2014 International Joint Conference on Neural Networks (IJCNN)
July 6-11, 2014, Beijing, China

Cognitive Functions of Aesthetic Emotions

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Abstract—**The paper introduces a scientific definition of "aesthetic" emotions compatible with known working of the mind. These are emotions related to knowledge and to satisfaction of instinct for knowledge. Cognitive and mathematical model arguments are presented that aesthetic emotions motivate us to acquire and improve knowledge. Near the top of the mental hierarchy they are experienced as the beautiful. Contradictions in knowledge experienced as emotions of cognitive dissonances interfere with acquiring knowledge. Overcoming cognitive dissonances is necessary for accumulating knowledge and sustaining human evolution. A multiplicity of aesthetic emotions required for overcoming cognitive dissonances are created by music; this is the evolutionary purpose of musical ability.**

I. Difficulties of defining "aesthetic"

A HUGE number of publications are devoted to aesthetic emotions; Google Scholar gives 319,000 references. Nevertheless finding a definition of what is aesthetic is not easy. Most authors use no definitions. Wikipedia (2013) gives a circular definition: "aesthetic emotions... are felt during aesthetic activity." This is similar to the "institutional theory of art" that defines art as what is considered so by an accepted art institution (Dickie, 1974). After 70 years of continuous discussions in every issue of the Journal of Aesthetic and Art Criticism this theory, despite its obvious flaws, remains accepted among philosophers of art. Scientists studying emotions should aspire for a more meaningful definition, including cognitive functions and evolutionary purpose, yet this has not been accomplished. I would name just few publications by distinguished scientists studying aesthetic emotions, (Scherer & Zentner, 2001) have not "attempted to identify the aesthetic emotions, particularly relevant to music... as a separate category ", (Trost et al, 2012) map aesthetic emotions in the brain, (Juslin, 2013) devotes a special section in his work introducing aesthetic emotions as a fundamental innovation of his theory of musical emotions, none define what is "aesthetic."

Difficulties of contemporary theorists attempting to define "aesthetic" might be related to difficulties encountered by Kant (1790). Kant rejected an older idea that aesthetic is related to a special perception ability (Baumgarten, 1750) and attempted to define aesthetic as related to knowledge. This article suggests that Kant came amazingly close to the contemporary scientific understanding, and it clarifies why he could not formulate this idea to his satisfaction. The best he could do is to say that aesthetic emotion is disinterested. On many pages he has repeated that this only concerns everyday mundane interests, that the beautiful is related to some of the most important human interests, that a better definition is needed, but "today" he could not give a satisfactory positive definition of what it is. From Schiller to this very day many discussions continue the false tradition of characterizing aesthetics and beautiful as disinterested (Wikipedia, 1913; Stanford Encyclopedia (de Sousa, Zangwill) 2013; Stolnitz, 1960; Scruton, 1974, 2007; Guyer, 1997; Juslin,2013; to name just a few among thousands).

This article defines aesthetic and the beautiful in correspondence with Kantian ideas, our deepest intuitions about the beautiful, the Aristotelian "unity in manifold," and in agreement with contemporary understanding of the neural mechanisms of emotions and cognition.

II. Mathematical models of emotions and cognition

Here is a short simplified summary of this complicated topic, which is an active area of research with thousands of publications; the mathematical model captures essential aspects of the mind mechanisms, it gives many predictions confirmed experimentally and does not contradict known data (many more details and references can be found in Perlovsky, Deming, Ilin, 2011). This summary is aimed at understanding the mental mechanisms of aesthetic emotions in the next section. Among the most ancient mind mechanisms are instinctual drives. According to the Grossberg and Levine (1987) theory of drives and emotions, instinctual drives can be modeled as internal sensors that measure vital bodily parameters and indicate their safe ranges. If a parameter is outside its safe range, this information is transmitted by neural signals to decision-making parts of the brain-mind initiating appropriate decisions and behavior. These neural signals are perceived internally as emotions motivating behavior. For example, we have sensors measuring sugar level in blood, when it is below a certain level we feel it as hunger and devote more attention to finding food.

