Time Pattern, Data Addressing, Coding, Projections and Topographic Maps between Multiple Connected Neural Fields - a Physical Approach to Neural Superimposition and Interference

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The paper is to investigate the role played by relativity of time and interference of signals (superimposition) in understanding informational principles in nervous system. In order to understand principles of superimposition (interference) of impulses between multiple connected neural fields or circuits, we will investigate simplest circuit models based on physical time-functions. Information between two fields can flow over all possible paths. Relationships between location of neurons in space and (time-) codes are of interest. We suppose incremental correct, length proportional delays in axonal and dendritic trees. Coupling within one field is omitted. Synapses have unit weights without modification. We ask wheater learning or mapping is possible with such simple constraints. We come to the interpretation that bursts are a method of addressing different data streams over one axon. We find zooming and moving projections as methods of addressing data dynamically. We find overlaying projections of excitement maps and discuss spectra. A formal algorithm, the interference transformation (HIT) is introduced to calculate interference projections. The paper continues by introducing a series of papers, describing relationships between locations of excitement and code stream in delaying, pulse-propagating networks.

Before one can measure a theory is necessary to be verified. In our case we will introduce a theory describing neural data addressing in sparse connected fields of pulse-propagated networks. According to Konishi, Lloyd A. Jeffress 1948 at Caltech had a simple idea to understand the principle of sound localization of barn owls [1]. As jet it is not known which phenomenal relevance this simple circuit has for understanding elementary, informational principles in neural bio-systems, see [7]. Jeffress' fundamental circuit, today we would call it an 'inter-medial interference circuit', shows important features of biological informatics from a new point of view: a connection between location of a neural excitement and axonal channel data streams, a connection between codes in space and time. Delay measurements in 1992 'Daumenversuch' [8] showed that our nervous system uses parallel transmission of excitement over different nerve fibres.

Hermann von Helmholtz was the first to measure velocities of nerves in frog experiments (1851). Further experiments where able to qualify such measurements. Erlanger/Gasser in 1930 published a complete list of nerve types, diameters and velocities. Furthermore we know substances that carry signals through nerves with ultra slow velocities: leucin (transport anterograde with 5µm/sec), acetylcholinesterase (retrograde, 2µm/sec) etc.. So we can calculate *geometric* length $ds = v\,dt$ of pulses dependent of the velocity v and the pulse duration dt and find them in a range between µm and cm [8].

The importance of relative timing to excite a neuron has been known very long [2]:

"No case is known in which excitation through a single synapse has elicited a nervous impulse in any neuron, whereas any neuron may be excited by impulses arriving at a sufficient number of neighbouring synapses within the period of latent addition. which lasts less than a quarter of a millisecond."

McCulloch/Pitts also introduced an *inaccurate modelling technique* for neural circuits marked by a discretisation of delay [2, 7]. They started the neural (and digital) age with an inaccurate description of bio-neural functionality in terms of discrete state machines as in termes of time-functions. It allows to interpret computers, but it is impossible, to interpret bio-neural systems. We find state-machines and matrix notations instead of time-functions and wave field descriptions to interpret pulse-interference circuits. Supposed, a neuron is excited by many different pulse-waves, it is impossible to destroy the timing structure of a network by using inadequat modeling techniques. To overcome the occurring problems we introduce time-functions with variable, length dependent delays.

In 1952 Hodgkin/Huxley [4] introduced a detailed model of electrical behaviour of nerve. According to them, the velocity of a nerve scales down approximately in square with the diameter. Thin nerves ('Nervenfilz') seem to have relative very higher delays. Different neuro-simulators allow calculation of networks with Hodgkin/Huxley-like equations (Synod, Genesis, Neuron [7]). But the model complexity limits network- and sequence-sizes. Necessary to discover interference phenomena are large nets with long sequences.

Until now was unknown, how a cat is able to localize any touch in a millimetre range with wide spliced nerves. Maruhashi at al [17] notes about areas of innervation zones at cat's skin:

"(e) A wide-receptive fibre is 2-5µm in diameter, and it has a receptive field ranging from 1500-4000 mm² which is sensitive to all kind of mechanical stimuli. (f) An afferent fibre associated with hair is 6-12µm in diameter, it innervates a large number of hairs over an area ranging from 100 to 500 mm²."

The paper is to investigate the rule played by relative timing and interference of signals (superimposition) in understanding informational principles in the nervous system. Especially it is to investigate, how to address excitement. We use examples of simplest interference circuits. Investigations need the simulation of thousands of neurons in thousands of time steps. To have any chance for numerical solutions, it is necessary to use simple and fast modelling techniques. Algorhythms being implemented in a a special simulator [7, 10], fast enough to calculate interdependence of two simple, neural fields connected via some fibres.

Assumptions to Demonstrate Effects Reasoned by Relative Timing

We suggest the following assumptions to be sufficient for demonstrating dynamic interference effects between pulse-propagating fields:
- the same event can not be here and there at the same time
- information flows in ionic systems not faster than light
- delays are floating, not integer values
- a neuron should be as more excitable, as more closed some exciting waves appear at the point of impulse reproduction (wherever it is)
- amplitudes at *locations* in 3D-space connects with time functions [11]
- a time function *f(t)* at any location of a nerve is different from that at another location *f(t-dt)* by at minimum a delay *dt*
- wiring delay includes synaptic delay
- time-functions are combined in mathematically and physically correct manner
- to make simple models, pre- and postsynaptic time functions do not necessary differ in qualities, only in velocities

- a non-linear threshold function is necessary to calculate excitement maps over long times (eqn. 5)

Notice that all wires drawn in this paper symbolize the existence of length-proportional delays without explicit to be noted in any parts of axonal or dendritic trees.

