Interference Networks - a Physical Approach to Nerve System in Structure and Behaviour

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"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

(Thesys) Introducing physical parameters like speed (or velocity) of nerves, spherical location of nerves and the character of (spiking) time functions we can use a nerve net structure to model the behaviour of a nerve network. We will call such networks "Interference networks" (IN). In difference to Neural Nets (NN) IN-wires need to have *distributed delays*. IN carry velocities, delays and spatial informations. Investigating wave interference in spatial, discrete (wired) fields [10] the paper sortes some of the main properties of IN the author found in the years since 1992. I'm hopefull, the paper can generate new questions on the way of mankind to understand one day possible pictures of thought [5].

Short History of Interference Networks (IN)

For a long time I studied advances in Neurocomputing. As more I read, as more I realized a defizit of physical realistic concepts to interprete nerve networks. A lot of well known researchers of Neuro-Computing like McCulloch/Pitts, Amari or Kohonen for all partially tried to include physics, but did not found a consequent way to wave interference systems. Thus in the beginning 90th we had knowledge about a lot of artifical "neuronal" nets, but we did not know anything about wave interference of small pulses in such systems. In September 1992 I found a main problem: Supposed a very 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 millimeter*: The geometrical length of a pulse can be very short in comparison to the size of a neuron! That means, neurons can be seen like cross-roads: the probability that cars (pulses) comming from different directions (dendrites) crashes on the cross-roads is as *higher*, as smaller the distances betweeen the cars or as longer the cars or as slowlier (!) they are ($s = vt$). (Static signals at logic circuits are comparable to infinite long trains crashing statically at the crossing). So in nerves with pulse/pause ratios of 1:10 to 1:10.000 the "crash probability" is very small, to small for a function of nerve net. That means, static signal processing (long trains, neural nets) is a very inadequat approach to nerval data processing. What now? The way to solve the question is, that we have to look for the crash places! We have to follow a single impulse over the network, hoping it meets his doubles at certain places - we have to look for (discrete) interference locations of signals "discrete pulse waves". Introducing this approach I found, that so called "neural" networks map the input pattern only *mirrored* to the output! But in September 1992 this was like a shock: It was not possible to find any scientific publication about a mirroring property in neuro-computing literatur! The shock was as higher, as more such wave analogi lead to optical projections. Like a interference circuit in nerve dimensions a simple, optical lense system mirrors the image! The next shock was, that I could not find much about elementary wave conditions for optical projections, looking for global, interferencial 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. A really great idea, I found later.

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 rought time or space grid or impropper 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 wavefronts 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.

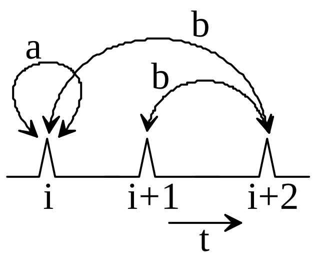
We summarize following properties of IN:

- Physical nets, continous 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 neuron 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 occured by the same origin meet again, we have to observe two, very different cases. The case if a single impulse *i* meet again his derivates *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).



Interference Integral

Supposed, that any neuron receives signals (waves) from n different sources, Fig.1. The (projective) sum of interferences $g(t)$ 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 vector M pre-delayed interference value [7]. Pre-delayed by a different $M' \neq M$ it reconstructs partial noise that growth in general, as more M' differs from M.

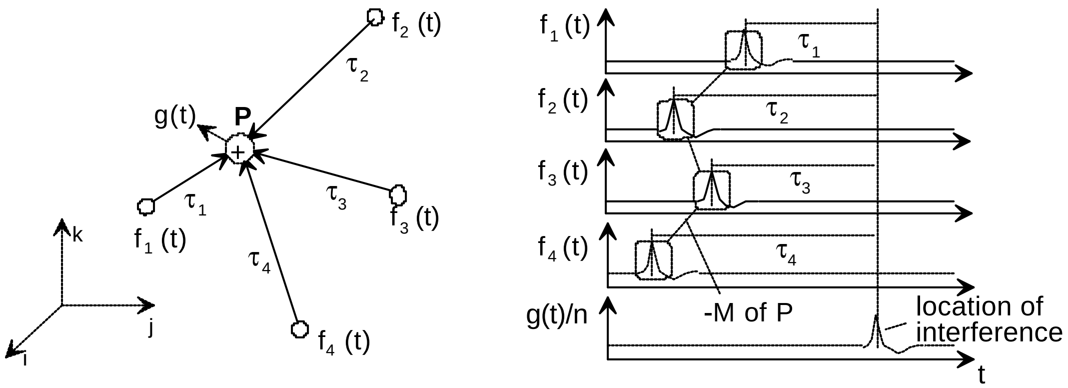


Fig. 1) Example: Time function *g(t)* of point *P* summating four sources $f_k(t)$

