Interference Networks to Model Nerve System in Structure and Behaviour*

Gerd Heinz, GFaI Berlin, heinz@gfai.de

(Theses) Introducing the physical parameters: velocity, spherical locations and time functions the net-structure models the behavior of a network in nerve like dimensions. We call such networks "Interference Networks" (IN). By contrast to Neural Nets (NN) wires of IN need to have distributed (inherent) delays. IN carry velocities, delays and spatial information. Investigating wave interference in spatial, discrete (wired) fields [10] the paper sort some properties of IN the author found in the years since 1992. The term "interference" means an universal interaction of (mostly non-periodic, spiking and delayed) time functions f(t-T) (waves). We find an abstract definition of wave interference systems without materialistic background. The paper addresses questions to understand pictures of thought, sound maps or movement maps [5] in nerve systems in the same way, as it addresses technical applications (Acoustics, Radar, Sonar, lens systems, feedback controls, GPS...) under one roof. The paper tries to give an overview about the high potential of signal interference in nerve like parametrization.

"The question, how the nervous system creates representations of its environment has fascinated philosophers and scientists since mankind began to reflect on its own nature."
Wolf Singer, 1993

History of Interference Networks (IN)

In 1990 mankind had knowledge about a lot of artificial "neuronal" nets, lots of works were written about learning nets, oscillatory nets or spatial-temporal maps. The output map of such a network represented mostly the input map. By coincidence in September 1992 I found a little problem: If we suppose geometrically small impulses that flow slowly through such nets, it is not possible to get non-mirrored output presentations that correspond to input maps. Like optical lens systems such nets can only produce mirrored projections!

How did I found this result? I thought about a simple 4...8 channel Radar system cars and found, that continuously running time in such systems can only produce mirrored maps with additional hints like axial-near sharpness known from optics. (Later I realised comparable ideas for acoustic images and films, the Acoustic Camera was born in 1997, see homepage.

Remark: this paper has nothing to do with electric or magnetic or acoustic fields: Solutions for mapping or locality of all these systems (nerve nets included) can be achieved using only wave properties of time-functions. Supposed limited velocity of nerve impulses (µm/s ... m/s) [10], [6], [8] any millisecond impulse becomes a geometrical wave length in the range between nanometer and millimetres ($v=ds/dt$): The geometrical length of a pulse can be very short in comparison to the size of a neurone.

Interference nets can be seen like cross-roads: the probability that cars (pulses) coming from different directions (dendrites) crashes on the crossing is as higher, as smaller the distances between the cars or as longer the cars or as slowly (!) they are ($ds=vdt$). Static signals (EPSP...) at logic circuits (soma) are comparable to infinite long trains crashing statically at the crossing. In nerves with

---

* reviewed and corrected

pulse/pause ratios of 1:10 to 1:10.000 the "crash probability" for excitement is very small. What to do? First we find, that static signal processing (pattern nets) is inadequate for data processing. Second, we have to look for "crash" places! We have to follow a single impulse or signal over the whole network, hoping it meets his double(s) at certain places - we have to look for (discrete) interference locations of signals, for "discrete pulse wave interference".

Introducing the approach we find, that so called "neural" networks map the input pattern only *mirrored* to the output. But in September 1992 this was a shock: It was not possible to find any scientific publication about a mirroring property in neuro-computing literature. The shock was as bigger, as more such wave analogies lead to optical projections. Like a interference circuit in nerve dimensions a simple, optical lens system mirrors the image. The next shock was, that I could not find much about elementary wave conditions for optical projections, looking for abstract wave-conditions.

So the idea was born to investigate the field of "discrete wave interference on distributed, wired nets". The idea was, the physical approach to neural nets (later called "interference nets") could create a connection between wave physics (optical, acoustical) and neuro-computing.

