# AN INVESTIGATION OF 'PICTURES OF THOUGHT' PROPERTIES OF PULSATING, SHORT CIRCUIT NETWORKS IN THEORY AND SIMULATION[1]

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## ABSTRACT

Throughout the nervous system we find 'projective' fields, 'projective' tracts and mirrored 'projections'. We shall try to calculate such projections using nerve pulses in physical dimensions. By careful control of the parameters, mirrored pulse interference projections can be simulated. We find overlay, interference overflow, and moving and zooming effects. Neural data addressing appears in short-circuit connectivity. Introducing new, physical basic functions of a neuron, bursts can be identified as neural addresses. A physical interpretation of pain is introduced. The paper offers a wave-theoretical approach for calculating the behaviour of short-circuit networks, trying to avoid reference to synaptic weights.

## 1. Introduction

Phenomena like pain, memory traces or moving dreams, that are said to be higher functions of the nervous system are well known. For years science has been trying to find an theoretical entry point for a deeper understanding of information principles of pulsating nerve systems. We know from anatomy and physiology that there are specific 'projective' fields where we find mirrored projections (Penfield 1950, Knudsen 1987). In order to understand things in physical detail, we need to understand how to combine short-circuit connectivity with directed data addressing, *i.e.* how to combine an understanding of pulse wave expansion in neural space with that of discrete excitements of single neurons *f.e.* to control a single muscle.

I shall follow a different approach from those of McCulloch/Pitts 1947 (published in Anderson 1990). In contrast the model draws on *physical relations* between space distances and wiring delays and on co-ordinates in space dimensions.

A simple idea was proposed in 1948 by Jeffress, see Konishi 1993, who conceived an circuit[2] to localize sound sources. His idea was, to use phase differences between the two ears to excite a neural chain in opposite directions. Is it possible to translate this idea to interpret mirrored projections in the nervous system? What theoretical background is necessary to calculate projectivity in wiring systems?

The first task was to ask what are main differences between neural and optical projection systems. An investigation of wave propagation over dense bundles of wires (Heinz 1993) has shown, that *optical space* can be seen as a *subspace of neural space*, in which the direction of wave propagation can be independend to the wave front. Optical refraction and reflection formulas have found to be sub-solutions of neural terms. So neural wave space research is more complex.

A second task is, to investigate the role played by space related delays in relation to medial velocities and geometrical pulse wave length and pulse distances (reasoned by neuron's refractory period). Has the length of some wires, the delay while pulses running on them and the pulse density any relation to the function of the network? And what is the influence of surrounding areas of the nerve tissue?

Starting the research, in 1992 we tried to study what kind of connectivity in nervous system exists with an experiment (Heinz, 1994, Ilmenau). The thumb was stimulated and the response of two nerves (n. medianus and n. radialis) was measureded with an electro-encephalograph (EEG). When the stimulating position is within the anatomical field of both nerves, pulses appear in parallel on both nerves. This result seems to be catastrophic - how is the brain able to recognize the thumb as the information source? Changing the angle of the thumb, we found time differences between impulses. They differ according to the thumb position with the wave front direction. So, the experiment seems to show something: First, that every excitement walks along all possible paths up to the brain. And second, that time differences between impulses on different nerves are an observable differentiating property that - behind other mechanisms - might be coding the position.

How might one detect where an excitement is coming? To ask for interpretations, we use a simple model, consisting of two dense neural fields connected via some axons, whereby every excitement can reach all connecting axons, Fig. 4. The question from a physical point of view is, to find how both fields can communicate in terms of projective wave space. The interference model we shall investigate consists of pulse-like time functions, length proportional delays in terms of space distances and a simplest, additive soma model (without synaptic weights or memory effects). We will discuss some interesting properties, dependencies between space, time and code. For simplification, and to be able to understand the results clearly enough, both neural spaces are *abstracted to be homogeneous delaying spaces* with delays proportional to distances.

To study the role played by pulse wave superimposition and spherical configurations in general terms and to simulate functions of thousands of such neurons of a simplified Hodgkin/Huxley-type (1952), we will start with some theoretical deductions that are necessary to develope a calculation technology and a special simulator for wave field experiments.

## 2. Time Functions in Space, Mask of a Location

Suppose, that an exciting impulse of any neuron moves into a multi-dimensional spheric space with a small velocity in all directions. Suppose further, that a neural soma receives waves from $n$ different sources. The sum of interferences $g(t)$ of $n$ delaying time functions $f_k$ that are able to excite a neuron is at time $t$ and location $P(x_0, y_0, z_0)$:

*(1)* $\quad g(t) = \sum\limits_{k=1}^{n} f_k(t - \tau_k), \quad k = 1...n$

The **_interference integral_** of $n$ by $t_k$ delayed time functions in a time interval $T$ (pay attention to the positive time axis for an inverse mask) may be