We perceive food and other objects by matching mental representations (memories) of objects to patterns in sensor signals (Kosslyn, 1994). Mental representations are organized into an approximate hierarchy (Grossberg, 1988) from perceptual elements, to objects, to contexts and situations, and higher up to abstract concepts. The evolutionary purpose of evolving the hierarchy is to enable abstract concepts. For example, the representation "professor office" unifies lower-level representations of objects (chair, desk, computer, books, shelves) into a unified concept of the office. Similarly, concepts of offices, lecture halls, etc. are unified into a concept of "university", "educational system," etc. A simplified description of the mathematical model of interacting emotions and cognition misses many details

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978-1-4799-1484-5/14/$31.00 ©2014 IEEE

(Pessoa, 2008, 2009), but it is sufficient for the purpose of this article.

III. The Knowledge Instinct, Aesthetic Emotions, and the Beautiful

The Grossberg-Levine (1987) theory of drives and emotions has been extended from bodily needs to learning (Perlovsky, 2001, 2006, 2007a, 2008a, 2013a,b; Perlovsky, Deming, Ilin, 2011). Satisfaction of bodily needs and our very survival requires understanding of the surrounding world. Therefore, possibly the most important instinct (for humans and higher animals) is an instinct for knowledge, driving learning, knowledge acquisition, and improvement of mental representations for better correspondence to the world. A mathematical model of the knowledge instinct has been discussed in the above references, and candidate neural mechanisms are discussed in (Levine & Perlovsky, 2008; Perlovsky & Levine, 2012). Similar to other instincts, satisfaction and dissatisfaction of this instinct are perceived emotionally. These specific emotions related to knowledge are called aesthetic emotions. An experimental proof of their existence has been given in (Perlovsky et al, 2010).

At lower levels of the mental hierarchy these emotional neural signals are below the conscious threshold. We are not elated with aesthetic pleasure when recognizing an everyday object. However, when not recognizing familiar objects or situations we immediately perceive these aesthetic emotions, we could become scared. This is one of the standard tricks of thriller movies. At higher levels of the hierarchy we may consciously perceive positive and negative aesthetic emotions. When one solves a problem he or she has been thinking about for a long time, one often feels positive emotion. This is not just a utilitarian emotion due to expecting a salary raise, or being closer to finishing a dissertation. One also feels aesthetic emotion due to satisfaction of the knowledge instinct. The "highest" aesthetic emotion of the beautiful is felt when the knowledge instinct is satisfied at the highest levels of the hierarchy.

IV. Dual Hierarchy of Language and Cognition

Discussion of aesthetic emotions in this paper relies on the mathematical model of the dual hierarchy of mind (Perlovsky, Deming, Ilin, 2011; Perlovsky, 2007a,b, 2009a, 2013b,c,d). As discussed in these publications, neural hierarchy of cognition (Grossberg, 1988) could only emerge based on the dual hierarchy illustrated in Fig. 1.

A fundamental aspect of acquiring mental representations is interaction between higher and lower (top and bottom) layers. In this interaction lower layer representations are organized in more abstract and general concept-representations at a higher layer. These interactions among bottom-up and top-down signals (BU and TD) are indicated in Fig. 1 by vertical arrows. Cognition is grounded in the world only near the bottom. The rest is grounded in language. The entire language hierarchy is grounded in the surrounding language. The mathematical description of this model is given by a similarity between BU and TD signals. We denote the total similarity as $\mathcal{L}$; a partial similarity at the hierarchical