Character of Interference Networks (IN)

By contrast to "neural" networks (NN) the wires of IN need distributed delays. Wires carry velocities, delays and spatial informations. The time functions flow on the wires with constant or variable speed, with or without attenuation. IN demand simulations in time domain. Choice of a rough time or space grid or improper use of time function parameters destroy the wave properties of an interesting IN immediately. Spatial arrangements of bundles of wires, studied in [10], showed the influence of geometrical changes to wave front on the bundle: "space codes behaviour". It is necessary to define the space arrangement of each wire. In meaning of interference we use the term "discrete wave" instead of "signal" to manifest this property.

We summarise following properties of IN:

- Physical nets, continuos in space and in time
- Distributed delays on wires (wires are not electrical nodes!)
- Wires carry time functions $f(t)$
- Spatial wire definition is necessary $f(x,y,z)$
- Classical neurone definitions are possible (integrate & fire etc.)
- Generated pulses are carried on different wires and meet again

Investigating such wave networks since 1992, I found enormous capabilities for informational tasks, like ***temporal to temporal*** coding (bursts), ***spatial to spatial*** coding (projections), ***temporal to spatial*** coding (frequency maps) or ***spatial to temporal*** coding (creation of behaviour). First lets remember some foundations.

Foundation: Self- and Cross Interference

If pulses occurred by the same origin meet again, we have to observe two, very different cases. The case if a single impulse *i* meet again his derivatives *i* (sorry for the abstract terms), we call *self-interference* (Selbstinterferenz, case a). If we use a sequence of source pulses (a pulse series *i, i+1, i+2 ...*), additional we have to investigate the correspondence of predecessors and followers. We call the interference of impulses with a different origin *cross interference* (Fremdinterferenz, cases b).

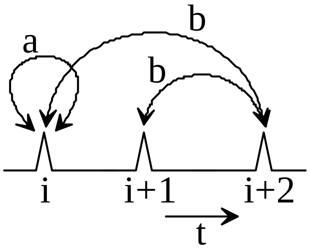


Fig.1) Self- and crossinterference of time functions

Interference Integral

Supposed, that any neurone receives signals (waves) from n different sources, Fig.2. The (projective) sum of interference $g(t)$ of n delaying time functions f_k is at time t and location $P(x_0,y_0,z_0)$

(1) $g(t) = \frac{1}{n}\sum_{k=1}^{n} f_k(t-\tau_k), \quad k = 1...n$ with delay vector (mask) $M = (\tau_1, \tau_2, ...\tau_n)$.

The ***interference integral*** of n by t_k delayed time functions in a time interval T is a value. By analogy to electrical systems for example the ***effective value*** is

(2) $y_{eff} = \sqrt{\lim_{T\to\infty} \frac{1}{T} \int_{-T/2}^{T/2} \left[\frac{1}{n}\sum_{k=1}^{n} f_k(t-\tau_k)\right]^2 dt.}$

The equation produces a delay vector M [7]. If predelayed by a different $M' \neq M$ $g(t)$ get more and more noise, as more M' differs from M.

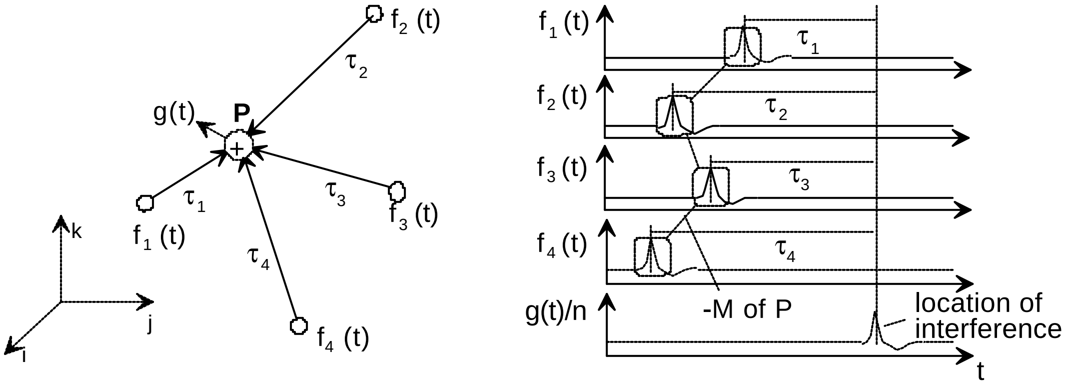


Fig.2) Example: Time function $g(t)$ of point P summating four sources $f_k(t)$

Maximum interference occurs in P if functions $f_k(t)$ appear predelayed with the negative vector $-M$ of P (velocity can be slow in neural space).

