A Bio-inspired Emotion Engine in the Living Mona Lisa

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ABSTRACT
This paper introduces the layered model of affects designed for the “Living Mona Lisa” research project. This model provides three distinct layers: emotions as short-term affect, moods as medium-term affect, and personality as a long-term affect. The implementation is based on a bio-inspired approach using a dedicated deep neural network.

Keywords
Artificial creature, emotion, affect, mood, deep neural network

1. INTRODUCTION
In this paper we introduce the emotion model of the “Living Mona Lisa” research project. The aim of this project is to design three complementary prototypes based on the famous painting “La Joconde” from Leonardo da Vinci. The first prototype is an interactive installation displaying an autonomous and animated reproduction of the painting at full scale. The second prototype is a connected brooch introducing the field of “Living Jewelry”. The third prototype is a personal version of the Living Mona Lisa running on a tablet or smartphone. This project is conducted in the spirit of the Living Art approach by a multidisciplinary team including researchers, artists and students from the Institute of Internet and Multimedia [1] and the Strate School of Design [2] in Paris. Living Art is a burgeoning field that uses Artificial Intelligence (AI) to create interactive works of art, bridging digital technologies and more traditional art forms [3]. We first describe the principle of the architecture underlying the three prototypes. The first one, that is the interactive installation, is shown as an illustration of this architecture. Then, we focus on the Artificial Intelligence module. We begin by introducing a new layered model of affects and then we describe its implementation using a deep neural network architecture. The paper concludes by emphasizing the importance of emotional interactions in this relatively new field of Living Art.

2. LIVING MONA LISA ARCHITECTURE
The Living Mona Lisa architecture is based on three major and straightforward building blocks: the Sensory Module, the Artificial Intelligence Module and the Display Module. These three building blocks are connected together and form with the user(s) an interacting closed loop (cf. figure 1).

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By looking (or not) at the painting, the user modifies his behavior, which is captured by the sensory system. Then, the AI module reacts to this information and modifies the behavior of the virtual Mona Lisa character. Then the loop is closed and starts from the beginning.

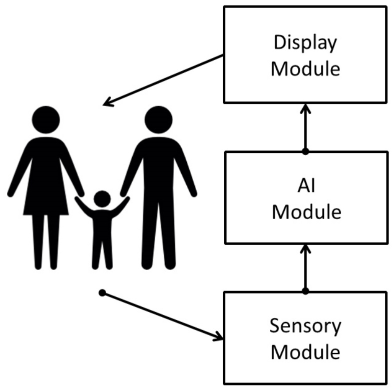

Figure 1. Living Mona Lisa general architecture.

The display module shows (embodies) the autonomous Mona Lisa character. In the connected jewel prototype, this module is composed of a small LCD display. In the interactive installation, the display module is a reproduction of the painting at its original scale (77 cm x 53 cm not including the frame). It uses an Ultra High Definition screen and a digital sound system. The image is composed of a 3D model (over 500.000 polygons) with advanced texturing techniques (cf. figure 2). We use the Unity Pro 3D rendering engine for real-time animation of this 3D model [4].

The sensory module is responsible for sensing the environment and sending pertinent information to the AI module. Typical information includes the presence of one or more persons, their position, their moves, facial expressions, recognition of some keywords, noise, etc. In the interactive installation version of the Living Mona Lisa, the sensory module is implemented using a Microsoft Kinect 2 sensor system allowing to detect up to six people with advanced facial tracking [5].

The AI module is the central part of the architecture. It is based on a dedicated deep neural network [6] that computes the emotional state of the virtual character. Its basic inputs are the signals coming from the sensory module and its output is a selected behavior within a finite set of animated behavior plus intensity. The next sections describe more precisely the underlying emotion model and its implementation.

Figure 2. Living Mona Lisa 3D Model.

