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Emotional Agents – State of the Art and Applications

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Abstract. In last decade, intensive research on emotional intelligence has advanced significantly from its theoretical basis, analytical studies and processing technology to exploratory applications in a wide range of real-life domains. This paper brings new insights in the field of emotional, intelligent software agents. The first part is devoted to an overview of the state-of-the-art in emotional intelligence research with emphasis on emotional agents. A wide range of applications in different areas like modeling emotional agents, aspects of learning in emotional environments, interactive emotional systems and so on are presented. After that we suggest a systematic order of research steps with the idea of proposing an adequate framework for several possible real-life applications of emotional agents. We recognize that it is necessary to apply specific methods for dynamic data analysis in order to identify and discover new knowledge from available emotional information and data sets. The last part of the paper discusses research activities for designing an agent-based architecture, in which agents are capable of reasoning about and displaying some kind of emotions based on emotions detected in human speech, as well as online documents.

Keywords: artificial intelligence, intelligent agents, design, emotion detection.

1. Introduction

With the development of the new computing paradigms of social and affective computing, emotion became an inter-disciplinary area, cross-cutting multiple and quite different subjects.

Recently, emotion recognition and simulation have become an important research topic in man-machine communication. Emotional intelligence as an emerging discipline deals with modeling, recognition and control of human emotions. It provides the key theory and technical basis for further studies of new generation sensor networks, intelligent information processing, intelligent services, and many other types of

applications. The ability to correctly interpret emotional signals is crucial in real-life situations.

Five essential domains for emotional intelligence are [1]: knowing one's emotions, managing emotions, motivating oneself, recognizing others' emotions, and handling relationships. Therefore, emotional intelligence deals with one's ability to perceive, understand, manage, and express emotion within oneself and in dealing with others.

In the late 1990s, many researchers in artificial intelligence and human-computer interaction began to take the notion of emotions quite seriously. A milestone was publication of the book "Affective Computing" by Rosalind W. Picard in 1997 [2]. The author presented a framework for building machines with emotional intelligence. In the following years, many other researchers in this area have built machines that can reason about emotions, and also detect, handle, understand and express emotions [3].

Efforts in building emotionally intelligent entities have been concentrated on: empowering the machine to detect emotions, enabling the machine to express emotions, and embodying the machine in a virtual or physical way.

Another research field connected to the application of emotional intelligence in real domains is multi-agent systems (MAS). Some researchers have been interested in developing logical frameworks for the formal specification of emotions. The main concern is to exploit logical methods in order to provide a rigorous specification of how emotions should be implemented in an artificial agent. Recent work in this area has been focused on enabling software agents to detect emotions via verbal, non-verbal, and textual cues, and also to express emotions through speech and gestures.

The focus of this paper is on proposing a distributed environment which utilizes agents for efficient processing of emotional information. We will use the term "multi-agent system" to refer to a software system which exhibits aforementioned features that stem from the usage of intelligent agents. While our agents still communicate and coordinate their actions and jobs, complex interaction patterns are deemed unnecessary and are avoided.

Influence of Emotional Intelligence on Intelligent Systems in contemporary research is unavoidable. Modern cognitive psychology considers human emotions to be caused by specific situations. Emotional change is a psychological phenomenon unique to humans, and can trigger a series of physiological responses through the nervous system, and form a unique subjective experience. This, in turn, may cause external expression changes, in form of gestures, actions, and so on.

With the development of artificial intelligence (AI) techniques, many new requirements have been put forward in real-life complex environments: the new generation of intelligent machines should have the ability to make personalized responses based on environmental perception.

In the last years, research in AI has addressed modeling and communication of emotional content. Such research has led to the development of different prototype: expressive personal assistants, embodied conversational agents (ECAs), virtual environments conveying emotional information for enhanced user experience, robots displaying emotional behavior, virtual agents for entertainment, etc. Thus, a major objective is to develop "believable" interactive systems that are more attractive and closer to the user. In this perspective, a technological challenge is to build machines capable of reasoning about emotions, predicting and understanding human emotions, and processing emotions while reasoning and interacting with a human user.

