

Notation - Laplace Transforms of Transfer Functions and Signals

Table 1: Notations of Laplace Transform

Category	Item	Laplace Transform
Transfer Function	Learning System (LS)	$L(s)$
	Feedback Controller (FC)	$C(s)$
	Biological Function (BFN)	$K(s)$
Signal	Internal Control Signal (ICS)	$x(s)$
	Output of BFN	$y(s)$
	Output of FC	$z(s)$
	Output of LS	$u(s)$

'Learning process' using biofeedback

Denoting the Laplace transform of each signal and each transfer function as shown in Table 1. we have the following equations:

$$z(s) = C(s) [x(s) - y(s)] \text{ - output of Feedback Controller}$$

$$y(s) = K(s) [z(s) + u(s)] \text{ - output of Biological Function}$$

$$u(s) = L(s) y(s) \text{ - output of Learning System}$$

where $x(s)$ - Internal Control Signal (ICS).

When the learning converges, $z(s)$, tends to 0. Therefore,

$$[1 - L(s)K(s)] y(s) = 0$$

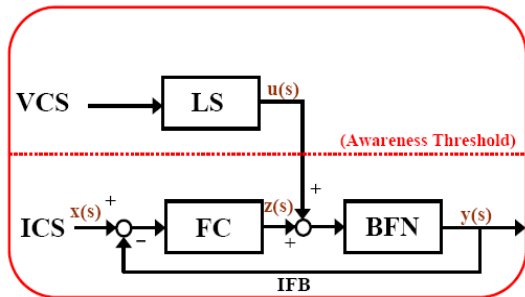
This leads to

$$L(s) = 1 / K(s)$$

showing that the characteristic of LS (Learning System) has become equal to the inverse characteristic of BFN (Biological Function).

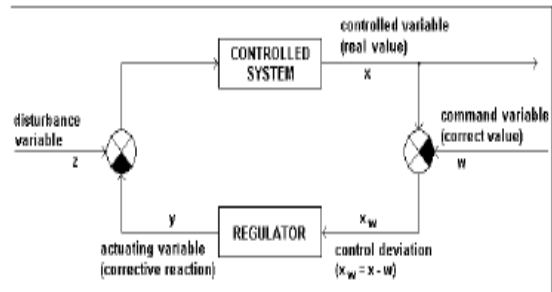
Thus, after convergence of learning, the cascade combination of LS and BFN forms a feedforward system, and when VCS (Voluntary Control Signal) is applied to LS the output of BFN directly follows it without OFB (Outer Feedback Pathway), i.e. voluntary control is made possible.

'Voluntary Control Mode' - OFB no longer needed

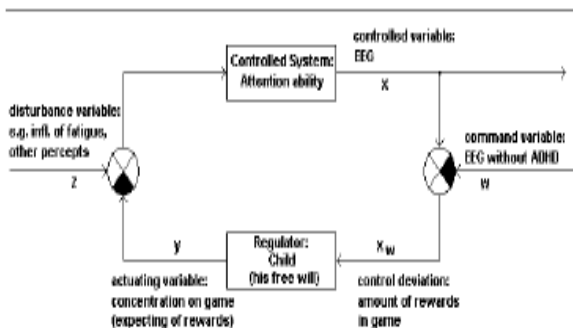


BFN: Biological Function, FC: Feedback Controller, ICS: Internal Control Signal, IFB: Inner Feedback Pathway, LS: Learning System, VCS: Voluntary Control Signal $x(s)$, $y(s)$, $z(s)$, and $u(s)$: Laplace transform of each signal

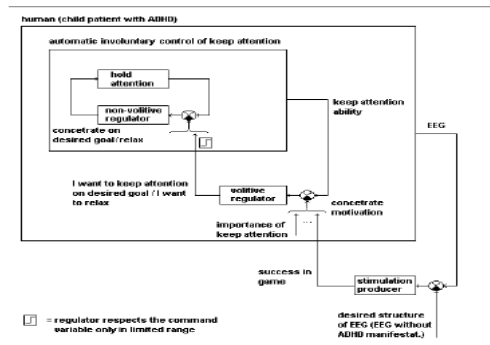
General operating scheme of a control circuit with the negative feedback



