Modeling evolution of the mind and cultures: Emotional Sapir-Whorf Hypothesis

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Abstract—Evolution of cultures is ultimately determined by mechanisms of the human mind. The paper discusses the mechanisms of evolution of language from primordial undifferentiated animal cries to contemporary conceptual contents. In parallel with differentiation of conceptual contents, the conceptual contents were differentiated from emotional contents of languages. The paper suggests the neural brain mechanisms involved in these processes. Experimental evidence and theoretical arguments are discussed, including mathematical approaches to cognition and language: modeling fields theory, the knowledge instinct, and the dual model connecting language and cognition. Mathematical results are related to cognitive science, linguistics, and psychology. The paper gives an initial mathematical formulation and mean-field equations for the hierarchical dynamics of both the human mind and culture. In the mind heterarchy operation of the knowledge instinct manifests through mechanisms of differentiation and synthesis. The emotional contents of language are related to language grammar. The conclusion is an emotional version of Sapir-Whorf hypothesis. Cultural advantages of "conceptual" pragmatic cultures, in which emotionality of language is diminished and differentiation overtakes synthesis resulting in fast evolution at the price of self doubts and internal crises are compared to those of traditional cultures where differentiation lags behind synthesis, resulting in cultural stability at the price of stagnation. Multi-language, multi-ethnic society might combine the benefits of stability and fast differentiation. Unsolved problems and future theoretical and experimental directions are discussed.

Keywords: Sapir-Whorf hypothesis, emotions, concepts, cognition, language, cultures, evolution, dynamic logic

1. EMOTIONAL SAPIR-WHORF HYPOTHESIS

Sapir-Whorf hypothesis (SWH) was a name later used for research of Benjamin Whorf (1956) and Edward Sapir (1985), who in a series of publications in the 1930s researched influence of languages on the way people think and behave. There has been a long predating linguistic and philosophical tradition, which emphasized the influence of language on cognition (Bhartrihari 5th CE, Humboldt 1836, Nietzsche 1876). Experimental linguistic evidence in support of this hypothesis concentrated on the categorial, conceptual content of languages; for example, the existence of words for colors influence color perception (Roberson, Davidoff, & Braisbyb 1999). Recently A. Franklin, G. V. Drivonikou, L. Bevis, I. R. L. Davies, P. Kay, and T. Regier (2008) demonstrated that learning a word rewires cognitive circuits in the brain, learning a color name moves perception from the right to the left hemisphere. This would stimulate studying higher cognitive effects of language. Emotional differences might be no less important (Perlovsky 2006a) but no computational models of emotional effects of language on cognition have existed, and limited experimental evidence suggested interaction between emotional contents of languages and cognition (Harris, Ayçiçegi & Gleason 2003).

Computational models of how conceptual and emotional contents of language affect cognition are derived in this paper motivated by neural mechanisms. In our attempt to model these interactions we are motivated by the knowledge about brain modules, rather than individual neurons. The next section reviews conceptual and emotional mechanisms of language and its interaction with cognition. Since existing direct experimental data is inadequate, we briefly review existing theoretical ideas and experimental evidence on language evolution, conceptualizing possible mechanisms, and emphasizing directions for future research. Section 3 summarizes previously developed neuro-mathematical theories of

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interaction between language and cognition (Perlovsky 2006a, 2009), which have been partially proven experimentally; these models are extended toward the heterarchy of the mind. Section 4 makes a step toward deriving cultural evolutionary models motivated by neural brain mechanisms. We demonstrate that certain types of cultural evolutionary paths are favored purely by cognitive-language mechanisms. In conclusion we discuss future theoretical and experimental research directions.

2. LANGUAGE AND COGNITION MECHANISMS

It is widely considered that language is as a mechanism for communicating conceptual information. Emotional contents of language are less appreciated within the scientific community, its role in intelligence, its evolutionary significance, and related mechanisms are less known. Still their role in ontology, evolution, and cultural differences is significant. Whereas many scientists concentrate on interfaces between mechanisms of language computation, sensory-motor, and concept-intention (Hauser, Chomsky, & Fitch 2002), it is important to keep in mind that primordial origins of language was a unified neural mechanism of fused voicing-behavior, emotion-motivation, and concept-understanding. It is possible that differentiation of these several mechanisms involved in language, voicing, cognition, motivation, behavior occurred at different prehistoric times, in different lineages of our ancestors, and this may be relevant to discussions of evolution of language and cognition (Botha 2003; Botha & Knight 2009).
The current differentiated state of these abilities is address here. Currently they are separated to a significant degree in the human mind. We also address mechanisms of interfaces-links, which make possible integrated human functioning. The paper concentrates on mechanisms of existing interfaces and their cultural evolution. Before describing in the next section the mechanisms of language, concepts, and emotions mathematically, we summarize these mechanisms below conceptually in correspondence with the general knowledge documented in a large number of publications, emphasizing certain aspects that have escaped close scientific attention in previous research.

