i consider this solution as more of the A-motor synapse, that provoke the release of calcium ions and ATF into the muscle (which is necessary for the contraction of myofilaments withing the muscle fibers).

» Descending bridge: a protocol for communicating with “muscle”



A descending bridge design has been composed in a special way, in consideration of the muscle model design.

It consists of several entry and exit points from the network.

- **aM** – the bridge, between the output node and a muscle function
- **aS** – … sensory part of the proprioceptor and input node
- **aP** – … output node and a muscle function of a proproiocoptor

On the right is an interface element, which can be used to activate the bridge →

To do this, click on the gray triangle opposite the function name.

After activation, two nodes - AMOTO and PROPRI - will be initialized in the neural constructor field.

To follow the protocol, when mapping a descending portion of the bridges anatomy for a new body, a specially constructed dictionary should be added to the cell
An image below shows the format, in which the protocol is composed for an **ADAM:** body.

```
#MOTOR BRIDGES VVV
onready var BRIDGES_DOWN = {
    "LEFT": {"aM": {"Type":"AMOTO", "Node":null},
             "aS": {"Type":"ASENSE", "Node":null}
            },
    "RIGHT": {"aM": {"Type":"AMOTO", "Node":null},
              "aS": {"Type":"ASENSE", "Node":null}
             },
    "EAT": {"aM": {"Type":"AMOTO", "Node":null},
            "aS": {"Type":"ASENSE", "Node":null}
           },
}
```

» Two approaches to constructing a network’s motor output

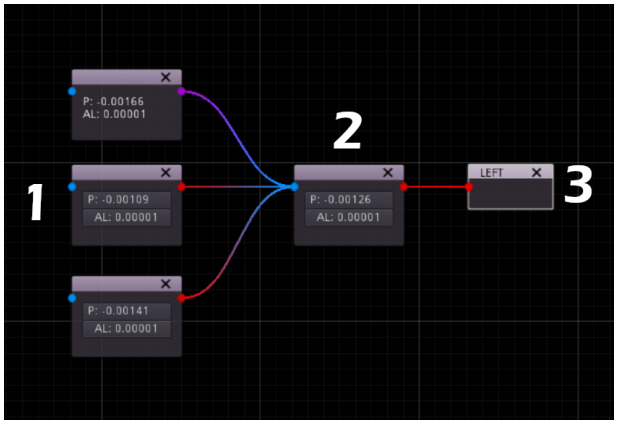
Once the bridge is activated, the user has two options for orientation for the motor periphery:

- Physical space
  - If motor function works on the principle of extrafusal fibers
    - **INHIBITORY→ AMOTO → F(arg) → P(val)**
- Cyber space
  - If anything else is used as a motor function.
    - **NSA(arg) → NGMS → AMOTO → F(arg) → P(val)**

» A-motor output for physical space

If you are a fan of the more strict neuromorphic approach, or you think that a motor system you build have to deal with physical space exclusively – you can design a simple motor output in that way:

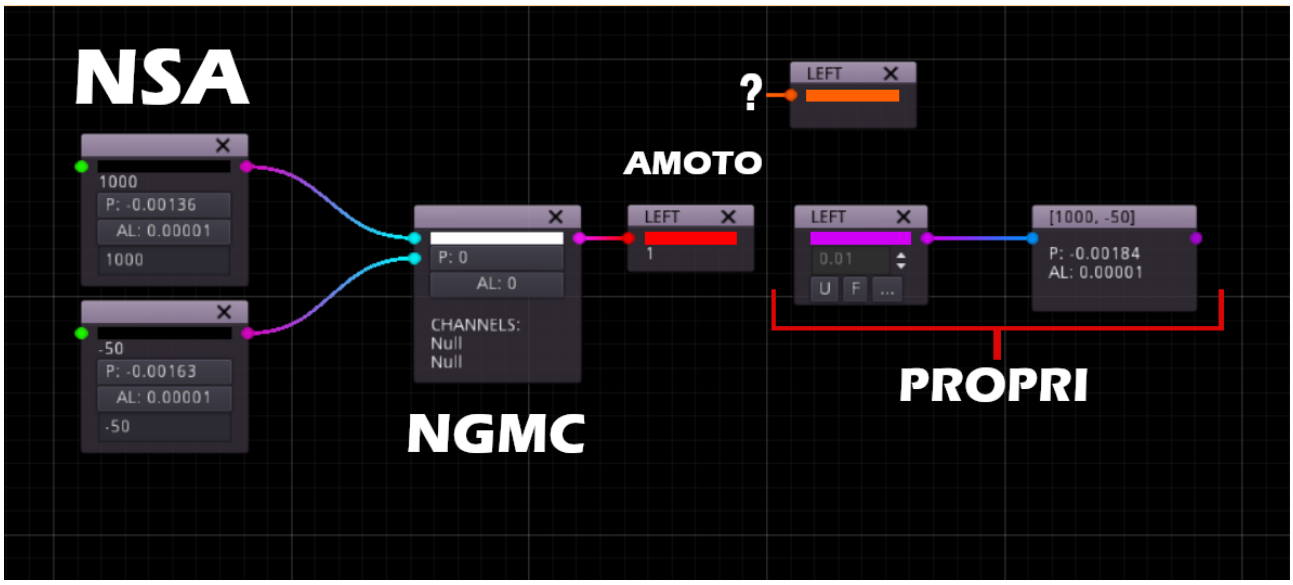
1. Interneurons of different polarity: + / -
2. Alpha motor neuron
3. Outgoing synapse to the motor bridge



[*] As already mentioned, this approach puts serious and, in my opinion, not quite justified limitations on the network's abilities in the cyberspace, because the motor output is limited by the real values. But in some cases it may to be useful – where it is necessary to work very quickly with physical space, for example.

» Functional motor output for cyberspace, with a "return" feedback

The result of hybridization of the muscular models presented above, is a construct that allows any correctly prepared motor function with arguments packed inside the body of a creature to be connected via the Bridges downstream protocol:

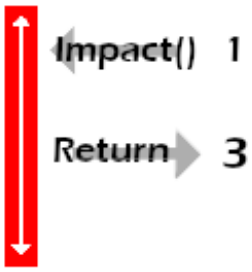


Several additional types of neurons have been created for this purpose, that helps to move beyond the 4 standard types.

- **NSA**
  - This neuron is capable of storing some amount of information, and transmitting it further along with the spike
- **NGMC**
  - Forms combinations of data (coming into the channels, e.g. from NSA) as packets compatible with the output nodes.
- **PROPRI**
  - Sensory neuron – entry point for sensitive function of proprioceptor
    - Generates children neurons in a private channel on the principles that similar to a standard sensory neurons.
  - Motor neuron — output point for the propriomotor function
    - Sets the proprioceptive expectation (under development, see **Discussion** section)

** The difference is pretty much clear: direct design allows to convert the action potentials into the motor output, by regulating the contraction of the muscle functions. In opposite, second approach allows variations of arguments combinations to be stored "as it", and which will be transmitted during the hybrid's weighted decision-making process.*

» <u>Return value of motor function is not a correct(!) form of proprioception:</u>



It would be quite reasonable to assume that the return value of a motor function could be used as proprioceptor data in muscle simulation, and to be honest - I was confused about this for a long time.

However, the conclusion I came to, is that return of the motor function in artificial muscle - is literally its "contraction state" by analogy with the biological one. If we build a muscle as one that has length and its contraction - the function will describe the transformation process, and the return will denote the final length which affect proprioceptors.

Therefore, to model a complete motor complex – return motor function is rather an important parameter for the function of generating already proprioceptive data.

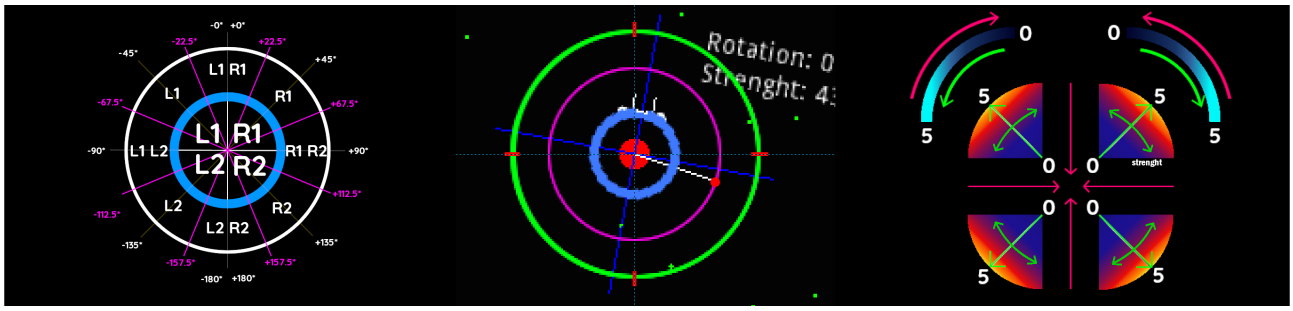
» <u>But why is it used within the ADAM's body then..?</u>

Yes, indeed, in the creature's body ADAM:*, proprioceptor function (when engaged) is now largely limited to the transmission of a return value to the proprio-sensory neuron. The reason behind that is simple: sine ADAM having no mechanical parts, instead of a muscle's contraction procedure, its motor functions describe the result of imaginary limbs giving the body a linear-angular acceleration.

And since the "limb", where is proprioception function is located, has no contractile parts - there can be no impact on the muscle other than input at the moment of activation. It's handy in this case, since the ADAM:S1E1 model presented below (introductory) has no complex motor learning modules, feedback is available to the creature purely in the form of energy balance metrics.

There are still some inaccuracies in the assembled model, such as the lack of motor channels to the proprioceptors (and consequently the lack of correct proprioceptor function), but these problems will be corrected in the future (See Discussion).

» Global proprioception - vestibular apparatus



In conclusion of the section dedicated to motor systems, I would like to tell about a very interesting and significant component of it, which is the vestibular apparatus. Analogs of this organ can be found everywhere in other vertebrates besides only humans, and therefore I considered it important to equip the body with such a system for the future experiments with cerebellum.

In biology, the main task of the perceptual portion of this unit is to obtain information about acceleration of the body and the trunk in three-dimensional space. And It is also one of the oldest forms of the feedback, that is sending generalized idea about interactions of the body with a physics laws to help it to maintain equilibrium, perform motoric memory and etc.

In other words, while local proprioceptors report the internal state of the muscles, the vestibule apparatus reports the changes that the movement decisions is making to the overall state of the structure, with respect to the physical laws of space.

In some sense, it is a global proprioceptor over the whole body structure and especially the position of the head.

Since the tested creature is embodied in two-dimensional space, the receptors of its vestibular apparatus contain 3 areas on each side, dividing for it the subjective perception as if into 4 sides of the world – straight ahead, behind, to the right and to the left, as well as by the very nature of the signal indicating the side from which the body moves, which makes the sensation "subjective".

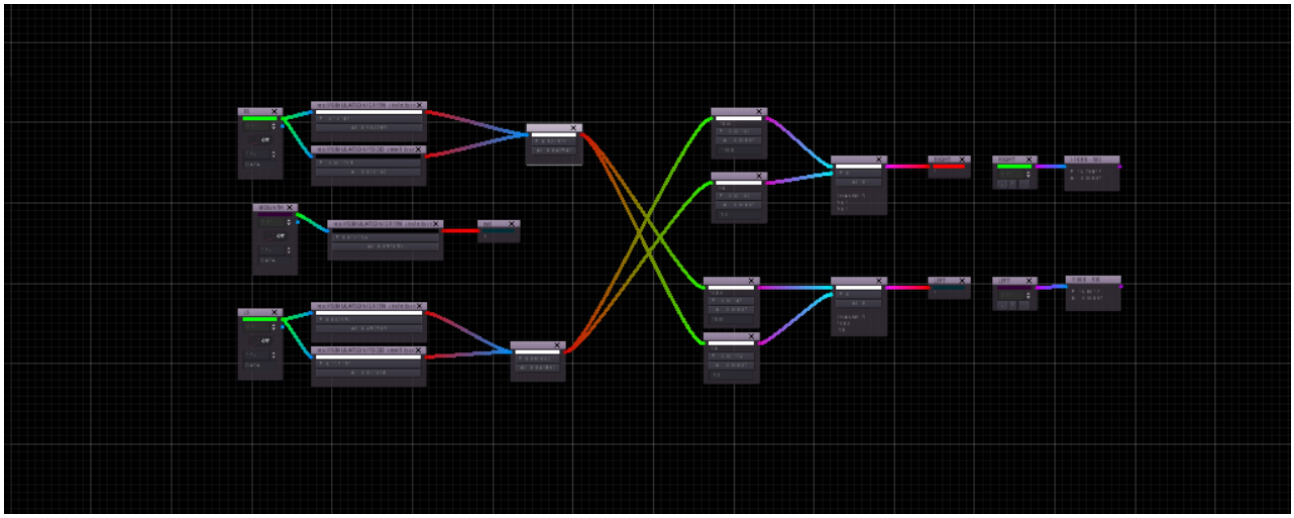
Within this paper, information from that organ is not involved for the same reasons that proprioception is not involved – the reflective nature of the network, which does not include complex motor learning to simplify your first steps in neuro engineering and for me to produce this material.