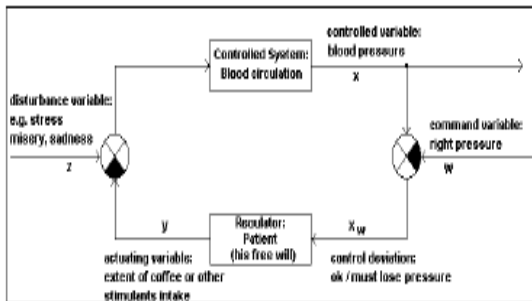
Control circuit that models a child with ADHD who learns to keep attention on a game



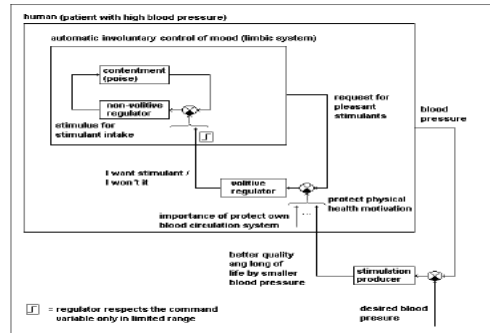
More detailed way how to model biofeedback in the case of a child with ADHD



Control circuit that models a patient with high blood pressure



More detailed way how to model biofeedback in the case of a patient with high blood pressure



Another definition of Biofeedback

Biofeedback control (BFBC) is the complex of research and medical procedures, when a patient is informed by means of an external circuit of the feedback on a condition and change this or that adjustable physiological processes.

Nikolay Suvorov
Russian Academy of Medical Science
Institute for Experimental Medicine, St.Petersburg

The main ideas relating to operant (instrumental) learning were announced by famous Polish physiologist Jerzy Konorski and by distinguish Russian academician Ivan Pavlov.

Synchronization of respiratory movements with cardiogram (CRG)

It promotes amplification of synchronizing processes in slow bioelectrical activity of the brain (the normalization or recovery of alpha-rhythm in EEG), that specifies activation of integrative processes at an intersystem level of regulation and control.

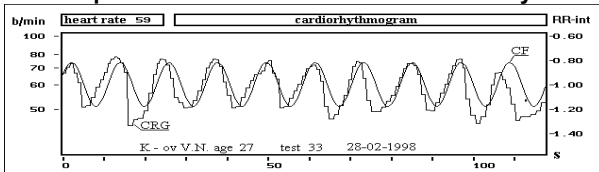
In such a manner oscillatory adaptive biofeedback control of patient's own cardiogram makes practicable nonpharmacological human state correction, helping to recover the **sympatheticovagal balance in the autonomic nervous system**.

The method can be used independently and in a combination with other therapeutics.

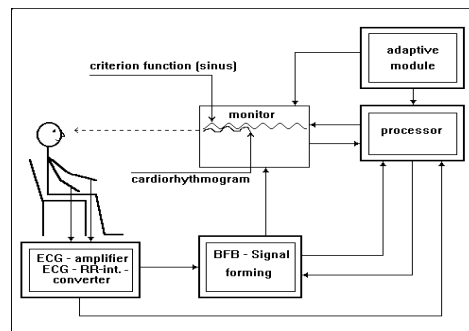
Oscillatory BFB control of cardiogram

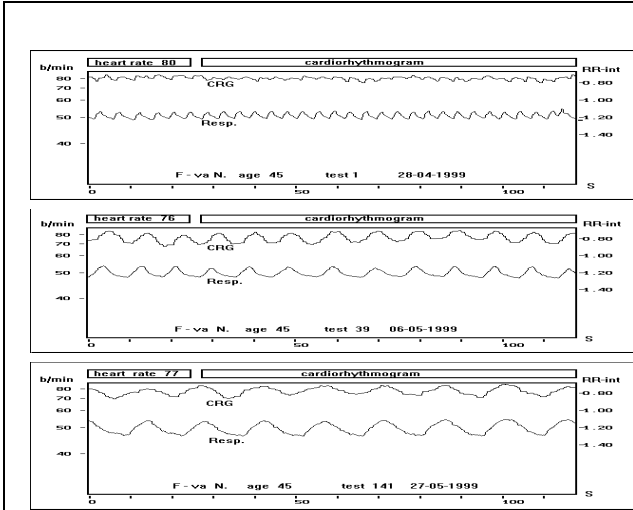
The biofeedback signal is displayed after processing on the monitor in real time as CRG of the patient describing the rate of the heart's beat. Simultaneously sine-wave curve as a criterion function (CF) is presented on the screen.