Maximum interference occurs in *P* if functions $f_k(t)$ appear pre-delayed with the inverse vector *-M* of *P* (velocity can be very slow in neural space).

In case a neuron produces an excitment at any location *P* it burns its delay vector *M* as an address into the resulting time functions (Fig.2). Any spherical shift of *P* follows a different delay vector *M*. That means, the delay vector represents the location of *P* in relation to the points showing the time functions of interest.

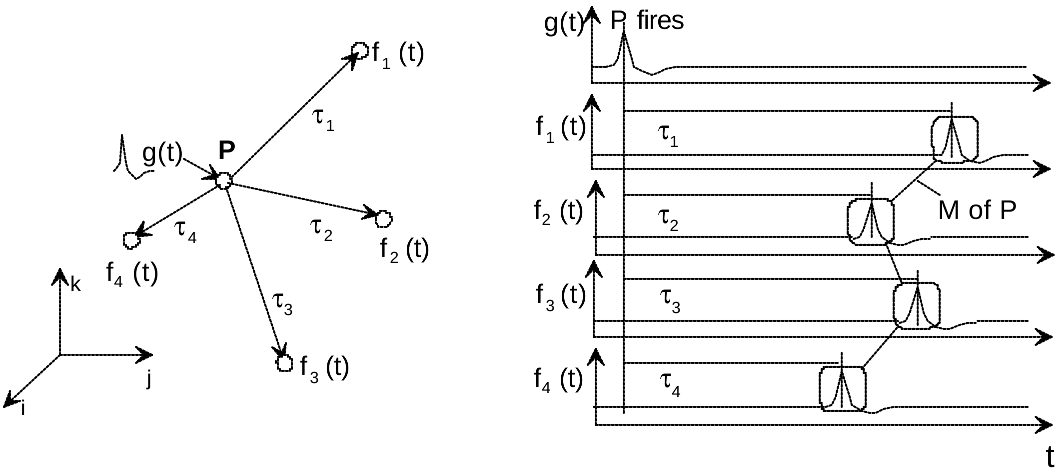


Fig. 2) Expansion of waves in 3D-space. A movement of *P* produces a different *M*

Projection Equation

Independent, if we consider optics or acoustics or neural nets we find an universal wave condition. We find locations of interference (the maximized interference integral) at the locations, where partial waves from the excitment point come into coherence again. The point of self interference has as additional condition, that the delay sums on all paths are equal. Then the sum of delay vectors 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 in components. *[1]* symbolizes the unit vector [7].

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

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

Projection and Reconstruction

For technical purposes we differ between *projection* (optics) and computational *reconstruction*. The projection appears mirrrored using forward going time, the reconstruction appears non-mirrored with inverse time. Reconstruction and projection can have nearly comparable interference integral images [7], as an example see Fig.4b). In case of reconstruction the τ in (3) is set to 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* (o.c.) projections (for example optical lense projections). With a smaller channel number the projection is *under-conditioned* (u.c.), it moves. For example we get hyperbolic excitment curves for the case of two channels on a two dimensional surface [5] ($n = d$: u.c.). For real space the dimension is limited to $d = 3$. Nerve system can encrease the dimension (and following the channel number) 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 dentritic and axonal size of a neuron [10], [8], [6]. A geometrical pulse width l determines the sharpness maximum of a pulse projection on the core (soma), it is defined by the pulse peak time τ_{peak} and velocity v

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

If each neuron must be adressable independent of neighbours, so the average distance between neurons is limited. Example: With 10 µm wave length, velocity 10 mm/s, pulse width 1 ms we can address maximum in a grid of 10x10x10 µm³ per liter 10^{12} neurons. Interesting: as slower the velocity (as slower the animal), as smaller is the geometric pulse width and as higher the capacity!

