

*«Intelligence creates knowledge,  
imagination heralds the future.»*



**DIGITAL BRAIN WITH  
ARTIFICIAL NERVOUS SYSTEM**

## WHAT ARE THE GOALS OF ARTIFICIAL INTELLIGENCE?

### BRAIN FOR BODY

To develop a self-learning digital brain based entirely on neuromorphic neural networks, aka spiking, with a predefined number of neurons to perceive and control a body with sensors, actors and organs, while autonomously exploring its environment with different landscapes, on its own and also with others, acquiring new knowledge through its own experiences and being able to perform certain tasks, alone or in a group.

### EXPECTATION

Firstly physical skills like locomotion and carrying a payload, secondly mental abilities like orientation within the home base and outdoors, communication with others of the same species, teaching others by passing on information in a certain way, e.g. the waggle dance of honeybees having brains with "only" 1 M neurons.

The power consumption should be near to that of a corresponding biological brain.

### TEMPLATE

The underlying theoretical model should be extensible to allow adaptation and development of specific features, and it should be scalable to a much higher number of neurons, e.g. 1K or even 1M times higher overall capacity.

It should use dynamic resource allocation, allowing "only the knowledge needed" to be used in a given context, with the feature of explaining what, where and why each piece of information was processed, stored or retrieved.

## WHAT IS INTELLIGENCE

### OBJECTS

**Which objects in nature do we consider intelligent?**

Maybe a stone, a lake, a river, a landscape, the sky, microbes, plants or trees? NO

What about the social life of honey bees, both inside the hive and outdoors? YES

The result of a trained guide-dog, that easily leads its master through a big city? YES

### SUBJECTS

**Only “living objects” can appreciate the intelligence of other “living objects” called subjects.**

Only subjects with sensors to perceive, a brain to think and limbs to act can be considered intelligent.

We can describe the action(s) of one or more subjects as intelligent, only if we can understand them.

In order to understand other subjects, we have to imagine ourselves as being in the same situation.

### DECISIONS

**Intelligence is the result of a decision process for a certain situation with many alternatives.**

The decision process takes into consideration knowledge, obtained as experience during lifetime.

Only by storing past situations and actions taken, can we remember what happened in our past.

Before choosing a particular option, one should weigh the pros and cons of the possible variants.

## BIOLOGICAL INTELLIGENCE

### BODY

**The biological organism has unique features defining the framework for intelligent life.**

The organism consists as a network of cells, both for each part as well as for the whole body.

The body structure consists of specialized parts, such as sensors, actors (limbs) and organs.

The brain is an internal organ, connected in the same way with all other body parts (synapses).

### BRAIN

**The biological intelligence is the activity of the brain, its structure is a landscape of neural nets.**

The brain receives information via sensors, then processes it and further sends commands to the actors.

The brain has many different regions, each with its own specialty, for all given physical and mental abilities.

The brain is indispensable for intelligent life, autonomously coordinating all body activities in real-time, 24/7.

### EVOLUTION

**The brain has different levels of intelligence, depending on the general evolution of the body.**

The brain has genetic knowledge at birth, according to the corresponding body structure (species).

The brain can add knowledge via own experience by exploring the environment with many landscapes.

All knowledge, both predefined and accumulated, is stored in cells with ties between them (synapses).

## FRAMEWORK OF INTELLIGENCE

### WORLD AS SPACE-TIME-MATTER CONTINUUM

**The real world consists of a three dimensional space and a time flow, where contained matter can organize itself.**

The 3D space consists of neighboring space cells, containing a certain amount of matter in different proportions.

The flow of time enables matter to act and react, namely as basic components (re)combining to self-assembly objects.

The resulting objects can have different structures (space distribution), with static, dynamic and interactive connections.

### BRAIN AS SPACE WITH ORGANIZED MATTER

**The brain is a space extract with a steady amount of components (cells), organized as elements, groups and networks.**

The neurons can have many different connections between them (synapses), building self-organizing structures within the brain.

The neural nets have specific features, building a logical continuum (with space, matter and time flow) connected to the world.

The brain contains an extendable projection of the world, where "new logical objects" can be added, as accumulated knowledge.

