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Theory of Mind and Empathy. Part I - Model of Social Emotional Thinking

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Abstract. There are two very different approaches to understand functioning of the brain. First, there is a huge progress in the research of the neurological and neurophysiological properties of different brain substructures, circuits, networks, single cells, synapses and their molecular properties. It contributes to the progress of research in the fields of basic medical sciences and the dramatic increase in average life expectancy. On the another side that does not directly follows neurological developments, it is our introspection related to individual ways of thinking in order to solve different problems that also involve human creativity (cognitive theory of mind). We use many diverse ways of thinking, and they depend on different circumstances. Especially interesting are influences of intuition, feelings and emotions on our creativity, which is in a large part are also related to the social interactions (affective empathy). In this work, we formalise emotional scales and transfer of emotions between individuals (social emotional thinking). We also demonstrate a continuity of the emotion transfer mappings, and an importance of the interactions between emotional faces. It is not only human specific to show and to react to face emotions, but strong and wide human social interactions are based on the precise emotional social thinking. By measuring

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critical values of face deformations that may influence mutual emotions, we can test precision and tolerance of human visual and emotional systems. By introduction *indiscernibility relations* between individual reading of face parts deformation, we have used rough set theory to probe social emotional thinking. As one of us have demonstrated that the visual system has properties that follows rough set theory (cognitive theory of mind), this work extends this concept to the social emotional interactions (cognitive and affective theory of mind).
As in modern world IT - information technology - has became driving factor in the process of globalisation by creating effective channels of information exchange; hence it becomes extremely important to analyse emotional meaning (cognitive empathy) for this vast information flow. By using as described here, rough set theory to determine, which parts of information have significant emotional influence, our model may give grounds to increase the collective well-being.

Keywords: amygdala, insula, similarities, driver and modulatory logical rules, cognitive empathy, affective empathy.

1. Introduction

As we have mentioned before [1], psychophysical experiments and our amazing capability to recognise complex objects (like faces) in different light and context conditions argue against symbolic representation and suggest that concept representation related to similarities may be a more appropriate model of the visual brain function. By looking into anatomical and neurophysiological basis of different objects classifications, we propose to describe computational properties of the brain by rough set (RS) theory invented by Zdzislaw Pawlak [2] . Concepts representing objects physical properties in variable environment are weak (not precise), but psychophysical space shows precise object categorisations. Previously, one of us [1] has estimated brain expertise in classifications of the objects' components by analysing single cell responses in the area responsible for simple shape recognition (visual area V4). The model is based on the receptive field properties of neurons in different visual areas: thalamus, V1 and V4 and on feedforward (FF) and feedback (FB) interactions between them. The FF pathways combine properties extracted in each area into a vast number of hypothetical objects by using "driver logical rules", in contrast to "modulator logical rules" of the FB pathways. The FB pathways function may help to change weak concepts of objects physical properties into their crisp classification in psychophysical space (cognitive theory of mind).

In the present work, we extend our RS model by studying how emotions influence our vision by comparing psychophysical experiments with neurological findings. We have areas with different resources and depend on our emotions and thinking we switch them on and off. Certain resources are vital and never switched off: like cardiovascular homeostasis and related respiration, or body posture. Other can get into conflict as they are incompatible because they compete for same resources, then one need to engage processes that have ways to manage such conflicts [3]. If we do not know solution of the problem we make a guess with attributes such as intuition, insight, creativity or intelligence. Working on some problems "reasoning by analogy" is our most usual way to deal with problems: What sort of things is this similar to? Have I seen anything like it before? What else does *k* remind me of? [3]. When solving problems, several differences are detected; the brain should first try to remove the most significant difference because this is likely to make a large change in the situation. General Problem Solver assigns different priorities to each kind of difference that it could detect [3]. Electrophysiological recordings support this hypothesis, looking at complex object, we recognise at first if it maybe a face and later if face what is its expression [4].

The RS approach it is in agreements with our previous model. At first, very rough approximation we have to decide what kind of object we see. The feedback pathways tune lower areas to objects features that makes boarder set smaller. These processes allow recognition of the face expressions and it consequence should evoke in the observer right emotions (positive or negative, leading to affective empathy). If observer has strong emotions before object's sensing, it may influence his/her perception: face expression may get wrong classification or even priority may reverse, subject may perceive angry faces all around. How can we explain these wrong classifications in RS or by whole and parts concept?

