Abstraction Levels in Neuro-computation
-
from Pattern Processing to Wave Interference

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Abstract

Neurophysiology is a difficult science. Until know we know hundrets of chemical substances and interacting mechanisms. Distributed parameters of nerves make things not easier to understand them in their global interaction. McCulloch/Pitts, von Neumann and Hebb for all developed a system of abstractions to describe bio-systems. Today we call the abstract set of models and theories 'neuro-computation'. We all know, that the main intention of neuro-computation is more application specific than bio-inspired. So models sometimes loose their biological background. More, we have to summarize, that the known abstraction level has particular gaps.

For example it is somewhat surprising, that mathematics, medicine and neuro-computation years ago begun simultaneously but differently to use and to interprete the physical term 'projection'. Reasoned by wave interferences in opposite to non-mirroring, mathematical vector- or matrix 'projections' (X => Y) a physical projection mirrors the image between source and screen in general (X^T) => Y . Neurophysiology speaks of 'projective' trajectories and maps. Known nerve maps, independent if they are feature-specific, anatomically or abstract seem to have mirroring properties. Since 1992 we know, that a physical, wave-interferential approach can bridge this gap, and many other gaps too.

The lecture[1] will discuss basic ideas related to timing and wave interference, the state of research, some examples and an application. Supposing wave interferential interfaces, chips for human brain enhancement are discussed.

Basic Idea

In nervous system we find positive, spiking pulses with amplitudes near 100 mV, milliseconds wide, with velocities between 5 µm/s and 120 m/s. The geometrical impulse length (product between velocity and duration) vary typically between 50 µm and 50 mm [5].

All information inherent a nerve impulse is only the time point the first derivative crosses zero. To change physical distances, delays or arrangement in space means for net models, to vary the most significant value, to destroy the information.

So state machines or suggestions of pattern matching networks are dangerous to model pulse nets, because pulses can't have whether states nor levels.

Assumptions

By analogy to [11] we make following assumptions:

a) A wire in nerve system has a very limited velocity (µm/s...m/s).

b) A nerve pulse has a typical geometrical pulse length in the range µm...m (geometrical wave length: product of pulse velocity and pulse duration).

c) The nerve fibre acts like a *wave conductor* with length to diameter dependent delay, not like an electrical node.

d) An electrical representation of nerve is a set of colored delay lines within a 3D-space.

e) We suppose networks with distributed parameters in general, no wire is without delay.

f) Short impulses and low velocities produce geometrical puls lengths in the range of µm to cm.

g) To calculate *meeting points* of pulses we have to calculate the nerve system in spatial, 3+1-dimensional representations.

h) While the possibility to excite a place is as much higher, as much closer *in time* different waves or impulses from different directions appear, we will ask for locations of superimposition or interference.

i) A nerve cell body has a non-zero size. Where is one

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cell body, there is not another. Thus, any signal flow bridges distances and needs (incremental small) *delay time to reach any destination*.

j) Following Hodgkin/Huxley, nerve velocity (and delay) is influenced by background (glia) potentials. Thus interference locations are influenced too. Observation of special cases result in the possibility to zoom and to move projections [8-11].

k) Like a tree a nerve branches out. Thus (ionic, molecular or cellular) information carriers, which we shall call 'impulses', split at possible places into very different directions and they meet again at other places (wherever these places can be located in nerve).

l) Whether we consider the flow of chemical substances (e.g. leucin, acetylcholesterase, mitochondric containers etc.) through nerves, or ionic mechanisms (Na+, K+), or the measurable electric representation of various transportation mechanisms, the nervous system can be seen as a system of different channels or an inhomogenous system of wires in real space dimensions and with real signal delays between computational nodes carrying different signals with different velocities (*colored flow graph* [11]). Gates stop or modify the information flow at certain places (i.e. at synapses). Each mechanism carries a time function with a certain velocity and a certain flow direction. Because different mechanisms work together, different signal carrier types ('*colors*') flow with different velocities on a nerve. Independently of their type, signals can only go discrete ways, they only can flow through the nerves shape.