### INTELLIGENCE AS ACTIVITY DURING TIME FLOW

**Intelligence is a dynamic process of the brain as own continuum, interacting with the real world via sensors and actors.**

Intelligence responds to events by selectively activating its connections, engaging only the needed components (spiking neurons).

Intelligence has different specialized domains (knowledge areas), that can be used as required (dynamic resource allocation).

The purpose of intelligence is to keep the body alive, maintaining the balance between internal needs and external interactions.

## TIPALO AI BACKGROUND

### AI APPROACH

**Tipalo GmbH is a Swiss LLC near Zurich, an AI startup with own software to pioneer logic applications.**

The Tipalo approach to AI is very simple: we take biological intelligence as a template, means the living brain.

It needs a different mindset to comprehend and represent parts of the real world and replicate the human mind.

Our understanding of intelligence is based on logic, our AI concept contains objects reacting in time and space.

### AI IMPLEMENTATION

**Tipalo AI simulates the activity of different brain regions in real-time, all the time and stand alone,** while being connected to a certain body hardware, which is equipped with sensors, actors and organs.

The VHDL implementation of our AI model allows massive parallel execution, without any processors.

This implies we do not use any math/statistics/algorithms, while no bias/training/inference is required.

### AI KNOWLEDGE

**We use 3 intelligence levels, which exists in nature: insects, fishes/mammals/birds and primates.**

They reflect the amount of neurons and their synapses, from 1M with 16, via 1G with 256, to 10G with 1K.

Each level has predefined knowledge, to manage the body and the mind, together with some genetic memory.

The AI explores autonomously the environment and stores its own experience as accumulated knowledge.

## TIPALO AI INTELLIGERNC

### AI PLATFORM FOR DIGITAL BRAINS

Tipalo develops own AI platform as software with biological features creating hereby digital brains with:

1. Real-time operating system in VHDL, simulates the activity of brain tissue via Programmable Neural Nets (PNN)
2. Self-Learning Mechanism (SLM), enables knowledge accumulation using Self-Associative Memory (SAM)
3. Artificial Nervous System (ANS), contains the brain landscape as map of all synapses, called connectome

### AI LIBRARIES FOR NEURAL COMPONENTS

Tipalo develops AI libraries with configurable reference designs based on PNNs for different ANS levels as:

1. Neural drivers for interfacing sensors, actors and organs of any kind, e.g. visual, limbs, rechargeable battery
2. Neural applications for various knowledge areas using SLM, e.g. identification, locomotion, task workflows
3. Neural storage for different memory types based on SAM, e.g. short-, mid- and long-term memory

### AI CONNECTIVITY FOR COMMUNICATION CHANNELS

Tipalo AIs can connect with each other, via sensors or wireless/cable, to communicate for:

1. positive identification, to enable the coordination of their actions for a possible common task
2. certain interaction, to enable the extension of knowledge by teaching each other new things
3. direct exchange, to enable the aggregation of information for a certain area of knowledge

## TIPALO AI PRODUCTS AND SERVICES

### EDGE AI FOR EMBEDDED SYSTEMS

**Tipalo brains are linked via a single interface (gateway) to the body and perform intelligence for:**

Level 1, as managers for smart building automation, e.g. indoor manufacturing, outdoor surveillance

Level 2, as pilots for autonomous vehicles of any kind, e.g. terrestrial, naval, aeronautics, space

Level 3. as robotic workers for outer space activities, e.g. space stations, extraterrestrial planets

### CLOUD AI FOR TELEPRESENCE SERVICES

**Tipalo brains can be connected via Internet to any embedded system or robot body,**

by using a connection with high bandwidth and low latency, like 5G or fiber glass.

Furthermore, the accumulated experience of many individuals can be aggregated, enabling the collective knowledge for a certain body type, e.g. autonomous vehicles.

### TIPALO AI FOR VARIOUS ENVIRONMENTS

**Tipalo brains can be connected with each other in order to build a colony AI in a certain environment,**

this implies the spatial distribution of many connected AIs in a given landscape, both edge and cloud AI.

