

<b>Topic</b>	<b>General-purpose AI</b>	A Digital Bio-Brain with an Artificial Nervous System
<b>Author</b>	<b>Walter Crismareanu</b>	Founder & CEO Tipalo
<b>AI startup</b>	<b>Tipalo, Switzerland</b>	<a href="https://www.tipalo.com/">https://www.tipalo.com/</a>
<b>AI approach</b>	<b>Biological intelligence</b>	simulation of different brain regions using Tipalo neural nets
<b>FPGA</b>	<b>Xilinx XCVU37P</b>	Virtex UltraScale+ HBM VCU128-ES1 FPGA Evaluation Kit
<b>Software</b>	<b>Bitstream</b>	real-time operating system for embedded systems with sensors, actors and organs
<b>Application</b>	<b>Digital brain</b>	ANS – Artificial Nervous System, consisting of connected neural nets

## 1. Common AI approaches

## 2. Tipalo AI approach

## 3. Tipalo AI structure

## 4. Tipalo AI concept

## 5. Tipalo AI implementation

## 6. Tipalo AI classification

## 7. Tipalo AI road map

# 1. Common AI approaches

## a. overview

### mathematical approach

machine learning using computational statistics, specific use for a well-defined task

this approach is commonly used, however the neural nets do NOT change in time

[https://en.wikipedia.org/wiki/Machine\\_learning](https://en.wikipedia.org/wiki/Machine_learning)

### academic approach

simulation of the mouse brain using supercomputer

this approach is used for R&D, due to the enormous capacity needed

<https://www.epfl.ch/research/domains/bluebrain/blue-brain/about/>

### application approach

dedicated models to be used in specific areas of expertise

**DARPA AI next campaign**, USD 2 billion project for the next generation AI

<https://www.darpa.mil/work-with-us/ai-next-campaign>

examples of topics for developing dedicated models

**Lifelong Learning Machines (L2M)**

<https://www.darpa.mil/program/lifelong-learning-machines>

**Explainable Artificial Intelligence (XAI)**

<https://www.darpa.mil/program/explainable-artificial-intelligence>

## b. AI background

### Biological template

In biology, **tissue is a group of similar cells** that together carry out one or more specific functions called specialty.

Furthermore, **tissue is a cellular organizational level between single cells and a complete organ.**

Organs are then formed by the functional grouping together of multiple tissues, each with own specialty.

This also applies to **biological neural networks**, where the similar cells are specialized cells called neurons.

### Assumptions

**We assume neural nets are the basis for intelligence**, therefore we create artificial neural networks, organized in sequential layers, where each node of a layer is connected to each node of the next layer, while weights between them are set by try and error trials.

At the end we need some algorithm based on arbitrary assumptions, to use these neural nets as components in a computer program.

**Is it intelligence or statistics, to build a neural database with millions of dog images, just to “guess” a dog in a new picture?**

### AI goals

The development of a general-purpose AI is the ultimate goal, in order to reproduce only the functionality of a biological brain, which could be used as a template for creating digital brains with various skills and knowledge, fit to adapt for multiple bodies.

**Behind the slogan AI, we are drilled to assume intelligence for any computer technology which includes an artificial neural net, but there is no explanation whatsoever as how biological neural nets are creating and developing higher forms of organization.**

## c. Why is it so difficult to develop a general-purpose AI?

### Theoretical concepts

Math is a toolbox, based on attributes we can count in physical space, using units of measurement defined by us to quantify an amount, but **measurements, formula calculations and algorithms imply everything we can put into numbers is linear**, like a straight line. **Biological intelligence is located in a living brain**, where **billions of neurons act in parallel**, each **autonomously and non-linear**, **AI needs a living entity, which can develop in time to accumulate knowledge by exploring its environment via own experience.**

### Explaining AI

When we use the term AI, then we compare its performance with the intelligence of a highly educated adult with much social experience. AI means Artificial Intelligence, but **there is no definition of what intelligence even is** or explain intelligence in biological neural nets. First we need to understand the basic principles, then develop a compelling theory about the structure of biological intelligence (=brain), at the end create a new technology, from inception via prototype to production of various product lines with different levels of complexity.

### Conclusion

**AI is difficult and complex**, biology says the brain is an internal organ, which interacts with the entire body in order to evolve, while **logic is the binding glue** to create an AI model as **software implementation** and **math is used to only optimize** the technology. **If a brain can be simulated and connected to an embedded system, intelligence could be portable from human to AI and back**, under these circumstances, we urgently need to reassess the value and social impact of every intelligence, as it would affect everybody.