Also, different logical methods have been recently exploited to provide a rigorous specification of how emotions should be implemented in an artificial agent and how agents should reason about and display emotions. Although the application of logical methods to the formal specification of emotions has been quite successful, there is still much work to be done. For example, there exists no formal model capable of adequately characterizing complex emotions such as regret, jealousy, envy, shame, guilt, reproach, admiration, remorse, pride, and embarrassment.

With the increasingly strict demands on robots, it has been suggested that more attention be shifted into the issue of vocal emotion design for man-machine communication. To upgrade the voice design of robots, it is necessary to analyze and understand the human vocal processing mechanism, and the acoustic features of vocal stimuli. It is expected that future designs of interactive robots need to be not only emotionally rich in vocal expression, but also capable of performing vocal emotion recognition.

The main objective of the paper is to present state of the art in emotional intelligence and agents, and analyze, select, and propose several appropriate applications. Such systems should be capable of reasoning about emotions, predicting and understanding human emotions, and processing emotions while interacting with a human user.

The principal contribution of this paper is to elaborate discussion of research questions and efforts needed for building usable emotionally-aware and expressive intelligent systems for various domains. Notably, research steps are identified and systematically ordered with the purpose of building a framework for producing such systems.

The rest of the paper is organized as follows. Related work is briefly presented in Section 2. Section 3 brings extensive overview of contemporary research of intelligent emotional agents. In Section 4, systematic order of research activities for building frameworks with emotional intelligent agents are proposed. Concluding remarks are briefly presented in Section 5.

2. Relevant Work

Emotional intelligence provides the key theory and technical basis for further studies of new generation of intelligent systems based on agent technology.

Emotion detection has been recognized as a very important factor in man-machine interactions. It can enhance student's performance in e-learning [4-5], improve driving experience [6], and increase customer satisfaction [7-8]. Therefore, significant research has been invested into devising efficient techniques for emotion detection.

By our knowledge there are only a few works conceptually similar to ours, proposing necessary steps and research activities in the area of development and using emotional agents. In [9] authors are concentrated on humans as affective beings and necessity to develop complex artificial agents that are capable of affective communication. They proposed five independent reasons for the utility of developing affective agents and also discuss some of the challenges that they have to address as part of this endeavor.

In another approach [10] the authors believe that intelligent agents or non-player characters (NPCs) in human interaction scenarios are required to react in ways that are

consistent to the training scenario. They aim to design a model for incorporating emotional enhancements (anger and sadness, anxiety and fear) into intelligent agents. The model allows NPCs in virtual training applications to simulate human behaviour in crisis management. They also review current research on models of emotions for intelligent agents in crisis simulations, discuss key challenges in the area, and promising research directions.

3. State of the Art and Applications

In this central section of the paper we will present most characteristic research activities and results in the area of emotional intelligence and agents in about the last 20 years.

Since the early works [11] a lot of different and interesting approaches have been realized. Authors address the issues of communication and esthetics of artificial life that possess this "human form" in modern society. In the presented example emotions are interpreted from human voices and emotional responses. It includes a comic character and a beautiful, sensual goddess. The same authors several years later offered a new system. They applied their emotion recognition algorithm to a computer agent that plays a character role in the interactive movie system.

First practical systems in the area i.e. the pioneering architectures has been presented in [12]. The authors proposed a general, flexible, and powerful architecture to build software agents that embed artificial emotions for conveying human emotions, thus allowing more effective, stimulating, and natural human-agent interactions.

Within the emotional intelligent agent domain three directions for emotion detection are: facial, vocal and text. Facial recognition raises the most complex set of problems, but some efficient solutions do exist. For example, a support vector machine can be used to classify motion signatures as either non-expressive, or belonging to one of the predefined six categories [13]. Alternatively, paper [14] includes adaptation and learning in a neuro-fuzzy system in order to analyze facial animation parameters.

The processing of vocal emotions generally consists of three stages [8]: feature extraction, data classification, and post-processing. Data classification and pattern matching represent the central point, and different approaches have been evaluated. These include k-NN and linear discriminant classifiers [7], artificial neural networks [15], support vector machines [16], and hidden Markov models [17]. More recently, improvements to generative classifiers, such as Gaussian mixture models, have been proposed in [18].