Introducing Time Functions

Independent of ionic mechanisms to transfer an impulse we use time functions to follow pulse-like excitements. If we suggest functions *f(t)* defined on a discrete value set *f(t) = {0, 1}* it is possible to use boolean abstractions, substituting a numerical operator through logic operators like AND, OR etc.. We can use threshold operators to do so with floating point or fuzzy-sets etc.
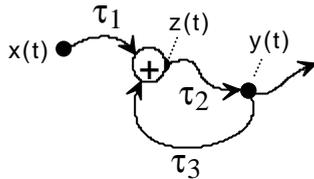
Interpretation referring to McCulloch/Pitts:

$$y(t) = x(t) + y(t-1)$$

Interpretation with time functions:

$$z(t) = x(t-\tau_1) + y(t-\tau_3)$$
$$y(t) = z(t-\tau_2) = x(t-\tau_1-\tau_2) + y(t-\tau_3-\tau_2)$$

Fig. 1:   Simple example to demonstrate the use of time functions instead of automaton models comparable to McCulloch/Pitts

Simplest Interference Circuit

One of the most simple interference circuit structure is shown in Fig. 2. It consists of an adder, a threshold function and input wires. We suppose inherent delays are not negligible, however small they are. If we look for the function of this circuit, it appears anything else than simple.
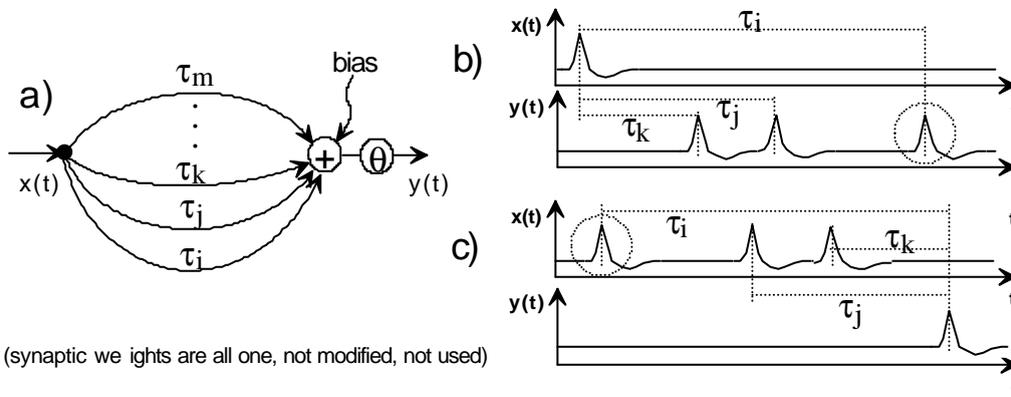
Fig. 2:   Some basic functions of a neuron or a neural group a). Burst generation with low bias b) and code detection c) with high bias

We can note the model function in form of time-functions:

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

The *q*-function may be a sigmoid-like, quasi-linear function to form the output pulse. Weights g_y may all be the same. A discussion shows some possibilities to interpret the circuit:

- If we suppose OR-character (high bias), a single input impulse produces a burst at the output, see Fig. 2b (*burst- or code-generation*)
- Supposing AND-character (low bias), only in case of equality between special time-differences of pulses of the incoming time-function and the delay vector of the circuit (mask), the circuit produces a single output impulse, Fig. 2c (*burst- or code- detection*)

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A third way in which the circuit works is discussed in [5] and [6] (*gating potential generation*). To be useful as input events $\{i, j, k\}$ in Fig. 2c) the output events from b) $\{k, j, i\}$ have to be time-inverted to excite a circuit with comparable structure. We found this effect together with Puschmann and Schoel inspecting simple circuits with Neuronet [18] in October 1994.

We introduce a map of delays $\{\tau_1, \in \tau_2, \ldots, \tau_k\}$ of any circuit in vector form as **mask M**.

Data Addressing and Neighbourhood Inhibition

Now we combine two such circuits in series each having n meshes. The first with mask M, the second with mask $M*$. In order to have a chance of exciting each other, delays over all paths have to be equal in components on all signal carrying paths:

$M + M* = T$ *(interference condition)*

We suppose an OR-type neuron at the left side, and an AND-type neuron at the right side of an axon. A vector notation shows a relation between masks M and $M*$ between the pulse- transmitting and the pulse-receiving circuit, masks have to be inverted.

$$\text{With} \quad M = \begin{pmatrix} \tau_1 \\ \tau_2 \\ \vdots \\ \tau_i \end{pmatrix} \quad \text{and} \quad T = \tau \begin{pmatrix} 1 \\ 1 \\ \vdots \\ 1 \end{pmatrix} \quad \text{follows} \quad M* = \begin{pmatrix} \tau - \tau_1 \\ \tau - \tau_2 \\ \vdots \\ \tau - \tau_i \end{pmatrix} .$$

In input impulse $x(t)$ produces a burst $y(t)$ that codes the special mask M of the producing neural circuit (Fig. 3). Only that neural circuit at the right side is able to convert a burst $y(t)$ to a single impulse $z(t)$ which possesses the inverse Mask $M*$ to the generating one. Thus the principle allows one axon to carry different data streams (*data addressing*). On the other hand this calculation shows that only neurons can communicate, which possess a tree or a part of a tree with inverse masks.
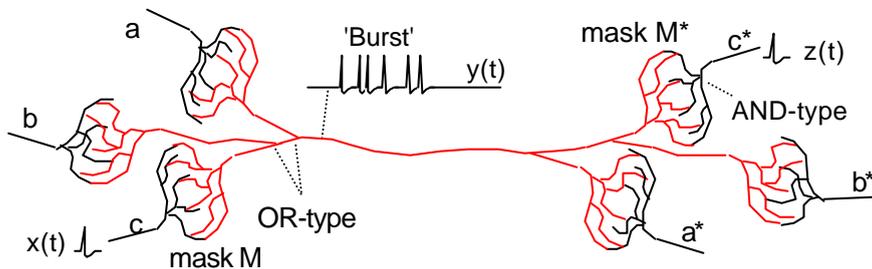

Fig. 3: **Directed, multiple data transmission via one axon. Only that receiver is addressed which possesses the complementary key in form of the inverse mask M* of the sender. Signal flow only c -> c* and c* -> c**

Neighbourly neurons with comparable tree structures have comparable masks (non-inverse!). Oscillations between them are prevented automatically (*interferential neighbourhood inhibition*). So neighbourhood inhibition can also be a consequence of physical properties.