## 2. Tipalo AI approach

### Origin

Intelligence can only exist in an environment as being part of a living subject with a certain biological structure, based on cell architecture. The subject receives signals from the outside world by using specific sensors, which will transform these signals into internal information. The subject intelligence (=brain) will process the information and will generate a response to this stimuli by sending new information to specialized body components, which on their side will cause a body reaction. This is the process we know about biological intelligence.

### Facts

There is an environment containing many objects of different size and complexity.

There are some objects, called subjects, consisting of many connected components.

Inside certain subjects, there is a specialized component, which does intelligence.

The structure of intelligence is given by certain elements, which build a system as networks.

**Extract as space, time and matter.**

**Organized matter as cell-based body.**

**Brain is organ of some living bodies.**

**Brain consists of neural nets.**

### Dependencies

The **body structure and the connected sensors, actors and organs.**

**Basic pre-defined capabilities**, depending on the connected devices.

**Extended capabilities**, as a result of the basic features and pre-defined capabilities.

**Basic thinking capabilities**, as a result of the embedded self learning mechanism.

**Body options** in landscape environment

**Reflexes** as parallel stream processing

**Instincts** as locomotion, communication

**Association logic**, stored knowledge

### Result

The purpose of every intelligence is the cooperation with all the other body components,

by doing its own specific tasks; means receive, process, store, retrieve and send information.

Intelligence is a system of elements connected to other components of a certain given body.

Intelligence is always active, means the processing is real-time, all-the-time and stand-alone.

**Body coordination**, via connectivity

**Information processing**, body reaction

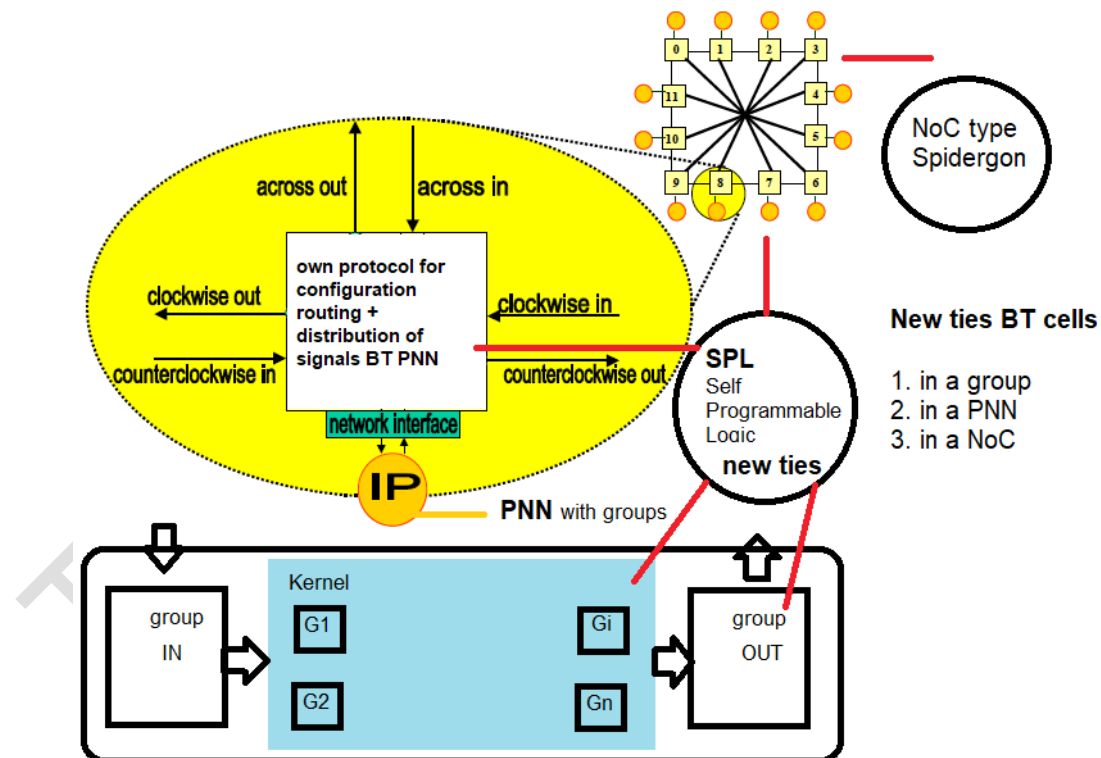
**Dedicated architecture**, as neural nets