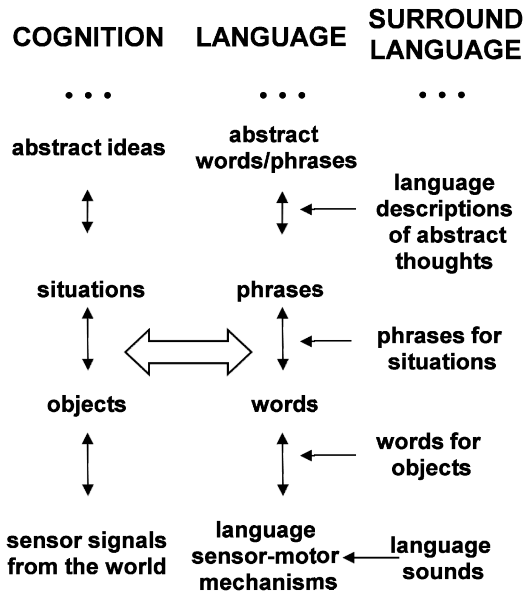

Fig. 1. The dual hierarchy. Language and cognition are organized into approximate dual hierarchy. Learning language is grounded in the surrounding language throughout the hierarchy. Cognitive hierarchy is grounded in experience only at the very "bottom."

level h between BU and TD signals, n and m, is denoted as ℓ(n,m,h). The total similarity in the hierarchy is given by (Perlovsky, Deming, Ilin, 2011):

$$\mathcal{L} = \prod_h \prod_n \sum_m \quad \ell(n,m,h). \tag{1}$$

Partial similarities ℓ(n,m,h) here are defined in terms of BU concepts i identified at the level h. A BU signal n is a collection of some concepts i and a large number of unrelated concepts; this creates complexity of identifying contents of the higher level concepts m. This long-term difficulty in learning abstract concepts have been resolved in (Perlovsky, 2009a,b; Perlovsky, Deming, Ilin, 2011) by (i) defining partial similarities as

$$\ell(n,m,h) = \prod_i \quad p_{mi}^{x_{ni}}(1 - p_{mi})^{(1-x_{ni})} \tag{2}$$

and (ii) maximizing the total similarity (1) over parameters p(m,i) by using DL. Parameters p(m,i) define contents of abstract concepts at level h.

The DL dynamics estimating these parameters is described in the above references. Together these equations define the knowledge instinct dynamics in the hierarchy. According to DL, initial contents of abstract representations are vague. Specific contents are first acquired by language representations, which are grounded in surrounding language containing them in a ready-made form. Cognitive representations do not exist ready-made in the world, they are acquired later from life experience under the guidance from language representations (Perlovsky, 2013b). Increases in the knowledge instinct (similarity (1)) model aesthetic emotions, and correspond to higher emotional feelings related to increase of knowledge in the system. This defines the

mathematical foundation of higher cognitive and emotional functions, a long thought goal of neural network research.

Some predictions of this model have been confirmed in experimental research. Price (2012) confirmed that neural mechanisms of language and cognition are separate but highly interwoven mechanisms; Binder et al (2005) confirmed that abstract concepts are vague, barely conscious, and are understood mostly due to contents of language representations. Developing cognitive representations according to language, in other words connecting sounds and meanings, is driven by a dedicated part of the knowledge instinct motivated by emotions specific to language sounds (Perlovsky, 2013b). As discussed later in more details these are emotions of language prosody, which even if subconsciously constitute the wealth of human emotional life and serve as foundations for musical emotions.

V. Aesthetic emotions and contents of the "highest" representations

Mental representations at every hierarchical level, as discussed, have an evolutionary purpose to unify lower level representations. The purpose of representations at the top of the hierarchy is to unify one's entire life experience. This unity is felt as the meaning of life; it is important for concentrating one's effort on the most meaningful aims, it is essential for survival, and for achieving the highest goals. For better understanding what this really means we have to go back and consider some details of learning mechanisms.