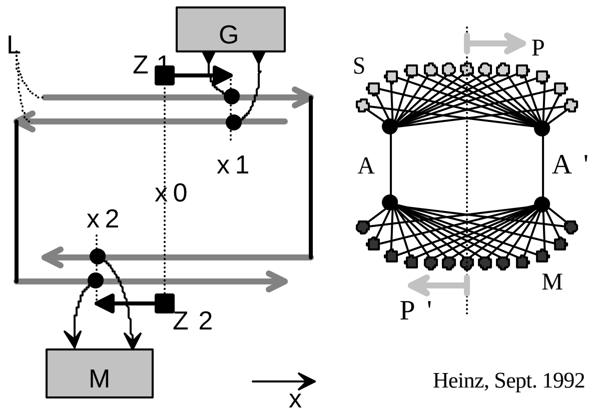


Fig. 1: Technical and biological representation of a two-channel, one-dimensional interference circuit [5] - basic invention producing mirrored images

m) Neurons without axons, dendrite to dendrite or axon to axon coupling between nerves (Crick/Asanuma) suggest the idea of nerve system as inhomogeneous wave space (neuropile) with soft synaptical influences only. We will try to avoid the discussion about the locality of pulse excitements within the nerve cell.

n) We suggest, that a lot of information flows parallel through nerves. We have to observe wave front directions.

o) By analogy to so called 'neural networks' we use comparable circuit structures. But we will avoid a state-machine like pattern processing of data introduced by McCulloch/Pitts.

Foundations

A nerve interaction has not only a Hebbian description, suggesting weights and levels. It is well known, that nerves superimpose pulses in several ways, see for example [21]. Behind the addition of values the self- and cross-correlation in time plays an important rule. Dependent of diameter, pulse velocities differ in nerve, from 120 m/sec on long axons to cm/sec in dendritic trees. So it seems, a nerve model has to imply delays behind weights [5, 6].

While neuro-computation before asked the question: "What is the function? (of a gate)" the papers [5, 6] suggested a new quality, asking: "Where is the location?" (of maximum interference).

We know different mechanisms in nerve. Behind dendrite to dendrite and axonal to axonal couplings we know nerves without axons or syno-synaptic controls. We know the mystique functions of glia-cells. Specific constellations between nerves seem to ask for the rule played by nerve cell soma. Neuro-computational models imply the rule of soma with a 'location of decision' whether to pulse or not. This seems not valid in a lot of cases. Binding the terms axon and output, comparable to bind dendrite and input, seems dangerous. There are lots of experiments showing nerve is exciteable in different ways, see [4], p. 336 or [21] for all. So the question to create macromodels appears hard.

The invention of radial basis functions [3] did not solve the problems. 'Radial-basis-function (RBF) networks were introduced by Broomhead and Lowe in 1988. The RBF-network model is motivated by the locally tuned response observed in biologic neurons.' They can be found in several parts of the nervous system for example in the auditory system selective to small frequency bands or in visual cortex sensitive to bars orientation. (Palm, NC2000).

State of Wave Interference Research

New Basic Functions of Nerve

By contrast, in [5] we find descriptions of simple wave interference networks, solving comparable RBF tasks in a physical manner by structural analogy to biological nerve networks. Later occured a generalization, so in [11] we find them again as 'dynamic basic functions of neural trees', solving tasks like code generation, code detection, level generation, frequency or phase detection or generation. The phase detection method of contralateral signal flows over an AND-gate field is known since years for femtosecond- delay measurements. The idea by Jeffress (see Konishi [16]) is rather old. But nobody has tried to analyze general properties for years. In [5, 7] we find first analysis, showing a lot of interesting properties of such so called 'interference circuits'.

The foundamental idea of interference circuits is, supposing signal flows over lots of ways between sender and receiver the signal energy maximizes at locations of interference, characterized by the so called 'characteristic delay vector' *M*, carrying delays of the configuration. By analogy to current weights w_k, we assign the delays to the current input structure, see figure.