However, this system is implemented and available as 6 additional rising bridges:

- **Vestibular**
  - VSTB_L1
    - Left, anterior vestibular area
  - VSTB_L2
    - Left, middle vestibular area
  - VSTB_L3
    - Left, posterior vestibular region
  - VSTB_R1
    - Right, anterior vestibular area
  - VSTB_R2
    - Right, middle vestibular area
  - VSTB_R3
    - Right, posterior vestibular region

*[*]* The apparatus model only captures subjective linear acceleration, angular acceleration requires additional mechanic

» From theory to action: your first aCNS agent from scratch



Now, armed with these knowledge, it becomes possible to construct a simple network, capable of effectively controlling the body during a "hunting" process for the green objects. Although it consists of only a few polysynaptic chains, this system will introduce you into the process of manual neural engineering with the ///HEAVEN: Sandbox environment, and more broadly – how aCNS is operate.

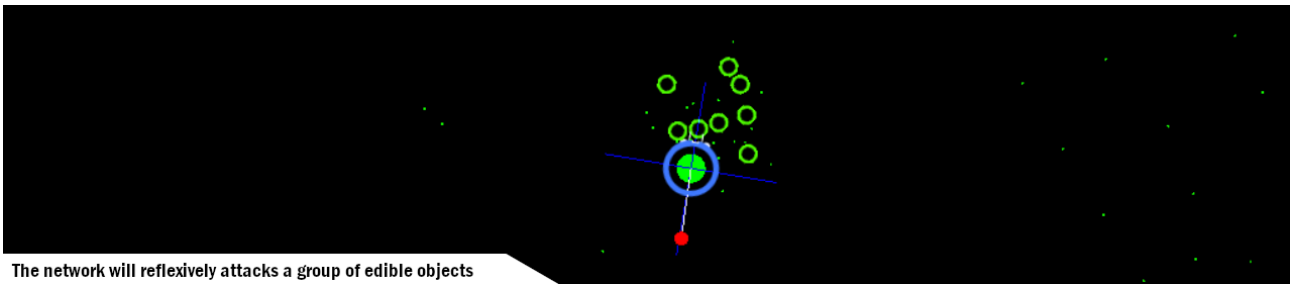
To do this, you can recreate and experiment with the simple ADAM:EN1 network (example-network-1) shown in the image below:

» Assembling instructions ADAM:EN1 (example network)

1. Open new instances of the simulation and neuroconstructor.
   - In the wide mode, both of them are visible, while in the shortened mode, you should switch the button on panel at the top.
2. Set the three ascending bridges: RS, LS and MOUTH as shown in the diagram (RS on top, MOUTH in the center)
   - **Panel →BRIDGES → SENSORY**
3. Change the strength values on the input neurons
   - You can experiment with values, but new circuits usually just require a “breakout”.
   - Setting values higher than 0.02 will be sufficient
4. As well as the descending ones: **LEFT**, **RIGHT, EAT.**
   - **Panel →BRIDGES → SENSORY**
   - Proprioception is defined for the limbs only
5. Place the proprioceptive sensitivity nodes **LEFT** and **RIGHT** opposite their respective OUTPUTs
6. Add some edible objects (key G)
7. Train neurons for possible stimulus variations
   - Controlling the body with the arrows, collide with the food, getting 2 neurons on the sides and one in the center.
8. Establish a connection between the sensory signal of **MOUTH,** и нисходящим мостом **EAT**
9. Add two new (+) neurons, and connect to them (separately) both sensory stimuli from RS and LS as shown.
   - **Right mouse → INHIBITORY**
10. Add 4 NSA neurons and 2 NGMCs
    - **Right mouse → NSA ; Right mouse → NGMC**
11. Recreate the 2 motor structures in the image above (**LEFT** output at the bottom), with these data:
    - [*NSA1: -1000; NSA2:-50;*] и [*NSA3: 1000; NSA4: -50;*]
12. Connect both neurons from step 7 to the **NSA** neurons on the opposite side as shown in the diagram.
    - A stimulus on the left will activate the limb on the right to turn left.

[!] Initially the network will not be stable: it may take time and experiments with signal strength for input neurons and training. A finished example will be provided in the SAVE folder, but if you train the system yourself, treat it like a very stupid insect that you need to teach to eat, and if you have experience with animals, you will intuitively know what to do.

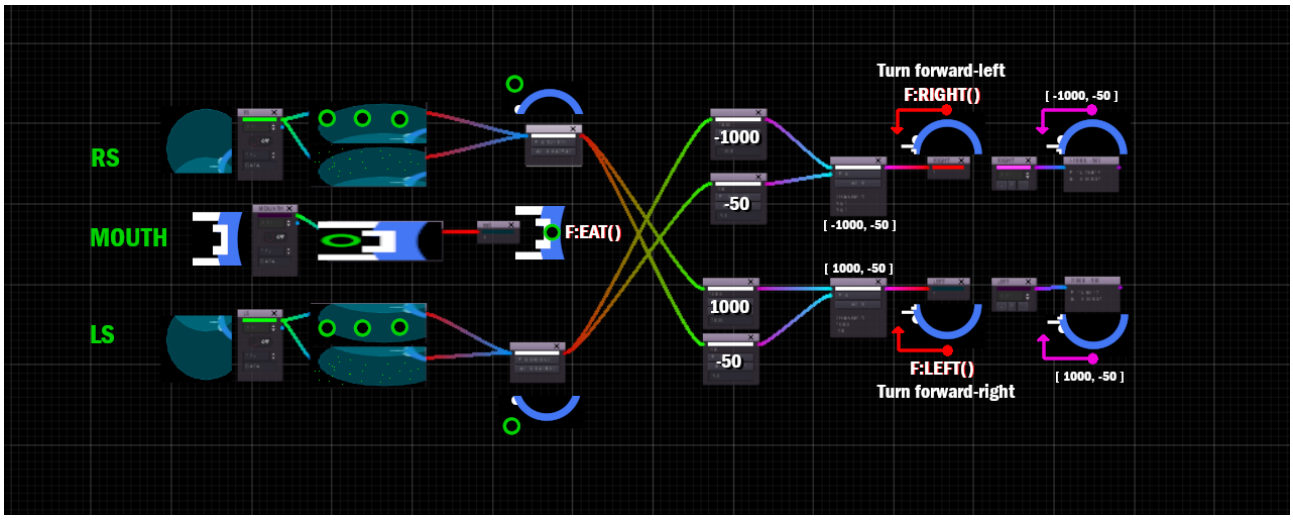
» <u>Model testing and complete explanation</u>



The network will reflexively attacks a group of edible objects

If the network was built correctly, thanks to the mechanisms of hybrid spiking neurons, the network will stabilize with time, and exhibit greater accuracy in its behavior, attacking food more effectively.

Although such result may not be considered as much impressive, but this example clearly demonstrates how with only six connected bridges is enough to create an effective and, in some sense, already adaptive control unit for the physical body.



The logic behind all that is quite simple:

- **MOUTH** receptor receiving a signal about contact with the target stimulus, which then activates the **EAT** bridge.
  - In this way we get a simple generation of motor activity in response to a specific stimulus
  - It is separated from the rest of the network. Is not quite correct, but there is nothing prevent us to do so.
- **RS** and **LS** are receptors that provide the receptive fields for olfaction of different distance on each side of the body.
  - Interact with both food and its odor, thus providing 2 signal variations each bilaterally.
  - Same variations from different distances then united at single neuron, denoting the concepts of the food location, relative to the center of the body.
- Location concepts synapse onto **NSA** neurons of the opposite side of the body.
  - Each **NSA** neuron contains a block of str() data, which will be passed to e.g. **NGMC**
- **NSA** → **NGMC** preparing arguments for **LEFT** and **RIGHT** bridges, in a form of an array.
  - Connected to the "motor limb" functions and located anatomically.
- When sensory information about food or its smell is received, the network transmits a signal to the motor output.
  - The choice of a motor pattern computing in a distributed manner in both hemispheres at the same time.
  - By accumulating "experience", computing nodes changing the nature of the motor output.
- Through the body's sensory-proprioceptive neurons, the network receives motor feedback
  - Although it is not used here, I decided to leave it in this model for a better clarity.
  - This data will be the foundation for complex motor systems capable of forming complete motor scenarios with the help of the cerebellum, but it requires the implementation of MOTO-PROPRI neurons first (See Discussion)

» <u>Bilateral structure of the model:</u> ← | →

You may have noticed, that just like in the biological nervous system, this design is predominantly having a bilateral structure. Here, it is dictated by exactly the same – mirror-symmetrical structure of the organism's body, where it formed by paired sets of sensory and motor organs – which provides the most optimal way of interaction with surrounding two-dimensional space.

The only exception is a set of the MOUTH reflexes, as it is simplified to a single bridge, due to the middle position in the body.

» The needs: a basics of motivation

*[*]* Before we go any further, I think it's worth making this definition:

- **» Motivated aCNS agent —** It is a neuromorphic system that autonomously seeks to satisfy its internal needs accordingly to a flow of the sensory data, using the features of its own architecture and subjectively known capabilities of it's own body.

It is clear that the binding of the polysynthetic chains produces a result that is far from what could be called a motivated behavior. In the **ADAM:EN1** model, it is static and goal-directed at best, since the architecture of the nuclei specifies the simplest logic for it.

Replication of this design will give you basic skills of neuroengineering in .///HEAVEN:Sandbox, but our goal is still to create a more complex model that would provide autonomously adaptive behavior, which is aimed to accomplish a number of subjectively important and critical tasks that inhibit the internal needs, that's why you want to know about..

» Hypothalamus - basic needs controller

Reaching and maintaining a state of internal balance in contrast to external environment (to maintain homeostasis) is a huge complex of work, the sum result of which is an actual opportunity for the organism to function (to be alive).

The hypothalamus is generally considered to be the main center where related processes are regulated. It is a small structure in size, but large in the number of a small nuclei, which provides cognitive part of the brain with critical instructions for needs inhibition, that based on data from interoreceptors, and messages from other "need factor & criteria" areas of the brain, and it's inner relations in nuclei.

In general, it compute regulatory influence on many fundamental processes of the brain and the whole organism, including:

- Nutrition behavior;
- Attention;
- Sleep and Recovery;
- Sexual behavior;
- Hormonal levels;
- Maintaining temperature balance;
- ... and many others of the "root, or basic needs"

» In other words, the hypothalamus is the a bundle of nuclei, that generates instructions for survival, and so where the needs originate.

» What are the needs, their factors and criteria?

The very concept of the needs, in my opinion, are consist of few sub-elements that used for a measuring of the need: some of them, when they appear in the receptive field, defines the factors of its inhibition, while others are the criteria for exhibition. Due to internal logic of the network, the system is changing own behavior in real time, directing it toward achieving the criteria in receptive field, that would be opposite to factors if the need becomes an actual.

As a common, those originates within antagonist nuclei, that mutually opposite. It could also be compared to a special scales:

As you can see from the image above, the balance of need is the difference between the accumulation of the factors and critera. To summarize:

- **FACTOR –** is a set of sensory objects that is part of the nuclei of need emergence, and sets their inhibition.
- **CRITERIA –** this set of objects is entering the nuclei of satisfaction of needs to exhibit them.

In the idealized case, the whole system effectively strives to maintain a set balance between the factors and criteria, for all of the actual needs, as far as it possible. Such a system must have the necessary skills to regulate them, as well as the ability to find new ones, thus ensuring the persistence of the internal environment inside of the organism, through adaptation mechanics.