Opposite case: If a neurone produces an excitement at any location P it burns its delay vector M as address into the resulting time functions (Fig.3). Any spherical shift of P is followed by delays of delay vector. That means, the *delay vector represents the location of P*. Looking back into the time functions of Fig.2, we find M looks like a "mask". So we called the *Heinz Interference Transformation* (HIT) mostly *mask algorithm*. To get any interference time function $g(t)$ we have to shift the delay mask M of $g(t)$ over the channels $f_k(t)$, adding vertically sample by sample over the holes. Using $f(t+t)$ for all pixels this is the main idea for the calculation of acoustic images and films.

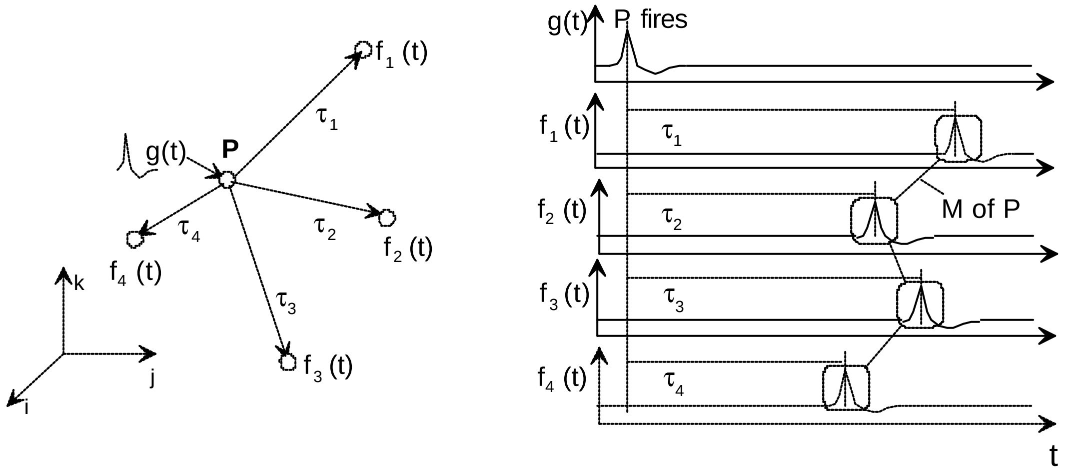


Fig.3) Expansion of waves in 3D-space. A different *P* produces a different *M*

Projection Equation

Independent, if we consider optics or acoustics or neural nets we find a well known but not named law: locations of interference (the maximized interference integral) are there, where all partial waves from the excitement point come into coherence again. This point of self interference has the additional condition, that delay sums on all paths are equal. The sum of delay vector elements of the generating field M_G, the delay vector of the transmitting lines M_T and the delay vector of the detecting field M_D have to be equal. *[1]* symbolises the unit vector [7].

(3) $[M_G]+[M_T]+...+[M_D]=\tau[1]$ (self interference condition)

By analogy we construct different cross interference conditions, see [10].

Projection and Reconstruction

For technical purposes we differ between projection (optics, beamforming) and (computational, non-causal) reconstruction. Using $f(t+t)$ we get the so called reconstruction (Acoustic Camera), using $f(t-t)$ we get the projection. While the reconstruction delivers a 1:1 image, the projection produces *mirrored* interference integral images [7] with axial sharpness problems know from optics, see Fig.4b). In case of perfect reconstruction the t in last equation will be zero.