**Logic alive**, inside the given body.

### 3. Tipalo AI structure

#### Organisation

- neuron** - can **create interactively new ties** with other cells, where the weights can be positive and negative
- neural group** - neurons are organized in distinct groups, where both **size and purpose can be pre-defined or user-defined**
- neural net** - organized in groups, allowing **multiple extensions of group size by adding new cells interactively**
- ANS** - represents **all neural nets including the connectivity layer**, which links all neural nets together
- main principle** - **many entities, which constantly react with each other in a space, result in a larger object**
- Result** - new ties can be created between cells: within a neural group, within a neural net and between neural nets



## Features

**PNN - Programmable Neural Net** is an own type of neural nets, **organized in groups, allowing new ties** between cells

**SPL - Self-Programming Logic** enables the individual neural nets to adapt by **creating new ties, implements the genetic part**

**SLM - Self-Learning Mechanism**, provides the accumulation and retrieval of knowledge, organized as **SAM, self-associative memory**

**ANS - Artificial Nervous System**, offers the **logic framework** needed to perform all neural nets required for specific **embedded system**

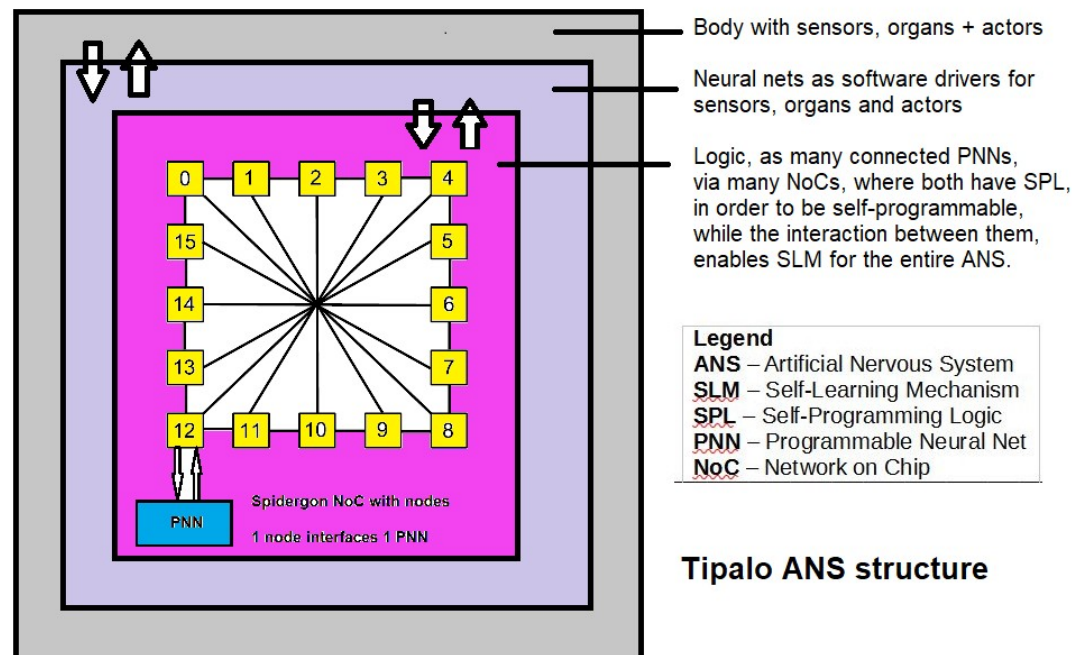
## Technology

The **generic ANS** is the logic library, which simulates all specific neural nets needed for the structure of the body hardware

The **dedicated ANS** of a product line has a certain **level of intelligence**, equipped with **pre-defined knowledge**

The **VHDL real-time operating system** creates a **time flow**, where **all active cells in 1 time cycle are processed within 1 ms**

The **corresponding body** contains the connected hardware with sensors, actors and organs of the **embedded system**





## 4. Tipalo AI concept

### a. Conventional neural nets

- conventional neural nets have layers, where **each neuron of a certain layer is connected with all neurons of the next layer**
- conventional neural nets are **pre-defined to a certain specific task** and can not be used for other common purposes
- conventional neural nets are integrated into a computer system using an **algorithm based on arbitrary assumptions**
- **An algorithm is always processed sequentially, following a static structure within the processing block**

### b. Tipalo AI background

- Tipalo sees a network as an extension of an algorithm, where the parallel processing consists of nodes and streams
- Programmable neural nets can change the structure, adding new cells and new connections with different weights
- Programmable neural nets can change the structure dynamically, enabling different streams and therefore results
- Programmable neural nets are performed in parallel, where the concurrent VHDL processes handle neural information