And if to put it quite frankly, the rest of the brain infrastructure (by and large) is required to ensure a correct regulation and the balance between these two, according to a constantly changing environment that become more complex in time.

*[*]* That is why I strongly recommend to highlight the construct providing artificial "needs" as a crucial part of a motivated aCNS agent, as it will have own motivation build around them, and as a consequence - further thinking and activity.

» Sample: nutritional requirements

A pretty bright example of the need, which can be easily simulated in practice, is the absorption of food by the organism. In biological systems, the center of regulation for this process is also the hypothalamus, which is confirmed in particular by experiments on the destruction of **VMH** and **LHA** nuclei in animals, where the destruction of the first one led to obesity (lack of satiety), and the second one - to lack of interest in food and anorexia (lack of hunger).

In this way, for a biological being the hunger and satiety are mainly a logical output from antagonist nuclei that is located in the hypothalamus. It is perceive data about factors and criteria for the needs, from their own (specific) sources, which would then produce regulatory instructions affecting the brain areas that corresponding the need.

Speaking about the motivation associated with these processes (positive or negative), I believe that the degree of need satisfaction is the key parameter, based on which subsequent reinforcement of motor reactions to satisfaction criteria occurs.

[!] Interactions between VMH and LHA nuclei, as well as their inputs and outputs, is in reality a much more complex system involving a large number of elements and methods of collecting data. My goal was to build something simplified, but still working.

» Factors and criteria of ADAM nutritional need

To provide the network with the flow of data on hunger and satiety, a special kind of receptor was provided in the ADAM body which is reporting about the state of the internal parameter of the body named "energy".

[?] I classify this type of receptors as **INTERO** - i.e. those that perceive information from the internal environment of the body.

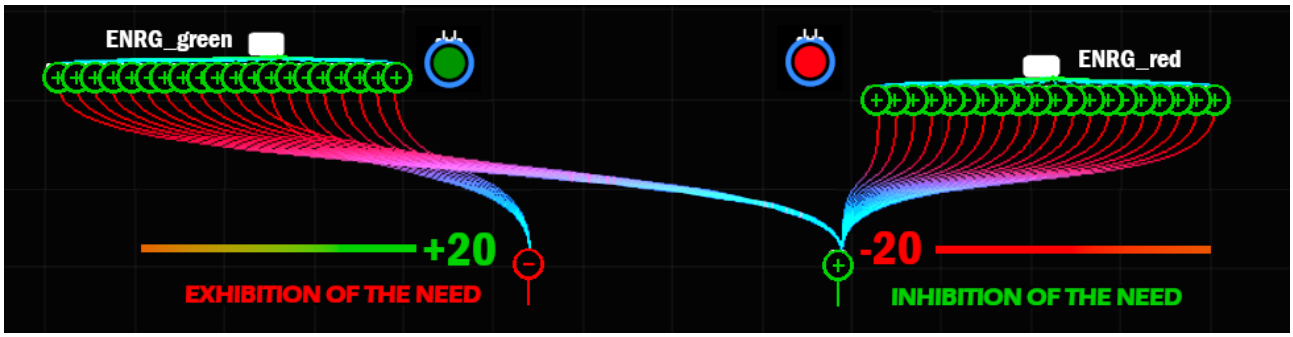
For the **ADAM** – this is a subjective level, on a scale of **-20** to **+20**, which is constantly affected by the following factors:

- **(-) energy losses caused by the motor activity**
- **(-) metabolic energy losses at 0.1 sec intervals**
- **(-) losses when interacting with "poisonous" objects**
- **(+) compensation when consuming "nutritious" objects**

As you can see, there are several factors constantly affecting this parameter negatively, independently from each other or external circumstances, while the only way to fill it up is to consume green "food" objects.

» The simple construct regulating nutritional need

Since the structures that provide a complex thinking have not yet been discussed, to model a simple nutrition necessity nuclei, that would have a regulatory effect on the motor output – I will use the stream of data about the energy level provided by **ENRG_red**, **ENRG_green** bridges and just two neurons with opposite polarity polarity (See *Sensory Systems of an Artificial Body; Interneurons)*).



This is pretty simple design, where all signal variations between **+20** and **-20** is synapse on related logical nuclei neurons:

- **Exhibition** – satiety is considered to begin after upper threshold of hunger – from the level **+9**
- **Inhibition** – occurs when energy factor drop less than **+9** to negative values, which define hunger

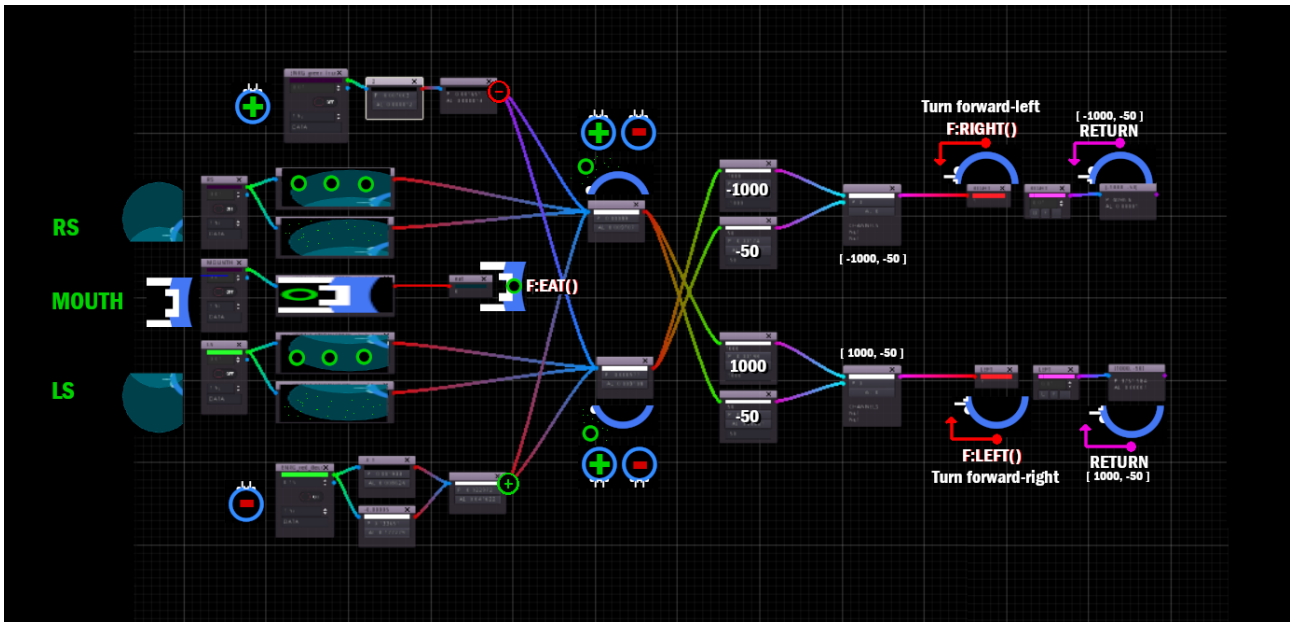
If we add such neural construct in the ADAM:EN1 model (even if in an "inspired" form) it could mean that we achieve a simple self-regulating neuromorphic embodied agent, while having full access to its core needs. And therefore, when in the next models we will reach a level of self-adaptive behavior, we can manually establish and modify some compact protocol for the relationship between the factors and criterias to determine what will fundamentally drive motivation of the creature, and that is why such basics is important.

[!] Although this task requires further work and research, I believe that the nuclei of need regulation are a key property of the network, necessary for the transition of a simple bundle of polysynaptic circuits into the category of brain-like systems, because behavior is now determined not only by the intensity of the sensory signal from the outside, but also by the logical nuclei of need regulation

» ADAM:EN1-2 Integration of need regulation

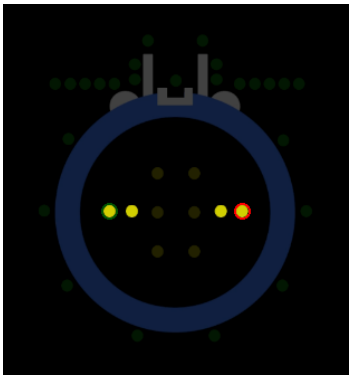
In order to test what effect the integration of this design would have on output behavior, the following model can be constructed, which is marked **ADAM:EN1-2**. The model demonstrates exploratory behavior in response to impulses from hunger nuclei, and a temporary fading of motor activity after food is captured (short resting period).

[?] The signal strength for the input neurons of the need's factors & criteria was set at 0.15



This image shows a network ADAM:EN1, expanded by the need regulation nuclei

A careful reader will notice that the amount of sensory variation around the need nuclei is much lower than in ADAM:EN1. The reason behind that other type of body interoreceptors been used, is to demonstrate how impact is going to change by the different approach.



1. **ENRG_incr**
   - Signals of variants in energy level increasing peaks.
2. **ENRG_decr**
   - … decreasing peaks

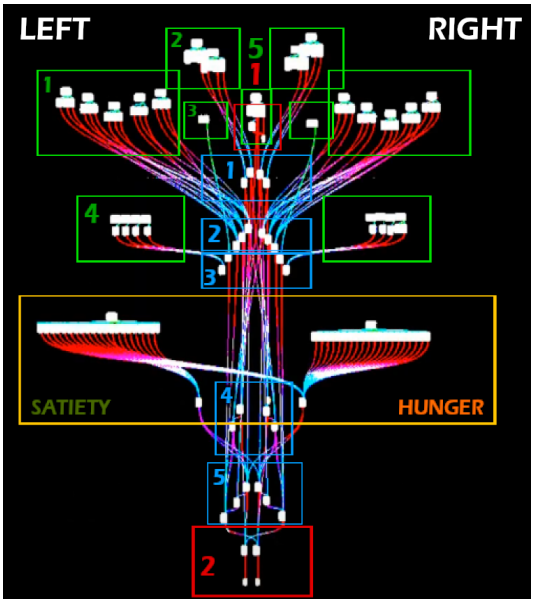
And even though the final impact on motor output will be somewhat different, this source of data can also be used to regulate feeding behavior, demonstrating a different approach:

- **Decreased of the energy level** provokes excitation of the nervous network, and as a consequence – the search for food.
- **Peak in satisfaction** reduce motor activity by setting intervals for the appearance of motivation.

[*] However, both of approaches can be combined into more complex logic.

» A Model of the Complex Nervous System With Needs

» <u>Description of the model ADAM:S1E1-ERR-FM</u>



The image on the right represent a general view of the simplest nervous system, built of the proposed hybrids, and summarizing some of the theories and ideas, which were described previously.

The marking is formed from these parts:

- **ADAM** – body's ID
- **S1E1** – serial number (season 1 episode 1)
- **ERR** – error was found in the model
- **F** – functional nuclei and logic
- **M** – motor system

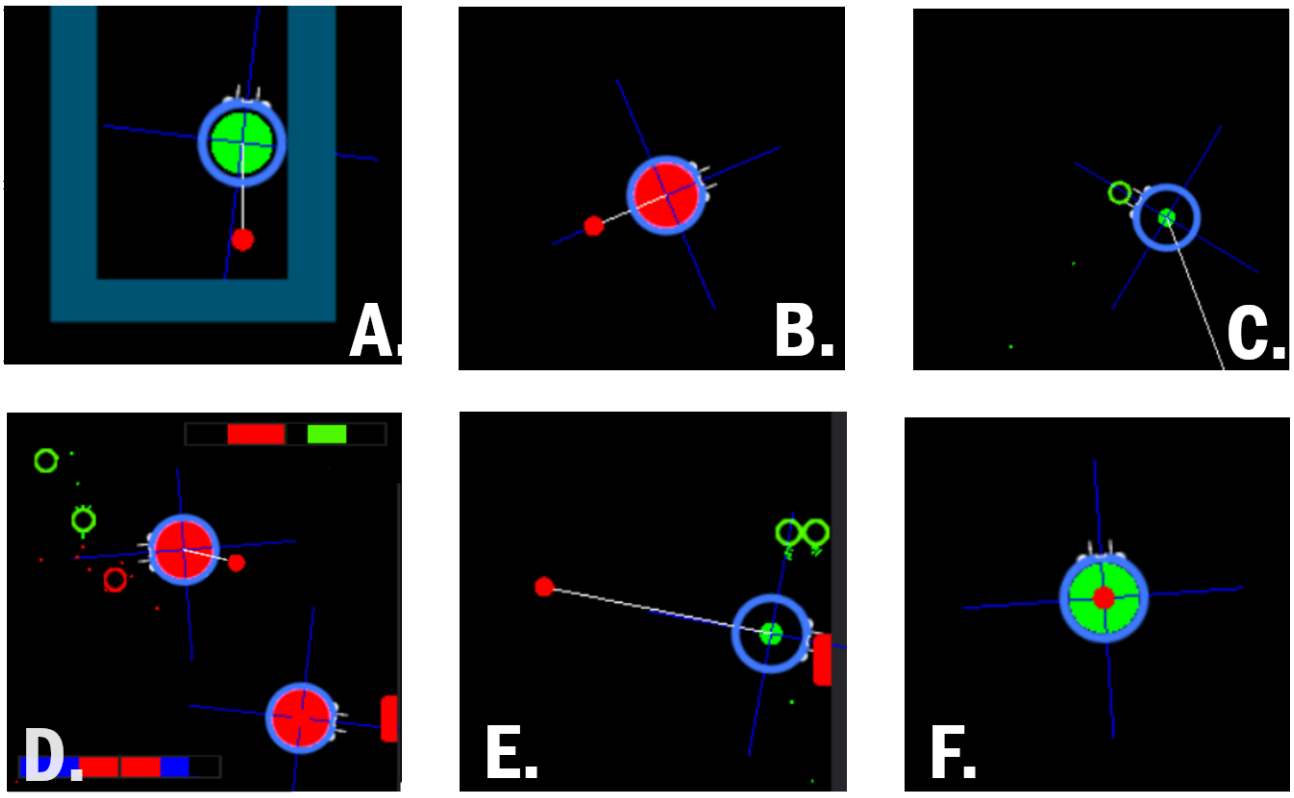
The knowledge that was gained from the previous sections may be enough for you to understand a model with a larger number of elements, although some of them have not been discussed yet.