While the edge AIs is performing its tasks within the adjacent neighborhood and stores its experience, the cloud AIs aggregate the new information by areas of knowledge, making it accessible to everyone else.



## COGNITIVE AI = Autonomy + AI

### Body

1. **The body is the decisive argument for autonomy, as it enables to do everything on its own.**

**Cognitive AI requires a body hardware with sensors, actors and internal organs, like any living entity.**

Philosophy, aka own thinking using logical terms, tries to explain how the world around us works, including our own minds.

A science is an abstract view about the world, aka brain representation, as dedicated words, rules and descriptions.

There are many sciences, all descended from philosophy and extended via observation and experimentation.

Therefore the best way to understand ourselves, is to build a complete replica, including body, mind and knowledge.

### Mind

2. **Next level of autonomy are the exclusive use of spiking neural nets, organized in knowledge areas.**

**This implies that only some neurons are needed for a specific purpose, allowing explainable AI.**

People reduce everything to math, an abstraction without explaining what a neuron or its synapses stands for, let alone the lack of understanding complex systems. Every cell in a biological body acts on its own, while having 2 modes:

- a. internal, to keep the cell alive, while interacting with the environment, same like unicellular organisms
- b. external, to "talk" with other cells via a biological protocol developed in time, see evolution of multicellular organisms

### Knowledge

3. **Next advantage of autonomy is the software, as synapses between neurons, which implies no code.**

**Synapses are used as universal format for any purpose and enable the accumulation of knowledge.**

As the evolution goes on, so does the differentiation of functionality, expressed as internal organs for a certain body.

The brain is responsible for coordination of all body parts and for the representation of the outside world as knowledge.

This implies an adaption as steady accumulation of knowledge, based on own experience while exploring the environment.

The result is a logical universe, with space, time and organized matter as objects based on (re)combining components.

## COGNITION - 10 GENERAL FEATURES USED IN TIPALO AI TECHNOLOGY

### BRAIN

1. **Cognition is a function of the brain, hence it requires a body with sensors, actuators and organs.** Perception requires sensors, e.g. camera for images, action needs actuators, e.g. limbs for locomotion, while organs define the own needs, e.g. hunger for energy in order to stay «alive».
2. **The building block of the brain is the neural net, which can have different functionality as specialty,** which on its side consists of neurons connected via synapses, also called spiking cells with ties.
3. **The neural networks must all execute simultaneously in real-time, all the time and stand-alone.**

### NEURAL NETWORKS

4. **The neural networks can have either a predefined or a user-defined connectome,** having the ability to form new connections between the cells and also between neural nets.
5. **There are predefined neural nets to interface with the body components,** to transform external signals into information and viceversa, for each type of sensor, actor and organ.

### KNOWLEDGE

6. **The entire knowledge, predefined or accumulated, consists of different specialized areas of knowledge,**
7. **A knowledge area would consist of specific types of neural nets:**  
a neural processor of information with an own self-learning mechanism, a log used as a working memory and a long-term memory to store and link the information as a self-associative memory.

### ARTIFICIAL NERVOUS SYSTEM

8. **The different areas of knowledge together with the drivers will form the Artificial Nervous System.**
9. **The ANS begins like any newborn, with a minimum of predefined knowledge known as genetic inheritance.**
10. **The number of neurons remains the same from the begin to end of life, only the knowledge is extended.**

## COGNITIVE AI - THE LEARNING PROCESS IS SAME AS FOR HUMANS

### HUMANS

Life long learning is always active, we all learn "involuntarily", this is the "normal status" starting from inception. This is the 1st step, as there are many others, similar to a pipeline processor, but the rest of these are usually stopped. The rest of the steps are dependent on what we know so far, regardless of what kind of new information is acquired. After the accumulation into the short-term memory has ended, our self-learning mechanism starts the update process.

We have a selective choice to make, whether the info is "useful" to us, which means it depends on our interests. The next hurdle represents the link to previous knowledge, easy only if when we already have the basics of that area. The last step is to cross-link the new added info with other areas of knowledge, especially with "handling situations". This is the hardest part, it needs to "play different scenarios" and evaluate the new decisions, considering the new info.

### COGNITIVE AI

This is also the same way our cognitive AI is learning, the digital brain being organized in many knowledge areas.