Delay Mask of a Location, Space-Time Properties

To find elementary relations between time and code in pulse-propagating networks we consider a space with some fibres.

Assuming a neuron (or a combination of neurons) is able to form an axonal tree (Fig. 4) and uniform velocities supposed, every excitement function appears as more delayed at the sink points E_v, as greater is the distance to the centre point P.

The time function for each $f_v(t)$, $v = \{a, b, c, d\}$ is:

$f_v(t) = g(t - \tau_v) = g(t - \frac{r_v}{v_v})$

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Note that different locations have different masks in channel data. Visa versa any input functions anywhere in 3D-space produce a time-function at any Point P depending on the actual distance to P. In this case, it is only important to observe that the mask of the location is equal to that of the time function. All other cases are of less importance, see Fig. 5.
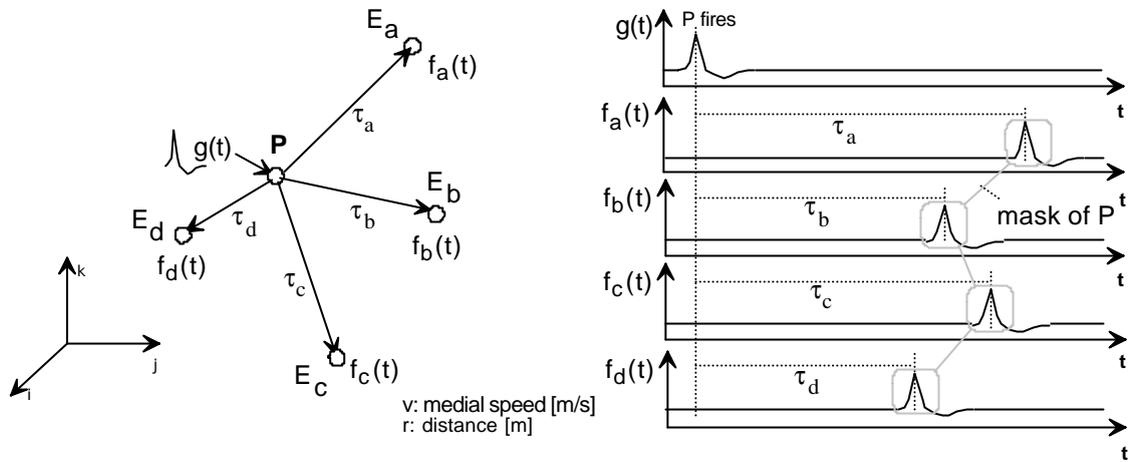

Fig. 4: Expansion of neural waves in 3D-space with time functions: Any location P burns its delay mask (its address) into channel data stream
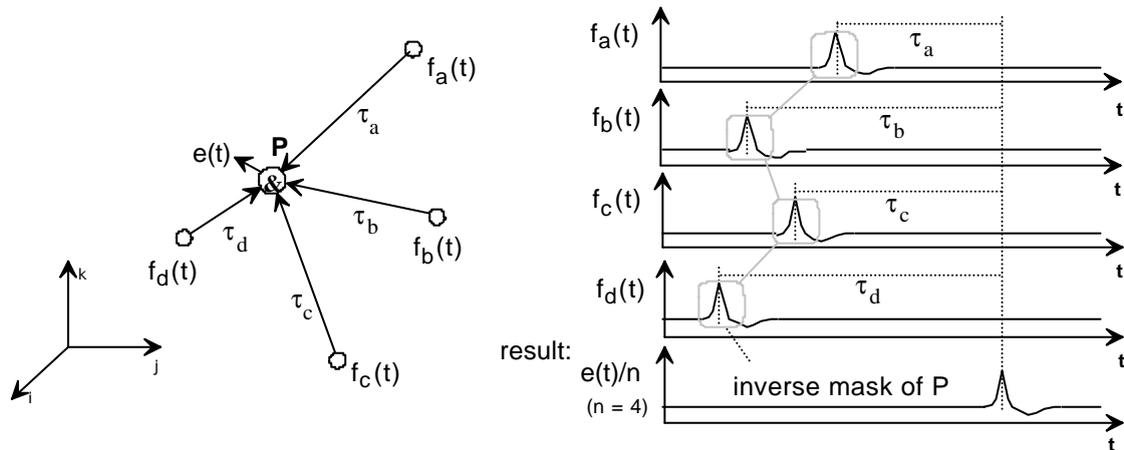

Fig. 5: Interference to a location. Maximum excitement appears if the mask of pulses in the channel data stream is inverse to the mask of the location (time direction of delays can be seen to be inverse)

A discussion of the time function

$$e(t) = \tfrac{1}{n} \sum_{v=1}^{n} f_v(t - \tau_v) = \tfrac{1}{n} \sum_{v=1}^{n} g(t - \tfrac{r_v}{v_v})$$

shows that a temporal maximum excitement can appear in case the inverse mask (left laying mask) of the location is equal to the mask of impulses in the channel data stream (drawn).

Note that expansion of exciting waves produces right laying masks, while concentration needs inverse, left laying masks.