*(2)* $\quad y(t) = \frac{1}{T} \int\limits_{-T/2}^{T/2} \sum\limits_{k=1}^{n} f_k(t - \tau_k)\, dt, \quad k = 1...n,$
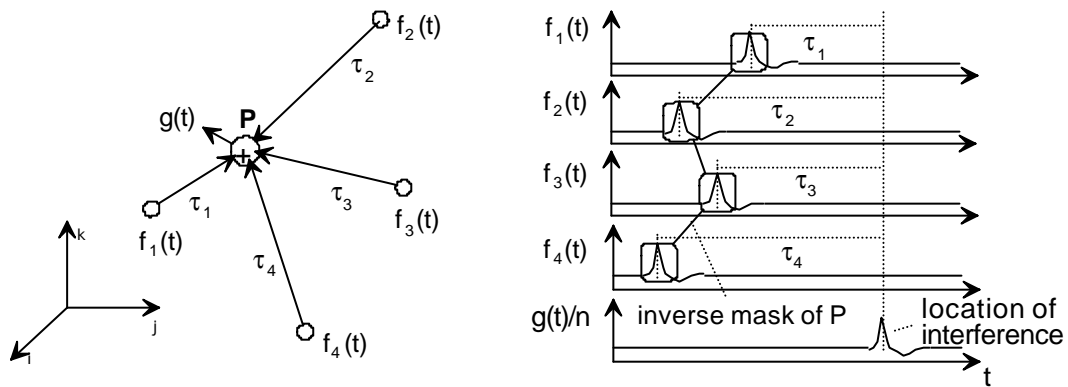


**Fig. 1:** Example: time function $g(t)$ of point $P$ summatig four sources $f_k(t)$. Maximum interference occurs in $P$ if functions $f_k(t)$ appear pre-delayed with the inverse mask $M$ of $P$ (drawn). Note, that the velocity in neural space is not infinite

The **_effective value_** by analogy to electrical systems is

*(3)* $\quad y_{eff} = \lim\limits_{T \to \infty} \sqrt{\frac{1}{T} \int\limits_{-T/2}^{T/2} \sum\limits_{k=1}^{n} f_k^2(t - \tau_k)\, dt}, \quad k = 1...n.$

Note, that times and delays are not integers, as introduced by McCulloch/Pitts. For **_inhomogeneous spaces_** (nerve cell assemblies) a measurement of delays $t_k$ is necessary. For **_homogeneous delaying spaces_** there exists a well known correspondence between distances *(dx, dy, dz),* velocity $v$ and delay $t_k$ over the space distance

*(4)* $\quad \tau_k = \frac{1}{v} \sqrt{(x - x_0)^2 + (y - y_0)^2 + (z - z_0)^2}$

The **_mask M_** of location $P$ in relation to **_sensing_** points is the vector of delays

*(5)*  $M = \{\tau_1, \tau_2, ..., \tau_n\}$

where *n* is the channel number. The ***mask M\**** of any location *P* in relation to *feeding* points is the vector of delays

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

with *{1}* as unity vector and $\tau$ as total delay between source point and interference point. In abstraction the equation is sometimes simplified to *M\* = -M.* Note that each point *P* in space has a single, characteristic mask if space dimension *D* is equal the channel number *n*,

*(7)*  $D = n - 1$.

## 3. Some Basic Functions of a Neuron or a Neural Assembly

Suppose a simple interference circuit, consisting of any code source point with an input time function *x(t)* and a summation point, creating an output *y(t)*, see Fig.2.

*(8)*  $y(t) = \theta(x(t - \tau_i) + x(t - \tau_j) + x(t - \tau_k) + ... + x(t - \tau_m) + bias$
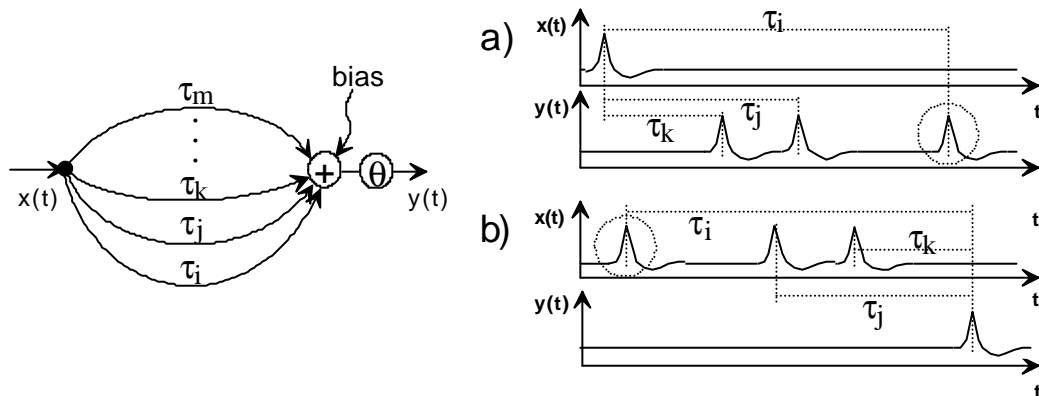


**Fig. 2:**  Equivalence circuit of a neuron with basic functions (example) for
a) code/burst generation; b) code/burst detection

Depending on the bias and the threshold function $\theta$, the neuron has different possibilities to answer any input function. Some special cases may be of interest. We use normalized time functions and weights. For an experiment, a simple ramp-like threshold function is used in the range 0 to 1, $\theta(\zeta)/d\zeta = 1$.