On another side, reduces emotion and feeling might play a roll in the decision-making failures (Elliot's case who lost parts of his frontal lobes and connections to amygdala [5]; in Parkinson's disease, or in autism). In such case, subject lost his critical part of thinking, and could not get over one small problem to solve whole issue like when sorting documents spent all his time reading one document [3, 5]. Also lack or reduced connections between amygdala (emotions) and area IT (visual area responsible for face classification) is assumed to cause prosopagnosia (impossibility to recognise different faces). In summary, emotions have an important and decisive role in our perceptions, and in our movements and creativity (see Discussion).

We propose a model of emotional perception based on rough sets theory and rough mereology. Its principal component is a theory of continuous in time approximation of faces parts. This theory takes into account the continuous process of sensing influenced by emotions: of the observed face and the observer. As the approximation of faces parts may change in time, the solution might get different logical values.

2. Results

In this section, we describe only our theoretical results, and their interpretation is presented in the next, Discussion section.

2.1. Emotional scale and transfer of emotions

We are concerned with reading and transfer of emotions between two observers, one of them "aggressive" i.e. having a tendency to raise their emotions the other rather peaceful i.e. trying to appease emotions. This setting will allow us to accommodate an analysis of two basic patterns of emotional behaviour.

First of all, we introduce a *scale of emotions*. We assume that emotions are evaluated on the basis of 2D image of a face. We assume that a face F consists of a finite number of *parts* $P_1, P_2, ..., P_k$, which have impact on reading emotions, from the face. In consequence of this assumption, we model the emotional scale as the upward rooted tree with the tree order as the order on values of emotions. It is very simplified model as for example after Plutchik's Wheel of Emotions (Fig. 1) we have

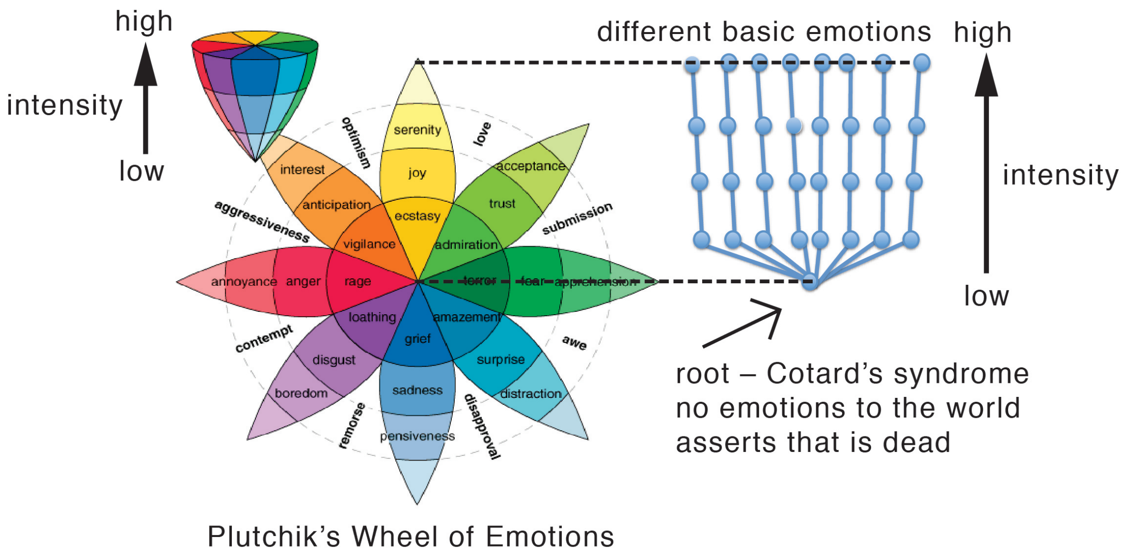

Figure 1. Mapping from the Plutchik's Wheel of Emotions to the Tree of Emotions

eight basic emotions: joy, trust, fear, surprise, sadness, disgust, anger, and anticipation with different intensities. These basic emotions not only may change their intensity but also may interact giving another secondary emotions in agreement with the Plutchik's Wheel (Fig. 1). We map different basic emotions as an emotional scale tree (Fig. 1 on the right). In this work, we begin with one branch of the