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A Difference between Homogenous and Fibre Space

If it is not possible, to get structural information about a net to be measured, we get masks M' different to homogenous space. Supposed the same speed, wiring delay is higher that of space distance in general.
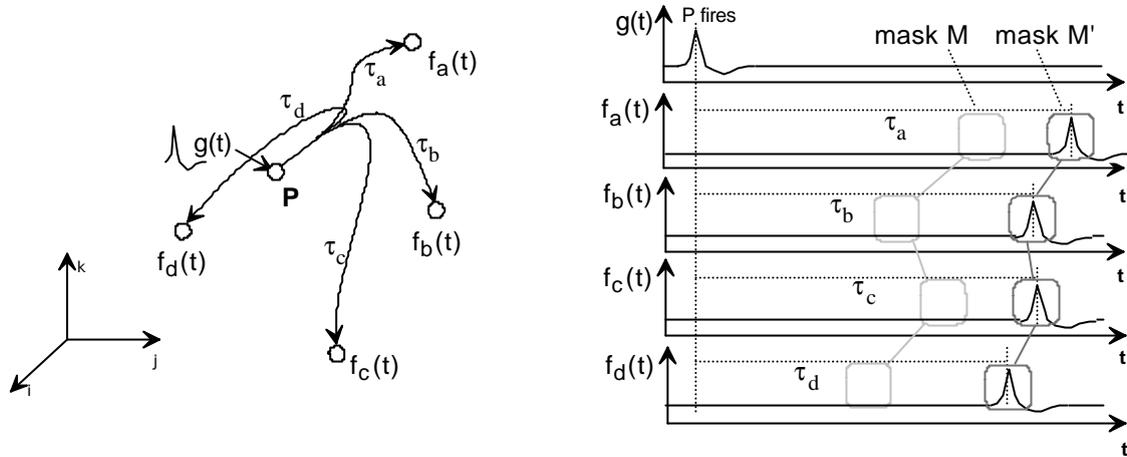

Fig. 6: **Because of fibres being not straight a mask M' of nerve fibres differ from mask M measured at the same locations in homogenous space**

A 'fibre'-mask having more than three delay terms (channels) omits no representation in homogenous space. If the nerve structure or delay structure is unknown, we have to reconstruct nerve signals in homogenous space (PSI-tools). The results appear stochastic, non-deterministic or non-causal.

$M' \geq M$

In consequence field-theoretical approaches basing on homogenous space models become inaccurate in relation to fibre space.

Two Neural Fields Connected with some Axons: Interference Transformation (HIT)

To understand which kind of data addressing mechanisms are possible in general between two sparse connected neural fields caused by superimposition of impulses, we construct a simple circuit model. Consisting of two neural fields ('generator- and detector field'), each input has a co-ordinate in 3D, each channel source- or sink-point has also such a co-ordinate. If the circuit structure is unknown delay is supposed at minimum to be proportional to the distance between any two points a, b.

$$\tau_{ab} = \tfrac{1}{v} \left| \sqrt{(x_a - x_b)^2 + (y_a - y_b)^2 + (z_a - z_b)^2} \right.$$

In case the circuit- or the delay-structure is known, we better use structural delays. We suggest each neuron of generator- and detector space to have a direct or indirect, length-proportional connection to channel fibres. To guaranty the possibility of qualitative excitement observations, interaction between generator or detector field neurons themselves is not considered.

We are interested in the question, at which locations on the other field interferences occur to excite neurons in general. We suggest, not all locations are positions of impulse wave interference.
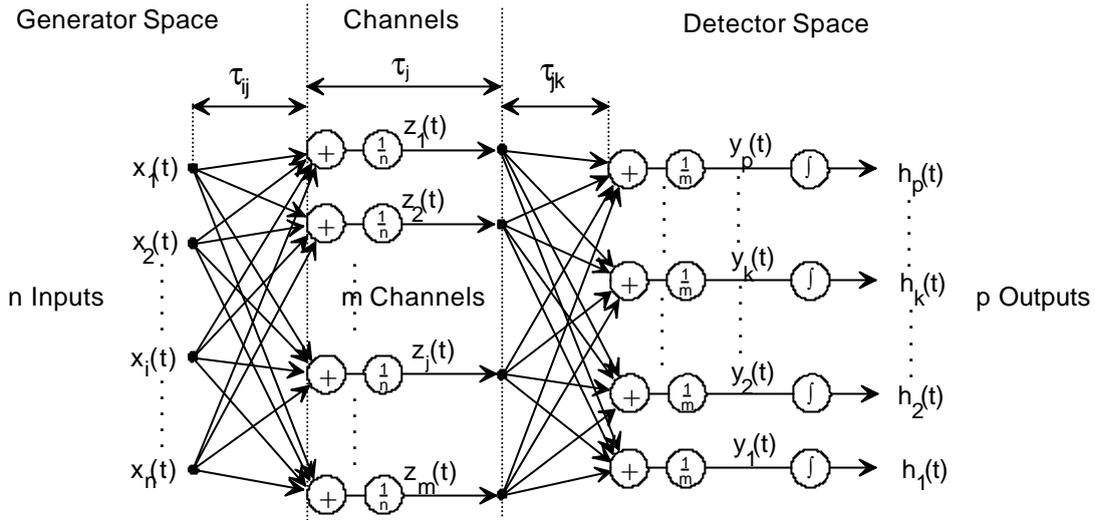
Fig. 7: **Timing model of two neural fields, connected via some axons. We suggest that each neuron of generator- and detector space has a direct or indirect, length-proportional connection to channel fibres**

We can read out the time functions according to scheme Fig. 7 for different parts.

Transformation Generator Space into Channels:

$$z_j(t) = \tfrac{1}{n}\{x_1(t - \tau_{1j}) + x_2(t - \tau_{2j}) + ... + x_n(t - \tau_{nm})\}$$

$$\boxed{z_j(t) = \tfrac{1}{n} \sum_{i=1}^{n} x_i(t - \tau_{ij})} \tag{1}$$

Transformation Channels into Detector Space:

$$y_k(t) = \tfrac{1}{m}\{z_1(t - \tau_1 - \tau_{1k}) + z_2(t - \tau_2 - \tau_{2k}) + ... + z_m(t - \tau_m - \tau_{mk})\}$$

$$\boxed{y_k(t) = \tfrac{1}{m} \sum_{j=1}^{m} z_j(t - \tau_j - \tau_{jk})} \tag{2}$$

The time function $y_k(t)$ may be interesting in inspecting wave fields. To get an excitement map we create the integral

$$\boxed{h_k(t) = \lim_{T \to \infty} \tfrac{1}{T} \int_0^T \theta(y_k(t)) \, dt} \tag{3}$$

The transformations is called 'H-Interference Transformation' (HIT) [9]. To calculate this simplest interference circuit numerically, we developed PSI-Tools [10]. PSI-Tools is able to record data streams, to synthesise them via eqn. (1) and to calculate interferential wave fields and interference integrals via eqn. (2) and (3).