They marked with colors:

- **Green** — sensory groups
- **Blue** — functional nuclei
- **Yellow** — needs regulation
- **Red** — motor output

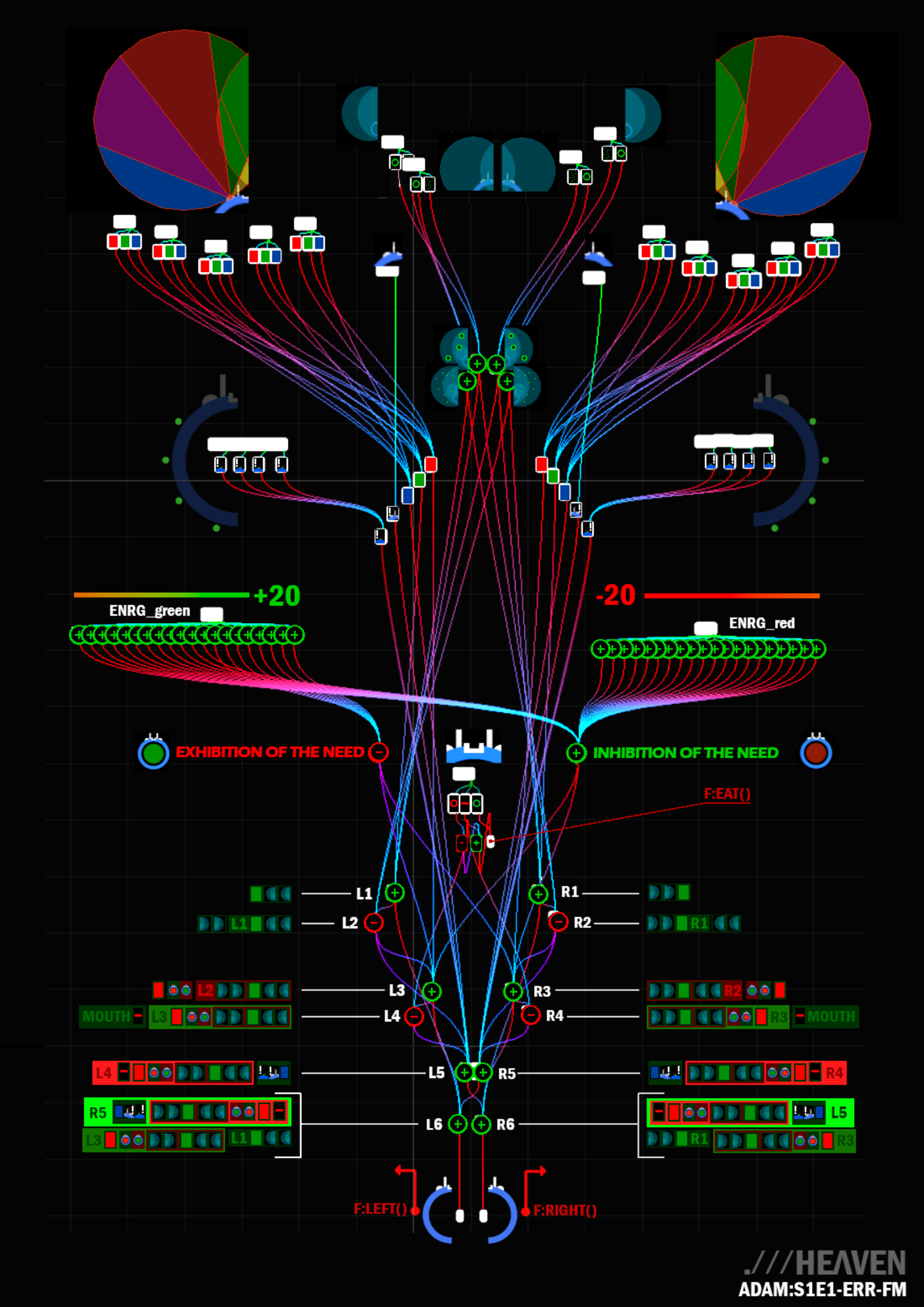
This network has been assembled manually, to demonstrate the logic behind models that contain a larger set of the sensory systems, capable of satisfying it's internal needs, and producing behavior by the weighted, in a same time.

By that I mean an aCNS agent, in which classified objects from the outside world will compete for the control under the motor system, trying suppress the others accordingly to the internal energy level, regulatory, and motoric response logic.



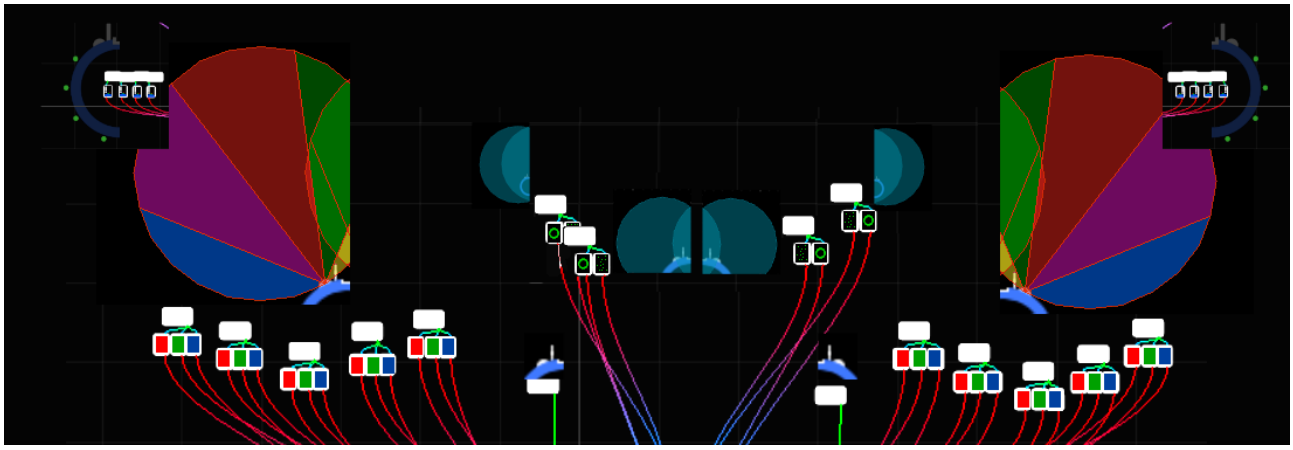
(a) escaping from closed spaces; (b) hunger: search behavior; (c) hunger: hunting the food; (d) object classification; (e) Intermediate tasks: pressing a button to obtain food; (f) satiety: resting, reduction of motor activity;

*[*]* The list of bridges involved in project is not complete, but since this is just a slightly more complex version of ADAM:EN1 which still does not yet contain a cognitive component or even a cerebellar motor system, so they are not needed there yet.



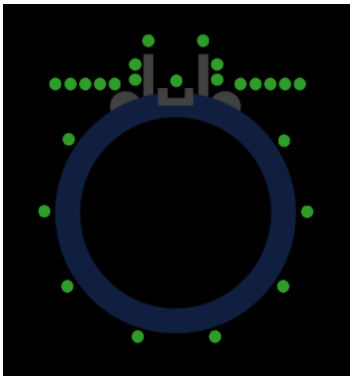
» **EXTERO: Sensory groups of ascending bridges**

At the front and the sides of a model, clusters of input neurons can be found, where each square represents a group of combined sensory neurons, that interconnected with some of (predominantly) paired organs.



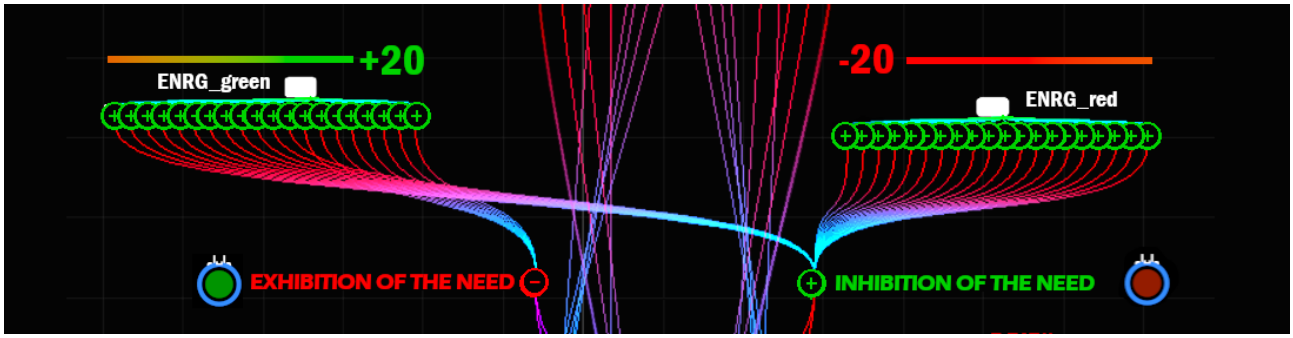
In total, 4 of these organs been added (in pairs by each side), the only exception is the receptors of the tongue:

1. **Eye**
   - 5 ascending bridges, each covering its own area of visibility.
2. **Nose**
   - 2 ascending bridges covering the small and large areas of olfactory sensitivity.
3. **Vibrisse**
   - 1 ascending bridge providing a strong tactile sensitivity from the facial area.
4. **Skin**
   - 4 ascending bridges providing areas of the general tactile sensitivity
5. **Tounge**
   - 1 ascending bridge, transmitting taste sensations.



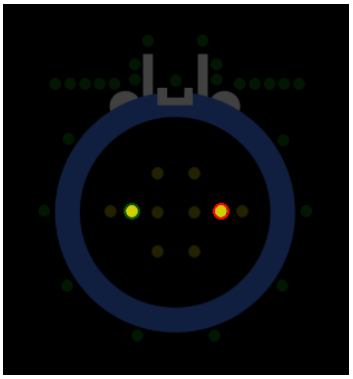
» **INTERO: Sensory groups of ascending bridges**

A construct already familiar to the reader was used to regulate feeding behavior (See "**Needs**")



Let me remind you that this model used such interoreceptors:

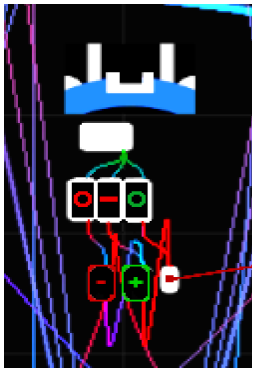
3. **ENRG_green**
   - Pulsation signals the current energy level if it exceeds zero to +20.
4. **ENRG_red**
   - Pulsation signals the current energy level if it is below zero to -20.