3. A LAYERED MODEL OF AFFECTS

There have been many artificial emotion models proposed in the past. One of the most complete ones, mixing short, medium and long-term aspects of emotional behaviors, was designed by Gebhard with ALMA [7]. We have also proposed a similar approach in 2004 with the first version of EVA [8]. We propose here a new layered model based on three main interacting forms of affects:

Emotion reflects a short-term affect, usually bound to a specific event, action or object, which is the cause of this emotion. After its elicitation emotions usually decay and disappear from the individual's focus [9].

Mood reflects a medium-term affect, which is generally not related with a concrete event, action or object. Moods are longer lasting stable affective states, which have a great influence on human's cognitive functions [10].

Personality reflects long-term affect. It shows individual differences in mental characteristics [11].

3.1 Personality

This layer is based on the "Big Five" model of personality [11]. It contains five main variables with value varying from 0.0 (minimum intensity) to 1.0 (maximum intensity). These values specify the general (affective) behavior by the traits of openness, conscientiousness, extraversion, agreeableness and neuroticism.

Openness (Op) is a general appreciation for art, emotion, adventure, unusual ideas, imagination, curiosity, and variety of experience. The trait distinguishes imaginative people from down-to-earth, conventional people. People who are open to experience are intellectually curious, appreciative of art, and sensitive to beauty. They tend to be, compared to closed people, more creative and more aware of their feelings. They are more likely to hold unconventional beliefs. People with low scores on openness tend to have more conventional, traditional interests. They prefer the plain, straightforward, and obvious over the complex, ambiguous, and subtle. They may regard the arts and sciences with suspicion, regarding these endeavors as abstruse or of no practical use. Closed people prefer familiarity over novelty. They are conservative and resistant to change.

Conscientiousness (Co) is a tendency to show self-discipline, act dutifully, and aim for achievement. The trait shows a preference for planned rather than spontaneous behavior. It influences the way in which we control, regulate, and direct our impulses. The benefits of high conscientiousness are obvious. Conscientious individuals avoid trouble and achieve high levels of success through purposeful planning and persistence. They are also positively regarded by others as intelligent and reliable. On the negative side, they can be compulsive perfectionists and workaholics.

Extraversion (Ex) is characterized by positive emotions and the tendency to seek out stimulation and the company of others. The trait is marked by pronounced engagement with the external world. Extraverts enjoy being with people, and are often perceived as full of energy. They tend to be enthusiastic, action-oriented. In groups they like to talk, assert themselves, and draw attention to themselves. Introverts lack the exuberance, energy, and activity levels of extraverts. They tend to be quiet, low-key, deliberate, and less involved in the social world. Their lack of social involvement should not be interpreted as shyness or depression. Introverts simply need less stimulation than extraverts and more time alone.

Agreeableness (Ag) is a tendency to be compassionate and cooperative rather than suspicious and antagonistic towards others. The trait reflects individual differences in concern with for social harmony. They are generally considerate, friendly, generous, helpful, and willing to compromise their interests with others. Agreeable people also have an optimistic view of human nature. They believe people are basically honest, decent, and trustworthy. Disagreeable individuals place self-interest above getting along with others. They are generally unconcerned with others' well-being, and are less likely to extend themselves for other people. Sometimes their skepticism about others motives causes them to be suspicious, unfriendly, and uncooperative.

Neuroticism (Ne) is the tendency to experience negative emotions, such as anger, anxiety, or depression. Those who score high in neuroticism are emotionally reactive and vulnerable to stress. They are more likely to interpret ordinary situations as threatening, and minor frustrations as hopelessly difficult. Their negative emotional reactions tend to persist for unusually long periods of time, which means they are often in a bad mood. At the other end of the scale, individuals are less easily upset and are less emotionally reactive. They tend to be calm, emotionally stable, and free from persistent negative feelings. Freedom from negative feelings does not mean that low scorers experience a lot of positive feelings. Frequency of positive emotions is a component of the Extraversion domain.