Resulting Transformation Generator to Detector:

$$\boxed{y_k(t) = \tfrac{1}{m} \sum_{j=1}^{m} z_j(t - \tau_j - \tau_{jk}) = \tfrac{1}{mn} \sum_{j=1}^{m} \sum_{i=1}^{n} x_i(t - \tau_{ij} - \tau_j - \tau_{ji})} \tag{4}$$

Properties of Self Interference Projections

Interference integrals become greyed in case of simple addition without eqn. (3):

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$$\lim_{n,m \to \infty} y_k(t) = \frac{1}{mn} \sum_{j=1}^{m} \sum_{i=1}^{n} x_i(t - \tau_{ij} - \tau_j - \tau_{jk}) = \qquad (5)$$

Locations between generator and detector are in maximum interference if they have equal delays over all paths (mirrored projection):

$$\tau_{ijk} = (\tau_{ij} + \tau_j + \tau_{jk})$$

$$\boxed{\tau_{i1k} = \tau_{i2k} = ... = \tau_{ijk} = ... = \tau_{imk}} \qquad (6)$$

In that case eqn. (2) becomes easier:

$$y_k(t) = \frac{1}{mn} \sum_{j=1}^{m} \sum_{i=1}^{n} x_i(t - \tau_{ijk})$$

$$\boxed{y_k(t) = x_i(t - \tau_{ijk})} \qquad (7)$$

Thus we call this transformation 'projective' in both, in physical *and* in mathematical sense:

$$F : \{X\} \to \{Y\} \text{ or } (x, y) \in F$$

Diagonal condition:

We find no spectral parts on the screen if the detector size in delay units *is smaller* than the distance between consecutive impulses.

$$max(space\_delay) < max(\tau_{ijk}) \qquad (8)$$

Properties of Projections in Fremd-Interference (Outside-Interference)

Fremd-interferences can be seen on the screen if the screen size in delay units *is greater* than the distance between consecutive spectral lines

$$max(space\_delay > max(\tau_{ijk}) \qquad (9)$$

$$\boxed{y_k(t) = x_i(t - \tau_{ijk} \pm qT), \ q \in N} \qquad (10)$$

For periodical functions we find

$$qT = \frac{q}{f} \quad \text{with} \quad q \in N$$

Results

Between two neural fields, sparse connected via some fibres any data addressing is possible only in two ways: 1) via length proportional attenuation resulting in a non-mirrored, smooth excitement mapping and 2) (impulses supposed) via pulse-interference. Interference projections appear mirrored in principle. Equations (1), (2) and (3) are the kernel of the HIT implemented in PSI-Tools [7, 10]. Besides the possibility to reconstruct acoustical generator fields [7], PSI-Tools is able to synthesise channel data streams from synthetic excitement maps in homogenous space. Channel numbers, channel locations, field sizes, velocities, impulse forms, pausing intervals etc. can be chosen freely. Remembering the mask M' of fibre space a projection onto neural areas can occur very different to that in homogenous space. To reconstruct neural space it is very important, to underlay a maximum of structure- or delay-information.

Moving Projection

To clear the importance of weak delay modifications in an pulse-interference circuit we try some experiments. Two fields (generator- and detector field) connect with three channels. First we vary the intrinsic delay of one channel.

Theoretical models [6] and [15] had shown the possibility to shift projective excitement maps through space. We find, if channels appear delayed, the excitement locations of the projection shift ('move') in direction to the delayed channel. If we remember the 'Daumenversuch' it means the projection map moves in a detector field with every movement of any joint on the nerves path.
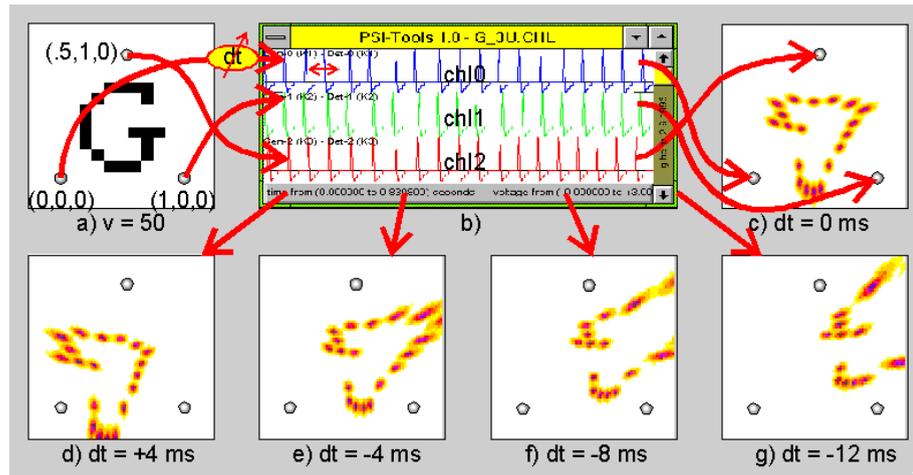
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Fig. 8: **Moving interference projections. Moving projections occur by variation of the delay of one channel. a) Synthetic generator space; b) Channel data; c)...g) Reconstructions with delayed left channel**