There are a number of efficient approaches for text emotion detection. The approach proposed in [19] is aimed at improving text-to-speech systems for children's fairy tales by recognizing emotions. Sentences can also be represented as sequences of semantic labels and attributes and then processed by a separable mixture model in order to calculate similarities to emotion generation rules [20]. Finally, in [21] several algorithms have been employed in order to classify news titles based on their emotional content.

Finally, there exist some combined approaches. It has been shown [22] that the combination of vocal and text recognition yields better results than when only a single approach is used. The authors of [23] have proposed a neural network-based approach to analyze facial/vocal input.

Intelligent software agents can be applied to and use both vocal and facial emotion recognition. Agents are distributed by nature, and can therefore be used to optimize selection, classification, and pattern recognition [24]. A special pedagogical agent is used in e-learning systems to guide and motivate students [25], [26]. Much research has also been invested for incorporating emotions into agents, resulting in a number of formal models for emotional agents [27], [28]. Finally, some challenges of developing successful embodied conversational agents are outlined in [29].

In the rest of the section we will present research activities in the area of emotional intelligence and artificial agents divided into several particular areas: modeling, learning, robotics, decision support, interactive environments, and classification and search.

3.1. Modeling Artificial Agent's Environments

First results in the direction of formalization of emotions in MAS are reported in [30]. Authors use the formalism of decision theory to develop principled definitions of emotional states of a rational agent. These notions are useful for rational agent design and essential during interactions with human agents. Formal bridges between the rich bodies of work in cognitive science and the AI architectures for designing rational artificial agents are presented.

In [31], authors have been studying the emotional algorithm evaluating an artificial emotional model. The efficiency of different characteristics of the agent with emotional algorithm is analyzed. A new traffic signal system, which optimizes the traffic flow by estimation of the driver's mind, is proposed. The emotional space within the system consists of four factors: "happy", "relief", "afraid" and "angry." The emotional function imitates the state of driver's mind, and the emotional function achieves the different characteristics of individuality. The authors propose the principal architecture of the emotional algorithm with an individual and a traffic signal system simulator.

In [32], a model that simulates emotional internal states of autonomous agents is presented. The model connects simulated touch-sensor inputs to an emotion-labeling output and includes emotional systems based on fuzzy emotions.

A model of interaction between users and animated agents with basic features of affective conversation and social interaction is given in [33]. As essential requirements for animated agents' capability, authors motivate reasoning about emotions, personality, and social role awareness. The main contribution is the incorporation of "social Elter programs" to mental models of animated agents. Implemented web-based system uses animated agents with affective and social behavior in a virtual coffee shop.

Animated software agents (avatars) represent a new paradigm. A computer model of emotions that can be easily integrated in an avatar-based interaction context is presented in [34]. The emotional avatars manifest expressive behavior, finally influenced by their personality definitions.

An interesting research topic is raised in [35]. Focus is on cognitive and a biological agent modeling in order to generate emotional states. Authors show how emotion reading can be modeled both at a cognitive and at a biological level, following the Simulation Theory approach to mindreading. Furthermore, a cognitive theory model for

emotion reading is presented. It is shown how the cognitive and biological agent models can be related.

To provide virtual, more realistic affective agents it is necessary that they have the capability to generate and regulate emotions, and the ability to reason about the emotion regulation processes of other agents [36]. The model based on Theory of Emotion Regulation has been developed using the modeling language LEADSTO.

Terrorist threats bring security actors to look for new training tools for major scale crisis. Simulation using MAS enables the actors to observe the effects of their actions. In [37], authors extended the BDI architecture to support physiology, emotion and personality, and illustrated how it is used to model crisis situations.

Paper [38] considers agent-based model for group emotion that supports teams in their emotion dynamics. An ambient agent, using model-based reasoning, analyzes the team's emotion level for present and future time points. The ambient agent supports the team and proposes a team leader. Appropriate simulation experiments have been performed.

A generic approach to modeling emotions is described in [39]. Existing computational models of emotions (based on different psychological theories) share common properties and emotional processes. The GRACE model is aimed at unifying existing models into a single architecture.

Newer approaches [40] reported some psychological phenomena in which dramatic emotional responses are evoked by seemingly innocuous perceptual stimuli. "Uncanny valley" is the effect where a near human-looking artifact can trigger feelings of eeriness and repulsion. The author illustrated "that differential perceptual distortion arising from stimuli containing conflicting cues can give rise to a perceptual tension at category boundaries that could account for these phenomena." The proposed model presents the first quantitative explanation of the uncanny valley effect and provides a mathematical explanation for a range of social situations.