Conditioning

If pulses of the same origin meet n-times again, the question of conditioning appears. Using a d-dimensional sphere, we need $d+1$ channels (waves) to mark precise the self interference location, $n = d+1$. Using more channels we get *over-conditioned* projections (for example optical lens projections). With a smaller channel number the projection is *under-conditioned* (u.c.), it moves. For example we get hyperbolic excitement curves for the case of two channels on a two dimensional surface [5] ($n = d$: under-conditioned). For real space the dimension is limited to $d = 3$. Nerve system can increase the dimension (and following the channel number) only using inhomogeneous spaces by *velocity-variation* (axonal/dendritic diameter changes) and *spatial convolution* (cortex) [1]...[10].

Address Volume

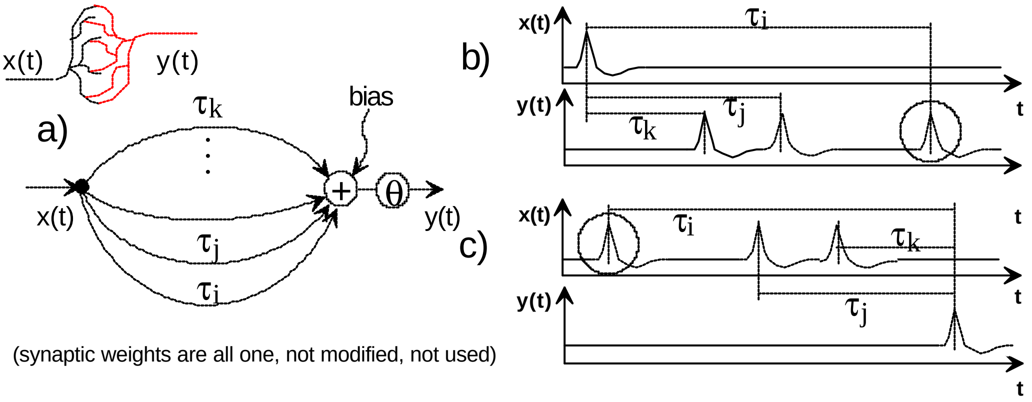
Nerve velocities and pulse length can be very small compared to the dendritic and axonal size of a neurone [10], [8], [6]. Any geometrical pulse width l determines the sharpness maximum of a pulse projection on a core (soma), it is defined by the pulse peak time τ_{peak} and velocity v

(4) $\lambda = \tau_{\text{peak}} v$.

If a neurone must be addressable independent of neighbours, the average distance between neurones is limited to l. Example: With 10 µm wave length, velocity 10 mm/s, pulse width 1 ms we can address a maximum grid of 10x10x10 μm^3 per litre, these are 10^{12} neurones. Interesting: as slower the velocity (as slower the animal), as smaller is the geometric pulse width and as higher is the capacity, however.

Temporal to Temporal Coding - Bursts

By analogy to FIR- and IIR-digital filters Fig.4 shows a neurone- like interference circuit, that produces time functions b) (bursts) or that works like a time-function (burst) detector c). All wires might have distributed delays [5]. Using a *b*-type neurone as generator and a *c*-type neurone with the negative delay vector *-M* as detector, such neurone pairs can communicate independent via special *bursts* on a single line. I called the principle *data- addressing*. If a neural pair has mask-pairs, that are not inverse, the neurones will not communicate. We can find this effect in case of two neurones with the same spatial structure. If they have identical delay vectors, they avoid uncontrolled feedback between them. So connected, nearest neurones with identical structure can not communicate! We call this *dynamically neighbourhood inhibition*. In case, the wavelength is much higher the size of a neurone, or pulses come overlapped in interference, a neurone has the ability to generate floating values, necessary for bias control or for velocity controls via glia-potential [7]. Burst generation, burst detection, data- addressing, neighbourhood inhibition and control level generation we find as new, elementary functions of neurones [5], [3].