2.1. Primordial undifferentiated synthesis

Vocal tract in animals and laryngeal muscles are controlled mostly from ancient emotional centers (Lieberman 2000). Vocalizations are more affective than conceptual. Mithen (2006) summarized the state of knowledge about vocalization by apes and monkeys. Calls could be deliberate, however their emotional-behavioral meanings are probably not differentiated; this is why primates cannot use vocalization separately from emotional-behavioral situations; this is one reason they cannot have language.

Language and its emotionality in primates and other animals is governed from a single ancient emotional center in the limbic system. Conceptual and emotional systems in animals are less differentiated than in humans. Sounds of animal cries engage the entire psyche, rather than concepts and emotions separately. An ape or bird seeing danger does not think about what to say to its fellows. A cry of danger is *inseparably* fused with the recognition of a dangerous situation, and with a command to oneself and to the entire flock: “Fly!” An evaluation (emotion of fear), understanding (concept of danger), and behavior (cry and wing sweep) – are not differentiated. Conscious and unconscious are not separated: Recognizing danger, crying, and flying away is a fused concept-emotion-behavioral *synthetic* form of cognition-action. Birds and apes cannot control their larynx muscles *voluntarily*.

2.2. Language and differentiation of emotion, voicing, cognition, and behavior

Evolution of ability for language required freeing vocalization from uncontrolled emotional mechanisms. Initial undifferentiated unity of emotional, conceptual, and behavioral-(including voicing) mechanisms had to separate-differentiate into partially independent systems. Voicing separated from emotional control due to a separate emotional center in cortex which controls larynx muscles, and which is partially under volitional control (Deacon 1989). Evolution of this volitional emotional mechanism possibly paralleled evolution of language computational mechanisms. In all contemporary languages conceptual and emotional mechanisms significantly differentiated as compared to animal vocalizations; languages evolved toward conceptual contents, while their emotional contents were reduced.

Understanding of the world, or cognition, is due to mechanism of concepts, or internal representations, or models. Perception or cognition consists in matching internal concept-models with patterns in sensor data. Concept-models generate top-down neural signals that are matched to bottom-up signals coming from lower levels (Grossberg 1988; Perlovsky 2000). In this process vague internal models are modified to match concrete objects or situations (Perlovsky 2006a).

How language determines and affects these cognitive processes by? Primates have cognitive abilities independent from language. It seems clear that the human ability for cognition significantly exceeds that of all other animals. A possible mechanism of how language could guide and enhance cognition has been discussed in (Perlovsky 2009). This is a mechanism of the dual model: every concept-model has two parts, cognitive and language. Language models (words, phrases) are acquired from a surrounding language by age of five or seven; they contain cultural wisdom accumulated through millennia. During the rest of life the language models guide acquisition of cognitive models.

2.3. Emotions, instincts, and the knowledge instinct

The word emotion refers to several neural mechanisms in the brain (Juslin and Västfjäll 2008); in this paper we always refer to instinctual-emotional mechanism described in (Grossberg and Levine 1987). The word instinct in this paper is used in correspondence with this reference to denote a simple inborn, non-adaptive mechanism of internal "sensor," which measures vital body parameters, such as blood pressure, and indicate to the brain when these parameters are out of safe range. This simplified description will be sufficient for our purposes, more details could be found in (Gnadt and Grossberg 2008; Grossberg and Seidman 2006) and references therein. We have dozens of such sensors, measuring sugar level in blood, body temperature, pressure at various parts, etc.
Mechanism of concepts evolved for instinct satisfaction. According to instinctual-emotional theory (Grossberg and Levine 1987), communicating satisfaction or dissatisfaction of instinctual needs from instinctual parts of the brain to decision making parts of the brain is performed by emotional neural signals. Perception and understanding of concept-models corresponding to objects or situations that potentially can satisfy an instinctual need receive preferential attention and processing resources in the mind. In this talk emotions always refer to neural signals connecting conceptual and instinctual brain regions.

Perception and cognition requires matching top-down signals from concept-models to bottom up signals coming from sensory organs; otherwise an organism will not be able to perceive the surroundings and will not be able to survive. Therefore humans and high animals have an inborn drive to fit top-down and bottom-up signals, which we call the knowledge instinct (Perlovsky and McManus 1991; Perlovsky 2006a; 2009). These references discuss specific emotions related to satisfaction or dissatisfaction of the knowledge instinct. These emotions are related purely to knowledge, not to bodily needs, and for this purpose they are called aesthetic or 'spiritual' emotions. They are inseparable from every act of perception and cognition.