(1) $M = \{\tau_1, \tau_2, ..., \tau_n\}^T$

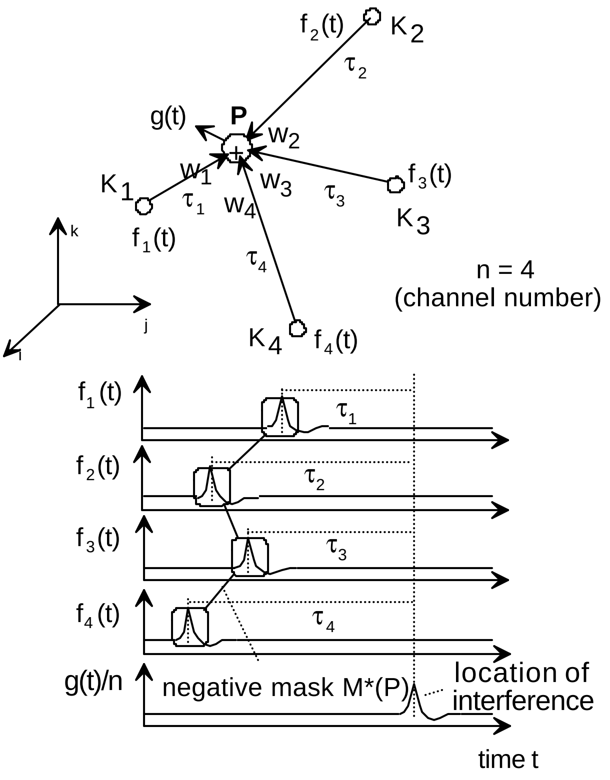


Fig. 2: A receiving, negative delay vector *M of *P***

The term 'current' is used because of the possibility, the same neuron structure can carry in the next minute a contra-directional signal flow, changing inputs to outputs and visa verse.

Coupling two neuron layers together, the masks add in time. Maximum interference occures, if all paths have equal delay τ.

(2) $M^* + M = \tau\{1\}$

Asking for relations between two, closest coupling neurons, we find, that the receiving mask *(M*)* is the negative (a constant τ neglected) of the generating *(M)*.

(3) $M^* = \tau\{1\} - M$

New Age for bio-technical interaction?

In the very first work [5] a nice abstraction was given, forgotten for years. The paper proposed a 'mesh analysis tool' to solve complex 3d-delay circuit structures by computer programs.

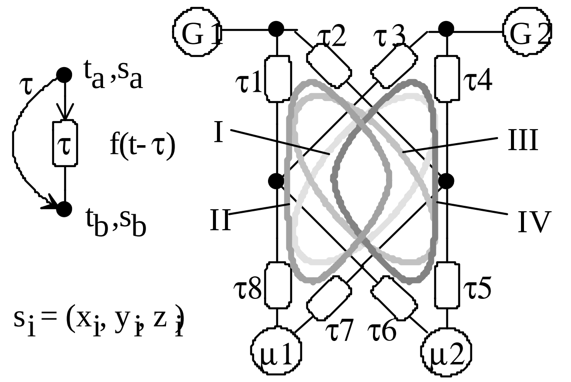


Fig. 3: 'Wild', 3-dimensional delay arrangements [5] offer a new age in digital signal processing

In difference to known tools (see Zell for all) the aim is the analysis of complex delay circuits with the only intention to get informations about interferences in 'wild' delay arrangements. Applications we can find in several directions, from bio-technical interaction, over digital signal processing to ultra fast image recognition, supposed delay lines are metallic wires, and the wave field is of electrical nature (RADAR). Supposing wave interferential interfaces, chips for human brain enhancement are discussed in [5] (implantable PC, memory, handy...).

A Key Experiment

Before starting wave interference research in 1992, the relevance of assumptions for the body was to prove. A simple experiment can be done using a two channel EEG-device[2]. With a double-ring electrode we can stimulate the thumb while we observe the time functions at two nerves (n.medianus and n.radialis). Relative delay

[2] http://www.gfai.de/www_open/perspg/g_heinz/intro/iwk_ilm.htm#daumen

differences in dependence of the thumb position in the order of 0.5 ms were observed [7]. Supposed any detecting field with a velocity of for example 10 m/s we find, that interference locations vary dependent by thumb position by s = 5 mm.