**a)** In the case of a large bias (boolean OR-type) each single input impulse appears delayed at the output. So I call this case ***burst generation*** or code generation, Fig. 2a, 3a.

**b)** Using a small bias near the inverse sum of weights $g_i(t)$ (boolean AND- type) all

inputs of the adder have to have the level 'one' to reach any output. This case is called code or ***burst detection***, Fig. 2b, 3b.

**c)** For a bias of zero, with a sum of weights near one and small delay differences, the circuit produces floating or ***gating potentials***, Fig. 3c.

**d)** If the receiving mask differs from the incoming burst, according to b) the neuron is not excitable, the mask acts like a key. So neurons, densely connected together, can not excite each other. I call this case ***neighbourhood inhibition*** (not drawn).
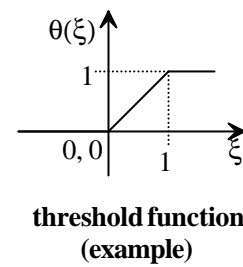
To understand role d), a special case seems to be helpfull: Suppose two symmetrical positioned neurons, connected at certain places in a plane and both neurons having a mask *M*. To be exciteable, a neuron needs to have a mask *M\* = T - M,* the so called inverse mask. So, the firing of one neuron is in general not able to interfere in the soma of the other, because both masks are identical.
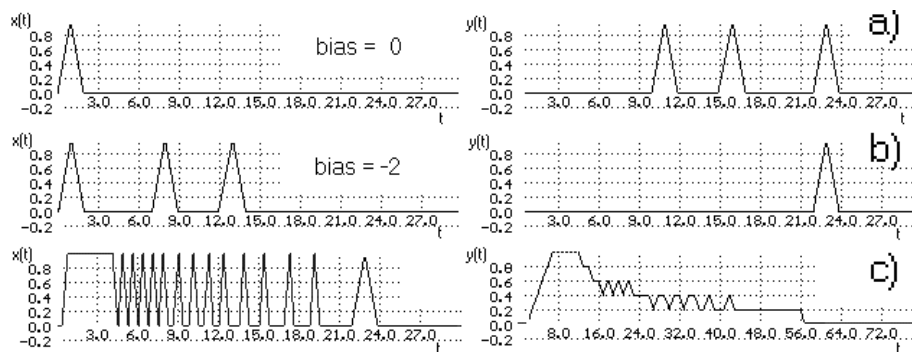
**threshold function (example)**



**Fig. 3:** Testing neural basic functions (example). a) code generation: weights $g_1 g_2 = 1$, bias = 0, delays = 10, 15, 22 samples; b) code detection: like case a) but with bias = -2; c) gating potential: six inputs, all weights = 0.2; delays = 1, 2, 3, 4, 5, 6; bias = 0, (x-axis incomplete drawn)

## 4. Two Neural Assemblies Connected via some Axons

Cortical neurons have on average thousands of synapses. Neural space is full of short circuits (Crick 1988). Suppose two neural assemblies connect via some axons, Fig. 4. The left may generate some impulses. Waves interfere in the right. For simplicity, neural spaces may have delays proportional to distances (homogeneous space). The delays $t_{ij}$, $t_j$, $t_{jk}$ depend on *distances in space only*, $i = 1...m$ (firing neurons)*, j = 1...n*

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[31] Experiments with 'Neuronet', Oct. 20, 1994. Neuronet: Gunnar Schoel, Peter Puschmann, FHTW Berlin

(n: channel number), $k = 1...p$ (detecting neurons). A signal crossing this circuit runs along all the different paths. Points of high interference are located in the opposite field, the circuit produces mirrored projections comparable to optical projections, but different to non-mirrored synaptic projections. The higher the multiple self correlation of a signal is, the higher is the effective value of the interference integral.

By the author 1993-1998 different properties of this circuit were studied. Some papers can be downloaded via internet[4]. It seems to be of some interest, that while *transmitting channels* can have *high velocities* or delays near zero, *field velocities* have by contrast to be *very slow* for sharp interference locations. The *slower* is the neuropile, the sharper is the interference localisation! In the most following simulations delays of transmitting channels are supposed to be equal and zero.
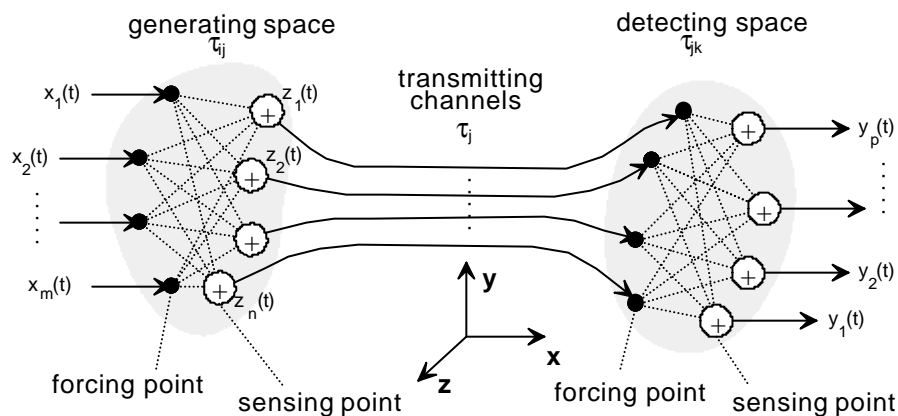