2.4. Grammar, emotionality of languages, and meanings

Animal vocalizations are controlled from ancient emotional brain centers and conceptual meanings are not separated from emotions. Human language and voice have separated from ancient emotional centers long ago, possibly hundreds of thousands of years. Nevertheless, emotions are present in language. Most of these emotions originate in cortex and are controllable aesthetic emotions. We consider their role in satisfying the knowledge instinct in the next section. Emotional centers in cortex are neurally connected to old emotional limbic centers, so both influences are present. Emotionality of languages is carried in language sounds, what linguists call prosody or melody of speech. This ability of human voice to affect us emotionally is most pronounced in songs, however, this is a separate topic, not addressed here.

Everyday speech is low in emotion, unless affectivity is specifically intended. We may not notice emotionality of everyday "non-affective" speech. Nevertheless, "the right level" of emotionality is crucial for developing cognitive parts of models. If language parts of models are highly emotional, any disagreement would immediately resort to aggression and there will be no room for language development (as among primates). If the language parts of the models are non-emotional at all, there would be no motivational force to engage into conversations; to develop language models, and possibly the motivation for developing higher cognitive models will be diminished. Lower cognitive models, say for object perception will be developed; first, because they are imperative for survival; and second, because they can be developed independently from language, based on direct sensory perceptions. But models of situations and higher cognition are developed based on language models (Perlovsky 2009). Emotional connections between cognitive and language models are required for knowledge to be meaningful.

Primordial fused language-cognition-emotional models, as discussed, have differentiated long ago, involuntary connections between voice-emotion-cognition dissolved with the emergence of language. They were replaced with habitual connections. The sounds of all languages have changed, nevertheless, if the sounds of a language change slowly, connections between sounds and meanings persist; it follows that emotion-meaning connections persist. This persistence is a foundation of meanings; because meanings imply motivations. If the sounds of language change too fast, cognitive models are severed from motivations, and meanings disappear. If sound changes too slowly, emotions are too strong and nails meanings emotionally to old ways; culture stagnates.

Doesn't culture direct the necessary language changes – as many assume, or is language the driving force of cultural changes? Direct experimental evidence is limited; it will have to be addressed by future research. Theoretical considerations suggest no neural or mathematical mechanism for culture directing language; just the opposite, most of the cultural contents are transmitted through language. Cognitive models contain cultural meanings separate from language, but cognitive models cannot be transferred from generation to generation separately from language. Cultural habits and visual art can preserve and transfer meanings, but they contain a minor part of cultural wisdom and meanings, comparative to language. Language models are the major container of cultural knowledge shared among individual minds and their collective culture.

The next step toward understanding cultural evolution, therefore, is to identify mechanisms determining the changes of language sound. It is controlled by grammar. In inflectional languages, affixes and endings are fused with the sounds of word roots. Pronunciation-sounds of affixes are controlled by few rules, which persist over thousands of words. These few rules are manifest in every phrase. Therefore every child learns to pronounce them correctly. Positions of vocal tract and mouth muscles for pronunciation of affixes are fixed throughout a population and are conserved throughout generations. Correspondingly, pronunciation of whole words cannot vary too much, and language sound changes slowly. Inflections therefore play a role of "tail that wags the dog," they anchor language sounds and preserve meanings. When inflections disappear, this anchor is no more; nothing prevents the sound of a language to become fluid and change fast from generation to generation.

This process occurred in the English language after transition from Middle English to Modern English (Lerer 2007). Most of inflections disappeared and the sound of the language started changing within each generation, this process continues today. English evolved into a powerful tool of cognition unencumbered by excessive emotionality, the English language spread democracy and technology around the world. This was made possible by conceptual differentiation empowered by language, which overtook emotional synthesis. But the loss of synthesis has also lead to ambiguity of meanings. Current English language cultures face internal crises, uncertainty about meanings and purpose. Many people cannot coupe with the diversity of life. Future research in psycholinguistics, anthropology, history, historical and comparative linguistics, and cultural studies will examine interactions between languages and cultures. Emotional differences among languages are suggested by initial experimental evidence (Harris, Ayçiçegi & Gleason 2003).

It follows that neural mechanisms of grammar, language sound, related emotions-motivations, and meanings hold a key to connecting neural mechanisms in the individual brains to the evolution of cultures. Studying them experimentally is a challenge for future research. It is not even so much a challenge, because experimental methodologies are at hand; they just should be applied to these issues. In following sections we develop mathematical models based on existing evidence that can guide this future research.

3. HIERARCHY OF THE MIND

Mathematical models of the mind mechanisms corresponding to the discussion in the previous section are summarized in this section. These models are based on the available experimental evidence and theoretical development by many authors summarized in (Perlovsky 2006a, 2009). The mind is not a strict hierarchy; there are interactions over several layers up or down, nevertheless, for simplicity we will call it the hierarchy.