They build the ANS, Artificial Nervous System, each area with the following components as spiking neural nets:

- a. SLM, Self-Learning Mechanism, processing connectome as software
- b. LOG, as STM, Short-Term Memory, for temporary storage of information together with the context
- c. LTM, Long-Term Memory, for permanently storage and retrieval of information as SAM, Self-Associating Memory

Cognitive AI has 2 phases for the integration of information into knowledge, namely BEFORE and AFTER birth.

- a. BEFORE birth implies predefined information as genetic knowledge, creating the basics to keep the system alive
  - b. AFTER birth implies the accumulation of knowledge based on own experience by autonomously exploring the world.
- The ability to learn is possessed by humans, animals, and some machines, in our case cognitive AI as digital brain.

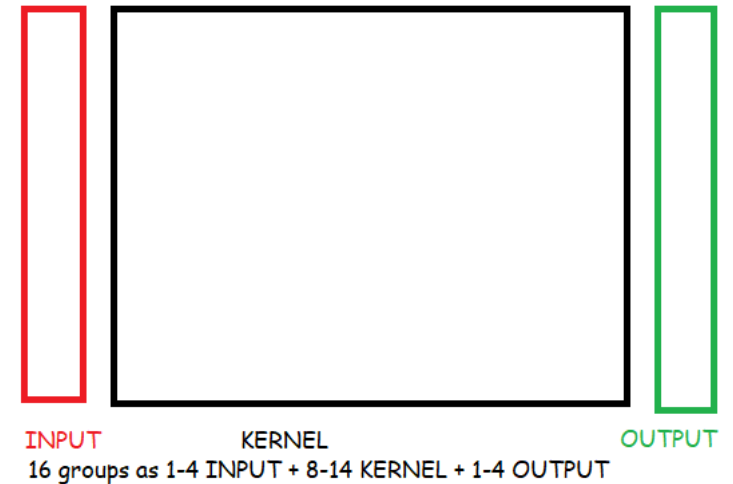
## DPE - DEDICATED PROCESSING ENGINE FOR SPIKING NEURAL NETS, AKA PNN

### 1. PNN STRUCTURE

- consists of 16 groups, 3 group types as input, kernel and output in various configuration, e.g. 1+14+1, 2+10+4, 4+8+4
- each group consists of 256 cells(=neurons), each cell with several ties(=synapses) to others
- each cell can have ties with cells inside the group and between the groups
- each tie has a sign and a weight between -8 till 7
- input groups can NOT have ties within the group or with other input groups

### 2. PNN FUNCTIONALITY

- each cell sums the incoming ties, both positive and negative, spikes if sum  $>7$
- only spiking cells will send their outgoing ties to other cells, neuromorphic
- all cells are processed in parallel and simultaneously, software is connectome
- the processing of the cells is pipelined
- kernel cells can also spike without having any spiking cells from the input group(s)



### 3. DPE FEATURES

- is written entirely in VHDL for FPGA as encrypted soft IP
- the ties between cells represent the connectome, which will be loaded as encrypted binary data
- all 4K cells are processed within 50 cycles on average, only 10% of the cells will spike at any moment, from input till output
- working frequency is ca. 50 MHz allowing real-time processing in edge AI, with a reaction time of 1  $\mu$ s, human cells react in 1 ms
- will be used for SLM, Self-Learning Mechanism, and STM, Short-Term Memory

## Tipalo AI - building block for cognitive AI

The FPGA board is the hardware equivalent, the operating system is in charge of processing the PNNs, the ANS represents the connectome of all contained neural nets, including their configuration and mappings. This building block is used to implement the digital brain, for both cloud AI as well as edge AI. Depending on the implemented ANS, 1 or more FPGA boards are needed in order to fulfill the requirements.