Temporal to Temporal Coding

Neuronal Elemantary Functions

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

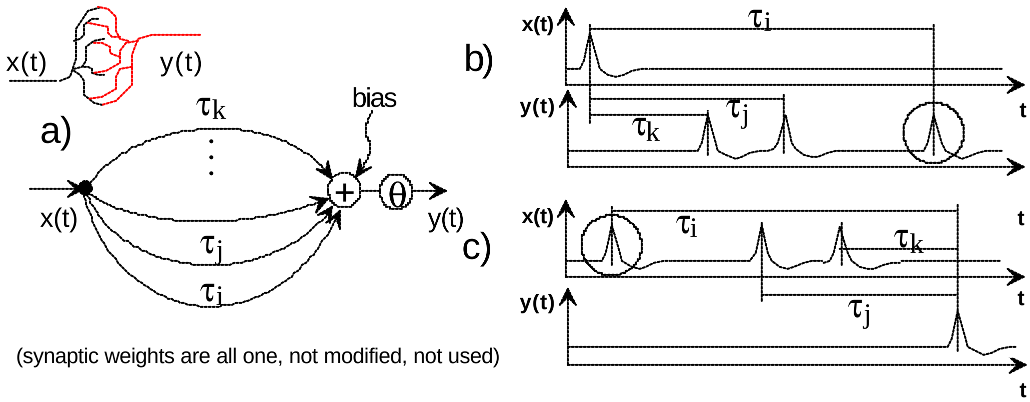


Fig. 3) Basic functions of a neuron or a neural group a) Circuit structure, b) Burst generation with low bias, c) Burst detection with high bias

Spatial to Spatial Coding

Self Interference Projections

A certain excitment (G) in Fig.4 produces a highest interference integral at the interference location (E). This is the position, 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 fast with simulations, the region of interest can be seen 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.

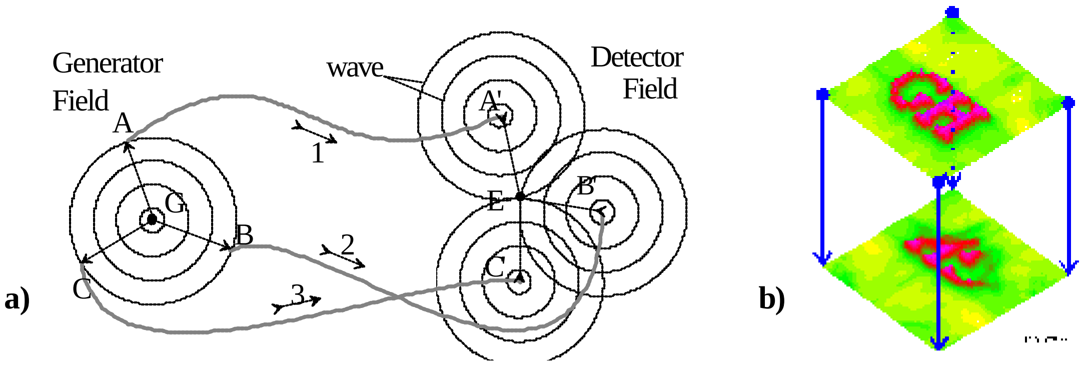


Fig. 4) Spatial self interference a) projection principle, b) example (over-conditioned reconstruction top and o.c. projection bottom)

In [7] first time some projection-variants were published. Changing the velocity between generator and detector field the projection *zooms* the size, the projected image becomes greater or smaller. Changing the delay on any pathway (channel) between generator and detector the projected image *moves* its possition, well conditioned projections suppossed (for example 3 channels for 2D 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 synchronized 1D-scenes (n=2) P12, P23, P34, P41 [10], [2].