3.1. Concepts, instincts, emotions, and the knowledge instinct

Mechanisms of concepts, instincts, and emotions were described in (Grossberg 1988; Grossberg and Levine 1987). Concepts operate like internal models of objects and situations; e.g., during visual perception of an object, a concept-model of the object stored in memory projects an image (top-down signals) onto the visual cortex, which is matched there to an image projected from the retina (bottom-up signal). Perception occurs when the top-down and bottom-up signals match. Concepts evolved for instinct satisfaction. We use the word instinct to denote a simple inborn, non-adaptive mechanism of internal "sensor," which measures vital body parameters, such as blood pressure, and indicate to the brain when these parameters are out of safe range. We have dozens of such sensors, measuring sugar level in blood, body temperature, pressure at various parts, etc. Satisfaction or dissatisfaction of instinctual needs is communicated from instinctual parts of the brain to decision making parts of the brain by emotional neural signals. Perception and understanding of concept-models corresponding to objects or situations, which potentially can satisfy an instinctual need, receive preferential attention and processing resources in the mind. Here we summarize a mathematical description of these mechanisms according to (Perlovsky 2006a, 2009).

An essential mechanism of perception is matching top-down and bottom-up signals. Therefore humans and high animals have an inborn drive to fit top-down and bottom-up signals. We call this mechanism the instinct for knowledge (Perlovsky 1991, 2006a). Brain areas participating in the knowledge instinct were discussed in (Levine and Perlovsky 2008). The knowledge instinct maximizes similarity between top-down and bottom-up signals:

$$L(\{\boldsymbol{X}\},\{\boldsymbol{M}\}) = \prod_{n \in N} \sum_{m \in M} r(m)\, l(n|m)\, pe(N,M)\, O(N,M). \qquad (1)$$

Here l(n|m) is a partial similarity of a bottom-up signal in pixel n given that it originated from top-down concept-model m. This partial similarity is for convenience normalized assuming object-concept m to be definitely present, which is not necessarily true; therefore coefficient r(m) models a probability that object-concept m actually is present; we call these coefficients rates. Function pe(N,M), penalizes for the number of parameters in the models, and O(N,M) penalizes for the number of computations. Modeling perception and cognition by maximizing this expression was described in (Perlovsky 2006a). This maximization procedure informs the following development; its principal aspect, called dynamic logic, proceeds from unconscious and vague concept-representation-models to conscious and concrete.

Similarity (1) is maximized by the knowledge instinct at a single level of the mind hierarchy. I'll repeat that the often used word heterarchy (Grossberg 1988) refers to the fact that the mind is not a strict hierarchy, it involves cross-interaction among multiple layers. When concentrating on higher and lower level structure of the brain, for simplicity we will use the word hierarchy. To describe the hierarchy, we will denote a single-layer similarity (1) and all characteristics of this layer by index h = 1,… H. The total similarity, specifying the instinct for knowledge for the entire hierarchy,

$$L = \prod_{h} L_h\,; \qquad (2)$$

Similarity (1), as discussed in (Perlovsky 2006a, 2009), models neural functioning of the mind in correspondence with a large number of publications and recent neuro-imaging data. Relating this neural brain modeling to cultural evolution can proceed by simulating societies of interacting agents, each one satisfying its instinct for knowledge (2), (Fontanari & Perlovsky 2008a;b; 2009). In this paper we make a step to deriving simplified expressions for similarity, which could be studied analytically, including maximization of similarity (2) and processes of cultural evolution. Similarity (2) determines dynamics of multi-agent societies not unlike the Lagrangian in physics determines behavior of complex systems. Correspondingly, we use a technique inspired by mean field theories in physics, which has been developed for studying complex systems by using average values for certain parameters in Lagrangian.

3.2. The mean field hierarchical dynamics

Expression (1) is a layer in (2), here we substitute bottom-up signals by activated models at a lower layer, $N_h = M_{h-1}$. The penalty function we model according to Akaike (1974),

$$pe(h) = exp\{ -p * M_h / 2 \}. \qquad (3)$$

Here, p is an average number of parameters per model (the layer index h we will sometimes omit for shortness). The penalty for a number of computations, O(h) = 1 / (number of operations); the number of operations is proportional to the product of bottom-up and top-down signals,

$$O(h) = c2(h) / (M_{h-1} * M_h * p), \qquad (4)$$

Here, c2(h) is a constant. At every layer h only a tiny part of all possible combinations of bottom-up signals M_{h-1} are organized into meaningful concepts M_h; a majority of combinations do not have any meaning; we therefore assign them to a "clutter" model, which should be considered separately from other models. Rates at layer h, r(m, h), are proportions of M_{h-1} signals associated with model m(h); we substitute them by their average values, r_h. According to the rate normalization (Perlovsky 2006a),

$$\sum_{m \in M(h)} r(m,h) + r_0 = 1, \text{ or } M_h * r_h + r_0 = 1; \qquad (5)$$