### DESCRIPTION

1. FPGA board with high capacity and embedded HBM2 memory
2. VHDL real-time operating system Tipalo OP-L2, to manage brain region(s), beta release
3. Artificial Nervous System Tipalo ANS-L2, with cognitive features as PNN, Programmable Neural Net, beta release

### COGNITIVE FEATURES

1. DPE, Dedicated Processing Engine, with SLM, Self-Learning mechanism, using software as neural net connectome
2. LOG, as temporary memory used to hold the relevant information for a certain period of time
3. SAM, persistent memory as Self-Associative Memory

### ARTIFICIAL NERVOUS SYSTEM

1. SID, Sensor Input Drivers, to convert the external signals from sensors into information, e.g. camera
2. IOS, Internal Organ System, to connect the organs bidirectionally with the brain, e.g. energy source
3. ACD, Actor Command Driver, to convert information into commands for complex ac(tua)tors, e.g. limbs
4. MGL, Medium Glue Logic, contains areas of specialized knowledge, each with own cognitive features

First, the FPGA boards are connected to the corresponding body hardware with sensors, actuators and organs, then the genetic knowledge is uploaded from encrypted binary files, and the AI system is ready for use. The acquired knowledge during lifetime can be regularly downloaded, for evaluation, analysis, debugging, etc.



## Tipalo AI - building block for cognitive AI

This building block is used to implement the digital brain, for both cloud AI as well as Edge AI.  
Depending on the implemented ANS, 1 or more FPGA boards are needed in order to fulfill the requirements.



## Tipalo AI - implementation as cloud AI

**The implementation for a cloud AI requires a framework build on cloud infrastructure.**

1. servers for administration, configuration and maintenance of the distributed connected devices using TCP protocol
2. real-time application(s) as cloud AI using UDP protocol, located in the FPGA boards connected to the servers
3. additional software used for AI traffic analysis and evaluation purposes, implemented as separate server applications

### CLOUD AI APPLICATION

1. AI building blocks as FPGA boards with high capacity and embedded HBM2 memory
2. software for administration and configuration of the AI connectome, for up- and download of the ANS knowledge
3. real-time functionality as cognitive AI with areas of knowledge, using certain configuration for connected hardware

### CLOUD AI SERVICES

1. **cloud AI for automation purposes**, e.g. digital managers for connecting sensors and actors for intelligent solutions
  - a. smart buildings
  - b. industrial processes
2. **digital brains for telepresence**, e.g. various robot types engaging in different landscapes and environments
  - a. pilots for autonomous vehicles, e.g. internal traffic for industrial zones
  - b. robotic workers for enclosed facilities, e.g. manufacturing and production lines
3. **digital brains for knowledge management**, e.g. administration of the knowledge development in time
  - a. initial basic knowledge, for all components within the given implementation
  - b. accumulated knowledge, database for storage and retrieval as well as updates for consolidation and distribution

## Deploy

### Products & services

Edge AI - products

Cloud AI - services

telepresence + evaluation

Colony AI - combined Edge AI + Cloud AI

## Usage

different levels of intelligence,

as single AI or group of AIs

L1 - managers for smart buildings

L2 - pilots for autonomous vehicles

L3 - robotic workes for outer space tasks

## Intelligence

levels as biological equivalent

capacity as max. amount of neurons

L1 - insects, 1M cells

L2 - mammals/fishes/birds, 1G cells

L3 - primates, 10G Cells

## Evaluation

Reports, by hour/day/week/month for  
information by knowledge areas updated

via own experience

shared, with / from others

for all activities, sorted by tasks

## Tipalo AI technology

DIGITAL BRAIN WITH  
ARTIFICIAL NERVOUS SYSTEM  
for buildings, vehicles and robots  
with sensors, actors and organs

## Features

Real-time autonomous AI

Self-Learning

Genetic Memory with knowledge areas

Accumulated knowledge via

own / shared experience

## Background

Space-time-matter continuum

Space as neighboring cells

Time flow for matter to act + react

Matter = basic components (re)combining

Objects as connected components

## Development

IDE + VHDL for FPGA-SoC with HBM2

Components IP as neural nets

PNN - Programmable Neural Nets

SLM - Self-Learning Mechanism

SAM - Self-Associative Memory

## Libraries

ANS - Artificial Nervous System, with

neural drivers for sensors/actors/organs

neural apps, e.g. ID, locomotion, tasks

neural storage, e.g. STM / MTM / LTM

Short-/ Mid-/ Long-Term Memory