**Fig. 4:** Two dense, homogeneous assemblies connected via axons - the basic interference circuit. Axonal delays may be unique, assemblies can have different speeds for this first investigation.

In reality we can find long axons myelinated to encrease pulse-velocities. Observing the circuit of Fig. 4, it seems to be identical to neuroscience's synaptic models. What is the difference? Supposing *equal* synaptic weights, any such circuit is not able to transmit information without pulses. But using pulses, this circuit works inverted: now it can *only* produce **mirrored** projections instead of the **non-mirrored** projections of the synaptic types. Because analytical solutions of such interference calculations were not available, a special software PSI-Tools[5] (PSI: *parallel and serial interference*) was developed to calculate the wave fields. It uses modified equations 1, 3, 4, 5, 6 in a basic algorithm called **H-Interference Transformation** (HIT).

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[4]  http://www.gfai.de/www_open/perspg/heinz.htm

[5]  for more see http://www.gfai.de/www_open/perspg/g_heinz/intro/intro_e.htm

## 5. Pulse Interference Projection via -Reconstruction, Over-Conditioning

Two tasks are of interest for the interpretation of time functions flowing through transmitting axons (channel data stream):

**a)** For technical purposes, the (non-mirrored) ***reconstruction*** of a generating field is demanded. It is realized by back-propagation of the time-functions

**b)** In neuro-simulations the (mirrored) ***projection*** into a detector field is of interest.

Reconstruction and projection are two sides of one coin. Using comparable spherical coordinates only the ***time direction*** of channel data stream decides between the two (Fig. 5c, 5d). Neural *projections* share the same problems as optical projections. Depending on the degree of over-conditioning (channel number versus space dimension), interferences decline the more one moves away from the central axis. While three channels reproduce all self interferences in 2D-space, higher channel numbers suppress progressively cross interference points. So the projection in Fig. 5d) is over-conditioned by one channel. On the other hand, reasoned by perfect delay compensation any reconstruction Fig. 5c) reproduces the image without image distortions and over-conditioning problems in general.
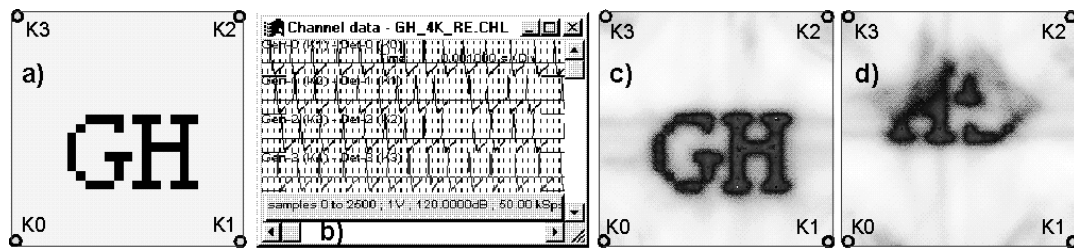


**Fig. 5:** Reconstruction and projection of an over-conditioned system ($N = 4$, $D = 2$) a) generating field with firing neurons as black pixels (channel origins K0...K3); b) channel data stream (four channels); c) reconstruction of the generating field appearing with time-reversed channel data; d) mirrored projection in the detecting field (Heinz 1996)

Parameters: field sizes 9 x 9 mm; velocity v = 3000 mm/s; average pulse distance 3 ms ~ 9 mm; 361 x 361 pixel; time function length 1600 samples = 80 ms; geom. pulse width = 0.1 ms ~ 0.3 mm; generator and detector field are set to identical co-ordinates; channel sample rate 50 kS/s

Using PSI-Tools, it is possible to synthesize the time functions. Firing excitement positions are drawn on a field (bitmap, Fig. 13 a) with firing neurons as black pixels, neurons fire one after the other or close together depending on refractory period. Channels are located at certain positions in space with starting points in the generating space and with end points in the detecting space.

## 6. Some Parameters of Pulsating Interference Systems

The *geometric pulse width* $l$ determines the sharpness of a pulse projection, it is defined by peak time $t_{peak}$ and velocity $v$,

*(9)* $l = t_{peak} \, v$.