Temporal to Spatial Coding

Cross interference as frequency map

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

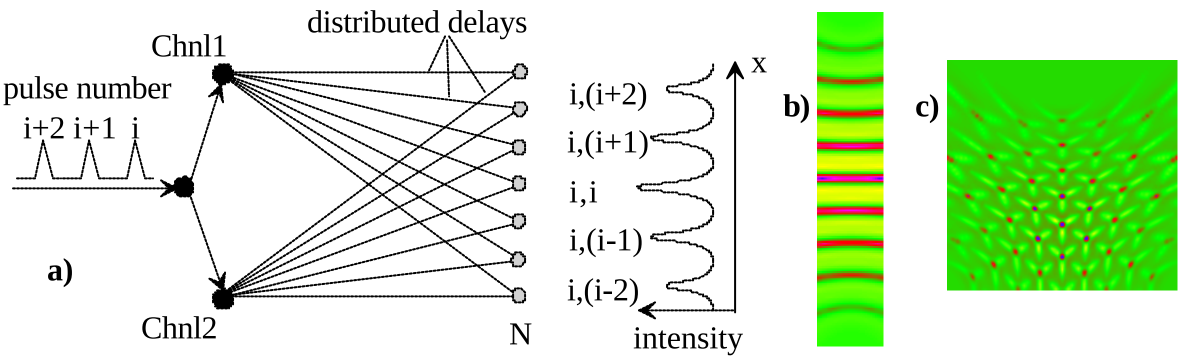


Fig. 5) Frequency maps. a) Two channel circuit example, b) simulation result c) spatial code of a frequency - three channel wave interference simulation result.

Cross interference produces spatial maps (f.e. [i, i+1] or [i, i-1] ...) around the self interference of wave *i* with wave *i* written: [i, i]. The distance between maximum excitment depends on firing frequency (wavelength) and geometrical proportions.

Spatial to Temporal Coding

Any code generator in form of Fig.3b produces an output time function, that is carried by the intrinsic delays of the structure. Each spherical arrangement produces a certain time-function. So the term "space codes behaviour" can be investigated on a simple level [10...1].

Mixed Coding Forms

Movement Trajectory Examination

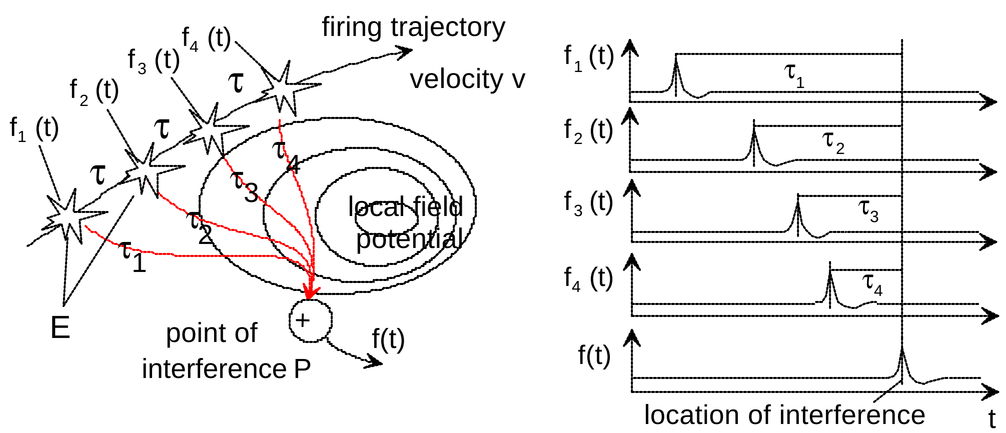


Fig. 6) Properties and example for trajectory examination

By contrast to mathematical methods for trajectory examination there is a natural way using interference locations. Supposed we have some in succession firing cells creating a trajectory in form of a moving figure. Neurons on the trajectory (Fig.6) fire successive one each other by velocity v. Interference maximum occurs in P for

(5) $\tau_n = \tau_{n+1} + \tau$ with delay vector M = $(\tau_1, \tau_2 ... \tau_n$

For equal delays between firing neurons we have $\tau = -\frac{ds}{v}$, if ds is the movement distance and v is the velocity of movement [10], [2]. Is there any *local field potential (glia)* that controls the velocity or the delays τ_n, different velocities can be observed by variation of the local field.

Fire Density, Holographic Projections and Pain

Lashley [11] analysed the location of memorization with trained rats. Independent, which part of the brain he removed, the rats could remember partially a learned behaviour, a way through a labyrinth. Remembering, that each impulse is followed practically all the time by further impulses, the self-interference figure is surrounded in general by cross-interference figures. Only the delay between pulses defines the cross-interference distance. Thus any memorization in interference nets is closely coupled to (what we call) *holographic figures*. So Lashley had theoretical no chance to find clear locations of memorized contents - what a genious concept of nature!