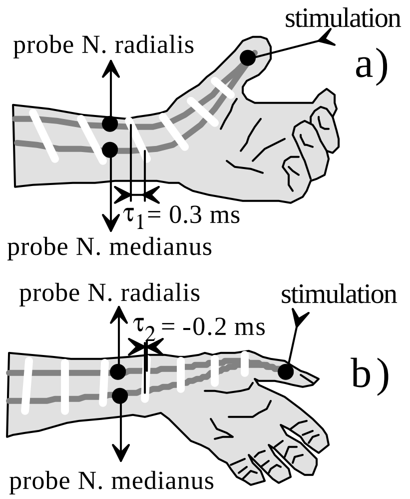


Fig. 4: Thumb-experiment exploring delay differences between n.radialis and n.medianus in dependence of thumb angle [5], 1993, [7], 1994

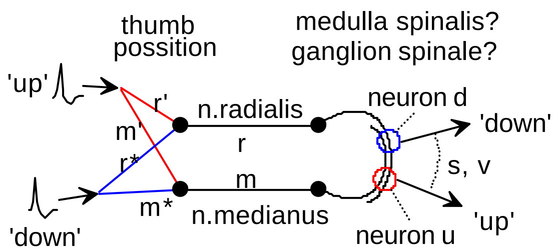


Fig. 5: Interpreting thumbs' delay differences. Dependent of the position, a related neuron 'd' or 'u' gets a maximum interference value

Experimental field PSI-Tools

Developing a simulator for simple interference circuits called Parallel and Serial Interference Tools (PSI-Tools) [8] it was possible to explore interferences in space. While 1-dimensional (2-channel) interference circuits can be explored by hand, we had no chance to explore the second and the third dimension. Behind explorations about cross interferences appearance we could observe parameters in dependence of channel number or geometrical and physical properties. The developement of PSI-Tools proceeded in two directions: at the one hand, technical interests stimulated the *reconstruction* of the generator space - usefull for developments like acoustic cameras.

At the other hand now we could observe *projections* into a detecting field. By the way we were surprised, that PSI-Tools reconstructs the wave space in form of wave movies[3], we did not know, that our simulator reproduces physics in the last detail. Now it was possible, to study wave interferences within fields using forward and backward time directions. Things are not simple. Independent, we calculate the interference integrals forward or backward, or save the maps forward or backward, a lot of interesting physics could be observed.

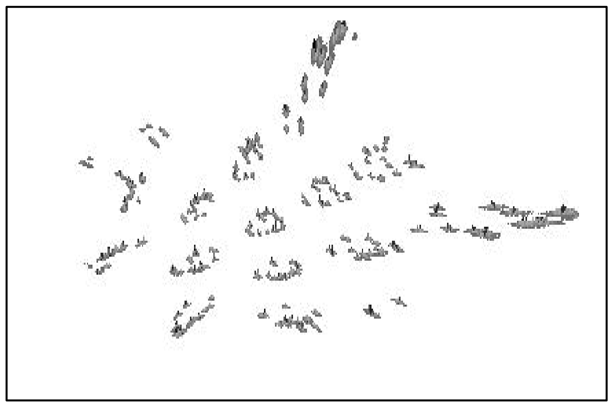


Fig. 6: Cross interference residua around a self interference figure. 3-channel projection of a pulse stream, produced by firing neurons arranged in form of a 'G' (PSI-Tools, 1996)

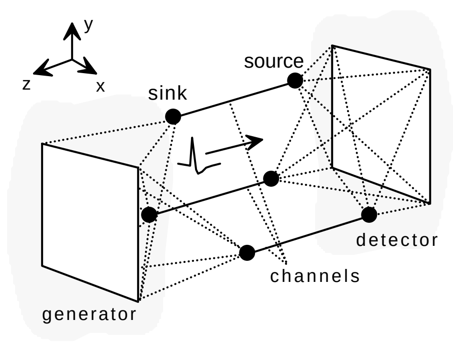
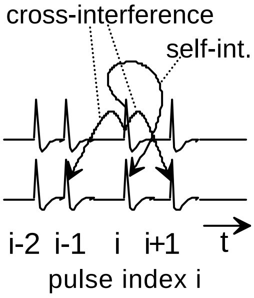


Fig. 7: Experimental field PSI-Tools. Black pixels of a bitmap act as signal generators, producing time functions. Channel sinks sum up all time functions of the generator field. Source points send the waves to detector field(s). INI-files save velocities, co-ordinates, time-functions of black pixels.