Zooming Projection

For better understanding the Jeffress experiment [1] in physical terms, it seems important to discuss the effect of varying the background velocity in the receptive field for example by the influence of neuro-glia. If the velocity v of all fibres in the detector space changes, the projection appears zoomed. Fig. 9 shows what happens if we use different detector speeds to calculate the interference integral.
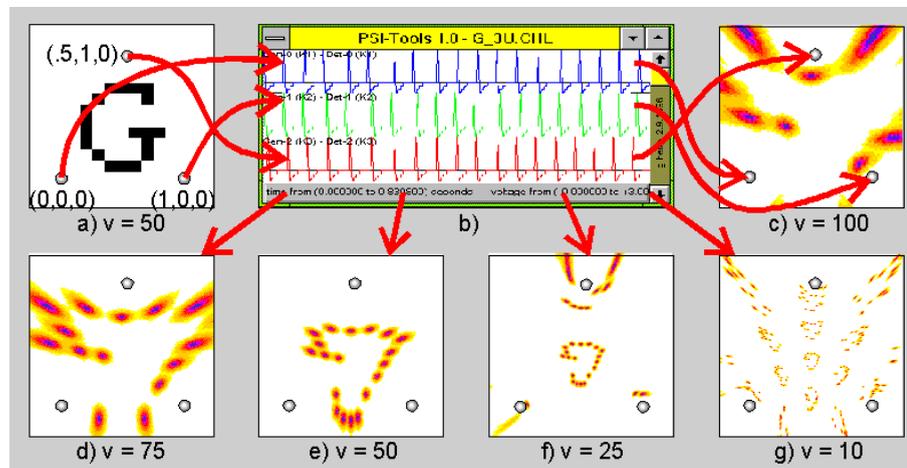

Fig. 9: **Zooming interference projections. a) Synthetically generator space with speed $v = 50$, black pixels fire one for one; b) channel data; c)...g) projections with different velocities v (normalised unit system)**

Again we find maximum excitation in the detector space at all positions where the delay distance on all paths to the generating excitation is equal. In g) we find spectral components occurring through a change between equations (8) and (9) reasoned by the variation of background speed. A constant cell grid of neurons supposed, we get a higher angle resolution with increasing background speed, compare [1, 5, 6, 15]. If we construct a detector having some layers (laminae) with different speeds, we are able to inspect a small central zone of a generator space together with the random area in one field ('coloured' projections [5]).
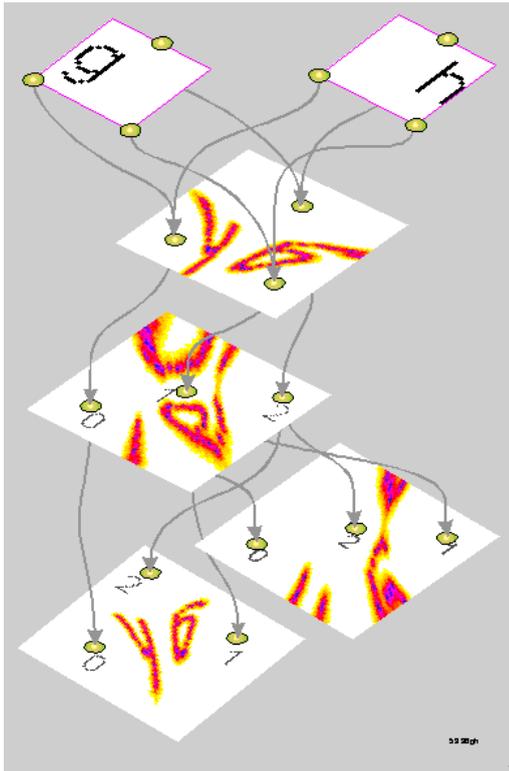
Conjunctive Projections

If we append or add channel data time- functions, as opposed to technical Video- RGB-signals, we find that no information is lost. Excitement maps stay topologically. A calculation of the interference integral over two appended channel data streams shows the left hand picture.

We can add any delay to an interference projection: if we add this delay at all channels, the projection becomes un-distorted. On the other hand we can vary the source locations with the effect that distortions appear. The projections stay topological.

Fig. 10 Conjunction of different neural excitement maps into one field. In relation to the channel source points the projections appear distorted, the interference locations vary.

Spectral Coding

Finally, let's split one channel into some more channels. A simple periodical function drives this arrangement.

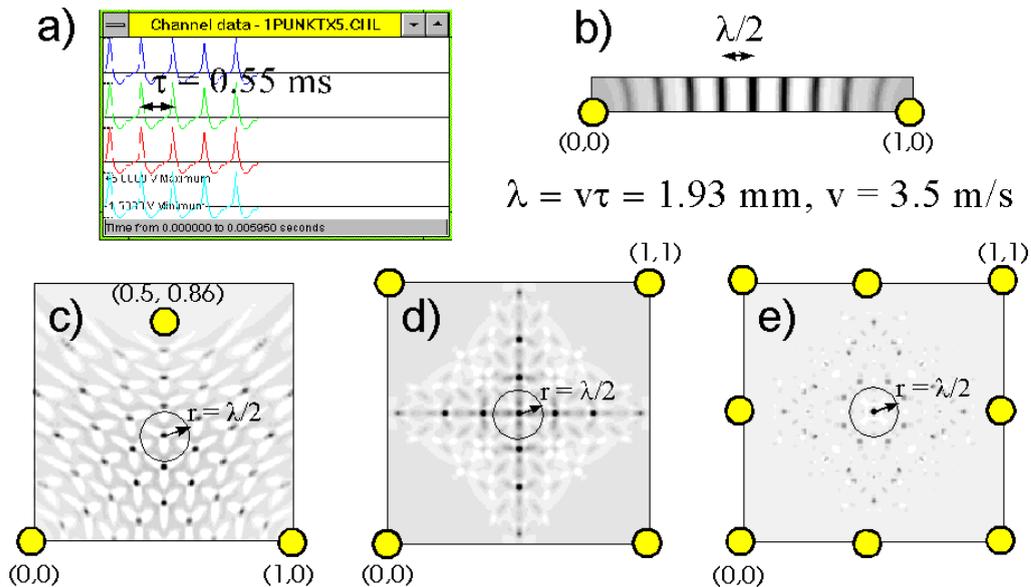$$\lambda = v\tau = 1.93 \text{ mm}, v = 3.5 \text{ m/s}$$

Fig. 11: Neural spectra of different channel arrangements in 2-dim. space. Electrode positions are marked. The higher the channel number, the higher is the peak of the central interference: b) 2-chl.; c) 3-chl.; d) 4-chl. with channel data in a); e) 8-chl. arrangement (PSI-Tools).

