Could Edward Lorenz wake Michael Schumacher up?

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Abstract: Recent studies suggest that the brain normally works in a kind of chaotic state, while in unconsciousness (and coma), there is more order. One may consider the brain as a whole and see if some simple models can produce complex dynamics related to the known facts about it. There is a simple chaotic model of the brain in the literature. A chaotic system can maintain its chaotic behavior for some ranges of the parameter values. However, usually there are some periodic windows embedded within those chaotic ranges. In a periodic window the rhythm of a chaotic system suddenly changes from a random-like behavior to an ordered periodic one. This resembles the situation of a coma. There are some control methods for putting a chaotic system into those windows, or conversely, for releasing it from periodic states. We propose a hypothesis that such methods may be used to help patients to recover from a coma.

Keywords: Coma; Brain; Chaos; Periodic windows.

Based on the recent study "*Large-scale signatures of unconsciousness are consistent with a departure from critical dynamics*" (Tagliazucchi, Chialvo et al., 2016), David Shultz has written an article entitled "*Consciousness may be the product of carefully balanced chaos*" in *http://www.sciencemag.org/news/2016/01/consciousness-may-be-product-carefully-balanced-chaos*. It suggests that the brain normally works in a kind of chaotic state, while in unconsciousness (and coma), there is more order.

One of the current theories about consciousness postulates that it emerges from the integration of locally generated information. This integration necessitates communication between brain regions pertaining to identified networks. Several types of fMRI and hdEEG analyses allow not only identifying regions that communicate with each other, but also indications of information integration. Dose-dependent and agent-specific breakdown of communication and integration in specific networks is observed during anesthesia-induced unconsciousness (or at least unresponsiveness). The agent-specific changes may be related to the different clinical patterns induced by the considered agent. These observations are arguments to sustain the information-integration theory. However we can change the whole viewpoint and look at the problem from a different angle. One may consider the brain as a whole and see if some simple models can produce complex dynamics related to the known facts about it. There is a simple nonlinear models of the brain (Baghdadi, Jafari et al., 2015b) and some papers referring to the investigation of some disorders from a nonlinear dynamics standpoint (Jafari, Ansari et al., 2013; Jafari, Baghdadi et al., 2013; Jafari, Hashemi Golpayegani et al., 2013; Hadaeghi, Hashemi Golpayegani et al., 2016). A chaotic system can maintain its chaotic behavior for some ranges of parameter values. However, usually there are some (in fact infinitely many) periodic windows embedded within those chaotic ranges. In a periodic window, the rhythm of a chaotic system suddenly changes from a random-like behavior to an ordered periodic one. This resembles the situation discussed in the first paragraph. An example of such situation can be found in the appendix using the model in (Baghdadi, Jafari et al., 2015a).

There are some control methods for putting a chaotic system into those windows, or conversely, for releasing it from being stuck in those periodic states (Kapitaniak, 1996; Chen, Moiola et al., 2000; Chen & Yu, 2003). There may be a way to use such methods to help patients recover from a coma. We may need a more serious look at the problem of coma, through the lens of nonlinear dynamics. Could Edward Lorenz wake Michael Schumacher up, before serious damage is caused by his long coma?

APPENDIX

There is a nonlinear neural network proposed in (Baghdadi, Jafari et al., 2015a) (Fig. 1) as a very simple model of the brain. Choosing appropriate values for the parameters leads to chaotic behavior (Fig. 2) while a change in some parameters can result in a periodic behavior (Fig. 3). The model input is composed of two main parts: First, sensory information received from the environment, and second, feedback information extracted from analysis and perception of that sensory information. The sensory cortex receives the input information and sends it to the inhibitory and excitatory parts of the brain with an amplification factor of w_i. These parts are attributed to the frontal cortex. In this model, $E(x)$ and $I(x)$ are the activation functions of two neurons whose outputs are respectively multiplied by (B) and (A). Hyperbolic tangent activation functions are considered for both $I(x)$ and $E(x)$. However, the output of $I(x)$ enters the output neuron with a negative value that models the inhibitory brain action, and the output of $E(x)$ enters the output neuron with a positive value that models the excitatory brain action. All coefficients ((A), (B), w_1, and w_2) are associated with the brain synapse weights that are regulated by the release of different neurotransmitters. The value of these coefficients can be varied to produce different behaviors.

$\mathrm{E(x) = tanh(x)}\,,\;\; \mathrm{I(x) = tanh(x)}$ $\mathrm{out(n+1) = B * E(x_1) - A * I(x_2)}$ $\mathrm{x_1 = w_1 * out(n)},\;\; \mathrm{x_2 = w_2 * out(n)}$ $\mathrm{out(n+1) \;=\; B * tanh(w_1 * out(n)) \;-\; A * tanh(w_2 * out(n))}$	(1)