3.2 Mood

The ALMA and EVA models where both based on the PAD model proposed by Mehrabian [12]. This model relies on three independent traits: pleasure (P), arousal (A), and dominance (D). In contrast, we choose a bio-inspired approach which tries to mimic the effects of three important monoamine neurotransmitters involved in the Limbic system. They are endogenous chemicals that transmit signals across synapses from neurons to other neurons.

3.2.1 *Virtual Neurotransmitters*

The three virtual neurotransmitters are:

Dopamine (D) is related to experiences of pleasure and the reward-learning process. It is a special neurotransmitter because it is considered to be both excitatory and inhibitory.

Norepinephrine (N) helps moderate the mood by controlling stress and anxiety. It is an excitatory neurotransmitter that is responsible for stimulatory processes.

Serotonin (S) is associated with memory and learning. An imbalance in serotonin levels results in an increase in anger, anxiety, depression and panic. It is an inhibitory neurotransmitter.

3.2.2 *The Lövheim Cube*

Let say that the values for these three virtual neurotransmitters are between -1.0 (minimum value) to +1.0 (maximum value). They form a three dimensional mood space called the "Lövheim Cube" of emotion [13]. In this model, the three monoamine neurotransmitters form the axes of a 3D coordinate system, and the eight basic emotions, labeled according to the Affect Theory of Silvan Tomkins [14] are placed in the eight corners (cf. figure 3).

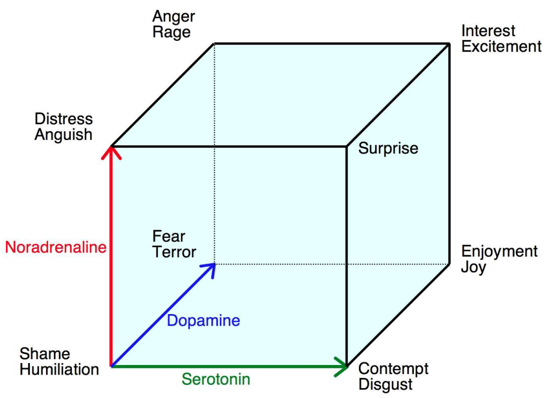

Figure 3. The Lövheim Cube.

This theory attempts to organize affects into discrete categories and connect each one with its typical response. For example, the affect joy is observed through the display of smiling. There are nine basic affects (2 positives, 1 neutral and 6 negatives) listed with a low/high intensity label for each affect and accompanied by its biological expression:

- **Enjoyment/Joy**: smiling lips wide and out.
- **Interest/Excitement**: eyebrows down, eyes tracking, eyes looking, closer listening.
- **Surprise/Startle**: eyebrows up, eyes blinking.
- **Anger/Rage**: frowning, a clenched jaw, a red face.
- **Disgust**: the lower lip raised and protruded, head forward and down.
- **Dissmell**: upper lip raised, head pulled back.
- **Distress/Anguish**: crying, rhythmic sobbing, arched eyebrows, mouth lowered.
- **Fear/Terror**: a frozen stare, a pale face, coldness, sweat, erect hair.
- **Shame/Humiliation**: eyes lowered, the head down and averted, blushing.

3.3 Emotion

Emotions are very short term affects with relatively high intensities. They are triggered by inducing events, which suddenly increase one or more neurotransmitters. After a short time, neurotransmitter values decrease due to a natural decay function. Most of the time, the system tends to return toward an attractor, which is a point in the system's phase space. This attractor is the transposition in the Lövheim Cube of the personality traits. This is not the neutral mood, which is by definition in the center of the 3D space (D = N = S = 0).

3.4 Primordial Emotions

Craig and Denton include pain in a class of feelings they name, respectively, "homeostatic" or "primordial" emotions [15-16]. These are feelings such as hunger, thirst and fatigue, evoked by internal body states, communicated to the central nervous system by interoceptors, which motivate behavior aimed at maintaining the internal milieu at its ideal state. They distinguish these feelings from the "classical emotions" such as joy, fear and anger, which are elicited by environmental stimuli. In our model, we use two important variables for modeling these primordial emotions:

Energy (E) is the machine transposition of internal feelings such as hunger, thirst and fatigue.