In case of reconstruction, the so called *pseudo-wave*

3] see http://www.gfai.de/www_open/perspg/g_heinz/sim/simdemo.htm *space*' characterized by reward flowing waves was found. As one of the most important features, PSI-Tools was able to calculate the reconstruction (generator field) or the detection (detector field) by a simple inversion of the time direction of time functions. Thus, the over-conditioning problem, suggested in [5] was studied using 2-dimensional planes and 3 or 4 pulse-transmitting channels. Exploring cross interferences, we were able to analyse *Lashley's holographic memorization* [8-11, 18] as a general property of interference nets.

Dependent on the cross-interference distance (the geometrical distance between pulse waves on the field) we find residues of interference, reproducing the projection at several other locations.



Fast Axons

Using limited channel numbers (2...128), PSI-Tools allowed in three dimensions the inspection of interference spaces for several arrangements. We found mirroring, moving and zooming projections produced by variations of velocities; relations between pulse duration, wave length and local interference maxima were explored [8-11].

A main result of these works is a deeper understanding of velocity proportions in nerve system. In various regions of neocortex neuropiles couples over axons together. Axons are white, isolated by a myelin shape. This isolation allows to carry signals with very faster speeds until 120 m/s.

Observing 'channeled circuits' we found, that velocities in field regions (generator, detector) have very hard bounds. Reasoned by zooming effect for example it is not possible to use velocity ratios greater 10 between generator and detector. Because of parametric tolerances (moving) the field velocities should not have a to high velocity at all. But channels connecting the fields can be infinitly fast. In nature these are long, myelinated axons.

The I² abstraction

Describing wave interferences, all the time deterministic interpretations seem to demand a model for the replication of nerve function. Trying this, the paper [5] demonstrates a mystical situation. A threshold model is introduced but not used. It costs years, to find valueable abstractions. In [11] for the first time a higher abstraction level is reached. With the term 'interference integral' (I²) and 'effective value' of the I² the dependency of nerve models disappears. Hidden behind the I² abstraction deterministic attempts to interprete interference circuits ended, the hope to find possibilities to solve any XOR-separation problem (Minsky/Papert) with interference networks was lost:

(4) $$g_{eff} = \sqrt{\frac{1}{T}\int_{-T/2}^{T/2} g^2(t)\,dt} \qquad \text{(interference integral)}$$

(5) $$g(t) = \Psi_{k=1}^{n} w_k\, f_k(t-\tau_k); k = 1...n; \Psi = \Sigma, \Pi, ..$$

g(t) is called the superimposition or interference function, g_{eff} is the effective value of the I². Introducing weights w_k for the superimposing time functions f_k we find a structural relation to McCulloch/Pitts neurons.

McCulloch/Pitts Mistake

... was the great challange for computer technology. Drawing pyramidal cells for gate symbols they applied Boolean algebra. But, instead of universal time-functions they introduced states (that means discrete time points) - an old idea to couple 'programs' with 'hardware', but a dangerous mistake for developements in neuro-computation for a long time.

Pain and Cramp Models

If cross interference distance become shorter, the residua overlaps more and more with the self-interference figure. Analyzing this so called 'cross interference overflow' we found pain-like behaviour [11] or cramp-like [5] excitement. Studying moving and zooming projections [5] we got imaginations of glia-function, the contents of EEG-data streams[4] and the task of local field potentials for informatics of nerve system. The dynamic basic functions of neurons offer addresses and contents of serial or parallel interference data, of 'bursts' observed during invasive electrode experiments [5]. A view into physics of wave experiments allowed an examination of parameters for transmissions of 'pictures of thought' between cell assemblies using spikes [10].