During training the patient tries to coincide two curves - his own CRG and CF; patient's attention was called to interdependence between CRG-variability and

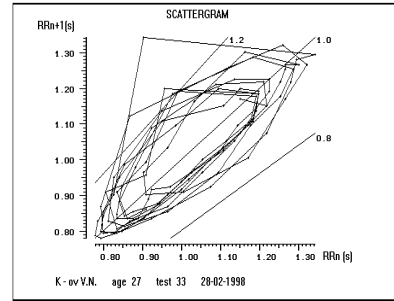


Cardiotraining system - Cardiorespiratory Synchronization

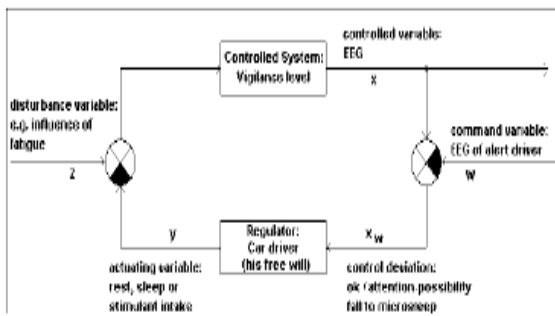




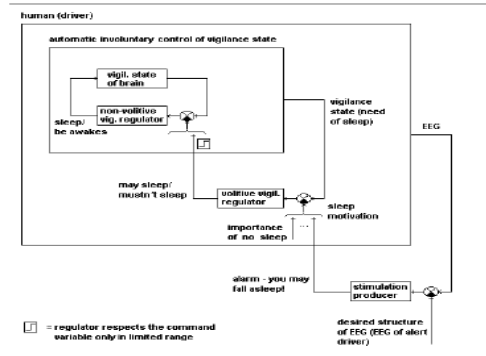
Deterministic chaos in HRV signal



Control circuit that models a car driver who must keep vigilant



More detailed way how to model biofeedback in the case of a car driver who must keep vigilant



Our sleep and vigilance models

Our models are based on *HDF* (D_f , Higuchi's Fractal Dimension) of a raw one-channel EEG-signal.

HDF is calculated directly in time domain, and should not be confused with fractal dimension of an attractor eventually observed when signal data are embedded in a phase space (e.g. using Taken's delay theorem)

HDF is a measure of *signal complexity*.

Great advantage: the model is very simple.

Importance of Nonlinear Dynamics methods, including Deterministic Chaos and Fractals

European Parliament's **STOA report** [on physiological and environmental effects of non-ionising electromagnetic radiation] states: "Future research sponsored by the EC, should incorporate the following recommendations: (...) *That systematic investigation be made (...) whether any observed changes in power spectra are correlated with changes in the level of deterministic chaos*".

Principle used for calculations of D_f

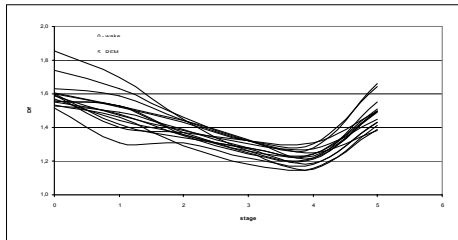
A simple curve has dimension $D_f = 1$, a plane has dimension $D_f = 2$, a signal if represented by a curve on a plane can be characterized by fractal dimension $1 < D_f < 2$, fractional part measuring what percentage of the plane the curve fills up, with 0% (i.e. $D_f = 1$) corresponding to a simple deterministic curve, and 100% (i.e. $D_f = 2$) to pure white noise; fractional part of D_f calculated in a time window (**running fractal dimension, $D_f(t)$**) is a measure of **momentary signal's complexity** that changes when the signal changes due to a psycho-physiological change.