Cross interference can occur, if a next wave $i+1$ comes into a field, while a wave $i$ has not lost the field. A smooth indicator is the *cross interference distance d* with the pulse distance (refractory period) $t_{pause}$ ,

*(10)* $d = t_{pause} \, v$.



To avoid cross interferences in general, the larger the space dimension, the greater should be the cross interferencee distance, see Fig. 6.

To get detailed projections without *over- and under-conditioning* effects, there is an optimum number of channels $n$ related to the wave space dimension $D$

*(11)* $n = D+1$.

For periodic time functions the suppression of cross interference is only possible using very high channel numbers. But with low channel numbers interference circuits only work using spiking time functions.

> Example: For an axonal refractoriness of 20 ms and average detector velocity of 0,5 m/s what is the maximum size of the self interference space? With a cross interference distance $d = t_{pause} \, v$ it is approximately 10 mm. This is the maximum region of topologic projections without cross interference pattern and without self-holography (see 'moving projections' = $d$).
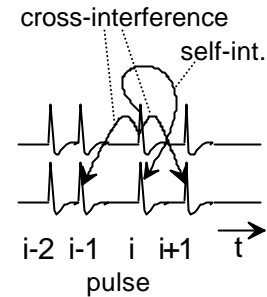
## 7. Cross Interference Overflow as Pain?

In some situations the cross interference distance becomes unbalanced, for example in the case of injuries. Generating neurons begin to fire with very high rates. Cross interference distances shrink, see Fig. 6. When the density of generating impulses is increased, more and more cross interferences appear in the detecting field - in physical sight an example for pain?

## 8. Projection Quality Depends on Distance

Is the relative distance between sensing and sourcing points relevant for a projection? To answer the question, we try a further experiment using PSI-Tools. Varying the distance '$a$' between source points and field produces different projection qualities. While near distances promote cross interference, high distances distroy the image, see Fig. 7.
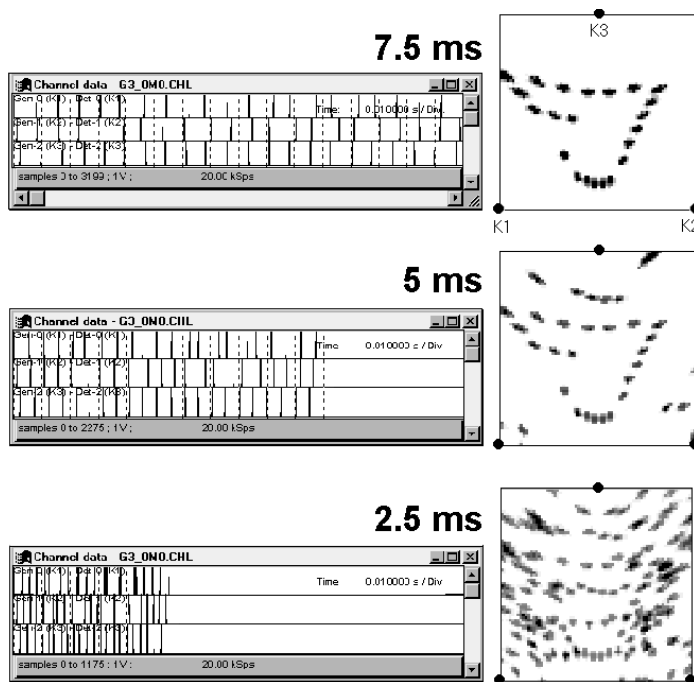
**Fig. 6:** Cross-interference overflow as a function of three different firing rates resp. pulse distances (average in milliseconds). Firing neurons of the generator arranged in form of the character 'G'; three channels feed the fields (K1, K2, K3)

Data: pulse distance variation 7.5 to 2.5 ms; field size 1x1 mm; velocity 200 mm/s; pulse peak ca. 0.1 ms ~ 20 µm; cross interference distance varies between 1.5 and 0.5 mm, channel feeding points located on the field
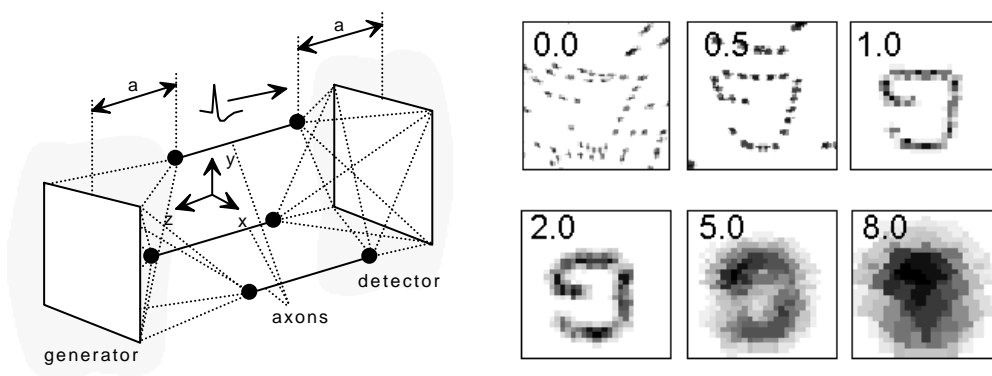


**Fig. 7:** Varying the distances between feeding points and fields, we find different projection qualities. Parameter is in mm.