Association variables l(n|m) average values are computed as follows. Following (Perlovsky 2006a), l(m|n) can be modeled by a Gaussian function, centered at the model indexed m, $\mathbf{M}_m$, with deviations of data, $\mathbf{X}$(n), from this center, $\Delta\mathbf{X}$, and covariance matrix $\mathbf{C}$,

$$l(m|n) = (1/2\pi)^{p/2} \det(\mathbf{C})^{-p/2} * exp\{-(\Delta\mathbf{X}\mathbf{C}^{-1}\Delta\mathbf{X}/2)\}. \qquad (6)$$

Dimensionality is taken equal to the number of model parameters, p. We evaluate an average value of l(m|n) for data n associated with model m. The average values of det($\mathbf{C}$) we denote σ^{2p}, so that σ has a meaning of an average standard deviation. The average value of the exponent, is simplified by taking into account that $\langle\Delta\mathbf{X}\ \Delta\mathbf{X}\rangle = \mathbf{C}$,

$$< - \Delta\mathbf{X}\ \mathbf{C}^{-1}\ \Delta\mathbf{X} / 2 > = -1/2\ Tr(\mathbf{1}) = -p/2. \qquad (7)$$

We obtain for the average value of partial similarity,

$$<l(m|n)> = (1/2\pi)^{p/2} (1/\sigma^p) \exp\{ - p/2 \} \delta_{mn}. \qquad (8)$$

Denote $c1 = (1/2\pi)^{p/2}$. Combining these results, a relatively simple expression for an average value of a layer h similarity is,

$$L_h = (c1*r/\sigma^p)_h^{M(h-1)} \exp[-p_h/2*(M(h-1)+M(h))]*O(h). \qquad (9)$$

This mean-field expression for similarity can be used now to derive the hierarchical dynamics of the knowledge instinct, which defines the knowledge-oriented "spiritual" individual ontological development (on average) as well as social dynamics and cultural evolution. This dynamics is given by the standard procedure of defining temporal derivatives along the gradient of similarity; this leads to evolution maximizing the knowledge instinct,

$$dM_h/dt=\delta\ dL/dM_h=\delta\ L*[-2/M_h-(p_h+p_{h+1})/2+\ln(c1*r/\sigma^p)_{h+1}]; \qquad (10)$$

$d\sigma_h/dt = \delta\, dL/d\sigma_h = \delta\, L/L_h * dL_h/d\sigma_h = \delta\, L(-p_h M_{h-1}/\sigma_h);$ (11)

here, δ is a coefficient that would have to be determined from empirical data.

This knowledge-instinct driven dynamics is one part of the hierarchical dynamics, the other part is given by the hierarchy growing or shrinking due to expansion or contraction of general concepts with standard deviations varying from a typical value for each layer. Modeling this process in the future will need to account for interaction between language and cognition, and for the distribution of standard deviations, σ_h, at every layer, which so far was neglected, as we modeled only the average value. Here we derive the equation for growth or shrinkage of the hierarchy following a simple assumption that the distribution of σ_h at every layer is similar. Then, the number of models moving between layers is proportional to the number of models at each layer

$$dM_h/dt = e(h)*(M_{h+1} - 2M_h + M_{h-1}), \quad (12)$$

Equations obtained above will be used in future simulations of the hierarchical dynamics. In the following section we use these equations as an intuitive guide for deriving simpler equations, which would in turn guide future research.

4. DIFFERENTIATION AND SYNTHESIS

Process of differentiation drives vague general concept-models to concrete specific and corresponding to few specific instances. In this process, according to eq.(11), standard deviation, σ -> 0, and according to eq. (10), the number of models grows. In this process, similarity L grows and the knowledge instinct is satisfied. However there is a limit to differentiation. As σ -> 0 and concepts become too specific, fewer patterns in the bottom-up signals fit each concept-model, r -> 0, similarity L diminishes and the knowledge instinct is dissatisfied. In plain English, the knowledge becomes exact, but it is about vanishing number of objects. Therefore there should be a balance between specificity of knowledge or differentiation (σ -> 0) and generality of knowledge (max r, r -> 1) or synthesis. Does this process of increased differentiation along with hierarchical synthesis converge? What are the properties of its attractors? Analytic maximization of similarity using equations in the previous section is a subject of the ongoing research; this research would have to consider different rates of differentiation of language and cognitive models. Here we derive simplified equations for the process to guide this future research in correspondence with properties of the above equations and their psychological interpretations discussed in previous sections.

The knowledge instinct determines both mechanisms, differentiation and synthesis. They are in complex relationships, at once symbiotic and antagonistic. Synthesis creates an emotional value of knowledge, which is the condition for differentiation; it leads to spiritual inspiration, to active creative behavior leading to fast differentiation, to the creation of knowledge, to science and technology. At the same time, a "too high" level of synthesis stifles differentiation. If the standard deviation, σ -> 0, according to eq.(11), similarity L grows, and if this growth is not counterbalanced by r -> 0, the result would be deep emotional satisfaction of the knowledge instinct by precise knowledge about few concepts, the knowledge growth (M) might be stifled.