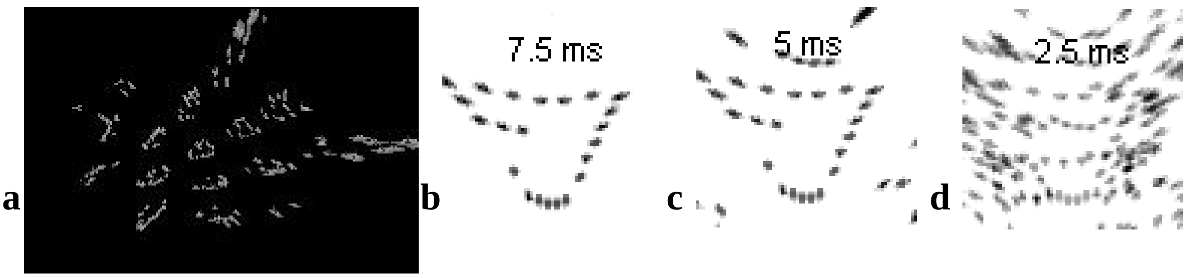


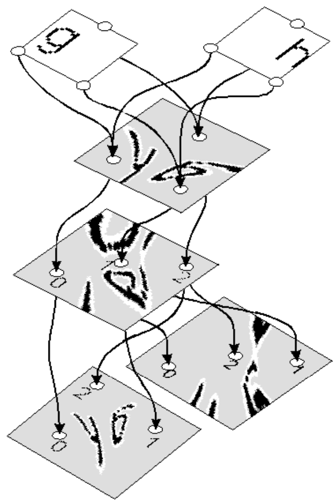
Fig. 7) 3-channel pulse-wave projection of a "G". a) Cross interference residua around a self interference figure (BIS2000). Cross interference overflow produced by higher fire rates b), c), d) with average fire delay in milliseconds

If we reduce the delay between firing of each neuron in the generating field, the cross interferences comes nearer and nearer [5]. At a certain point the cross interferences overlay the self-interference locations: the projection disappears! If we remember, that the fire rate of sensory neurons increase in case of an injury, we can now imagine the mechanism of pain?

Topomorphic overlayed projections

In our imagination it is possible, to overlay images or impressions without problems. Are there theoretical foundations for such behaviour? To test this, we overlay two channel data streams. The generating fields have identical channel numbers and they project into the same field, Fig.8. Using two generator fields, the firing neurons are arranged in form of a '*g*' in the first and in form of a '*h*' in the second field. We add the generated time functions of both fields. Both generator images combines. If channel source points are moved in the detector field, the projections become distorted. But the projections of 'g' and 'h' maintain in a ***topomorphic relation***. It is not possible to separate them again.

Fig. 8) **Topomorphic relations. Overlay of timefunctions of emissions of two wave fields "g" and "h" [7]**[1)] **->**



Technical Applications

Also unknown, we find a lot of technical applications. Behind GPS or our acoustic camera [4], digital filters (FIR, IIR) are most popular. A digital filter (Fig.10) for example can be seen as a discrete, very simple interference network variant of Fig.3:

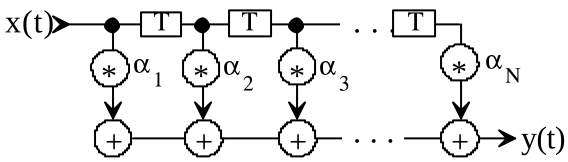
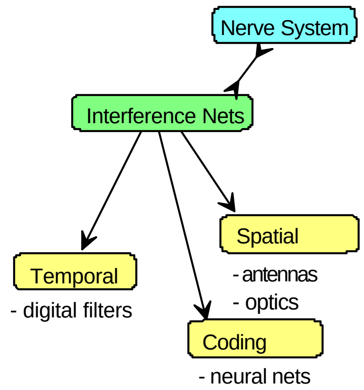


Fig. 10) Digital FIR-filter as modified IN

Fig. 11) Classification of interference networks ->



Summary

Interference networks give a huge possibility to synchronise knowledge of different scientific fields. They have the potential to combine wave optics, neural nets, acoustics, filter theory, electro-physics and neuro-science under a closed, physical formulation. Thus the IN-approach creates a high potential for education of students if introduced as basic lecture.

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