Depending on how we arrange these spliced channels, we get different spectral maps.

Wave Fields (Movies)

Now we use the HIT to study the movement of any wave field. PSI-Tools is used to inspect interference values of all pixels of the detector field at each time step. Each pixel value appears as the addition in the mask of that pixel at this time step. Thus we consider homogenous space for the reconstruction, we find concentric waves.
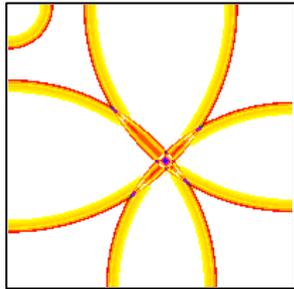

Fig. 12 **Wave field produced through stepwise interference transformation (HIT) with four channels. The picture shows a calculation of all pixel interference values for one time step. Centrally an interference appears between four waves. Channel sources lie in the corners (PSI-Tools).**

Projection, Reconstruction and Direction of Time Axis

A calculation of the generator's excitement map from channel data is called *reconstruction*, whereas the mapping into a second receiving field is called *projection*, Fig. 13. The difference between reconstruction and projection is the direction of delay in the mask. If we use masks, positioned into time direction (right-hand masks), we get the reconstruction. If we use time-reversed masks (left-hand positioned), a projection appears. PSI-Tools only works with right-hand masks. Thus, to calculate a projection, we have to invert the time axis.
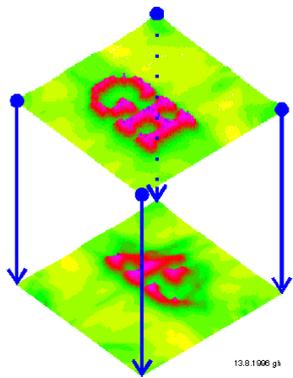

Fig. 13 **Comparison of a reconstruction (top) and a projection (bottom) of the same channel data stream. The projection is over-defined with highest interference qualities in the central region. The picture symbolises a 'wired' projection between two neural fields, connected via four channels (axons), source [6].**

Acoustic 16 Channel Application of HIT with PSI-Tools

From dolphins and bats we know fantastic SONAR localisation techniques. Ultrasonic methods find wide applications in medicine. To find out possibilities, to improve the quality of acoustic images with discrete amounts of channels we work with 16 microphones hanging out of the window a) in the eighths floor. Picture b) shows the view out of this window. Behind finding cars on the way in the foreground we recognise different cars at the street far in the background. A bus crosses the street in the background from right to left (Rudower Chaussee, distance 170m). Four interference integrals are taken with 1000 samples each/10kHz subsequent with 1/10 second, the picture dimension is 6x5 meters each. We find the bus has a speed of 51.4 km/h. The pictures imagine, which localisation capabilities an average, single neuron with 7600 synapses can have. If 16 channels (synapses) allow to recognise an excitement in a distance, that is 40-times larger as the sensor

arrangement, it is possible, that the smallest cortical neuron can feel any toe in a distance of two metres - supposed that the information is carried on different ways and the delay mask of the neuron is that of the location to detect.
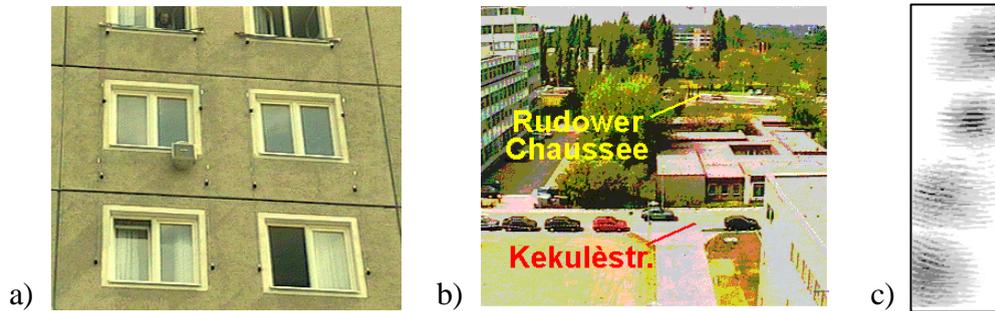

Fig. 14: Microphone arrangement a), microphone horizon b) and acoustic image of a bus c) crossing in 170 m distance (interference integrals 1/10 sec, image size 6x5 m, excitement movement 4.28 m = 51.4 km/h)

ECoG-Analysis

To prove conductivity models for cortical excitement we used interference integrals. We find best quality of 2kHz sampled channels in the range of background speeds between 40cm/s and 1m/s. Unexpected, interesting images give different new questions, see homepage [7].
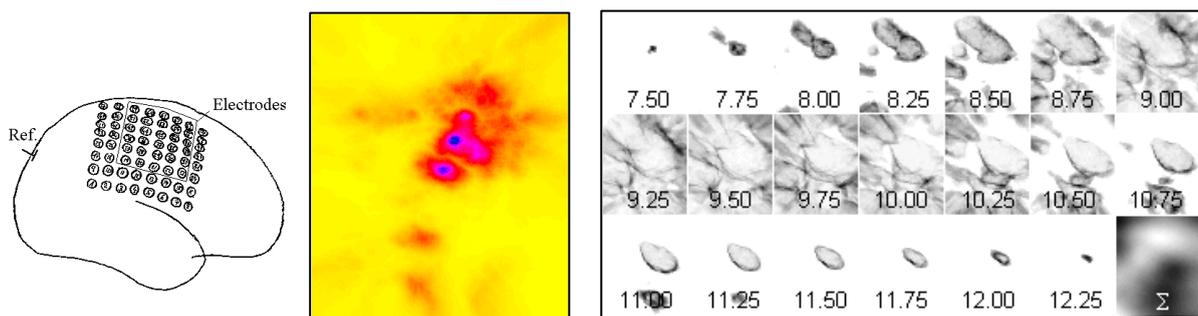

Fig. 15: Interference Analysis of 30 channel electrocorticogramme. a) arrangement, b) long interference integral 50cm/s, c) class analysis

Summary and Discussion

The paper is a short abstract from different sources [5-10], [12-16]. In short form it demonstrates the importance of incremental correct delay calculations in pulse-propagating networks. Instead to follow a single signal flow we investigate multiple signals. The location of superimposition appears as the data address. We find relationships between code and space with simplest modelling techniques. In interference networks the geometry of a net defines relative timing and locations of projections. Thus, the shape of a nerve net defines functional properties. Interferences can clear the role of special drugs, changing only the velocity of nerves.