(synaptic weights are all one, not modified, not used)

Fig.4) Basic functions of a neurone or a neural group a) Circuit structure, b) Burst generation with low bias, c) Burst detection with high bias

Spatial to Spatial Coding - Self Interference Projections

A certain excitement (G) in Fig.5 produces a highest interference integral at the interference location (E). This is the place, where all partial waves meet again in self-interference, the delays are equal on all pathways $\tau_1 = \tau_2 = \tau_3$. To find locations of interference numerically, the region of interest can be considered as very dense mashed - like a continuous, free wave surface, b). Each co-ordinate in the generator field *maps mirroring* on a certain co-ordinate in the receiving field.

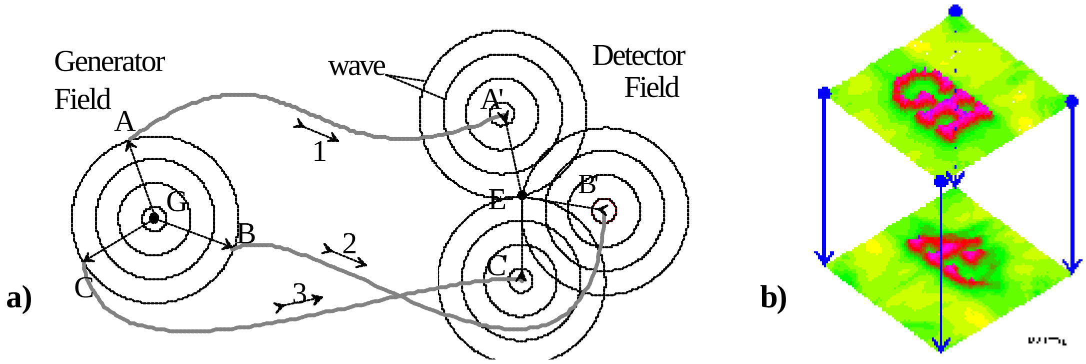


Fig.5) Spatial self interference a) projection principle, b) example (over-conditioned reconstruction top and projection bottom)

In [7] some projection-variants were published. Changing the velocity between generator and detector field the projection size *zooms*, the projected image becomes greater or smaller. Changing the delay on any pathway (channel) between generator and detector the projected image *moves* to a different place, well conditioned projections ($n=d+1$) supposed (for example 3 channels for 2-D surfaces) [7]. A special sort of projections, called scene composition or decomposition, changes the dimension of an interference projection. For example a 3D- scene ($n=4$) *P1234* can correspond to different synchronised 1D- scenes ($n=2$) *P12*, *P23*, *P34*, *P41* see [10], [2].

Temporal to Spatial Coding - Frequency Map

If a "split wave" (time function) with the same origin meets again, we obtain a cross interference map. The geometrical distance of the cross interference maxima appears as function of the geometrical arrangement and as function of the time function parameters (pulse frequency or the pause between pulses - refractory period).

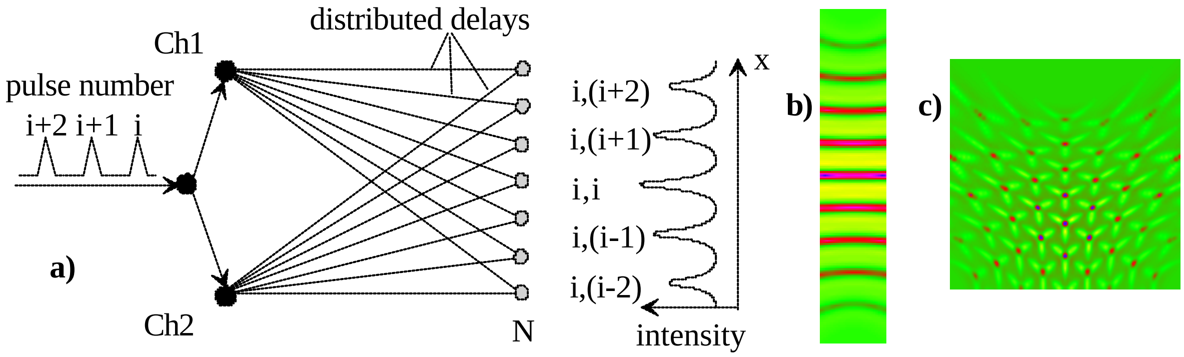


Fig.6) Frequency map as spatial code of a frequency. a) Two channel circuit example; b) result for two channels and c) three channels. Simulation: PSI-Tools, gh 1996

Function: While a self interference of wave *i* with wave *i* (written: [*i*, *i*]) produces the centered emission only (-> projection), any cross-interference of events (pulses) *i* with *i-1*, *i+1*, *i-2*, *i+2* ... produces a map with emission distances proportional to pulse pause (refractory) distance, a frequency map.