This tendency to "precise knowledge about nothing" (σ -> 0, r -> 0) might be counterbalanced, depending on parameter values. The number of concepts, M and r, will grow driven by the last item in eq.(10). Psychologically, this growth cannot continue indefinitely, emotions of the knowledge instinct satisfaction, when "spread" over large number of concepts would not sustain growth in the concept number, M. This is well known in many engineering problems, when too many models are used; a penalty function counterweights (the middle term in eq.(10)), and the number of models falls. Thus, whereas emotional synthesis creates a condition for differentiation (high value of knowledge and growth of M), conceptual differentiation undermines synthesis (value of knowledge and M fall). This is modeled as follows:

$$dM/dt = a\, M\, G(S), \quad G(S) = (S - S_0)\, exp(-(S-S_0)/ S_1),$$
$$dS/dt = -b\, M + d\, H,$$
$$H(t) = H_0 + e*t. \quad (13)$$

Time is denoted t; M is a number of concepts (differentiation); S models synthesis, emotional satisfaction of the knowledge instinct; H is a number of hierarchical levels; a, b, d, e, S_0 and S_1 are constants. Analyzing the dynamics of H qualitatively from the above equations is difficult, so instead we just consider a period of slow growth of the hierarchy H. The number of models M grows proportionately to already accumulated models (according to eq.(12), assuming there are many more models at lower layers), as long as synthesis S is maintained at an average level, $S_0 < S < S_1$. Synthesis grows in the hierarchy; growth in M, however, reduces synthesis. At moderate values of synthesis we obtain a solution in Fig. 1. The number of concepts grows until a certain level, when it results in a reduction of synthesis; then the number of models falls. As the number of models falls, synthesis grows, and the growth in models resumes. The process continues with slowly growing, oscillating amount of knowledge (models).

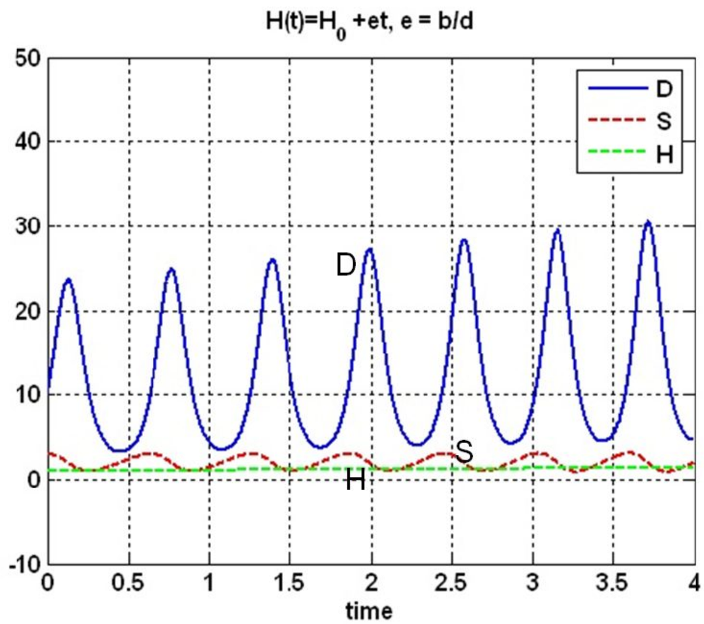

Fig. 1. The evolution of culture at moderate values of synthesis oscillates: periods of flourishing and knowledge accumulation alternate with the collapse and loss of knowledge (a = 10, b = 1, d = 10, e = 0.1, S_0=2, S_1=10, and initial values M(t=0) = 10, S(t=0) = 3, H_0 = 1; parameter and time units are arbitrary). Over time the number of models slowly accumulates; this corresponds to slowly growing hierarchy.

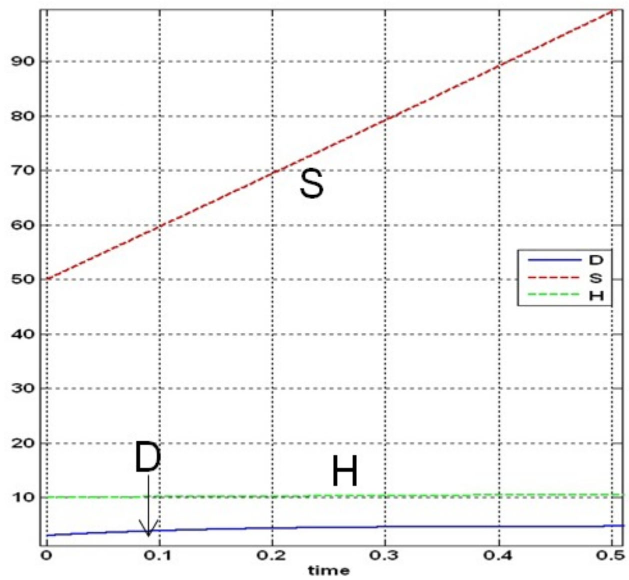

Fig. 2. Evolution of highly stable, stagnating society with growing synthesis. High emotional values are attached to every concept, while knowledge accumulation stops (M(t=0)= 3, H_0 = 10, S(t=0) = 50, S_0 = 1, S_1 = 10, a = 10, b = 1, d = 10, e=1).