### c. Tipalo ANS background

- **Tipalo neural nets** called **input drivers** convert the sensor information into internal format, ready to be further processed
- **Programmable neural nets** create and store new information as accumulated knowledge, which can be retrieved on demand
- **Tipalo neural nets** called **output drivers** convert the final result from internal format to commands, which activate the actors
- **All neural nets** are executed in parallel, while the processing of all **active neurons** within one time cycle takes only 1 ms

## d. Tipalo neural nets

- **Tipalo neural nets** are not organized in layers, but in separate groups of neurons, which can connect with each other
- **Tipalo neurons** can connect with other neurons as follows: between neural groups, neural nets and within ANS
- **Tipalo neurons** use weights in signed int4 format, as positive and negative integer values from -7 to +7, with 0 excluded
- **Tipalo neurons are active depending on situation**, only some neurons are active at a certain time, multiple not single ones

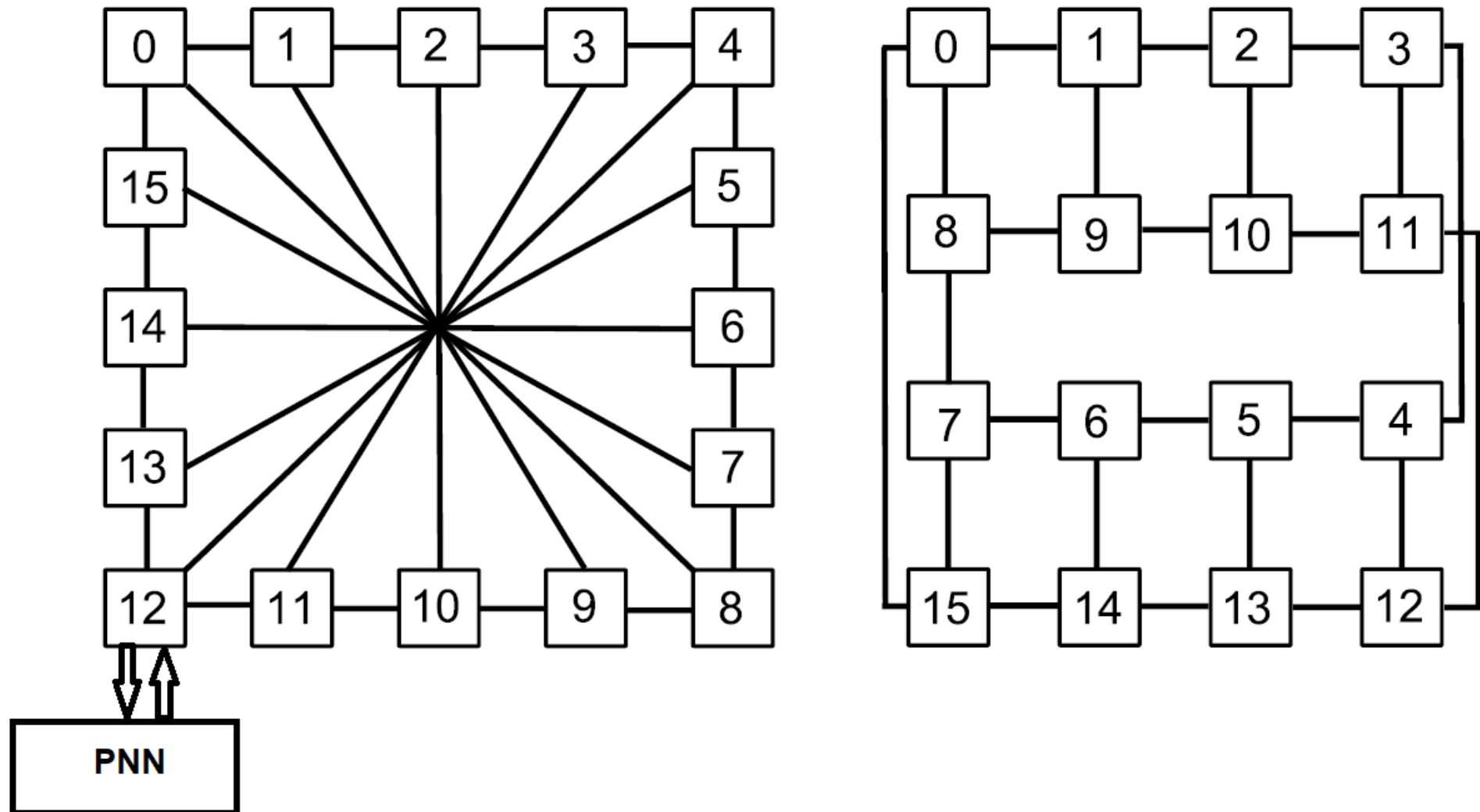
## e. Programmable neural nets connectivity