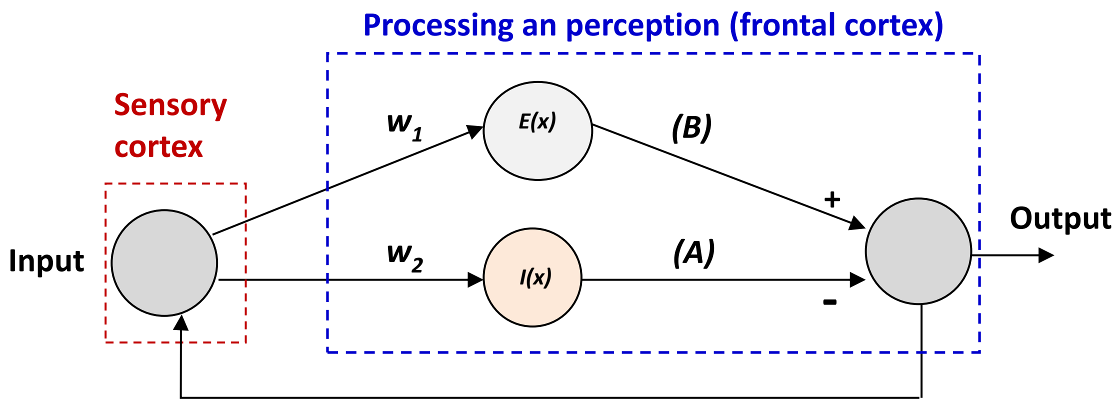

Fig. 1. A behavioral chaotic neural network model of ADD. *E(x)* and *I(x)* are the activation functions of two neurons whose outputs are respectively multiplied by *(B)* and *(A)*. Both *E(x)* and *I(x)* are hyperbolic tangent functions. *I(x)*(-A)* models the inhibitory brain action and *E(x)*(+B)* models the excitatory brain action. *(A)*, *(B)*, and w_i are values that amplify the output of the neurons.

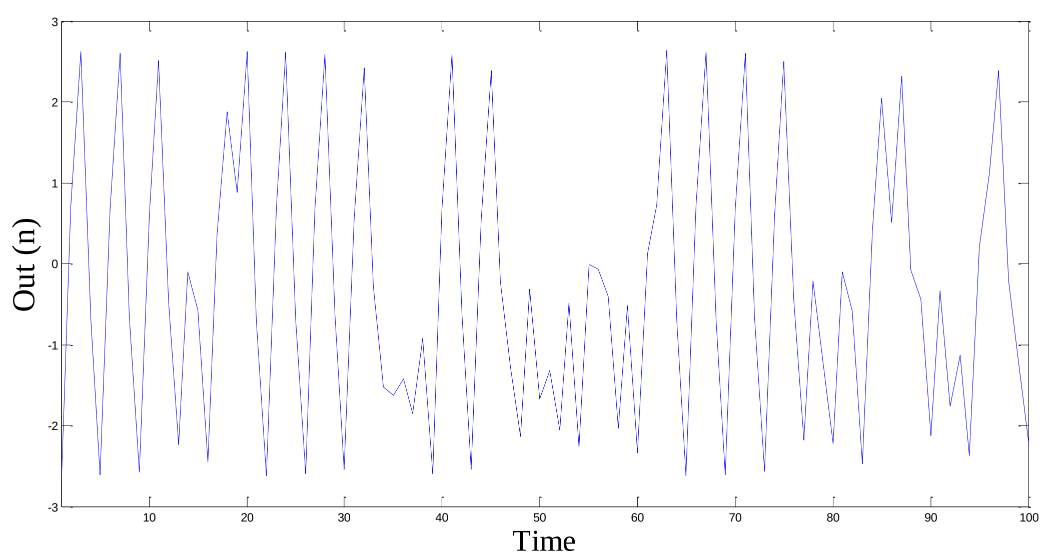

Fig. 2. The model output for *A=12.43, B=5.821; w1=1.487; w2=0.2223.*

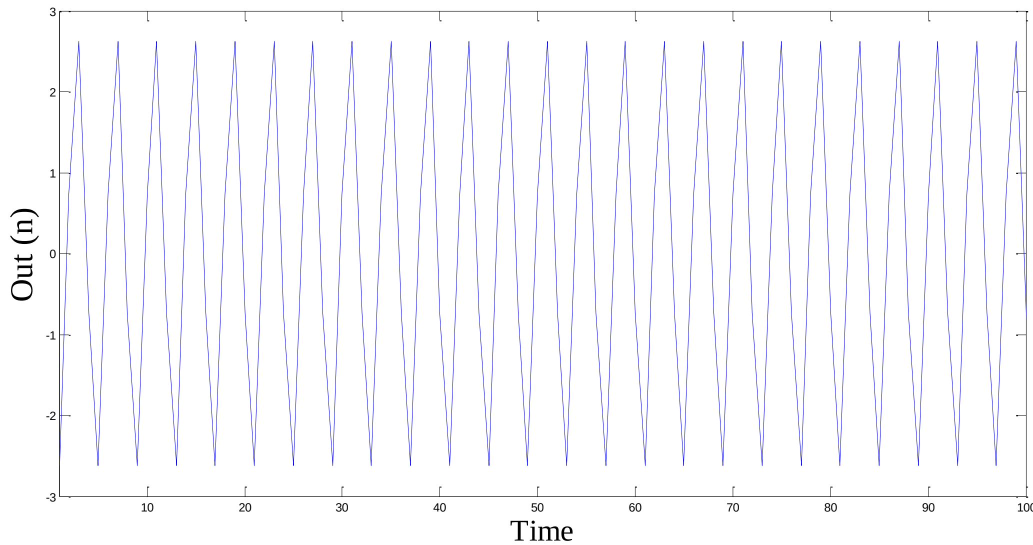

Fig. 3. The model output for *A=12.473, B=5.821; w1=1.487; w2=0.2223.*

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