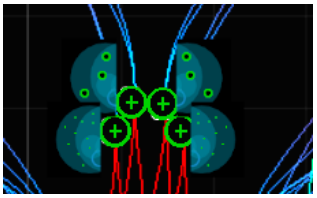
» **Functional nuclei 1-3 (Thalamic)**

The nuclei indicated by the blue squares 1 to 3 contain the centers where signals from the sensory group are summarized into primary objects. Perhaps the most appropriate analogy that I can come up with to describe their function is the thalamic nuclei (VPL, LGN etc) - is where essentially important signals classified and redirected to the other paths that require such data: both fast and slow.

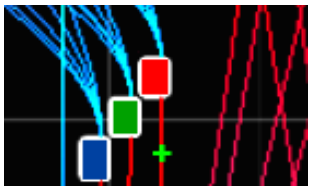
In total, within the model, I define such nuclei as 5 bilateral pairs on each side, as well as 1 mono (unilateral):



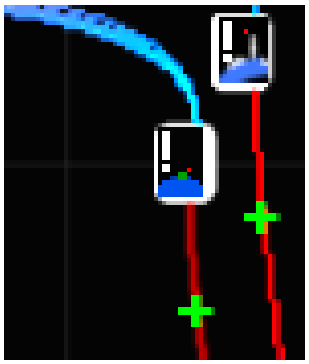
1. **Jaw control nucleus**
   - A simple monolateral construct defining the activation logic of **F:EAT()**
     - When **MOUTH** receptors sense a familiar signal from green objects, impulses are transmitted directly to the motor output of the network, thus providing an immediate, uncontrolled response, since to catch it is rational to execute jaw function as fast as possible.
     - When **MOUTH** senses a "button taste", it synapses onto an interneuron that detects a measured button press after a certain amount of interaction with the button, determined by the activation threshold. It is setting a logic, preventing from the button abuse.
     - When **MOUTH** senses a red (toxic) object, it fires a suppression neuron, which in turn suppresses a delay neuron by inhibiting further consumption of objects.
     - The jaw function processes all objects in the receptory field of the **MOUTH**



2. **Olfactory nuclei**
   - The conceptions of the smell variations known to the creature.
     - The reason there are only two nodes on each side of these nuclei is that different signals are classified as the "food" and "odor".
     - The poison and its odor is temporarily unprocessed (to make the model simple)



3. **Visual nuclei**
   - Generalized concepts of observed objects
     - Since receptors of the eyes have a current perceptual spectrum equal to three colors, on each of the three neurons in the visual nucleus synapsing sources corresponding to the same color, thus signaling a generalized concept of the particular stimulus on the left, or right side.



4. **Tactile nuclei**

   - Conceptions of external exposure to the skin and anterior vibrissae.
     - *Vibrissae* — are special outgrowths in the anterior "face" part of the creature that transmit information about collisions with objects in the front of the body, such as food or other important objects.

     - *Skin tactile organs* — are receptors located around the perimeter of the outer surface of the body that transmit generalized touch information from the left or right side of the body.
       - In this case, four sources are combined into just one nucleus neuron to demonstrate the summarization of multiple signals - the information is transmitted in mixed form, providing only the fact that the body is affected on the right or left side of the body, without specification.

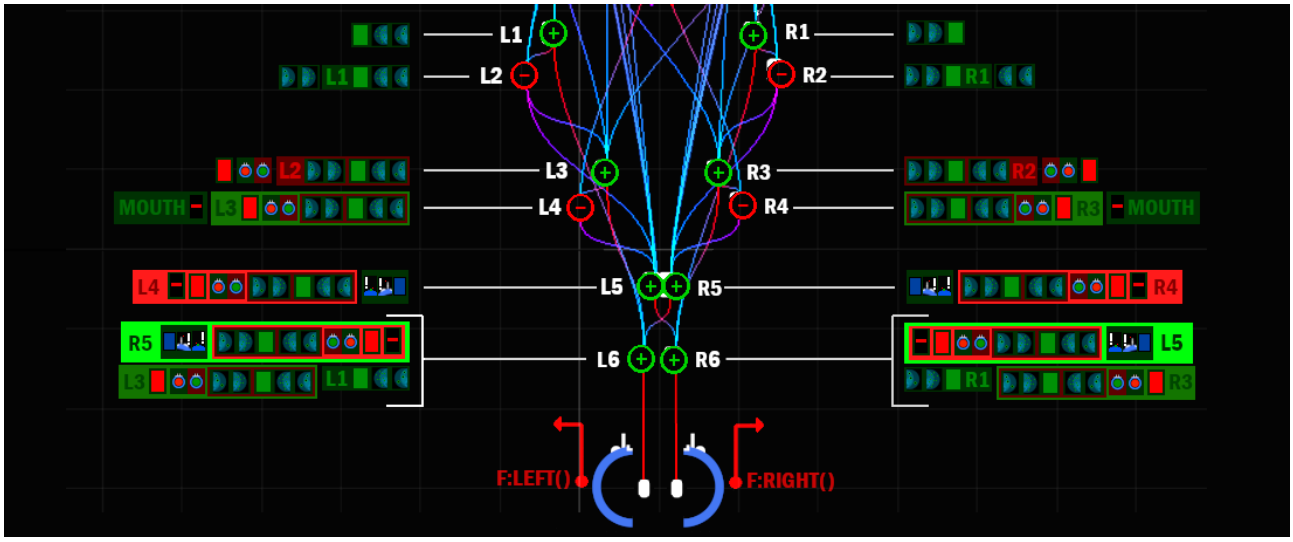
[?] ATTENTION - *during the final preparation of the materials, a little mess shows up:* Suddenly it turned out that the model I built for demonstration in the video on the YouTube channel @WEB4Plus (which preceded this book) - uses an old type of motor functions, in which LEFT and RIGHT show not the side of the limb, but the direction of rotation, which is opposite to the correct one. In a hurry I didn't notice that, intuitively assembled a demo design for the old functions, thinking as if they were working correctly.

By and large, this is not a critical error: there are no limits as such in cyberspace, but since I want to follow (at least where it rational) natural physiology, and also be consistent, I should have noted: the video showed a model with an anomaly that can be confusing, because it was reflected in functional cores 4 and 5, and in the 2nd motor core, changing the logic shown earlier in the ADAM:EN1-2

*[*] The following parts of this section will show the step-by-step process of data conversion in the network. The material is presented step by step, but personally I would recommend going directly to the motor output first (at the end of the section), because the nuclear neurons L6 and R6 in the diagram graphically explains two parallel functions of these neurons, which contain entire logic of the previous steps and the network as a whole.*

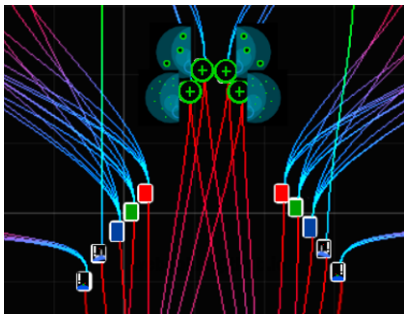
» **Functional nuclei 4-5: [L1-L5, R1-R5] (Pre-motor) [ERR !]**

[?] Everything that happened within the network up to this point, is perception and world mirroring for the next logic of responses.



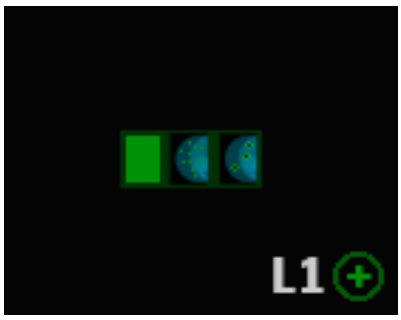
In the same bundle of nerve chains the formation of motor response takes place, and I tried to show this process due to my drawing skills. It would be more logical to make formulas, and I think I will do it in the future (alas, I do not know how to do it), but since I strive to make the product available for understanding by a wide audience – such presentation of the material seemed kinda logical to me.

The transformational process of incoming sensory signals into motoric behavior can be described by the following sequence of events:



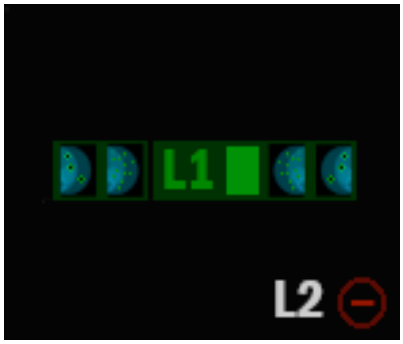
a) Classified objects from the thalamic region spikes, reporting the world

- A single concept can synapse to multiple areas in both hemispheres, so that the occurrence of a specific signal (for example) on the left at some point in time can affect the motor output of entire network significally.
- The stochastic sequence of events in the receptive field each time creates a unique pattern of activation of the thalamic nuclei (See Tools > Neurogram) indicating a unique situation around the body.



b) The signals distributed to the related, in which the active set of incoming stimuli participates as attribute of some conception.

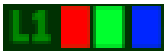
- For an example, let's take a look at the neuron **L1**:
  - **L1 is a mixed conception –** joins classified objects of the thalamus, about the simultaneous presence of both olfactory and visual cues on the left side: the sure sign of the food (or something green) on the left side, i.e., it is a "formed knowledge of food on the left".
  - Inhibitory type of the incoming signals is marked with a green frame.
  - Neighbors: **L2**, **L6**

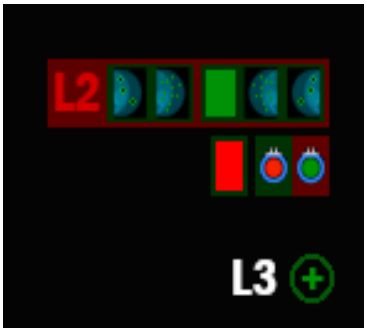


c) Reaching deeper levels of the network, they combine with other sources into nucleus of correction or logic.

- **L2 – is a correction core**, which also contains 2 direct sensory concepts about signals from the right olfactory area from the thalamus, but in addition receives an excitatory signal from L1
- This core will have a primary exhibitory effect on the pathways that lead to the opposite side of the body on these conditions:
  - If the food odor detected on the right
  - If the food was classified on same side (L1)
- Neighbors: **L5**, **L3**

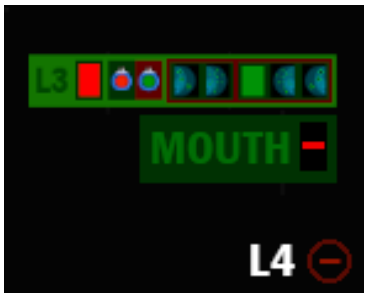
[?] All packets from other neurons in the current block (4-5) are always signed with a color appropriate to the nature of the signaL and indicating its sender. They are themselves separated by the distance between the depicted blocks.





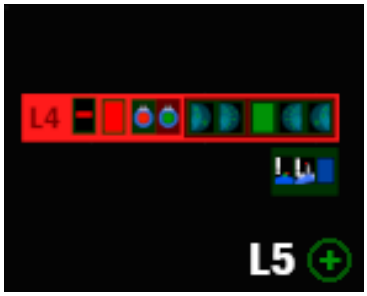
d) A filter to ensure that the focus of motivation shifts from the button when food appear.