Pain (P) measures the amplitude of unpleasant feelings often caused by intense, noxious or damaging stimuli. When the pain value becomes negative, it means that the artificial character feels pleasure.

In real organisms, pain is a complex phenomenon. At the lower level, there are specific neurons called neuroceptors and a neurotransmitter called Subtance P. In our model, the effects of E and P on mood are implemented using combinations of DNS stimuli given the following scheme:

- D is both excitatory and inhibitory and mainly involved in pleasure/rewards.
- N is excitatory and increase active vs. passive feelings.
- S is inhibitory and increase positive vs. negative feelings.

4. THE EMOTION ENGINE

The Emotion Engine implements the previous layered model of affect using an artificial neural network called ANNA (Algorithmic Neural Network Architecture). This architecture can be described as a deep neural network [6], where each cell implements an arbitrary and potentially heterogeneous non-linear programmed function. Most of the cells are grouped in feed-forward layers, but some of them may have feedback connections. Like classical neural networks, each cell has a list of weighted inputs and a single output. Outputs of cells represent inputs of other cells based on a layered network graph.

The next figure gives a simplified diagram of the Emotion Engine. The inputs are the stimuli coming from the Sensory Module. Its outputs control the behaviors of the character in the Display Module. Lifepulse is a cyclic signal triggering the update loop of the neural network.

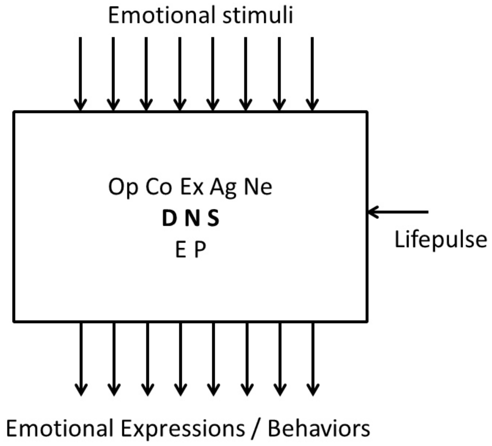

Figure 4. The Emotion Engine.

5. CONCLUSION

In this paper we introduced the layered model of affects designed for the "Living Mona Lisa" research project. The model provides three distinct affects: emotions as short-term affect, moods as medium-term affect, and personality as a long-term affect. This model is based on a bio-inspired approach of the natural emotional metabolism and implemented as a dedicated deep neural network.

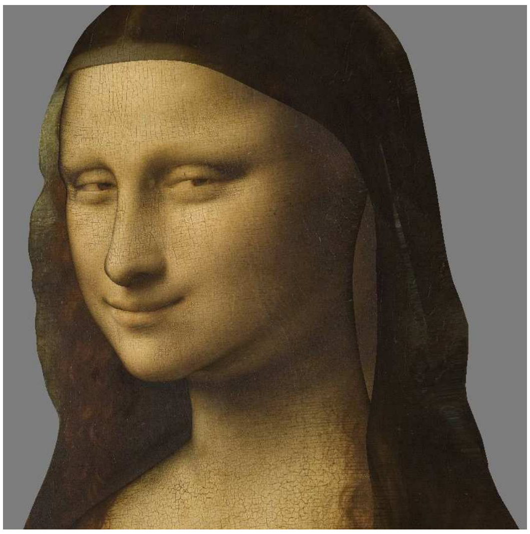

Figure 5. The Living Mona Lisa showing new emotions.

First results are encouraging and show that the system is successfully functioning in the respect of the masterpiece and known history of the real Mona Lisa character. Figure 5 is an example of the Living Mona Lisa prototype displaying a different emotion compared to the original the painting. We think that this work opens an important trend of research focusing on emotional interaction in the field of Living Art.

6. ACKNOWLEDGMENTS

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