A different solution corresponds to an initially high level of synthesis, Fig. 2. Synthesis continues growing whereas differentiation levels off. This leads to a more and more stable society with high synthesis, in which high emotional values are attached to every concept, however, differentiation stops.

These two solutions of eqs.(13) can be compared to Humboldt (1836) characterization of languages and cultures. He contrasted the inert objectified "outer form" of words vs. the subjective, culturally conditioned, and creative "inner form." Humboldt suggested that the inner form of language corresponded to the culture of its speaker and that the differences between languages parallel those between speakers. These insights concerning "inner form" continue to stir linguists' interest today, yet seem mysterious and not understood scientifically.

Humboldt's thoughts can be interpreted as follows in terms of neural mechanisms. Humboldt's "inner form" corresponds to the integrated neural dual model (Perlovsky 2009), in which the content of the cognitive model is being developed guided by language models, which accumulate cultural wisdom. "Outer form" of language corresponds to an inefficient neural dual model, in which language models do not guide differentiation of the cognitive ones. This might be due to either too strong or too weak an involvement of emotions. If the emotional involvement in cognition or language is too weak, learning does not take place because motivation disappears. If emotional involvement is too strong, learning does not take place because old knowledge is perceived as too valuable, and no change is possible. This second case might be characteristic of "too strongly" inflected languages, in which sound changes "too slowly" and emotions are connected to meanings "too strongly;" this could be the case in Fig. 2. The first case might be characteristic of non-inflected languages, when the sound of language changes "too fast," and emotional links between sound and meanings are severed. This could correspond to a persistent state at a trough of Fig.1; this persistence, deviating from Fig. 1 dynamics, might be due to continually changing sound and continually severed links between sounds and meanings. A brief look at cultures and languages certainly points to many examples of "traditional" highly inflected languages and correspondingly stagnating cultures. Which of these correspond to Fig. 2 and the implied neural mechanisms? The exact meanings of "too fast" or "too slow," and which cultures and languages correspond to which case will require much psycholinguistic and anthropological research.

The integrated dual model assumes "average" emotional correspondence between language and cognitive models, which fosters the integration and does not impede it. Humboldt suggested that this relationship is characteristic of inflectional languages (such as Indo-European), inflection provided "the true inner firmness for the word with regard to the intellect and the ear." The integrated dual model assumes an average value of synthesis, Fig. 1, leading to the interaction between language and cognition and to the accumulation of knowledge. This accumulation, however, does not proceed smoothly; it leads to instabilities and oscillations, possibly due to cultural calamities; a significant part of European history from the fall of Roman Empire to recent times corresponds to this characterization.