3.2. Emotional Intelligence and Different Forms of Learning

Learning agents and educational activities are very attractive for incorporation of emotional aspects.

Initial works on learning in the emotional intelligence domain can be found in [41]. Architecture of learning companion agent with facial expression of emotion is proposed. Based on existing (ABC and ToK) architectures, the new emotion agent architecture contains five modules to realize the interaction. The most important achievement is realization of the transition between emotion space in the emotion module and facial expression space in the facial expression module. The emotion agent demonstrates different facial expression within experimental website. The aim of the paper [41] is providing the student with a more personalized and friendly environment, i.e. artificial learning companion agent. But the crucial problem is to make it more believable. A framework of learning companion agent with Personality and Emotions is proposed.

One of the most popular topics in this research area is combining the empathic virtual human with the learning system [42]. However, there are few studies on designing interactive pedagogical agents with empathic strategies. Authors proposed an empathic interaction model according to Davis' processes and Lester's model. Experiments

included 12 students and some interactive suggestions when students suffered negative/positive emotions were performed and influenced students' higher engagement.

The emergence of the concept "Affective Computing" makes the computer's intelligence no longer a purely cognitive one [43]. Authors believe that current e-learning systems cannot instruct students effectively any more, as they do not consider the emotional state in the context of instruction. They proposed a mobile agent emotional e-learning system that recognizes and analyzes the student's emotion state, so a virtual teacher's avatar regulates student's learning psychology based on learning style.

The paper [44] proposes the Conscious Tutoring System - CTS. It in fact proposes a biologically plausible cognitive agent based on human brain functions, capable of learning and remembering events and any related information. Episodic memory and learning mechanism are similar to multiple-trace theory in neuroscience, contrary to other mechanisms integrated in cognitive agents. Such an agent is able to improve its behavior by remembering previously selected behaviors influenced by its emotional mechanism. With the help of data mining algorithms, the architecture incorporates a realistic memory consolidation process.

Authors in [45] tried to incorporate several aspects for student interaction in an educational environment: speech recognition, emotion inference and virtual agents. By analyzing the captured speech they are able to indicate the emotion status of the target student and provide suitable dialogue for student-agent interaction. Experiments indicated high application potential for such system.

A similar approach, i.e. reacting accordingly to some other emotions is presented in [46]. The central part in the system is an emotional agent who affects the attitude of students towards learning. This synthetic character helps students to overcome learning obstacles in face to face communication. Various synthetic characters have the potential to expose emotions by recording user's emotions and reacting accordingly in improving e-learning processes. Experiments with 52 students are conducted.

Abovementioned approaches take into account gender issues [47] and the reactions of male and female students to the presence of animated pedagogical agents that provided emotional and motivational support. Experiments with the Intelligent Tutoring System (with affective pedagogical agents) for Mathematics include one hundred high school students with/without learning companions. The system improved affective outcomes of all students, but particularly female students. Female students reported being more frustrated and less confident prior to using the system.

Study [48] explains effects of the affective states exhibited by students using an intelligent tutoring system for Scatterplots with and without an interactive software agent, Scooter the Tutor. Scooter the Tutor had been in previous research of the authors shown to lead to improved learning outcomes as compared to the same tutoring system without Scooter. Affective states and transitions between them were very similar for students in both conditions. Experiments imply that, although students like Scooter, it does not have a strong effect on their affective states.

Empathetic behavior has been suggested to be one effective way for Embodied Conversational Agents - ECAs [49] to provide feedback to learners' emotions. In the focus of this study are self-assessment tests for students. Authors analyzed impact of ECAs' emotional facial and tone expressions combined with empathetic verbal behavior when displayed as feedback to students' emotions: fear, sadness, and happiness. Three

identical female agents with different procedures were used for experiments. Results indicate that an agent performing parallel empathy displaying emotional expressions relevant to the emotional state of the student may cause this emotion to persist.

Aforementioned approaches considered different kinds of emotional agents in tutoring systems. Completely different approaches to learning of emotional, affective, virtual human-like agents are presented in the next two papers.