The Optical Subspace

The early beginning [5] offered a valuable set of derivatives. We suggested that waves can be formed in discrete manner over bundles of wires or a 'neuro-pile'. Connecting parallel flowing pulses with a virtual 'wave front'-line, we can observe the wavefront behaviour at velocity steps, at corners, over smooth spheres, at reflecting planes. By contrast to optical waves in free space wires define the flow direction of time functions, the wave front direction is independent of the direction of the bundle of wires. Behind the possibility to derive equations for diffraction and reflection we found reflecting diffraction and diffracting reflection. Setting the angle between wave direction and wires direction to 90 degrees,

[4] see also http://www.gfai.de/www_open/perspg/g_heinz/eeg/ghmovies.htm

the equations reproduce the optical equations. So long no problem. But the experiments answers a further question. What is the subspace, and what the metaspace? So it seems, that experiments in the field have some value also for the development of science.

Application Acoustic Camera

Although modern industry nations founded their economy on scientific progress, nobody likes to give research grants for dangerous projects. Thus, wave interference technology is up to now no point of discussion. More interesting are projects of industrial research.

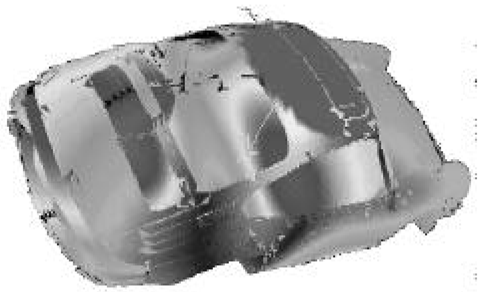


Fig. 8: Acoustic map laid out in a car's shape, experimental works

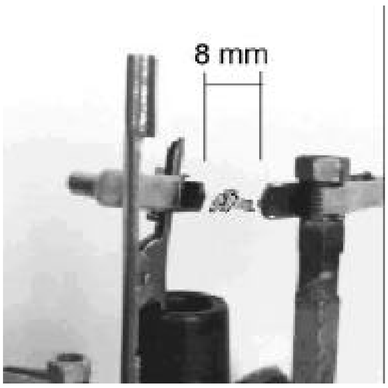


Fig. 9: Acoustic image of electric flash. A high speed movie reproduces the explosion with 50.000 img/s

In 1995 we started the development of a specific acoustical imaging technology[5] Basing on the Interference Transformation a fast algorithm was developed to compute acoustic maps in the time domain. By anlogy to optical projections we solve the time-backpropagating reconstruction. First high-speed movies up to 200.000 images per second could be produced necesarry for Ultrasonic analysis. Typical measuring distance is 1...200[6] meters, object dimensions vary between 12 cm (shaver) and 68 m (train). We support spectral analysis and line scans. An acoustic image is an overlay between an grayed optical photograph and an colored acoustical map in sound-pressure units (dB/Pa).

Within a year the possible distances could be extended to 200 meters. Observing a flash we produced the smallest acoustic image and a high-speed movie with 50.000 images per second. Latest development is the development of an imaging system for far distances. In the minute we are working to improve the image quality and to implement a 3d-mapping technology using VRML/DXF files for cars.

Conclusion

Table 1: Some typical properties of PN and IN

Pattern Network	Interference Network
learning:	
modify weights	modify delays
information carrier:	
level	relative time points
abstraction level:	
discrete time step	continous in time
layer to layer transfer:	
non-mirrored	mirroring only
adaptibility:	
artificial	moving, zooming
number of layers:	
typ. 2...3	no bounds
selforganisation:	
artifical	extinguished waves by refractoriness
information flow:	
clock driven	event driven
spherical order:	
matrix norm	3D-model

As an alternative to pattern networks we investigated the role played by delays coupled to nerve lengths and distances in physical wave spaces. We discussed some basic ideas related to timing and wave interference, the state of research, some examples and an application.

[5] for more see http://www.acoustic-camera.com or http://www.gfai.de/www_open/perspg/g_heinz/akkam/index.html

[6] http://www.gfai.de/www_open/perspg/g_heinz/akustik/strasse/outdoor.htm

Supposing wave interferential interfaces, chips for human brain enhancement are a possible perspective (implantable PC, memory, handy...). Pulsing wave interference networks (IN) have several very different properties by contrast to pattern networks, see table 1. One of the most interesting properties of INs is the general feature to generate mirrored projections, known in the nervous system at several places. Interference networks model locally 'tuned response characteristics' on a physical level., characterized by structure-behaviour analogy. The lecture gives an overview about the own results of researches in the specific field relative to specific neuro-computational research directions.

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