FRAMON™

for automatic vigilance monitoring

Principle used - Higuchi's fractal dimension in wakefulness may differ between individuals, but it diminishes from wakefulness to stage 1 sleep; **FRAMON™** can monitor vigilance of e.g. truck driver based on a single EEG-signal: first it automatically individualizes value of D_f in wakefulness (so establishing alarm's threshold for the user), and then alarming by a ring or by a voice message that the person may be falling asleep when D_f diminishes below this threshold.

The model works well for vigilance monitoring because D_f certainly decreases from wakefulness to sleep stage 1.



Higuchi's fractal dimension of different sleep stages for 15 healthy persons
 0 - wake
 5 - REM
 1,2,3,4 - stages 1,2,3,4, respectively

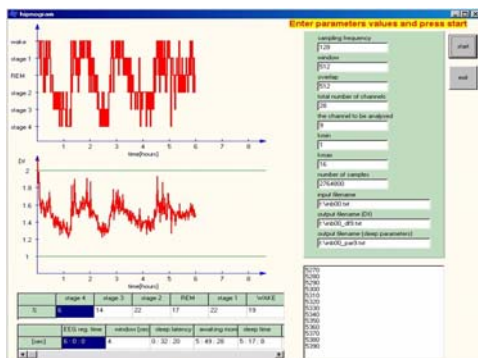
Automatic Sleep Stager **FRAST™**

To play movie, click left mouse's button on program's screenshot.

When the movie is finished, push the button [PgDn].



Automatic Sleep Stager **FRAST™**

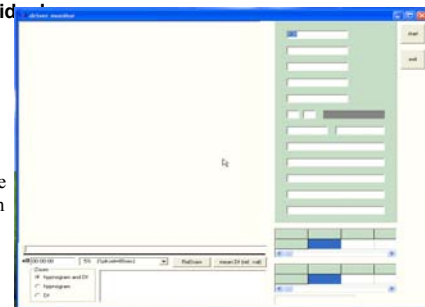


FRAMON™ - program for drivers' vigilance monitoring

Calculation of mean fractal dimension, D_f , in vigilance for the individual

To play movie, click left mouse's button on program's screenshot.

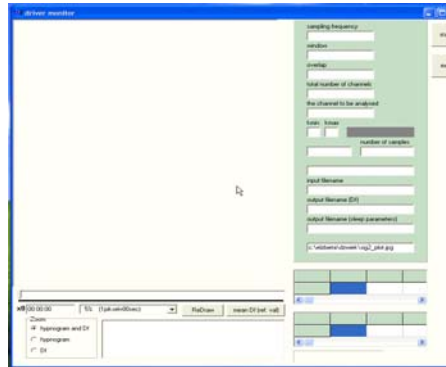
When the movie is finished, push the button [PgDn].



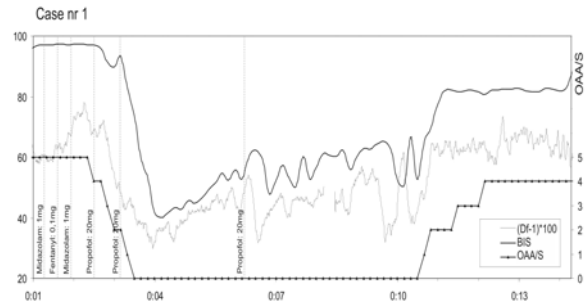
FRAMON™ - program for drivers' vigilance monitoring

Choosing the waking sound

To play movie, click left mouse's button on program's screenshot. When the movie is finished, push the button [PgDn].



FRANES™ Monitoring of the depth of anesthesia - fractal dimension of EEG is like BIS



Why not linear methods, like Fourier ?

Adam Wazyk (actually Adam Wagman, 1905-1982) „Poem for adults” Nowa Kultura, nr. 34, Warsaw, 1955, translated from Polish by W.Klonowski

**Day-dreamer Fourier did forecast
That seas would be filled with lemonade.
And isn't that so?
They drink sea water
They shout –
Lemonade!
They noiselessly get home
To throw up,
To throw up.**

Chaosology -

Nonlinear Dynamics in Psychophysiology

What is the difference between **feeling and thoughts?**

‘Central Executive Structure’
- a new era Maxwell’s Demon

In Physics everything is a question of time scale!!!