- **Programmable neural nets** can self-program via **SPL - self-programmable logic**, enabling **SCR - self-configurable routing**
- **Programmable neural nets** can connect with many other neural nets, with each of them in a different way
- **Programmable neural nets** can connect with each other, building a higher form of organization called neural process
- **Tipalo neural processes** can connect with each other, building a higher form of organization called neural application

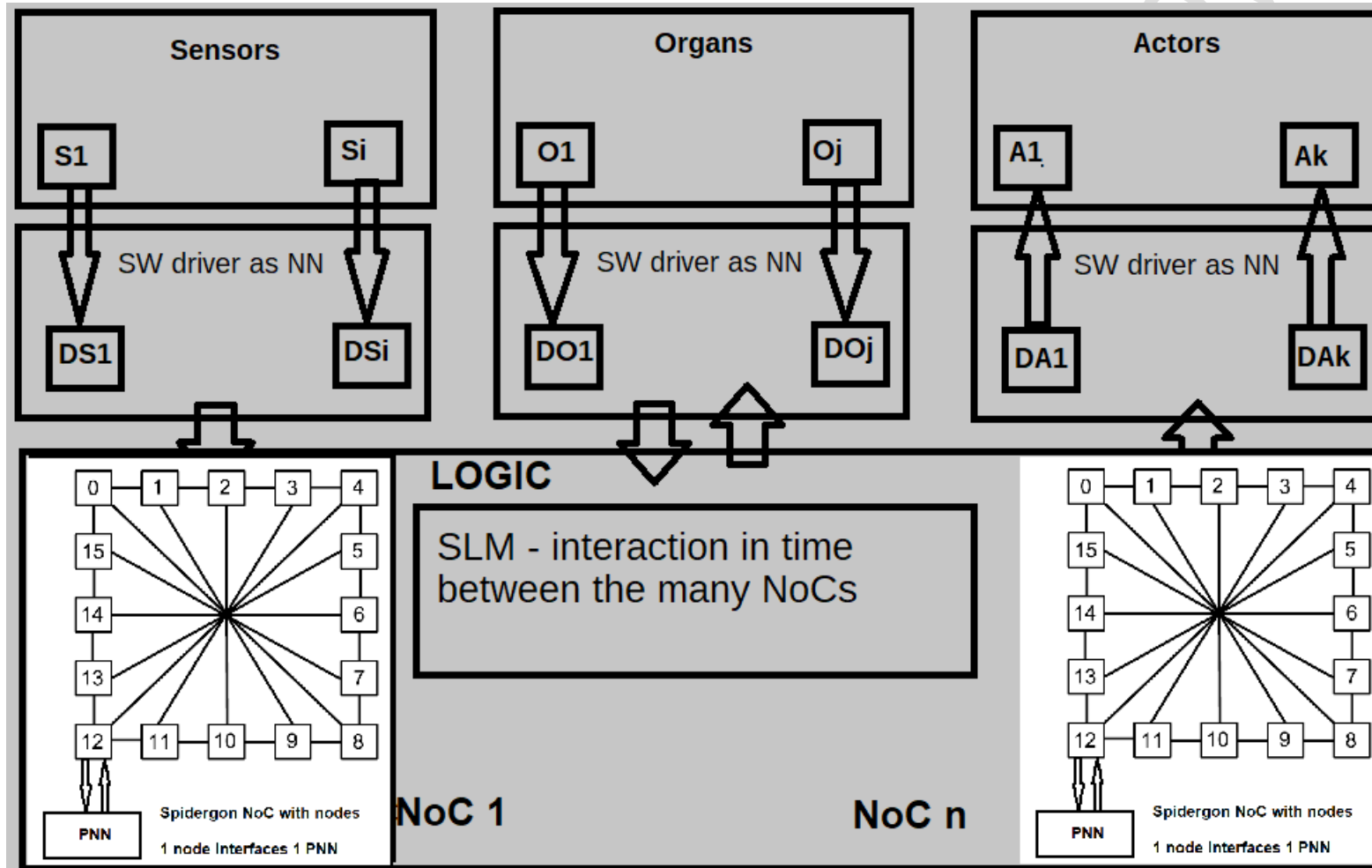
## f. Tipalo NoCs

- **Tipalo neural nets use the Spidergon NoCs as infrastructure**, to connect with each other
- **Tipalo NoCs use own protocol**, for configuration, routing and distribution of information between nodes
- **Each Tipalo neural net is connected to only one node of only one dedicated NoC**
- **Programmable neural nets can connect interactively to other neural nets**, enabling **SCR - self-configurable routing**