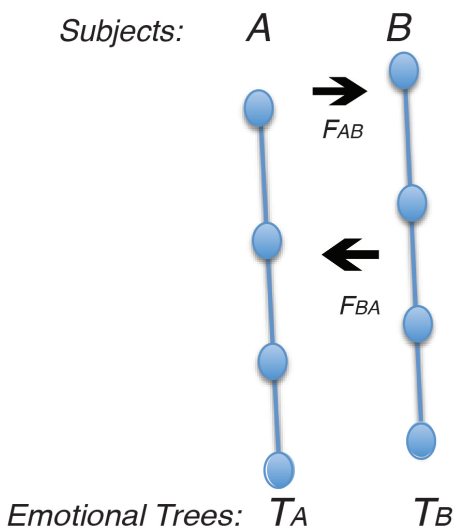

Figure 2. Mapping between Trees of Emotions for two subjects: A and B

emotional tree for each of two different subjects. Each subject may be on a different branch related to the Pluchik's Wheel of Emotions (Fig.1). We are looking for emotional interactions related primary to mutual intensity interferences (Fig. 2), but homotopies related to deformation of different parts of the face (activation of different AUs - see the Discussion section for details) may move emotions on the same branch or may cause ramification to the other branch(es) (see below).

We consider two mutual observers, A and B, possessed of emotional scale trees T_A, respectively, T_B. Transfer of emotions between A and B is effected by means of monotone increasing mappings $F_{AB} : T_A \to T_B$ and $G_{BA} : T_B \to T_A$. Monotone character of those mappings reflects the fact that higher emotions at A transfer to higher emotions at B and vice versa.

We will be more precise in our modelling and in order to model B as a type of aggressive emotional behavior and A as a type of 'peacemaker', we assume that mappings F_{AB} and $G_B A$ form a *monotone Galois connection* i.e. the following relation holds between them

$$F_{AB}(x) \leq y \Leftrightarrow x \leq G_{BA}(y) \text{ for each x } \in T_A \text{ and y } \in T_B. \tag{1}$$

In terms of emotions, one can interpret the above duality by saying *if x is too weak an emotion to induce the emotion y then y induces an emotion stronger than x* .

It follows from (1) that

$$x \leq G_{BA}(F_{AB}(x)) \text{ for each x } \in T_A, \tag{2}$$

which witnesses that B raises emotion above the emotion x shown by A.

The dual to (2) relation

$$F_{AB}(G_{BA}(y)) \leq y \text{ for each y } \in T_B \tag{3}$$

witnesses that A lowers emotion below the level shown by B.

2.2. Topologies for emotion scales and continuity of emotion transfer mappings

We have two possible topologies [6] on trees T_A, T_B: upward and downward order topologies. In the upward topology, basic open neighborhoods are of the form $(x, \to)$ i.e. they consist of all elements y greater than x in the tree ordering; in the downward topology, open basic neighborhoods are of the form $(\leftarrow, x)$ i.e. they consist of all elements y smaller than x in the tree order.

Due to different character of emotional behavior of A and B, we will examine continuity of mappings F_{AB} and G_{BA} in adequate but distinct topological settings.

2.2.1. Continuity of F_{AB}

We assume that trees T_A and T_B are endowed with downward tree order topologies. Continuity of F_{AB} means that

$$if\ F_{AB}(x) \in (\leftarrow, y_x) \text{ then there is } w_x\ s.t.\ x < w_x \text{ and if } t < w_x \Rightarrow F_{AB}(t) < y_x$$

in consequence, in those notations,

$$t < w_x \Rightarrow t < G_{BA}(y_x).$$

It follows that $w_x \leq G_{BA}(y_x)$.

The moral is that downward topologies are adequate for the mapping F_{AB}: it is continuous by its monotonicity and Galois duality property in those topologies which agrees with the type of emotional behavior of A as calming emotions down.

2.2.2. Continuity of G_{BA}

To express continuity of G_{BA} we endow both trees T_A and T_B with upward tree order topologies. Continuity of G_{BA} means

$$if G_{BA}(y) \in (w_y, \rightarrow) \text{ then there is } z_y \; s.t. \; y > z_y, \text{and if } t > z_y \Rightarrow G_{BA}(t) > w_y,$$

hence,

$$F_{AB}(w_y) \leq z_y.$$

It follows that G_{BA} is compatible with upward topologies on trees T_A, T_B.