Example - radioactive decay:

$$dz/dt = -a \cdot z \quad (1)$$

$$z(t) = z_0 \cdot \exp(-t/\tau) \quad (2)$$

τ is characteristic time – the greater is τ the slower is the process
 $\tau = 1/a = \tau_{1/2} / \ln 2 \quad (3)$
 where $\tau_{1/2}$ is half-life

We may drastically simplify description of the system by classifying variables into three classes:

1. those changing quickly, i.e. their characteristic times are much shorter than the period of observation;
2. those changing slowly, i.e. their characteristic times are comparable with the period of observation;
3. those changing very slowly.

Quasi-stationary states

Quick variables (those for which characteristic times are much shorter than the period of observation we are interested in) reach their **stationary values**, while **very slow variables** (those for which characteristic times are much longer than the period of observation) **stay constant and may be treated just as parameters.**

We need to solve only equations for **slow variables** (those for which characteristic times are comparable with the period of observation). **Tikhonov’s Theorem** enables elimination of quick variables.

<p style="text-align: center;">Brain's phase space</p> <p><i>Brain phase space, B</i> , may be defined as follows: $B = (I , M , R , E , C , O)$</p> <p>where I denotes the set of <u>input variables</u> i.e. those describing influence of the environment and of the body on the brain (e.g. impulses from sense organs); M denotes the set of <u>memory variables</u>; R denotes the set of <u>operational memory variables</u>; E is the set of <u>variables defining the emotional state</u>; C is the set of <u>variables defining the state of consciousness</u>; O is the set of <u>output variables</u> i.e. those describing influence of the brain on effectors.</p> <p>In general, time evolution of the state of brain is given by a map: $F : B_t \rightarrow B_{t+1}$</p> <p>where index t denotes the given moment and 1 denotes the time unit - characteristic time of the process.</p>	<p style="text-align: center;">State of consciousness is defined by slow variables; Emotional state is defined by quick variables.</p>
<p style="text-align: center;">Feelings, thoughts, and awareness (1)</p> <p>Several emotional states may have changed before the state of consciousness does change, i.e. there exist processes that change emotional state without changing state of consciousness (for simplicity we assume that input, output, and memory variables also remain unchanged)</p> $F_e : E_t \rightarrow E_{t+\tau}$ <p>where τ denotes the unit of time scale of quick variables; such processes we will call <i>emotional processes</i> or <i>feelings</i>.</p>	<p style="text-align: center;">Feelings, thoughts, and awareness (2)</p> <p>Similarly, processes that change the state of consciousness</p> $F_c : C_t \rightarrow C_{t+T}$ <p>where T denotes the unit of time scale of slow variables (T is much greater than τ), we will call <i>thinking processes</i> or <i>thoughts</i>.</p> <p>Processes that cause a change of the state of consciousness at the moment $t+T$ depending on the emotional state at moment t</p> $F_a : E_t \rightarrow C_{t+T}$ <p>we will call <i>awareness processes</i>.</p> <p>Characteristic time scale of awareness processes, T, is of the same order as characteristic time scale of thinking processes.</p>
<p style="text-align: center;">Psychology and Nonlinear Dynamics (1)</p> <p>Processes that change the state of consciousness, i.e. thinking processes and awareness processes, we shall also call <i>cognitive processes</i>.</p> <p>So, the difference between emotional processes and cognitive processes lies in the difference of characteristic time scales – none ‘Central Executive Structure’ is necessary.</p>	<p style="text-align: center;">Psychology and Nonlinear Dynamics (2)</p> <p>In the short time scale emotional processes change <i>structure of the brain phase space, B</i> (at least locally), reaching a kind of a stationary emotional state; cognitive processes act on such a phase space that has already changed its geometry (structure) due to emotional processes.</p> <p>This way some parts of the phase space become more easily reachable. This may correspond to the well-known psychological phenomenon of ‘thoughts being concentrated on the object of feelings’.</p>

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Neurobiology of plants