### Spidergon topology as architecture with nodes and physical layout



g. Tipalo ANS – Tipalo neural nets connected via multiple Spidergon NoCs, using own protocol



Tipalo ANS consists of one or more applications, depending on the level of complexity and the connected body hardware

## h. Tipalo SLM – Self-Learning Mechanism

### Basics

- **Tipalo SLM** is based on biological templates, see brain information processing or digestion system from intake till distribution
- **Tipalo SLM** has 2 distinct phases: accumulation and update of knowledge areas, using **SAM - self-associative memory**
- **Tipalo SLM** accumulation phase stores the automatically collected information in a temporary log, which is also a neural net
- **Tipalo SLM** update phase reads the log and updates the specific areas, extending them with the corresponding new info

### Working modes

- **Tipalo SLM** temporary log is circular, so when new information reaches the end, it will start again by overwriting the existing
- **Tipalo SLM** needs a certain period of time, in order to update the knowledge areas with the new info, pausing regular activity
- **Tipalo SLM** update phase will end by clearing the log, the regular activity will resume and SLM can again enter accumulation
- **information retrieval** needs **selection process** during regular activity, in order to retrieve the corresponding stored/updated info

### Usage

- **Tipalo SLM** to **autonomously collect information** and **store it in knowledge areas** using **SAM - self-associative memory**
- **Tipalo SAM** has **high storage capacity**, type and size of knowledge areas depends on ANS structure and intelligence level
- **Tipalo SLM** can be **switched on/off on demand**, as it is embedded into the ANS framework as interaction between neural nets
- **Tipalo SLM** could be **used between 2 systems**, as **one teaches the other**, same way like the **waggle dance** of the honey bee

## 5. Tipalo AI implementation

### a. hardware

#### **FPGA in combination with HBM2 and Optane DIMM, while using only Ethernet as external interface**

- **FPGA** enables massive parallel processing with high capacity + low processing frequency + strong encryption
- **HBM2** is volatile memory with high bandwidth + high capacity + low power consumption, builds system-in-package with FPGA
- **Optane DIMM** as persistent memory with high bandwidth + high capacity + low power consumption + strong encryption
- **Ethernet interface** is the network standard for bidirectional connectivity, including the World Wide Web, also known as Internet

### b. software

- **real-time operating system, implemented in VHDL for FPGA as encrypted bitstream**
  - executing **PNN, Programmable Neural Nets**, as follows:
    - access input signals on-demand, process them according to own specialty and generate output signals to other(s)
    - being able to adapt themselves by using **SPL self-programming logic** their internal and external connectivity
  - running **SCR, Self-Configurable Routing**, to enable communication between neural nets by connecting the PNN among themselves, in order to build applications
    - applications among themselves, to build the ANS
- **software package, implemented as ANS, for encrypted storage of binary files in Optane DIMM**
  - applications**, for simulating various brain regions, including **neural drivers applications** for sensors, actors and organs
  - self-learning mechanism**, storage and retrieval of accumulated **knowledge**, using **SAM - self-associative memory**

## Operating system for general-purpose AI

### Features

- a. **hardwired**, written exclusively in VHDL for FPGA SiPs containing HBM2 memory, e.g. Xilinx XCVU37P
- b. **massive parallel processing**, for executing exclusively Tipalo dedicated self-programmable neural nets
- c. **self-programmable dedicated networks on chip** - connecting all neural nets including the i/o neural drivers
- d. **real-time**, enabling human-alike reaction times, e.g. 1ms for all simultaneously active neurons
- e. **made for embedded systems**, requires a connectivity to sensors and actors of a corresponding body

### Components

- a. **applications**, as brain areas/regions with multiple neural nets connected to an ANS
- b. **support for self-learning mechanism**, which is implemented as the interaction between neural nets
- c. **Interfaces**, for Ethernet only, as 10/100/1000 Mb, **10/25/100 Gb only starting with OP-L2**
- d. **support for HBM2**, to be used for storing kernel applications, **only starting with OP-L2**
- e. **support for Optane DIMM**, to be used for storing accumulated knowledge, **only starting with OP-L2**