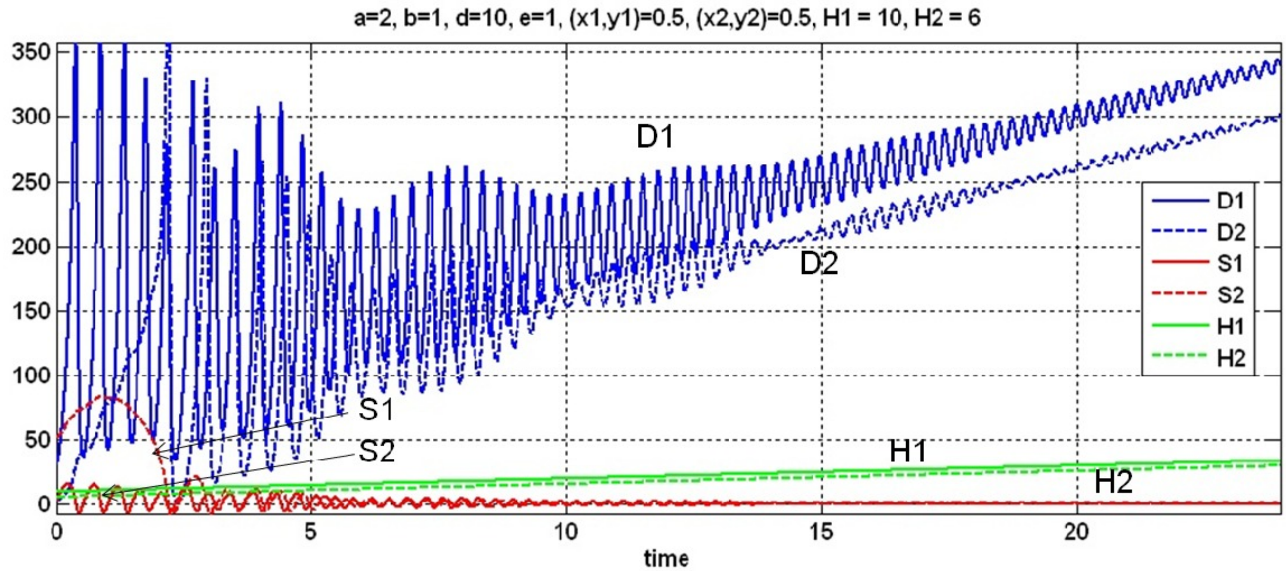

Figure 3. Effects of cultural exchange (k=1, solid lines: M(t=0)= 30, H0 = 12, S(t=0) = 2, S0 = 1, S1 = 10, a = 2, b = 1, d = 10, e=1, x = 0.5, y = 0.5; k=2, dotted lines: M(t=0)= 3, H0 = 10, S(t=0) = 50, S0 = 1, S1 = 10, a = 2, b = 1, d = 10, e=1, x = 0.5, y = 0.5). Transfer of differentiated knowledge to less-differentiated culture dominates exchange during $t < 2$ (dashed blue curve). In long run ($t > 5$), cultures stabilize each other, and swings of differentiation and synthesis subside while knowledge accumulation continues.

Much of contemporary world is "too flat" for an assumption of a single language and culture, existing without outside influences. Fig. 3 demonstrates an evolutionary scenario for two interacting cultures that exchange differentiation and synthesis; for this case eqs. (13) were modified by adding a quantity of xM to the first equation and yS, where M and S were taken from the other culture. The first and second cultures initially corresponded to Figs.1 and 2 correspondingly. After the first period when the influence of the first culture dominated, both cultures stabilized each other, both benefited from fast growth and reduced oscillations.

5. DISCUSSION AND FUTURE RESEARCH

This paper is but a first step toward connecting neural mechanisms, language, emotions, and cultural evolution. The proposed theory requires much experimental evidence and theoretical development. The influence of language on culture, the Bhartrihari-Humboldt-Nietzsche-Sapir-Whorf hypothesis implied by the discussed mechanism adds a novel aspect to this old idea, emotional contents of languages could be more important in influence on cultures than their conceptual contents.

In the milieu defined by Chomsky's assumed independence of language and cognition the Sapir-Whorf hypothesis (SWH) has steered much controversy:

"This idea challenges the possibility of perfectly representing the world with language, because it implies that the mechanisms of *any* language condition the thoughts of its speaker community" (Wikipedia, "Sapir-Whorf hypothesis").

A naïve view of "perfectly representing the world" is seriously considered in Wikipedia as a scientific possibility; as pointed by (Hurford 2009), this is indicative of a problematic state of affairs in linguistics's adherence to uniformitarianism: "the prevalent commitment to uniformitarianism, the idea that earlier stages of languages were just as complex as modern languages." With the development of cognitive and evolutionary linguistics currently the diversity of languages are considered as a evolutionary reality, and it becomes necessary to identify neural mechanisms of language evolution and language-cognition interaction.

Proposed here neural mechanisms and models inspired by these mechanisms, are but a first step in this line of research. Future mathematical-theoretical research should address continuing development of both mean-field and multi-agent simulations, connecting neural and cultural mechanisms of emotions and cognition and their evolution mediated by language. The knowledge instinct should be developed toward theoretical understanding of its differentiated forms explaining multiplicity of aesthetic emotions in music and in language prosody (Perlovsky 2006b). This theoretical development should go along with experimental research clarifying neural mechanisms of the knowledge instinct (Levine & Perlovsky 2008), the dual language-cognitive model.

Experimental results on neural interaction between language and cognition (Franklin et al 2008) should be expanded toward neural mechanisms of the dual model, interaction of language with emotional-motivational, voicing, behavioral, and cognitive systems.

Anthropology should evaluate the proposed hypothesis that the primordial fused system of conceptual cognition, emotional evaluation, voicing, motivation, and behavior differentiated at different prehistoric time periods—are there data to support this hypothesis, can various stages of prehistoric cultures be associated with various neural differentiation stages? Can different humanoid lineages be associated with different stages of neural system differentiation? What stage of neural differentiation corresponds to Mithen's (2007) hypothesis about singing Neanderthals? Psychological, social, and anthropologic research should go in parallel, documenting cognitive and emotional contents of historical and contemporary cultures and languages evolving along various cultural paths and correlations between them.

Correlation between grammar and emotionality of languages proposed here can be verified in direct experimental measurements using skin conductance and fMRI neuro-imaging. The emotional version of Sapir-Whorf hypothesis should be evaluated in parallel psychological and anthropological research. More research is needed to document cultures stagnating due to "too" emotional languages; as well as the impact of "low" emotionality of language in English-speaking countries.

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