We find that *interference nets map without modifications of synaptic weights*. By varying dynamic parameters, such as velocities or diameters of nerves, we are able to modify the functionality of interference networks. In this sense *interference networks appear as a second group of learning networks* behind synaptic learning networks.

As opposed to logical circuits interference circuits can move and zoom projections in space, overlay different projections and mix spectral components with image parts. Moreover, interferences offer the chance of addressing data in stochastic (chaotic) switched networks in different ways: We find the delay-code of bursts as static addresses of data and we find moving and zooming as a form of

dynamic addressing. *A neuron can only excite a neuron with an inverse delay mask. But identical geometries exclude inverse masks nearly complete*. A simple *interference provides self-excitement and short-cuts between nearest neighbourly neurons* which are multiple connected.

The question of whether an interesting bio-system has interferential or non-interferential properties becomes clearer: interference projections appears mirrored between generator and detector space, while non-interferential projections appears non-mirrored. In this sense, Penfields Homunculus can appear as an interference network between the medulla spinalis and the gyrus postcentralis/gyrus precentralis [7]. The conjunction of parallel time-functions shows possibilities of learning in interference networks. Works demonstrate that delay measurements have more impact on understanding pulse processing in bio-neural networks than already known. With PSI-Tools [10] we developed a simple measuring and simulating system to make first investigations. Simulations show, that interference can be the method to locate mechanical events with fibres having large receptive areas [17].

References

[1]	Konishi, M.: Die Schallortung der Schleiereule. Spektrum der Wissenschaft, Juni 1993, S. 58 ff.

[2]	McCulloch, W.S.; Pitts, W.: A logical calculus of the ideas immanent in nervous activity. Bulletin of Mathematical Biophysics 5: 115-133

[3]	Rumelhart, D.E., McClelland, J.L.: A Distributed Model of Human Learning and Memory. in: Parallel Distributed Processing. Bradford/MIT Press Cambridge, Massachusetts, vol. 2, eighth printing 1988.

[4]	Hodgkin, A.L., Huxley, A.F.: A Quantitative Description of Membrane Current and Its Application to Conduction and Excitation in Nerve. Journ. Physiology, London (1952), 117, pp. 500-544

[5]	Heinz, G.: Neuronale Interferenzen. Über die Relativität elektrischer Impulsausbreitung in neuronalen Netzwerken. GFaI-Report 1993 ff. 300 pages

[6]	Heinz, G.: Projections and Coding in Pulsepropagating Networks. GFaI-Report, March 1996, 25 pages. To Appear in Elsevier's "Neurocomputing"

[7]	Heinz, G.: Internet-Homepage http://www.gfai.fta-berlin.de/www_open/perspg/heinz.htm (25MB)

[8]	Heinz, G.: Relativität elektrischer Impulsausbreitung: Schlüssel zur Informatik biologischer Systeme. 39. Int. Wiss. Kolloqium an der TU Ilmenau, 27.-30.9.1994, S. 238-245

[9]	Heinz, G. Interferenztransformation. Private communication only. GFaI 1993, 6 pages

[10]	Höfs, Sabine; Heinz, Gerd: Parallel and Serial Interference-Tools (Software PSI-Tools V.1.0). Downloadable via Internet-Homepage. See the enclosed Help-file PSI.HLP for further informations

[11]	Dobesch, H., Sulanke, H.: Zeitfunktionen. Verlag Technik Berlin, 1964

[12]	Heinz, G., Höfs, S., Busch, C., Koepp, I., Kittner, D. u.a.: Verfahren und Prototyp zur Rekonstrution eines dreidimensionalen, neuronalen Interferenzraumes. Projekt-Abschlußbericht BMWi 415/94 (Bundesministerium für Wirtschaft), GFaI-Berlin, 20.12.95, 60 S.

[13]	Heinz, G., Höfs, S., Koepp, I.: Parallel Interference Transformation to Simulate Nervous Activity. PowerX'plorer User Report, 2nd Edition, June 1995, Jan Knop, Ingo Schreiber, Heinrich-Heine-Universität Düsseldorf, June 1995, S. 131-136

[14]	Heinz, G., Hoefs, S., Koepp, I., Kittner, D., Busch, C.: Verfahren und Prototyp zur Rekonstruktion eines dreidimensionalen, neuronalen Interferenzraumes. GFaI Jahresbericht 1994, Seiten 63-72

[15]	Heinz, G. , Höfs, S., Busch, C.: Verfahren und Prototyp zur Rekonstruktion neuronaler Interferenzräume (NEURO-3D). GFaI-Jahresbericht 1995, Seiten 78-87

[16]	Heinz, G.: Modelling Inherent Communication Principles of Biological Pulse Networks. SAMS 1994, Vol.15, No.1, Gordon & Breach Science Publ. UK, Printed in the USA.

[17]	Maruhashi, J., Mizuguchi, K., Tasaki, I.: Action currents in single afferent nerve fibres elicited by stimulation of the skin of the toad and the cat. Journal of Physiology (1952) 117, 129-151

[18]	Puschmann, P., Schoel, G.: Neuronet-Nutzerhandbuch. Fachhochschule für Technik und Wirtschaft Berlin, 1994.