In [50], agents' learning abilities are in focus. An actor-critic reinforcement-learning algorithm was run on a small-scale MAS with an initially unpredictably environment. Experiments were conducted to compare two approaches: having fixed learning parameters, and using modulated parameters that were allowed to deviate from their base values depending on the simulated emotional state of the agent. The latter approach gave marginally better performance when distracting hostile elements were removed. It is an open question whether emotion-modulated learning can lead to closer approximation of the optimal policy in a destructive environment, by focusing learning on more useful input and avoiding suboptimal strategies.

In [51], using emotional concepts and MASs, the traffic flow forecasting is analyzed. The concept TD Q-learning with a neuro-fuzzy structure, improved by emotional learning, is discussed here for the first time. The proposed forecasting algorithm is capable of finding the optimal forecasting approach by the reinforcement learning. The real traffic flow signals are obtained from interstate motorways in Minnesota City, USA and Gent–Antwerp, Belgium.

3.3. Emotional Agents in Robotics

Robotics is another productive area for application of emotional intelligence and appropriate kind of agents.

Realization of an agent for intelligent interaction between humans and robots is presented in [52]. Authors combine a computational model of artificial emotions with learning and self-adaptation features. A robot can change its "emotional state" based on human gestures, which is exhibited by means of integrated visual media, environmental lights, and changes in robot's style of movement and behavior. Implemented system stimulates the human creativity.

The same research group continued work on improving the proposed system [53]. Realization of cooperative works between welfare agent robots that support a user in a welfare system is crucial. Agent robots have a common control mechanism and during performing tasks it is desirable to observe the user spontaneously. Human-agent cooperation is generated during the dynamic determination of each robots action. Robot's welfare oriented active vision is realized using a model of a knowledge, emotion and intention.

It is necessary that an intelligent agent in mobile robotics should be adapted to the conditions of the environments based on its physical and mental capabilities [54]. Recently, the interest in the creation of robots with emotions has been one of the principal topics. Emotional systems were seen as powerful models for intelligent robots. Authors proposed a real-time agent based on: concepts, emotions and conscious processes. The motivation was to achieve behaviors that are consistent with intelligent performance in the real world.

In papers [55-56] the same group offered new insights. The essential role of emotions in the control and the organization of the behavior of robotic systems have been identified. Authors proposed a real-time emotional architecture (RTEA) that allows the regulation of the behavior of robotic agents. RTEA helps robots to fulfill the goals based on its emotional state, and mental capabilities. It also permits the robot to have a more suitable control of the mental capacity and to guarantee the system integrity.

A structure model of emotional multi-agent robot harmonizes interaction between the human and computer [57]. Authors extensively considered affective model construction, learning model, and the perception agent of the emotional model. Primary factors that attribute to the generation of robot's emotion are extracted, and then an affective model construction method based on grey system theory is introduced. The robot's learning model is based on probability and then the concept of affective correlation in the perception agent is given. Finally a modeling method based on grey prediction for the affective correlative model is presented. Experiments showed that the robots possess significant ability of affective and intelligent interaction.

Article [58] considers interactive robots and games, as instruments that may help the emotional development of children with mental-health problems. They expect people to show empathic behaviors and to take into account their emotions. Limitation of current technology is that it cannot recognize the emotions of children. Two crucial problems exist: existing systems do not model affective dimensions, e.g., intensity, but only discrete categories; and gesture is not yet a concern as a channel of affective communication in interactive technology. Research of [58] is concentrated on a multi-agent based interactive system that can quantify child's emotion with intensity of emotion, in real time.

Paper [59] is devoted to a vehicular agent situated in a motorway driving scenario. Agent architecture (combination of psychology and robotics models) for an enhanced theory of intent prediction with affective evaluation of expectations is presented. It has been used to create an online situation appraisal mechanism for preferential evaluation of predicted future states. The architecture required more than goal-directed planning: the agents must model the behavior of others, and predict and evaluate future states.

Memory of experiences is extremely important in long-term human-robot interaction. In [60] episodic memory system for an affective robot with emotions has been proposed. Storage, retention and retrieval of episodic memory are modeled with psychological bases. For verification of the system authors implemented a pet-like virtual agent with reactive emotion generation model.