### ANS support

- a. **configuration**, as place + route + connect + activate all neural nets within the ANS
- b. **support for modes**, execution pause for certain period of time, on/off switch for self-learning mechanism, etc.
- c. **support for encrypted storage**, means the entire ANS is stored internally and encrypted
- d. **upload/download**, via Ethernet interfaces, **only for development purposes**
- e. **debugger**, as debug, trace and log neural net activities via Ethernet interface, **only for development purposes**

### ANS - Artificial Nervous System

1. **requires operating system OP for general-purpose AI**
2. **neural drivers**, for connected sensors, actors and internal organs of an embedded system
3. **neural nets**, as applications, which simulate various brain regions
4. **self-learning mechanism**, integrated within the neural net application framework
5. **accumulated knowledge**, with storage and retrieval of information using **SAM - self-associative memory**

## 6. Tipalo AI classification

There are 3 different levels of intelligence, we have the following **bottom-up vertical classification**, where, in terms of neuronal capacity, each level is ca. 100 to 1000 times higher than the previous level, thereof the sensory-associative structure represents ca. 20% on average, depending on the ANS purpose.

Levels of intelligence								
Level	equivalent (biology)	AI product lines	capacity (cells)	density (ties/cell)	IC (chip)	memory on-chip	SiP RAM	non-volatile
L1	insects	robodogs, drones	1M	16	FPGA	large	none	none
L2		pilots for autonomous vehicles	1G	256	FPGA ASIC / 3D-IC	large TBD	HBM2 TBD	Optane DIMM TBD
	mammals fishes birds	cars, trucks, etc. ships, submarines, etc. airplanes, helicopters, satellites, etc.						
L3	primates	robotic workers	10G	1024	TBD	TBD	TBD	TBD

### Remarks

1. **Some animal species are self-aware**, means recognizing themselves in a mirror  
 e.g. mammals like elephant, bonobo; birds like Eurasian magpie; fishes like cleaner wrasses, etc.
2. **Self-aware does NOT mean free will**
3. **Free will does NOT imply that an organism has an inconsiderate and aggressive behavior towards the entire world**



## a. ANS level 1, corresponds to insects, enables the following skills:

- **max. capacity of the ANS is 1 million neurons, 1 M cells,**  
**min. number of connections between neurons is 16 ties/cell**
- simple sensor input drivers, allows perception of different element  
e.g. visual black+white, gyro, pressure, etc.
- simple actor output drivers, allows commands of simple actions of body limbs,  
e.g. locomotion with small speed, etc.
- simple glue logic, allows pre-defined reflexes for processing as input to output connectivity  
e.g. fixation on sensor element with certain attribute(s) and follow the trail accordingly
- internal connectivity, between body components and sensors + actors  
e.g. sensors + actors + internal organs
- self-learning mechanism, allows user-defined connectivity between different parts of the ANS  
e.g. memory and connectivity of certain parameters

### Usage

It consists of an embedded system with the operating system OP-L1, a generic ANS-L1 and a corresponding hardware body.

This is a MVP, minimum viable product, to be used as a study for the unique and complex Tipalo approach.

## b. ANS level 2, corresponds to mammals/fishes/birds, enables the following skills:

- **min. capacity of the ANS is 1 billion neurons, 1G cells, average number of connections between neurons is 256 ties/cell**
- complex sensor input drivers, allows perception of objects  
e.g. visual color as RGB, audio, gyro, pressure, etc.
- complex actors output drivers, allows commands of complex body actions,  
e.g. locomotion with different speed, sense of balance, coordination of own body parts, etc.
- memory, means storage of many and different objects and landscapes  
e.g. objects can be grouped, which allows a classification based on user-defined templates
- medium glue logic, allows multiple pre-defined own status quo induced by situations  
e.g. situation triggers imminent danger caused by a crowded landscape
- self-learning mechanism, allows user-defined behaviour based on multiple factors  
e.g. analysis of a situation with different objects within a certain landscape

### Usage

It consists of the operating system **OP-L2** and a generic **ANS-L2** for a corresponding hardware body.

This will enable autonomous pilots for different vehicles, such as:

- **terrestrial**, e.g. cars, trucks, heavy-duty vehicles, etc.
- **naval**, e.g. boats, yachts, ships, etc.
- **aero**, e.g. UAVs, planes, high-altitude pseudo satellites, etc.
- **space**, e.g. low earth orbit telescopes, high earth orbit satellites, deep space robotic spacecrafts, etc.