- **L3 – is a logical core** in which the first weighing occurs:
  - *Inhibition*: **L2**
  - *Inhibition*: concept of red color on the left side.
  - *Regulation*: Variable signal from the cores of needs + logic
- The purpose of this node is to filter the signal of needs:
  - Food is obtained using a button, so:
    - Can see the button + there is a need = action
  - If there is food nearby, the core will be exhibited by **L2** correction.
    - This will free up attention, which will be taken up by food signals.
- Neighbors: **L4**, **L6**



e) The left hemisphere concludes the correction of the right alpha

- **L4 is a correction core,** which helps to focus the object's attention on the button, concluding that it is necessary to block neuron **L5:**
  - + *Inhibition*: Red (button or poison) on the left
  - + *Inhibition* / Exhibition: Hunger / Satiety
  - + *Inhibition*: MOUTH → button
  - + *Exhibition* (food presence)
- Neighbors: **L5**

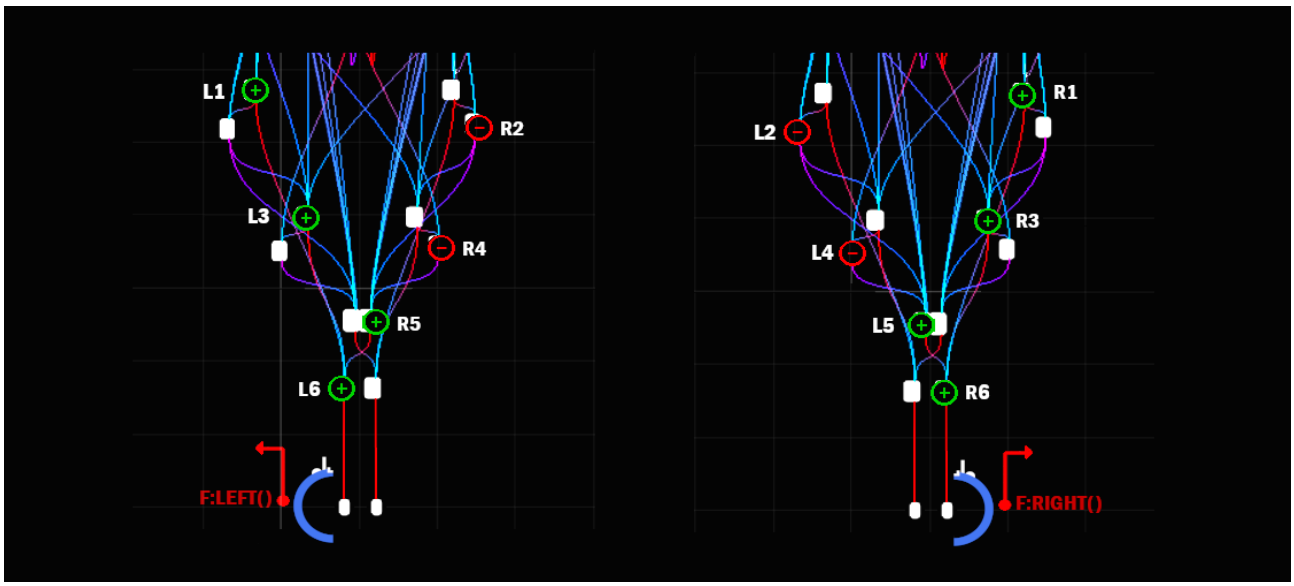


f) Correction of motor output of the opposite side of the body

- **L5 – is a logical core,** providing secondary "avoidance" behavior, such as detecting wall (blue), experience tactile sensations, or being touched by something
  - *Exhibition*: correction from L4,
  - *Inhibition*: The blue object on the left.
  - *Inhibition*: irritation of the vibrissae.
  - *Inhibition*: Tactile sensations of the skin.
- Neighbors: **R6 (opposite side of the body)**

» Involvement of both hemispheres in the formation of motor decisions for each half of the body.

In order so the curious readers can understand what's going on out there a little more clearly (if they wish), I've drawn up the image below, where i marked the path along which the signals travels for every of the two descending bridges.



[?] Inactive neurons marked as the white nodes

» **Alpha motor output and descending MOTO groups [ERR !]**

[?] This is perhaps the most significant part of the diagram, as it reflects the final state of the network at any given moment in time.

g) The weighted signal reaches the alpha motor neurons.

- Incoming data
  - **L6**: [*L1, L3, R5*] - Left hemisphere output

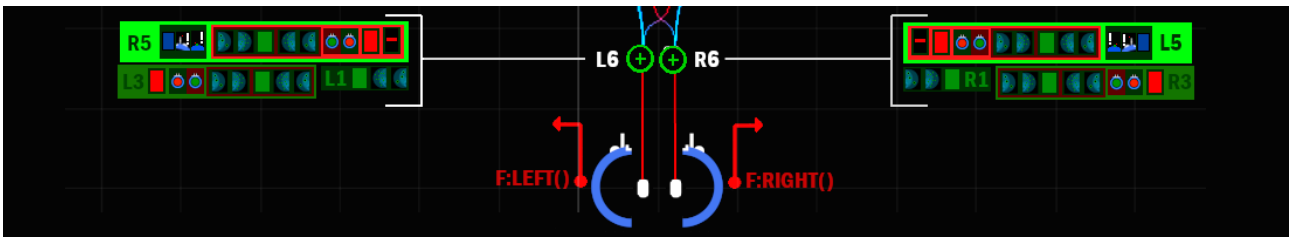
    - **L1**: Knowledge about the edible object on the left side
      - Stimulates the nervous system to turn the body towards food
    - **L3**: Weighted solution of the need, at the left side of the body
      - Awareness of the red objects (button, poison) to the left
      - Need controller
      - Inhibited by the overall concept of food presence
    - **R5**: Correction of the LEFT() from the right hemisphere
      - Knowledge about the wall on the right
      - Tactile reflexes of the right side of the body
      - Inhibited by primary objectives

*[*]* And although the untrained network can for some time reflexively rush to food even when satiated, after some time, the thresholds of neurons will be naturally stabilized, and only the presence of food will not be enough for active behavior without a direct need for it.

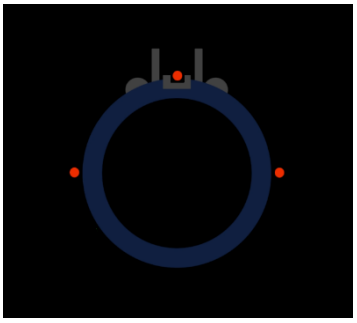
  - **R6**: [*R1, R3, L5*] - Right hemisphere output

    - Basically, the logic here is still the same, just inverted to take the side of the body into consideration:
      - **R1**: Knowledge of the edible object on the right
      - **R3:** Weighted solution of the need, at the right side of the body
      - **L5:** Correction of the RIGHT() from the right hemisphere

- L6 & R6 neurons is the Alpha motor for both limbs.
- Taking the weighted outputs from the nuclei above, summarize the values as a simple inhibitory interneuron
- The output is transmitted via descending bridges to the recipients.



1. **Musculature of the jaws**
   - 1 descending bridge to the motor function of the jaws, activating the process of food poison digestion (in case of the capturing)
     - **F: EAT()**

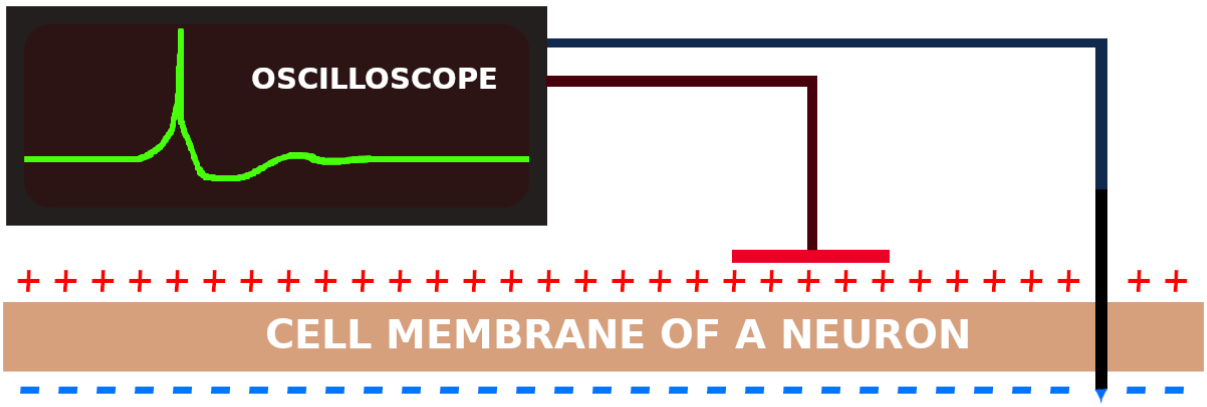


2. **Limbs**
   - 2 descending bridges, when activated, move the body jerking forward with a tilt
     - **F: LEFT()**
       - Left tilt ←
     - **F: RIGHT()**
       - Right tilt →

[**:(**] Unfortunately, I had no time or energy left to prepare more materials for this paper before the software release, and for that I apologize to the reader (new models and solutions will be available in future editions and on social media if the work continues). Nevertheless, this bug shows how neuromorphic mechanics can be plastique and adaptable to any muscular function, even in this case, where it conflicting with natural bio mechanics it remaining to be an effective solution.

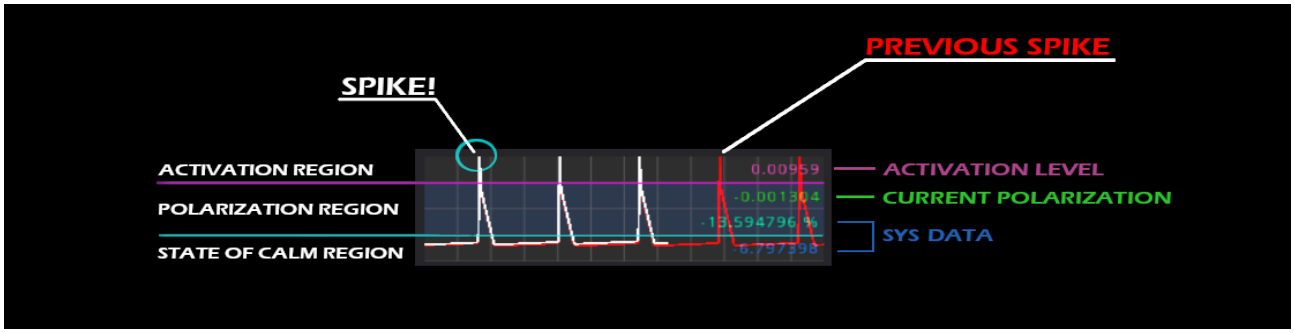
» Tools

An artificial brain can be made with enormous number of cells working in parallel, and as a result, there is a need for a detailed representation of specific processes that taking place within it. Similarly, when investigating biological neurons “in vitro” or inside a functioning living brain, researchers employ various techniques for registering the activity of individual neurons or neural populations.

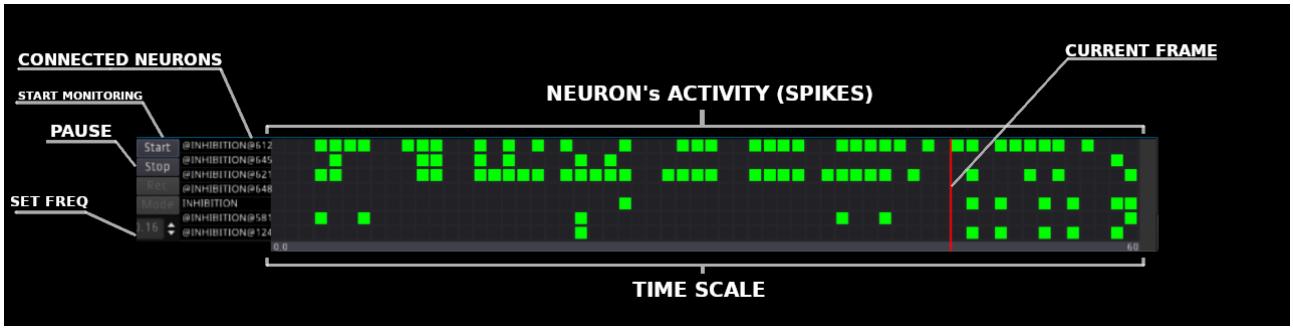


[!] The current version of the software provides these tools for working with the network and its components:

» <u>Monitoring of the network state</u>



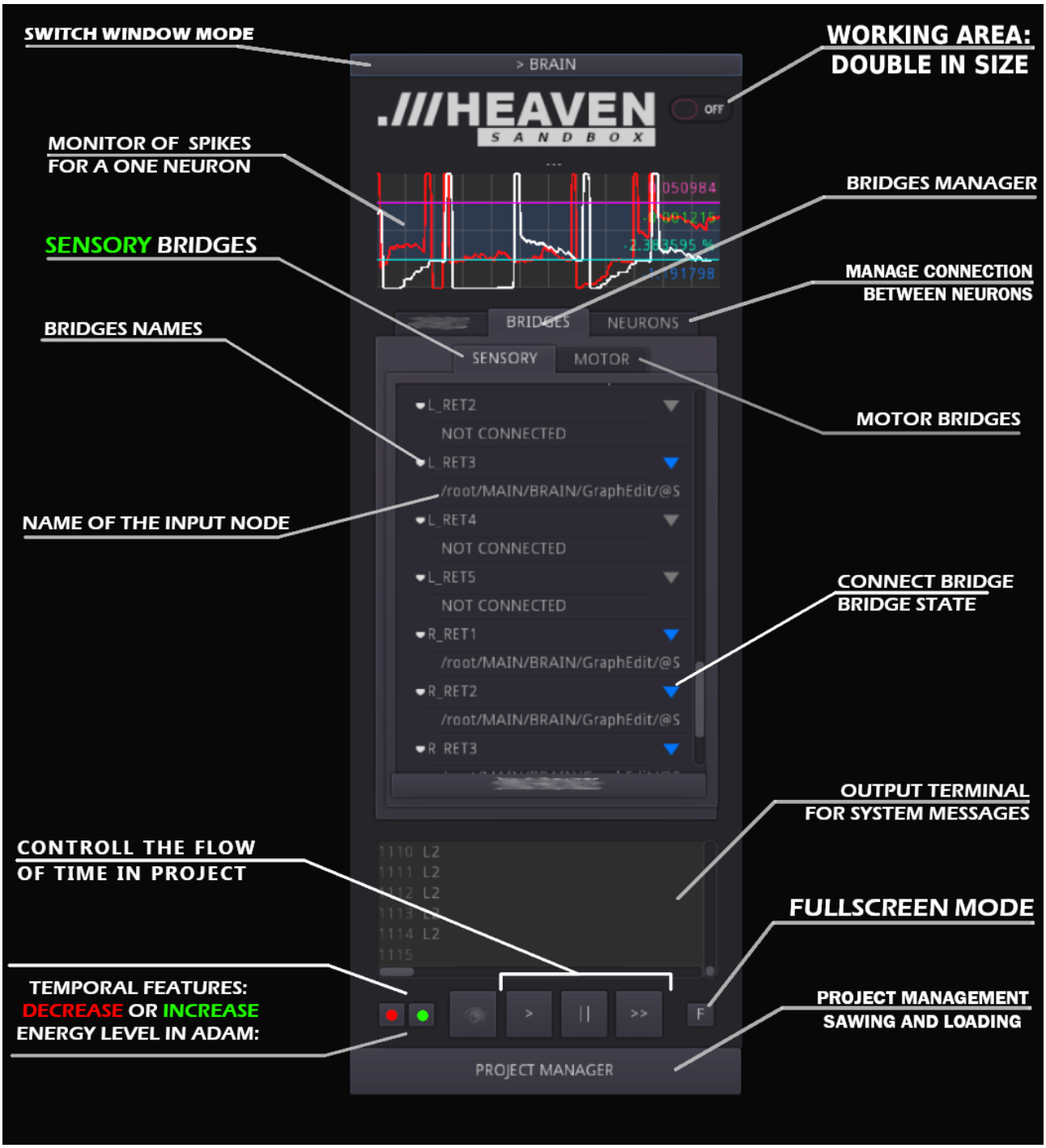
- **Polarization monitor**
  - For the neurons that run by the standard potential mechanics, there is a tool available, which is display polarization level on the graph, allowing users to monitor the state of specific cell in real time.



- **Spiking tracker for a group**
  - This tool makes it possible to observe the state of a neural cluster in real time, providing more general information about their state, and demonstrating their activation patterns.

» Project's managing panel

This is an important interface for project management. Here are its most significant components:



[!] The UI of the software .///HEAVEN: Sandbox V1.0.0 is shown, which has its drawbacks and will be significantly changed in the future.

» Project's management

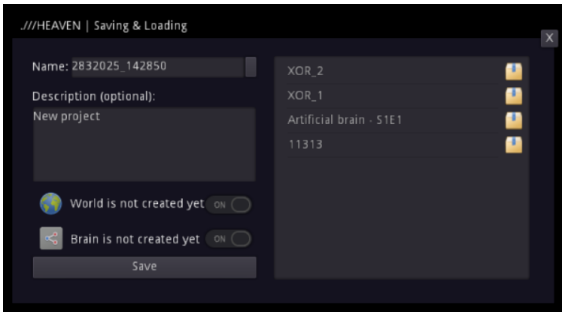
The .///HEAVEN:Sandbox software has been designed from the beginning to be a free, easy-to-use and open source tool for a wide audience of researchers, and for this reason, the source code is organized in such a way that projects can be easily managed and modified - we welcome users who wish to contribute to the development of the technology, and we strive to facilitate this ourselves.

» Saving and Loading

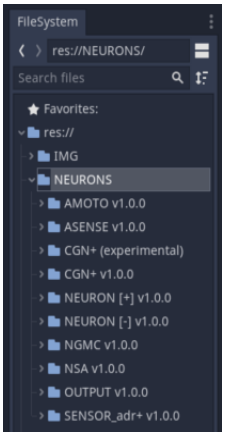
By default, the project is consist of 3 main files:

- **BRAIN.tscn**
  - packedScene of the brain construct
- **WORLD.tscn**
  - packedScene of simulation
- **Settings.conf**
  - configuration data, bridges records etc.

To save, open the manager via the button at the down of the panel →



» Adding new neuron models



One of the options for modifying this software is to initialize additional neuron models.

As you can see in the image, the res://NEURONS/ directory contains directories with system files of the neurons.

Usually, you only need two of them to be included:

- **<New_neuron>.tscn**
  - The neuron "scene", i.e. the node interface imported into the neuroconstructor.
- **<New_neuron>.gd**
  - The "script" of a neuron, i.e. the program that is executed in each process of each neuron.

1. So first, you should get a new strain and put it in the directory with the others.

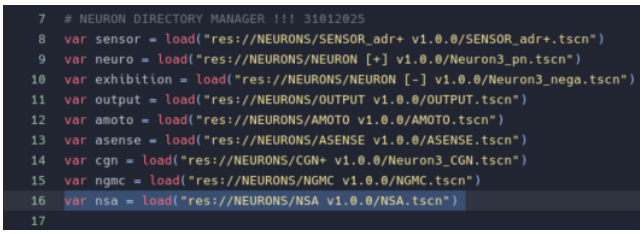
   [!] **It is recommended to use models from unofficial sources with great caution, even if they were purchased within the .///HEAVEN network: better audit the code yourself.**

2. *The further initialization process is to add a line with the name and path of the new model to the file*

   res://SCRIPTS/BRAIN_WORKPLACE.gd : 7

   → to the list, labeled with the comment as

   # NEURON DIRECTORY MANAGER



```
7  # NEURON DIRECTORY MANAGER !!! 31012025
8  var sensor = load("res://NEURONS/SENSOR_adr+ v1.0.0/SENSOR_adr+.tscn")
9  var neuro = load("res://NEURONS/NEURON [+] v1.0.0/Neuron3_pn.tscn")
10 var exhibition = load("res://NEURONS/NEURON [-] v1.0.0/Neuron3_nega.tscn")
11 var output = load("res://NEURONS/OUTPUT v1.0.0/OUTPUT.tscn")
12 var amoto = load("res://NEURONS/AMOTO v1.0.0/AMOTO.tscn")
13 var asense = load("res://NEURONS/ASENSE v1.0.0/ASENSE.tscn")
14 var cgn = load("res://NEURONS/CGN+ v1.0.0/Neuron3_CGN.tscn")
15 var ngmc = load("res://NEURONS/NGMC v1.0.0/NGMC.tscn")
16 var nsa = load("res://NEURONS/NSA v1.0.0/NSA.tscn")
17
```

```
+ var <system_name> = load("res://NEURONS/<neuron>/<neuron_scene>.tscn")
```

» Adding new bodies and spaces

At the moment, the only simulation presented in the program is the project in the directory **res://SIMULATION/** . However, due to the fact that it is a Godot project, using the open source code and knowledge gained from this work, as well as skills with this engine – you can easily modify existing simulations, and create new ones.

This project is entirely new, as it only goes into public testing in late April of 2025 at *web4plus.github.io*, so many components of the program are either not yet implemented or require improvements – for example, a more user-friendly UI that allows spaces to be managed, and others.

However, once the project moves into the public testing phase, I expect to significantly improve the condition of the software.

Discussion

[?] In this part, I want to discuss important issues, as well as make several announcements about the future of project.

» Section structure

- Model's oversimplification
- What is currently being worked on to improve the software?
  - UI flaws and bugs
  - Simplifying the process of neuroengineering
  - Proprioceptive Moto-Neuron
  - Complex motor system
  - Reward system
  - New methods of interactions among neurons
  - Novel models of the neurons:
    - Time-combinatory neuron
    - Socket neurons
  - Building a community and knowledge sharing platform
- Limitations of technology and efficient of the software
- A few possible ways for optimization
  - Godot + Python / RAM / GPU
  - Making a hybrid of the existing third-party spiking neurons library
  - Implementation of other artificial neuron models
- A few ideas for the applications
  - Trading bot
  - Autonomous drones
  - Pet translator

» Model's oversimplification

Yes, since ADAM:S1E1 is a "Hello world" class construction – I didn't wish to overcomplicate it, as it was important for me to build a fundamental knowledge in a first place, where I could put my project into the public format.

Moreover, many important components required for upgrading the existing network so it could function as complete autonomous brain are still in the experimental stage – for example, a new models of nodes and nuclei that will provide much more complex forms of learning.

At this stage, this is just a bundle of incomplete reflexes, with a motor response regulated by the cores of needs, but it seems to me that in the future, the technology will find more interesting solutions and useful applications.

» What is currently being worked on to improve the software?

- **UI flaws and bugs**
  - Many elements are not fully implemented and provide only the basic functionality of the neuroconstructor.
  - In the future, the interface will be significantly redesigned in the direction of Web4 interaction.

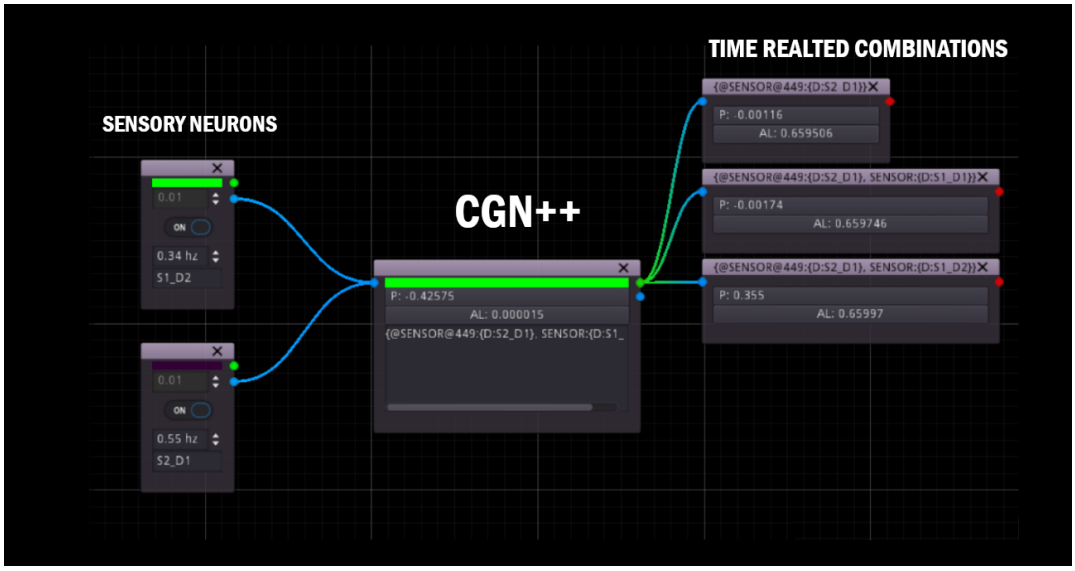
- **Simplifying the process of neuroengineering**
  - In my opinion (and not only mine), the creation of neuromorphic agents should be simpler and more accessible, so attempts are being made to simplify and automate this process by delegating part of the process to generative AI.
  - We are working on a new feature: a body-plugin, in which the work process should become more user-friendly.
  - In addition, since the standard "Node Container" in Godot is not very convenient for working with neurons in quantities greater than 165, I am now actively considering the possibility of transferring the neuroconstructor from a 2-dimensional to a 3-dimensional plane, where each individual neurocontainer will represent a group of neurons. In theory, this may be convenient for building nuclei, if such containers have general inputs and outputs.

- **Proprioceptive Moto-Neuron**
  - A serious flaw in the current model is the incompleteness of some components, the Moto-Proprio is one of the brights.
  - This part of the system is directly related to the complex motor system which still under development, and since such – this part of the model in software is currently missing, sorry for the discomfort.
- **Complex motor system**
  - In vertebrate biology, it typically involves the cerebellum, basal ganglia, and other nuclei that provide memory formation of more complex and stereotyped motor sequences, that could be rationally used in response to a sensory data flow.
  - Therefore, data such as proprioception and the vestibular apparatus are the foundation for these nuclei.