Mental representations are not as clear and crisp as perceptions of objects. Consider an object in front of your eyes, then close your eyes and imagine this object. The imagination is not as clear as the perception with opened eyes. Imaginations are produced by neural projections of representations to the visual cortex. Vagueness of imaginations testifies to the vagueness of representations. Vagueness of representations has been experimentally demonstrated in brain imaging experiments (Bar et al, 2006; Kveraga et al, 2007; Perlovsky 2009c). In addition, it has been shown that vaguer representations are also less accessible to consciousness. It follows that abstract representations higher up in the hierarchy, which are based on multiple, vague lower level representations, are vague and barely conscious. Their cognitive contents are mixed up with their emotional contents.

However, we can consciously and in detail discuss the meaning of life, and argue for or against its existence. Does this not contradict the above thesis about vagueness and unconsciousness of higher representations? No. And the reason is that language and cognition are separate systems; closely connected, but still separate. Even so, we cannot clearly differentiate them in our subjective consciousness; mathematical models of interacting language, cognition, and emotions let us understand how they interact (Perlovsky 2009a,b, 2013c). Predictions of these models, in particular that abstract concepts are vague, barely conscious, and are understood mostly due to language, are confirmed experimentally (Binder et al, 2005; Price, 2012).

The separateness of language and cognition explains why it is difficult to agree about the meaning of life and the aesthetic emotion of the beautiful. Because these ideas are so important all great thinkers for millennia have discussed them, cultures have developed them, and language makes this accumulated knowledge accessible to everyone. But because our subjective perceptions of these ideas are vague, doubts remain. There are no direct subjective conscious confirmations of these cultural constructs, and so far scientific evidence is limited. An important scientific challenge for the near future is to demonstrate that the beautiful is an aesthetic emotion related to satisfaction of the knowledge instinct at the top of the mental hierarchy. Cognitive representations near the top of the hierarchy are vague and unconscious, their contents are "veiled" from our consciousness by language, and therefore "measuring" emotions of the beautiful related to improving these contents is very difficult. The beautiful is a rare emotion because the meaning of life is not learned like more simple concepts. Most of us can hope for a rare experience confirming that the meaning really exists; at such a moment one experiences emotions of the beautiful.

VI. Multiplicity of aesthetic emotions

Human emotional life is rich with a variety of emotions. We can experience a huge number of emotions, possibly a continuum, not just a few for which we have words, like fear, sadness, joy, etc. The English language has about 150 emotional words, and among these only between 5 and 20 are appreciably different (Petrov et al, 2012). The most advanced scales for rating musical emotions still use emotional words for a few emotions (Zentner et al, 2008). But emotional experiences are much richer than just the few emotions found in English language. The diversity of emotions is most apparent when listening to music; virtually every musical phrase produces a new emotion. What is the origin and cognitive function of the multiplicity of emotions?

The knowledge instinct does not just maximize a single similarity between all representations (knowledge) and all sensor patterns; it acts at every level of the hierarchy, maximizing similarity between bottom-up and top-down signals. In addition it drives the mind to resolve contradictions between knowledge and instinctual drives, and between various elements of knowledge. These contradictions, known as cognitive dissonances (Festinger, 1957; Harmon-Jones et al, 2009), are perceived emotionally.

There is a degree of contradiction between every pair of representation-concepts, and every contradiction is potentially experienced as a different emotion. Resolving these contradictions requires abilities for the conscious experience of a large number of emotions. Therefore, a huge number of emotions is needed to maintain diverse knowledge in our minds and for the entire human evolution (see more detailed discussions in Perlovsky, 2008b, 2010, 2012a,b, 2013a). These emotions evolved along with language. As language vocalizations have been losing their emotionality, a separate ability for highly emotional vocalization evolved into music; the still remaining emotionality of language

prosody is essential for the continued evolution of languages and cultures (Perlovsky, 2013a,b). Some of these theoretical predictions have been confirmed experimentally (Bonniot-Cabanac et al, 2012; Masataka & Perlovsky, 2012, 2013; Cabanac et al, 2013; Perlovsky et al, 2010, 2013).