Spatial to Temporal Coding

Any nerve fibre delay is proportional to length. A code generator in form of Fig.4b produces an output code (time function), that is carried by the intrinsic delays of the structure. So each spherical arrangement produces a certain arrangement of time-functions - space codes behavior or structure defines the function [10].

Mixed Coding Forms

Trajectory Examination of a Moving Source

Looking on interference locations, we get a natural way to detect trajectories of moving sources. Supposed we have some in succession firing cells creating a trajectory in form of a moving figure. Neurons on the trajectory (Fig.7) fire consecutively. Interference maximum occurs in P with deley vector $M = (\tau_1,\tau_2,... , \tau_n)$ for $\tau_n = \tau_{n+}$ + , with $t = ds/v$, if ds is a distance and v is the velocity of movement [10],[2]. If a local field potential (glia) controls the velocity or the delays τ_n, different velocities can be observed by variation of field potential.

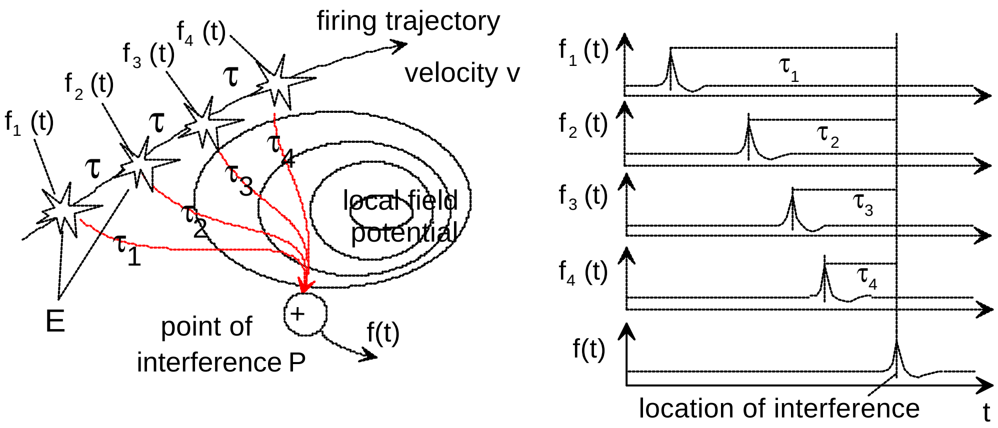


Fig.7) Trajectory examination. If an event (for example a pulse) runs along the trajectory, a specific set of delays will detect it

Fire Density, Holographic Projection and Pain

Lashley [11] analyzed the location of memorization with trained rats. Independent, which part of the brain he removed, the rats could remember partially a learned behavior, a way through a labyrinth. Remembering, that each impulse is followed practically all the time by a further impulse, self-interference emissions in form of a G are surrounded always by cross-interference figures, Fig.8a. What a surprise, they look similar! The delay between pulses defines the cross-interference distance, the distance between the "G" figures. Any memorization is closely coupled to, what Bohm or Pribram called, holographic content. So Lashley had theoretically no chance to find clear locations of memorized contents - what a genius concept of nature!