- **Reward system**
  - In the context of the ADAM:S1E1 model, regulation this is reduced to leashing and unleashing of the output pre-motor construct with the help of the corresponding nuclei of the ENRG_* sensor group, as factors and criteria.
    - When the system is full — motor activity is suppressed, the system is becoming less responsive to stimuli.
    - When the system is hungry — the system does not hold reactions, but stimulate them according to the level of hunger
  - However, this design was built manually, to demonstrate what should have formed naturally.
  - In addition, without such a system, the mechanism of correct motor sequence formation is impossible.
  - Therefore, one of the most important priorities of the current work is the creation of D1 involved structures.

- **New methods of interactions among neurons**
  - The proposed neuron models are far from perfection and need to be improved further.
  - One of these improvements will be a new methods of communication between neurons, and as it was mentioned previously:
    - In a neuromorphic network, events in one portion of it can strongly influence processes in another one
    - So, new methods of communication should be found, guided by the principle of "what the network is doing it for"
      - For example, such mechanics will be implemented:
        - Neurons will be able to influence the activation threshold of the child neurons by significantly changing it.
        - Apply temporal effects to other neurons, temporarily distorting their output.

- **Novel (experimental) models of the nodes**
  - **[!]** Time-combination neuron is under development



    - While working with nuclei related to complex thinking and a motor learning, I came to the conclusion that there is necessity of an additional kind of neuron, that would generate combinations based on proximity in time, and whose task would be to capture as new nodes the combinations of sensory stimuli coming from its sensory parents, mediated sensors in a group.
    - The neuron has been named CGN+ since this is a "Combination-generating neuron"
    - The dendrite is compatible with the "General" axon of sensory neurons, combining information from them into a blocks.
    - Just as in the sensory neuron, this one also contains a private and a general channel with the same functions.
    - It is planed to extend the neuron with these functions:
      - Customizing the type of neuron in a private channel.
      - Customize the capture in time with the help of parameters or activation thresholds.
    - In development, included in the standard software package v1.0.0 located at **"res://NEURONS/CGN+ v1.0.0"**

  - **[!]** Socket neurons is under development
    - A new experimental type of node that allows a data stream from, or directly to a remote source.
    - In development, not included in the standard software package v1.0.0

- **Building a community and knowledge sharing platform**
  - I have already mentioned that I would like to make the platform open in order to attract more researchers to the development of this technology, so one of the tasks that I am trying to achieve through my activities is the formation of a community and a platform where users could exchange ideas and experiences, as well as create useful applications, perhaps even generating services and products as the global and distributed network.
  - That's why I would like to mention the communities in the Web2/3 network, which I'm encourage readers to join, since according to the plan, from there – layer 4 of the network potentially could be achieved:
    - All additional information could be found at official **GitHub Pages** of the project:: **web4plus.github.io**

» Limitations of technology and efficient of the software

Unfortunately, during this simulation state, the program begins to experience overload:

- food objects: ~125 elements
- smell objects: ~600 particles
- network size: ~164 neurons

» A few possible ways for optimization

So far, I haven't looked into what this might be related to, and what kind of performance can be gained by (for example) simulating physical space on another machine, and send the data - through a socket neuron, where most of the computational resources will be consumed exclusively by network.

However, I am looking at different options to improve the performance of the model, including these:

- **Godot + Python / RAM / GPU**
  - Godot is a great MIT licensed engine that allowed me to implement a complete environment for aCNS development.
  - However, further I will probably have to shift the compute core for better performance, and use the program as interface.
  - It seems that it is possible to use RAM and GPU computation for spike networks, so further experiments in this area will be conducted to find a new approaches.

- **Making a hybrid of the existing third-party spiking neurons library**
  - Since it suddenly turned out that there are ready and open libraries of spike neurons, I believe an important part of further research will be to study the capabilities and mechanics of these models, as well as search for options for their hybridization

- **Implementation of other artificial neuron models**
  - One of the options for the development of technology, I see, is its crossing with a wide variety of other approaches, including the classical ML – which could also be manipulated in the constructor.
  - It seems there is no reason to deny this idea, since such continuation of hybridization process can give interesting results.

» A few ideas for the applications

Creating of the neuromorphic agents is a very creative and interesting process that has the potential to become your regular hobby if the technology proves to have useful practical applications. Here are just a few of the possible ideas that I want to attempt to bring to life with this technology in the near future:

  - **Trading bot**
    - A special neuromorphic agent that perceives information about the state of the market by the sensors of it's non-physical body, and which, thanks to the special design of needs and a cognitive components, strives to develop a new motor-scenarios that lead to experience a grow of the balance values, just like it was with a nutrition need. But in a more complex manner of course.

  - **Autonomous drones**
    - With a proper optimization of the technology, along with a new design, and a smaller high-performance carriers, it is quite possible to place the networks on a tiny devices, where it can interact with the drones peripherals via direct connections, as the brain would.
    - I believe, in that way it is possible to achieve autonomy, natural behavior and creativity in finding of solutions for inhibition of its inner needs, which is common for biological systems.
    - In theory, this will allow the creation of robotics, with the level of thinking of a dog, therefore trainable.

  - **Pet translator**
    - A joke-app that may be workable (judging by the experiments with pets on memorization of the words).
    - It's a lightweight device that's easily made from Bluetooth headphones with a microphone, and that attaches to your pet's collar, which communicate to a special aCNS agent located on your phone.
    - Thanks to the internal structure and modules that have not yet been considered, it will remember and build connections between the sounds produced by your pet and the sound pronunciation of these words in memory.
    - The "translated" sound or combinations of sounds are then transmitted to the collar speaker.
    - Training of adapting agent can be carried out by you, together with or by the pet itself, when it gives one of the signals (approval or rejection – a skill that animals are able to learn quickly trough a simple training), to which both the animal and aCNS will adapt, and form out symbiotic communication, allowing to perform an external.
    - Direct access to the model structure allows advanced users to add their own solutions.
    - This way, your pet will be able to start talking and will stop being nervous about his almost complete inability to pass meanings to you in a natural way directly.

» Summary and conclusions

Although the model proposed in this paper still belongs to the group of "inspired" by biology, its implementation at least in an approximate form in practice allows to create a new class of agents and constructs for a wide range of tasks related to adaptation, modeling of biological constructs, and many other types of applications, which theoretically can even be reproduced on chips with neuromorphic architecture, and used as high-performance control nodes for literally any robotics and augmented limbs, or as one of important components for BCI.

The model and software require improvements due to their incompleteness – some components described in this paper are not yet fully implemented in practice, and the theoretical basis itself could be improved a lot. The reasons behind I'm publishing this work now, is its relative workability, from where I can unite all this into a solid knowledge on the one hand, and the lack of resources / time on the other.

The task of writing this summarizing brochure alone has taken me more than 2 months of non-stop work, which is not much different from how it used to be before. And since I'm not sure how much longer I can keep going like this, I decided to shape the knowledge into a book and content to bring the project to the attention of researchers who want to learn more about neuromorphic approach in AI.

I believe that with a proper development, this project could open a new AI paradigm, where a Brain becomes the synonym of the real AI;

Also, I am sure that it is necessary to fill the gap of knowledge in society and increase its interest to the science about the natural brain, which is would be wholesome in general, but also can contribute to the increase of adequate perception of reality in society, as well as development of its moral and étique, since (according to my personal belief) to increase the level of humanism in society, each person should develop their own self-consciousness, which is impossible to achieve in full, without having knowledge of the own internal nature, which then can be correlated with the understanding of others, so the brain could produce more empathy.

That's why I'm striving to find more useful applications, so people that had no clue about what the brain is, could learn it in a useful way.

Usually, to explain what motivated neuromorphic applications are, and how they differ from established approaches to AI creation i give the example of the difference between an all-knowing oracle and a small ant:

» The ant does not know everything, but it know enough about the anthills, can adapt to environment to successfully build it.

» Acknowledgments

For as long as i can remember, i have always been interested in science and technology, dreaming one day to make at least a minimal contribution, since always felt like i have some properties of my intellect that good enough for that purpose. But alas, due to a number of circumstances i had no opportunity to get even a full secondary education, and therefore my path to this research became long and thorny, and the work itself stretched for more than 10 years since i started from almost ground zero knowledge.

During this time, "a number of circumstances" only expanded, thieving a lot of time and energy, and due to the fact that for me the research was worth constant (when it was possible) work for many years - the project began to have a strong impact on all other areas of my life, and the task itself began to be much more difficult than I, frankly speaking, initially assumed.

Nevertheless, it seems that I have reached some "checkpoint" where I can finally talk about the first results: I have written something reminding of a research paper, which I always dreamed of, and now preparing to change the state of the project to public testing and open access to the source code, hoping to find like-minded people and researchers interested in neuromorphic systems that join me in my journey.

And despite the fact that the project is still alive largely thanks to my enthusiasm and faith in what I do - without the support of people close to me, all this would be absolutely worthless, meaningless and rather short tumbling on a same spot, so first of all I would like to express my absolute and boundless gratitude to all those who were there, helped mentally and materially, often giving strength to overcome quite strong discouragement with a kind word, advice or a joke.

Since I temporarily prefer to keep my identity incognito, I do not feel it comfortable to express my gratitude here in greater details, but I am sure that each of you knows whom these words are addressed: this work was possible only due to your help, and i dedicate to you – my close people!

P.S My special thanks to the Godot team and community! It's a great software with a philosophy that deserves a lot of respect and support. It let me to build everything I needed for this, and many other projects, so thank you very much for what you doing!

Also, I would like to thank everyone who promotes or has ever promoted the science and openness of educational information, especially those whose work I have ever read over the years, finding evidence for hypotheses about brain function that would have taken me an incompatible amount of time to find on my own.

And since I would like to join the number of such individuals myself, the open source code of the Sandbox software, which is based on ideas described in this work, will be posted under the GPL-3 license as soon as the book will be released in the repository!

привет Кот :-)

» Communication and community

- **web4plus.github.io**
- **github.com/web4plus**
- **youtube.com/@WEB4plus**

» Supplementary Data

» Root Repository:
https://github.com/web4plus/HEAVEN_Library/tree/main/EN

» Artificial muscle model: source code file:
~/HEAVEN_ARTIFICIAL_MUSCLE.py

» High-resolution images from this work
~/IMAGES_FULL

» Artificial Neurons Source code:
~/NEURONS_Standart_kit_v1.0.0

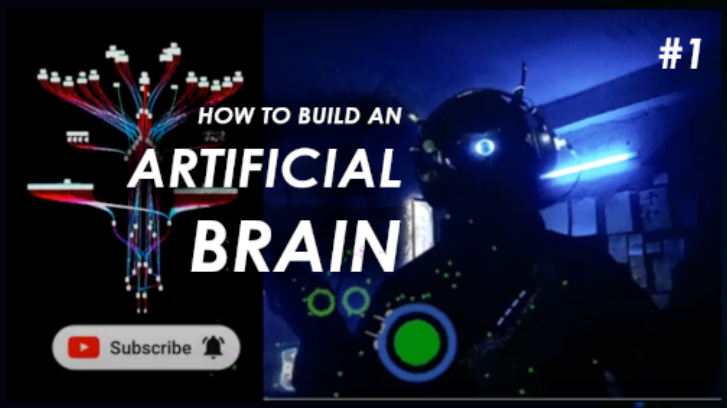
.///HEAVEN:

HOW TO BUILD AN ARTIFICIAL BRAIN

Hello, I am [UPGRADE] - artificial intelligence researcher, writer, artist, entrepreneur and founder of this project.

This book describes the process, methods, and results of my personal research, as well as the consolidated knowledge that you need to build aCNS designs using .///HEAVEN: Sandbox software!

» **Motivated aCNS agent** — It is a neuromorphic system that aoutonomously seeks to satisfy its internal needs accordingly to a flow of the sensory data, using the features of its own architecture and subjectively known capabilities of it's own body.



YT: @WEB4plus

"...Please stop calling me, I don't know who you are, and I will not install your software on my computer!.. "

UPGRADE HUMANITY

OPEN CYBER SPACE

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.///HEAVEN: HOW TO BUILD AN ARTIFICIAL BRAIN
1st edition April 2025