VII. Emotional Prosody And Its Cognitive Function

It is difficult to notice the difference between language and cognition in subjective consciousness. The dual model, the mathematical model of their interaction (Perlovsky 2009a, 2013b), and brain imaging data supporting this model (Binder 2005; Price, 2012) suggest that language and cognition are two closely related but separate mechanisms. The dual model implies connections between language and cognitive representations. These neural connections have to be developed and maintained. This requires motivation, in other words, emotions. These aesthetic emotions are necessary in addition to utilitarian meanings of words, otherwise only immediately useful words would be connected to their cognitive meanings. Also these emotions must "flow" from language to cognition, so that language is able to perform its cognitive function of guiding acquisition of cognitive representations, organizing experience according to cultural contents of language. These emotions therefore must be contained in language sounds, before cognitive contents are acquired.

This requirement of emotionality of language sounds is surprising and contradictory to assumed direction of evolution of language. Evolution of the language ability required rewiring of human brain in the direction of freeing vocalization from uncontrollable emotions (Deacon, 1997; Perlovsky 2009b). Yet, the dual model requires that language sounds be emotional. Emotionality of human voice is most pronounced in songs (Perlovsky 2010, 2012a,b, 2013b). Emotions of everyday speech are low, unless affectivity is specifically intended. We may not notice emotions in everyday "non-affective" speech. Nevertheless, this emotionality is important for developing the cognitive part of the dual model. If language is highly emotional, speakers are passionate about what they say, however evolving new meanings might be slow, emotional ties of sounds to old meanings might be "too strong." If language is low-emotional, new words are easy to create, however motivation to develop the cognitive part of the dual model might be low, the real-world meaning of language sound might be lost. Cultural values might be lost as well. Indeed languages differ in how strong are emotional connections between sounds and meanings. This leads to cultural differences. Thus the dual model leads to Emotional Sapir-Whorf Hypothesis (Perlovsky, 2007b, 2009b, 2012b). Strength of emotional connections between sound and meaning depends on language inflections. In particular, after English lost most of its inflections, it became a low emotional language, powerful for science and engineering. At the same time English is losing autonomous connections to cultural values that used to be partially inherent in language sounds. Fast change of cultural values during recent past is usually attributed to progress in thinking, whereas effects of change in emotionality of language sounds have not been noticed.

Emotional prosody is essential for overcoming cognitive dissonance. Cognitive dissonance as discussed interferes with accumulation of knowledge. It is resolved by discarding contradictions. If a new word contradicts existing knowledge its meaning might be discarded. Emotional prosody, songs and music are fundamental mechanisms that overcome cognitive dissonance and enable keeping new contradictory knowledge (Masataka & Perlovsky, 2012; Perlovsky, 2013a).

VIII. Research challenges

Human emotional life is rich; we can experience a huge variety of emotions, most of which are aesthetic. The immediate challenge is to develop experimental techniques for measuring multiplicity of aesthetic emotions. One difficulty is that aesthetic emotions might be subjective and change over time for each individual depending on internal states and external circumstances (e.g. Chapin, 2010). Therefore, averaging over individuals often leads to losing fine emotional differentiation and to detecting the most ancient and robust aspects of emotions, such as valence and arousal. Another difficulty is the use of emotional words in most experimental studies (e.g. Eerola & Vuoskoski, 2011);words are not suitable for measuring emotions inexpressible in words, such as emotions in prosody and music, which are postulated to evolve for a specific purpose to complement the emotional limitations of language. Detecting a large number of aesthetic emotions, in particular musical emotions, could be approached by subjective estimation of the differences among musical excerpts, and then applying multidimensional scaling to these measures.

IX. Acknowledgements

I am thankful to my colleagues Dan Levine, Angelo Cangelosi, and Yuri Dimitrin for discussions.

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