Data: field size 1x1 mm, velocity 200 mm/s; pulse peak ca. 0.1 ms ~ 20 µm; average pulse distance (refractoriness) 4 ms, cross interference distance ca. 0.8 mm

## 9. Overlayed Projections, Topomorphism

In our imagination it is possible, to overlay images or impressions without problems. Is there a theoretical background for reproducing such behaviour? To test this, we overlay two channel data streams.

**Fig. 8:** Overlay of two data streams, generated from independent sources 'g' and 'h'
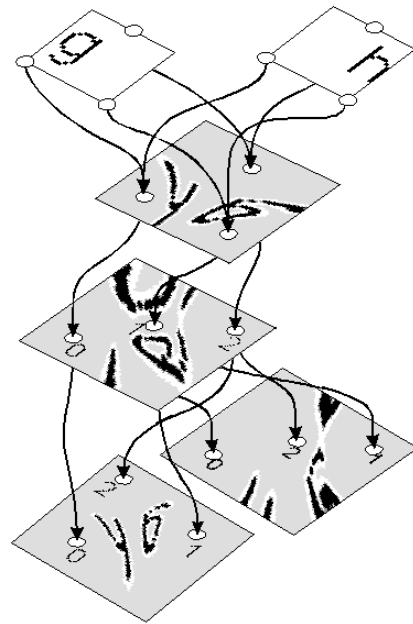
We suppose, that all channels have the same channel number and project into a comparable space or field. Using two generator fields, the firing neurons are arranged in the form of a '*g*' in the first and in the form of a '*h*' in the second. We add the generated time functions sample by sample and channel by channel. The projection into different detector fields shows, Fig. 8, that both generator images have been combined. If channel source points are moved in the detector field, the projection become distorted. But the projections of 'g' and 'h' maintain a ***topomorphic relation***. It is not possible to separate them.

## 10. Moving Projections and Floating Images

In our mind, imagination is closely linked to images, as the word imagination itself confirms. Our brain seems to be connected to the natural world of images, movement and sound. Abstract thinking with numbers, for example, appears as a hard task, if one tries to do it without the help of 'images'. Up to now, we did not know technical systems able to produce floating images or movies without using picture-series.

Suppose that one channel is delayed by a parametric change  *dt* of any connecting axon between generator and detector field. Then the interference locations change in such a way, that impulses meet each other at shifting locations, Fig. 9. So, images become 'floating' according to an amount of a single channel delay variation!

## 11. Zooming Projections

Over large areas of cortex one can measure weak glia-potentials, known as the EEG. In the Hodgkin/Huxley model any volume potential change varies the propagation velocity of a neural path. Let us suppose that the background velocity changes within all neurons in the detector space influenced by such a glia-potential.
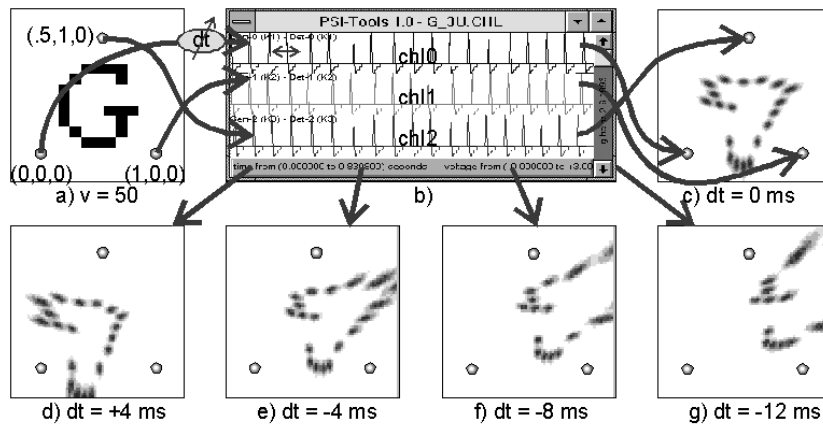
**Fig. 9:** Moving projection produced by a single delaying axon (chl 0). a) generator field; b) generated time functions; c)...g) detector field; c) no channel delayed; d) K0 delayed by 4 ms; e)...g) negatively delayed
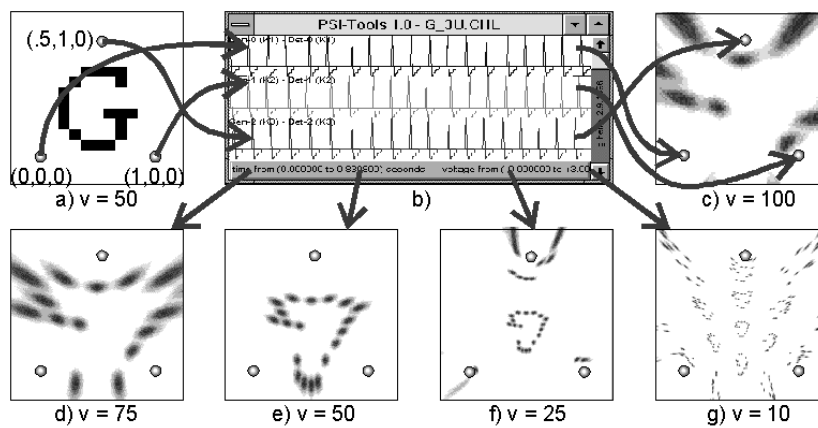