2.3. Emotion values from faces

We assume that perception of face emotions are determied by deformations of different parts of a face (in common language: grimaces). Thus, we consider a part P of the face and its deformation $D(P)$. We introduce a *measure of part deformation* $\mu(D(P))$ based on the distance ρ among points in the 2D image of the face, viz.,

$$\mu(D(P)) = max\{max\{dist(x, P) : x \in D(P)\}, max\{dist(y, D(P)) : y \in P\}\}, \tag{4}$$

where

$$dist(x, A) = min\{\rho(x, y) : y \in A\}. \tag{5}$$

Measure of face deformation is

$$\mu(D(F)) = max\{\mu(D(P)) : \; P \, a \, part \, of \; F\}. \tag{6}$$

Deformations are formally described as homotopies i.e. mappings of the unit interval into the space of the 2D image containing the image of the face, acting separately on each part of the face [7]. Given a node x in a tree of emotion scales, if the node x has been obtained as a value of the homotopy h_P on the part P, then each emotion value y obtained by further deformation h_P satisfies $x \leq y$ in the tree order i.e. it continues the branch of the tree from x. If at the value x of emotion, deformations happen at some other parts P', P^2, etc., then at x the tree ramifies into appropriate branches going upward, with values on those branches greater in the tree order than x.

Homotopical deformation of a part causes the image of the part to occlude some pixels in images of other parts, and to avoid this, images of other parts are moved sequentially to eliminate the occlusion.

In our setting, we allow the participant A to observe the image of the face of B and B to observe the image of the face of A. Evaluations of emotions are expressed by the two mappings

$$\phi_A : \text{ image B} \rightarrow T_A$$

and

$$\phi_B : \text{ image A} \rightarrow T_B.$$

Both those mappings are monotone in the sense that each homotopical deformation of the current node in the tree makes a node with higher value in the tree order. It is illustrated in Fig. 3 where subject B has higher intensity of face emotional expression that shifts emotions in subject A higher and vice versa as presented schematically in Fig. 3.

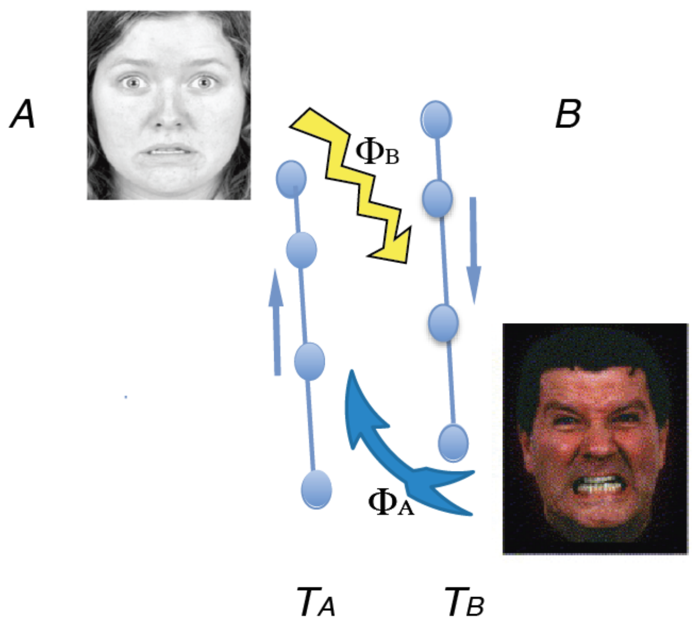

Figure 3. Evolutions of Emotions between two subjects watching their faces

Each of participants receives the value of their current emotion by means of compositions

$$F_{AB} \circ \phi_A$$

sending B their emotions read by A and

$$F_{BA} \circ \phi_B$$

sending A their emotions read by B.

2.4. Kernel and closure of emotions

There is a critical value δ with the property that deformations $D(F), D(F)'$ with

$$|\mu(D(F)) - \mu(D(F))'| < \delta$$

are not distinguishable. This induces *indiscernibility relations*

$$IND_{AB}, IND_{BA}$$

defined as follows

$$IND_{AB}(D(F_B), D(F_B)') \Leftrightarrow F_{AB} \circ \phi_A(D(F_B)) = F_{AB} \circ \phi_A(D(F_B)') \tag{7}$$

for deformations $D(F_B), D(F_B)'$ of the image of the face of B and

$$IND_{BA}(D(F_A), D(F_A)') \Leftrightarrow F_{BA} \circ \phi_B(D(F_A)) = F_{BA} \circ \phi_B(D(F_A)') \tag{8}$$

for deformations $D(F_A), D(F_A)'$ of the image of the face of A.

In conformity with rough set theory, any set X of emotions of B is perceived by B as the pair (the lower approximation $L_{AB}(X)$, the upper approximation $U_{AB}(X)$) and any set Y of emotions of A is perceived by A as the pair (the lower approximation $L_{BA}(Y)$, the upper approximation $U_{BA}(Y)$). The lower approximation can be called the *kernel* of the set of emotions and the upper approximation can be called the *closure* of the set of emotions.