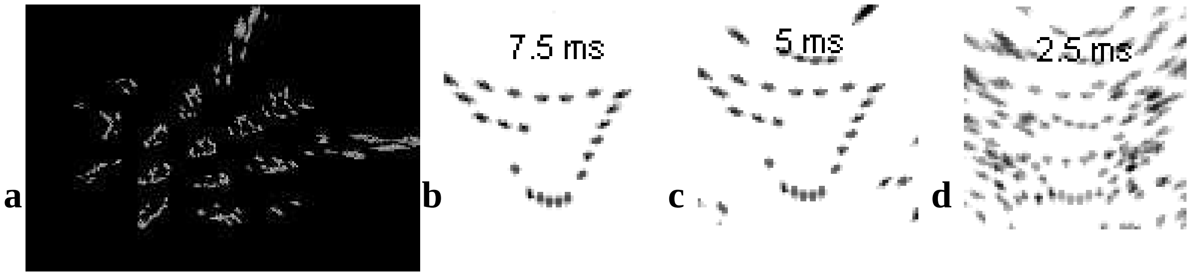
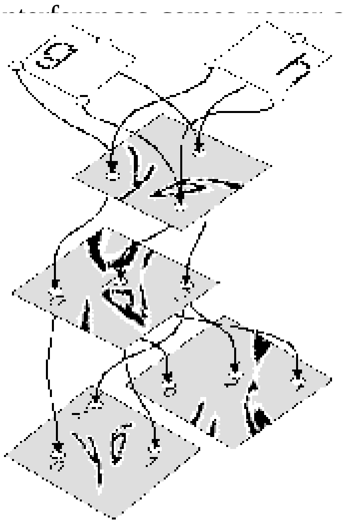


Fig.8) 3-channel projection of a "G". a) Cross interference residua around a self interference figure; b), c), d) cross interference overflow produced by increasing fire rates

What happens if we reduce the pause between pulses? The cross nd nearer, Fig.8b...8d [5]. At a certain point the cross interference nce locations: the projection disappears. If we remember, that the fire r ase dramatically in case of injury, we can imagine a possible mechanism



Topomorphic Overlayed Projections

In our imagination it is possible, to overlay images or impressions. Is there any theoretical evidence for such behavior? To test this, we overlay two channel data streams. The generating fields 'g' and 'h' have identical channel numbers. They project into the same fields, Fig.9, [7] by overlaying (add, append) the channel data streams. Both generator images combine in the receiving fields. If channel source points are moved in the detector fields, the projections become distorted. But the projections maintain in topomorphic relation. It is not possible to separate them again.

Fig.9) Topomorphic relations between time functions of two sources 'g' and 'h' interfering on different fields ->

Technical Applications

Also unknown, we find a lot of technical applications. Behind GPS or our the Acoustic Camera [4], digital filters (FIR, IIR) or control loops can be modelled. A digital filter (Fig.11) for example can be seen as a discrete interference network variant of Fig.4.

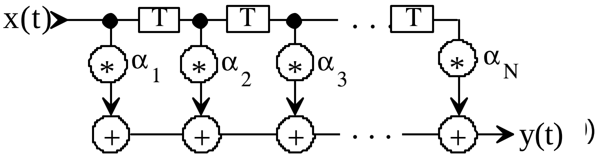
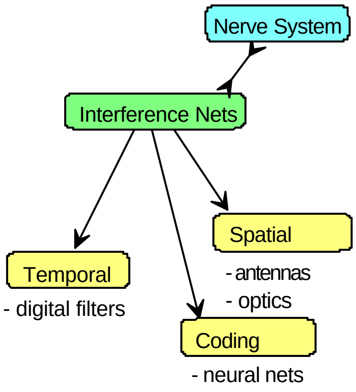


Fig.11) FIR-filter as specific interference network

Summary



Interference networks give a huge possibility to synchronize knowledge of different scientific fields. They have the potential to combine wave optics, neural nets, acoustics, filter theory, electron-physics and neuro-science under an abstract, physical formulation. The IN-approach creates a high potential for education of students if introduced as basic lecture. All papers of the author can be found on www.gfai.de/~heinz/publications. Find short introductions at www.gfai.de/~heinz/historic .