**Fig. 10:** Zooming and self holographic repetition. a) generator field; b) channel data stream; e) projection with identical field velocity v = 50; c) and d) zooming projections for higher velocities: f) and g) reduced projection sizes appear for smaller velocities in the detecting field

Data: field sizes 1x1cm; $v_{gen}$ = 50 cm/s; $v_{det}$ = 10...50...100 cm/s; average pulse width 1ms; pulse wavelength 0.1...0.5...1 mm; average pulse distance 20 ms ~ 1...10...20 mm; 10 kS/s

We find that velocity changes $v$ in the detecting field have a zoom effect on the projections, Fig. 10. From this viewpoint, EEG-probes can be interpreted as measurements of control potentials only, reproducing a mathematical difference between a memorised code, image or function and a real input.

## 12. The Neural Hologram (Pribram 1974)

Lashley (Lashley 1950) studied the formation of memory by lesioning various parts of rat brains. Large areas could be removed, but animals were still able to reproduce the learned behaviour.  Fig. 10 g) demonstrates such an effect. In case of low velocities $v$ or large field areas, waves come into cross interference in the field, because the  **cross interference distance** will become smaller and smaller. Wave $i$ interferes with followers $i+k$ and with previous waves $i-k$ of the other channels. A kind of holographic projection appears with reference waves coming from the other channels. We will call this effect '**self-holographic**'. Because every impulse has following and preceding waves, interference systems can be seen as self-holographic in general if delays between sourcing points are higher than the pulse-distances.

## 13. Burst as Neural Address, Communication over single Axons

Let us return to the basic functions of a neuron. We have seen, that a neuron or a set of neurons is able to produce a burst. We know bursts for example in the brain-stem (Langhorst & Lambertz 1992). To reproduce a single impulse it is necessary, to use a neuron having the inverse mask. For detecting neurons we use complementary masks.
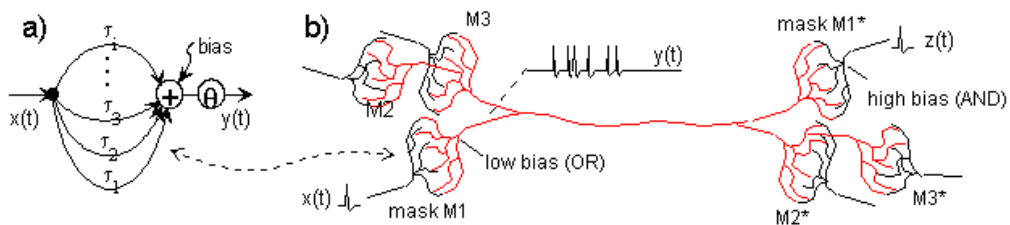


**Fig. 11:** Bursts as neural addresses to transmit different data streams on a single axon.  a) neural equivalence circuit; b) example arrangement

We find that each neuron on the left side (Fig. 11b) communicates  *only* with a special neuron on the right side. In the example, masks *Mx* and *Mx\** are inverse. The neuron with mask *M1* communicates with *M1\**, *M2* with *M2\** and *M3* with *M3\**. So bursts can be seen as neural addresses, allowing communication between different neurons across a single axonal path. It may be of some interest that this kind of communication works in both directions. Neurons can work bi-directional if the bias can be modified.

## 14. Conclusion

In difference to the McCulloch/Pitts approach we investigated the role played by delays coupled to nerve lengths and distances in physical space.

By selecting appropriate neurophysiological parameters, we studied pulse interference projections between two short-circuit neuro-piles without using synaptic weights. The parameters varied were *delays*, *velocities* of pulses on nerves, *impulse duration*, *impulse distance* and *co-ordinates* of feeding and sensing points in spherical arrangements.

Introducing the mask of a location we find new *basic functions of a neuron* or a neural assembly. *Bursts* appear as neural data addresses. Different neurons can communicate over a single axon.

Our experimental arrangement consists of two short-circuit subspaces connected via some axons. Changing the field velocity, projections begin to *zoom*. Modifying axonal delays counterwise, projections *move* across the detecting field.

Because every impulse has following and preceding waves, interference systems can be seen as *self-holographic* in general.

Fast firing into a field produces cross interference overflow suggesting *pain*. Varying the *distance* between axons and field changes the projection quality.

Projections can be *overlayed* and remain topomorphic. Moving the axonal source points over the field, projections become distorted and remain topomorphic too.