3. Discussion

We have proposed a simple model of empathy based on the mirroring emotions: we can see our emotions by comparing them with others. The principle of this influence is related to so-called mirror neurons [8] that in the frontal motor cortex respond in a similar way when subject performs or observes different, but particular for each neuron, movements [8]. Experiments in humans and monkeys have demonstrated that the mirror mechanism enables the observer to understand not only the goal of the observed motor act but also the intention behind it [9]. In addition, by observing the expressiveness of movements, on the basis of how the action is performed, enables one to understand the internal psychological state of the observed subject (so-called vitality affects) [10]. Authors from Rizzolatti's group [10] found that dorsocentral insula is activated (fMRI) during performed movements with different expressions. Both the vitality form execution and recognition suggests that neurons of this sector of the insula might be endowed with the mirror mechanism transforming visual representations of the perceived vitality forms into their motor representations [10]. The dominating part of the human intelligence is related to self-with-feelings activity (self-image, ego) generating an innate spatio-temporal context for the emotional meaning of movements in the interaction with the environment. Whereas, the anterior part of insula is activated during both expression and recognition of disgust [11], and feeling pain and recognising it in others [12]. These processes are necessary for the integrative brain activity in order to carrying out *sensori-motor intentions* with ease and creativity. They are related to the relationship between emotion and cognition, and in consequence to the affective values for sustaining the *core vitality*. Their impairment in the neurodegenerative diseases such as Parkinson's is mainly related to the lack of the 'reward' neurotransmitter - dopamine with such consequences as peripheral and axial movements [13, 14] and cognitive disorders, 'poker faces', and depression. The 'core vitality' impairments during the development lead to several forms of autism (ASD - autism spectrum disorder). ASD is characterised by social-interaction difficulties, particularly affect expressive movements in communication, and a tendency to engage in repetitive behaviours. In ASD is markedly impaired vitality form recognition, the lack of responsive attention, and difficulties in communicating their intention in gestural acts, and in sensing the dynamics of another's intentions from their movements. In other words, it means that the emotion social transfer is not only important from the social point of view, but also for our self expression and health. One of our model assumption is that the mapping of emotions transfer between subjects is continuous.

Our model mainly concentrates on the face's parts deformations (part of axial movement system) and their meaning for the mutual emotional transfer, but it is universal as it may also deal, in a similar way, with peripheral movements and their emotional meanings. However, thanks to Paul Ekman's several-decades research in understanding of nonverbal behaviour, encompassing facial expressions and gestures (summarised in his recent book [15]), we have concentrated on the universal, emotional meaning of face expressions. Ekman found that facial muscular movements responsible for facial expressions could be identified through empirical research [15]. Human are capable of making over 10,000 facial expressions, but only 3,000 are relevant to emotion and are mostly cross-cultural universal [15] (this idea in fact was originated by Charles Darwin in 1872). Ekman found a high agreement in facial expressions across different cultures, describing them as universal: anger, disgust, fear, happiness, sadness, and surprise [15]. In our proposal, we have started from only positive and negative emotions that can be extended to the list of above basic emotions.

In 1978, Ekman and Friesen had developed the *Facial Action Coding System (FACS)*, an anatomically based system that is capable to describe all observable facial movement for every emotion. Each observable component of facial movement is called an *action unit - (AU)* and all facial expressions can be decomposed into their constituent core AUs [15]. In 2000s FACS was renamed to F.A.C.E. (Facial Expression, Awareness, Compassion, Emotions) and redeveloped as a tool to learn about identifying and recognising facial expressions in the human face [15].

Recently, a group of scientists from Affectiva (Waltham, USA) were using Ekman's AUs to classify different facial expressions in a large-scale of 1.5 millions facial videos collected in different counties [16]. They have successfully classified and then clustered facial events (k-means algorithm, unsupervised learning). In the next step they have verified samples with different dynamics from each cluster by humans (supervised learning), and in facial videos they classified face expressions by learned clusters instead AUs making this process considerable more efficient [16].

As Ekman with help of others had performed such extended and precise studies, we found that their results make a strong foundation for our theoretical approach. In this work, we have only studied face expressions transfer and interactions related to the strength of the positive and negative emotions, but it is easy to extend this approach to different emotions as different branches of the tree as the projection of the Plutchik's wheel of emotions [17] into a tree structure. In principe, we are describing changes and interactions between AUs of two subjects. How observers cognitive and affective empathy (limbic) systems recognise and read AUs of another person, react (subconsciously and consciously) to them and caused reactions. These mechanisms are basic for our social interactions, and as well, for our creativity and inner well-being.

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