Fig.12) Classification of interference networks ->

Sources

[1] Heinz, G.: Introduction to Interference Networks. Invited plenary speech and regular paper. First International ICSC Congress on NEURO FUZZY TECHNOLOGIES. January 16-19, 2002, Havana, Cuba

[2] Heinz, G.: Abstraction Levels in Neuro-computation - from Pattern Processing to Wave Interference. Invited plenary lecture and regular paper #1504-436 for the International ICSC Symposium on

BIOLOGICALLY INSPIRED SYSTEMS (BIS'2000) as part of the ICSC Congress on Intelligent Systems and Applications (ISA'2000) December 11-15, 2000, University of Wollongong, Australia

[3] Heinz, G.: Space-time Relations in Wave Interference Systems with Attention to Nerve Networks. Regular paper #1402-028 for the Second International ICSC Symposium on Neural Computation NC'2000, May 23-26, 2000 at the Technical University of Berlin

[4] Heinz, G., Döbler, D., Nguyen, T.: Acoustic Photo- and Cinematography basing on the H-Interference Transformation (HIT). ASA'99: 137th meeting of the Acoustical Society of America, 2nd Conv. European Acoustics Ass. and 25th German Acoustics and DAGA Conference at TU Berlin, Germany, March 14-19, 1999

[5] Heinz, G.: An investigation of 'Pictures of Thought' - properties of pulsating, short circuit networks in Theory and simulation. Int. School of Biophysics "Neuronal Coding of Perceptual Systems", Cassamicciola, Isle of Ischia , Naples, Italy, Oct. 12-17, 1998. Published in Backhaus, W.: Neuronal Coding of Perceptual Systems. Series on biophysics and biocybernetics, vol.9 - Biophysics, World Scientific, New Yersey, London, Singapore, Hong Kong, 2001, ISBN 981-02-4164-X, p. 377-391

[6] Heinz, G.: Wave Interference Technology - Übergänge zwischen Raum und Zeit. 43rd Int. Scien. Coll., TU Ilmenau, September 21-24, 1998, p. 645-651

[7] Heinz, G., Höfs, S., Busch, C., Zöllner, M.: Time Pattern, Data Addressing, Coding, Projections and Topographic Maps between Multiple Connected Neural Fields - a Physical Approach to Neural Superimposition and Interference. Proceedings BioNet'96, GFaI-Berlin, 1997, pp. 45-57, ISBN 3-00-001107-2

[8] Heinz, G.: Relativität elektrischer Impulsausbreitung als Schlüssel zur Informatik biologischer Systeme. 39. Internationales Wissenschaftliches Kolloqium an der TU lmenau 27.-30.9.1994, Abgedruckt in Band 2, S. 238-245

[9] 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.

[10] Heinz, G.: Neuronale Interferenzen oder Interferenzen in elektrischen Netzwerken. Autor gleich Herausgeber. GFaI Berlin, 1992 bis 1996, Persönlicher Verteiler, 30 Exempl., 300 S.

[11] Kohonen, T.: Self-organized Formation of Topologically Correct Feature Maps. Biol. Cybern., Vol. 43 (1982), pp. 59-69

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

[13] McCulloch, W.S., Pitts, W.: A logical calculus of the ideas immanent in nervous activity. Bulletin of Math. Biophysics, vol. 5 (1947), pp. 115-133

[14] S.-I. Amari: Neural theory of association and concept formation. Biol. Cybernetics vol. 26, 1977, pp. 175-185

[15] Heinz, G.: Interference Networks - a Physical Approach to Nerve System in Structure and Behaviour. The lecture hold: Dr. Olaf Jaeckel (GFaI). Congress "Bionik 2004", April 22-23, 2004, HANNOVER MESSE Convention Center (Germany)

[16] Heinz, G.: Interference Networks - a Physical Approach to Nerve System in Structure and Behaviour. Congress "Bionik 2004", April 22-23, 2004, HANNOVER MESSE Convention Center

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

[18] Jeffress, L.A.: A place theory of sound localization. Journ. Comparative Physiol. Psychol., 41, (1948), pp.35-39