We find *mirroring projections* into a detecting field and *non-mirroring reconstructions* of the generating field. The difference between projection and reconstruction is to find in the time-flow direction of the time functions (channel data). The velocity diagram of a neuropile is important for the calculation of interference locations.

Unlike synaptic, neurocomputing networks (see Anderson 1990 for many), pulse projections appear *mirrored* in general. Prior to synaptic coding we have to suppose, that *delays code the neural space* in a second, different way.

Interference circuits show the role of myelinization of long axons and slow neuro-pile velocities in combination. While animals in biologic evolution need short reaction times for the chance to survive, pulse-propagating nets show the opposite: neural communication, data addressing and information processing couples to a *slow flow* of information in interference regions, to get *small* geometrical pulse-width. Only the connecting channels between generator and detector spaces (axons) can be infinite fast without influence on the information processing. Too in reality we find axons with myelin-insulation to propagate pulses with highest speeds over far distances.

Physical simulations of simple neural assemblies by network simulation can

reproduce different known, mutual higher brain functions. Suggested for a long time from neuroscience, pulse projections over axons show the possibility for an *image-like information processing* on uncertain, uniform neural subspaces with higher space dimensions.

If neural delays and codes depend on space distances, independent of weights and thresholds *neural functions are coded by* locations in space and thus by the geometry of the *neural tissue*. Space dependent delays appear as the 'coding institution', the code is the location, space codes the timing and so the nerval tissue codes the behaviour.

Interference locations bound to certain districts in space for the special case *channel_number = space_dimension + 1*. Over-conditioning problems appear if the channel number is greater the space dimension plus one. Interference locations become indifferent. Because nerve fibres have different velocities and caotic connectivity scemes, neural delay space is to suppose as higher dimensional. This allows interference locations for higher channel data streams without over-conditioning.

## Acknowledgements

## References

Anderson, J.A., E. Rosenfeld (1990) "Neurocomputing - Foundations of Research", *MIT Press*, *Cambridge*, MA, 5th printing

Crick, F., C. Asanuma (1988) "Certain aspects of the Anatomy and Physiology of the Cerebral Cortex", in: Parallel Distributed Processing. *Bradford/MIT Press* Cambridge MA, vol.2, eighth printing 1988, pp. 333-371

Heinz, G. (1993) "Neuronale Interferenzen", *GFaI-Report* 15.06.93, 300 S.

Heinz, G. (1994) "Modelling Inherent Communication Principles of Biological Pulse Networks", Gordon & Breach *J. Systems-Analysis-Modelling-Simulation*, vol.15, no.1, pp.151-158

Heinz, G. (1994) "Relativität elektrischer Impulsausbreitung", *Proc. 39. IWK*, TU Ilmenau, 27.-30.9.1994, Bd.2, pp.238-245

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Heinz, G., S. Höfs, C. Busch, M. Zöllner (1996) " Time Pattern, Data Addressing, Coding, Projections and Topographic Maps between Multiple Connected Neural Fields - a Physical Approach to Neural Superimposition and Interference", in: *BioNet '96, Proc. 3rd Workshop on Bio-Informatics and Pulsprop. Networks*, Nov. 14-15, GFaI Berlin, pp.45-57

Heinz, G. (1998) "Wave Interference Technology - Übergänge zwischen Raum und Zeit", *Proc. 43. IWK*, TU Ilmenau, Sept. 21-24, Bd.1, pp.645-651

Hodgkin, A.L., A.F. Huxley (1952) "A quantitative description of membran current and its application to conduction and excitation in nerve", *J. physiology* 117, pp.500-544

Konishi, M. (1993) "Die Schallortung der Schleiereule. *Spektrum der Wissenschaft*, 06/93, pp.58 ff

Knudsen, E.I., S. du Lac, S.E. Esterly (1987) "Computational maps in the brain", *Annual Review of Neuroscience*, 10, pp.41-65

Langhorst, P., M. Lambertz (1992) "Different modes of dampening influence from baroreceptors", *J. of the Auton. Nervous System*, 41, pp.141-156

Lashley, K.S. (1950) "In search of the engram. *Society of Exp. Biology Symp.*, No.4, *Cambridge University Press*, pp.454-480

McCulloch, W.S., W. Pitts (1947) "A logical calculus of the ideas immanent in nervous activity", *Bulletin of Math. Biophysics*, 5, pp.115-133

Packard, A. (1995) "Organization of cephalopod chromatophore systems: a neuromuscular image-generator", in N.J. Abbott et all: *Cephalopod Neurobiology*, Oxford University Press, pp.331-337

Penfield, W., T. Rasmussen (1950) "The Cerebral Cortex of Man", *Macmillian, New York*

Pribram, K.H., M. Nuwer, J. Baron (1974) "The holographic hypothesis of memory structure in brain function and perception", *Contemporary Developments in Mathematical Psychology*, vol.II, W.H. Freeman, San Francisco, pp.416-457

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