### c. ANS level 3, corresponds to primates, enables the following skills:

- **min. capacity of the ANS is 10 billion neurons, 10G cells, average number of connections between neurons is 1024 ties/cell**
- little language processing, assuming 2 different pre-defined specific applications  
e.g. center for speech interpretation, center for speech production
- accumulation of knowledge, by using among others also some language processing  
e.g. physical, logical and abstract terms for building and using an user-defined dictionary
- imagination, requires retrieval on demand of memorized objects and landscapes  
e.g. internal representation and processing of possible scenarios
- complex logic processing, which includes selection and association of terms and actions  
e.g. physical, logical and abstract terms for building and using an user-defined encyclopedia
- self-awareness, recognition of own body within the internal representation of perceived objects  
e.g. proved via the mirror self recognition test

#### Usage

**It consists of the operating system OP-L3 and a generic ANS-L3 for a corresponding hardware body.**

**This will enable robotic workers of different shape, size and structure.**

## 7. Tipalo AI road map

### a. Products

**A product with the intelligence level 1 is estimated to be available in 2021.**

It consists of an embedded system with the operating system OP-L1, a generic ANS-L1 and a hardware body. This is a MVP, minimum viable product, to be used as a study for the unique and complex Tipalo approach.

**A generic product with the intelligence level 2 is concurrently in development.**

### b. Custom-design

**products, for development of custom product lines**

- brains as **administrators for smart buildings**, e.g. habitats, towers, factories, etc.
- brains as **pilots for vehicles** in different environments, e.g. terrestrial, naval, aerospace, etc.

**services, for development and access of cloud based product lines**

- brains as **remote control of embedded systems** with certain body hardware
- brains to **create a unified knowledge** with daily updates from several brains

### c. Cooperation

**hardware** - **add new devices for the real-time operating system**, e.g. sensors, actors, organs, engines, batteries, etc.

**design** - **develop own ASIC / 3D-IC for different technologies**, e.g. 22FDX with NV embedded memory, 3DSOC, etc.

## d. Perspectives

**Tipalo AI technology is not similar with anything conventional,**  
meaning it neither uses ML with conventional neural nets as software,  
nor does it use MCU or other conventional processors as hardware,  
as it uses **neural cells as processing engines and storage elements.**

~ **soft IP**  
~ **hard IP**  
~ **neural IP**

**Therefore, the core unit is the PNN, Programmable Neural Net,**  
organized in **distinct neural groups, with pre- or user-defined purpose,**  
hereby **enabling new ties with diverse weights and signs between cells,**  
**for different entities:** inside a group, between groups and between PNNs.

~ **organization**  
~ **interaction**  
~ **connectivity**

**Our general-purpose AI is self-learning and unlimited scalable,**  
the number of ties between cells can be dynamically increased,  
as well as the number of used PNNs can be raised on demand,  
while using multiple Spidergon networks with different configurations.

~ **density**  
~ **capacity**  
~ **routing**

**Tipalo AI products are used as digital brains in autonomous embedded systems,**  
connecting **input and output devices** with an Ethernet interface, e.g. video, servos  
linking **bidirectional IO devices and subsystems,** e.g. communication, MEMS  
while internal and external **components** can be integrated, e.g. engine, power source

~ **sensors and actors**  
~ **digital and analog**  
~ **organs and limbs**

## e. Semiconductor technology

Tipalo AI technology has the potential to unify the FPGA and ASIC design, by replacing entirely the conventional hard IP and soft IP with **only neural IP**, creating a new generation of bio-inspired "self-programmable logic" ICs, while using **condensed design** and **advanced semiconductor manufacturing**:

### hard IP

**logic architecture** with multiple PNNs, enabling new ties between neural cells ~ **self-programmable logic**  
**FPGA routing**, 80% die space and many metal layers, with 2D-Spidergon topology ~ **self-configurable routing**  
**multiple interfaces** with one Ethernet-based interface allowing different speeds ~ **adaptable communication speed**

### soft IP

**static algorithms** with interactive behavior to accumulate specific knowledge ~ **self-learning mechanism**  
**storage** with persistent embedded memory organized in knowledge areas ~ **self-associative memory**  
**static resource utilization** with interactive usage of specific knowledge ~ **dynamic resource allocation**

### design and manufacturing

**different layers of storage and logic** with multiple layers of memory and logic in one ~ **combined memory and logic**  
**clock circuits** with asynchronous design for low power, modularity and immunity ~ **adaptable resource usage**  
**bulk CMOS** with FD-SOI technology to enable applications in different landscapes ~ **various difficult environments**