3.4. Emotional Intelligence in Decision Support Processes

Emotions have an important role in intelligent behavior and influence the human decision-making process. The rest of this section presents results of several research groups on emotional agents in the decision making process.

In [60] authors are investigating emotional agents in the decision making process of a mobile robot. A fuzzy logic model that captures the inherent uncertainty of emotions was proposed. Decisions are generated based on internal and external states. Sensory information is used to extract environmental conditions. The agent reacts to a changing environment and performs action according to a mixture of emotions generated by

multiple states. The model deals with negative emotions: fear, pain and anger. An emotional agent based on fuzzy logic is developed on a small mobile robot.

MASs have already proved their efficiency in simulating complex interacting systems [61]. Authors worked on the simulation of human groups to study behavioral patterns, MASs and psychological issues. Based on BDI architecture OCC emotional model and the PerformanSe behavioral model, they proposed a new model of emotional agent: Emotion, Feeling, Temperament agent (EFT). The simulation of brain-damaged people's behavior on a production line is a concrete implementation of the model.

Decision making in a disaster environment is significantly affected by the structure of the agent personality [62]. The more the agent is able to control its emotions in damaging environments, the better it can perform its task. A new structure (based on human emotional intelligence) for decision making in emergency situations is presented. The model combines personality traits of an agent, its emotional behaviors and the external events that can affect him. Three types of rescuer agents in an environment have been implemented, using different kind of intelligence. The purpose of this system is to help disaster managers by optimizing their rescue management.

Emotions should be embedded in the reasoning process of an intelligent agent (robot) when it aims to emulate human reactions [64]. This paper presents a behavior decision model of an intelligent agent based on emotion psychology and artificial emotion. The model incorporates emotions, motivations and behavior decision. D-S evidence theory is used for the mapping relationship between exterior stimulates and emotion. Also, a Markov decision process is used to map emotion states to behaviors.

A system for assessing the state of horror emotion that the intelligent agent-based system may sense when it faces an annoying event has been presented in [65]. Also, human-like behaviors of emotional agents in terms of the way their emotional states evolve over time have been described. Three parameters related to human horror emotion are considered as inputs of this system. The system outputs are intended to be used in the agent decision making process. A more interesting application of the system could be for choosing a proper person for team work by combining the intensity of horror to other emotion intensities.

Constrained Rationality is a specific reasoning framework to analyze and rationalize about strategic decisions/conflicts in MAS. The framework [66] is extended by mechanisms to: "1) model the agents' priorities, emotions and attitudes within the context of the conflict; and 2) elicit the agents' cardinal and ordinal preferences over their alternatives using the amount of achievement the strategic goals of the agents can harness from each alternative, given the collective goals, constraints, priorities, emotions and attitudes, the agents individually have." The paper offers an illustrative example.

Traffic and driving processes are presented in [67]. Here the motivation is considered as a crucial issue. Drives, which are represented on multiple levels, are modeled as the motivational element for agents' actions. Authors adopted bionic approach, a multi-level motivational system to enable autonomous agents to perform their own tasks in an environment. Also as a consequence, both extrinsic (homeostatic) and intrinsic (non-homeostatic) internal motivations are modeled integrating emotions as a co-determinant of decision making.

A new approach to the generation and the role of artificial emotions in the decision-making performed by autonomous agents-drivers (physical and virtual) is presented in [68]. As usual the decision-making system is biologically inspired and highly based on

motivations and emotions. The agent drives within a certain range, and motivations are assumed as what moves the agent to satisfy a drive. Having in mind that agent's well-being is a function of its drives, the agent's goal is to optimize it. The novelties of the proposed system are that each artificial emotion is treated separately, i.e. generation method and the role of each of the emotions are not defined as a whole. Experiments are performed on virtual agents living in a simple virtual environment. The usefulness of the artificial emotions is proven by carrying out the same experiments with and without artificial emotions, and then comparing the agents' performances.

3.5. Emotional Intelligence in Interactive Environments

Interactive environments that support man-machine communication and usually recently include artificial creatures and avatars are also natural settings for employment of emotional intelligence.

Interactive environments need believable characters (agents) [69]. Their particular personality and emotions should increase the emotional immersion of the human actor. Authors presented a new application-independent model where agents possess individual personalities and dynamic emotions. The model allows rendering a rich set of behaviors for virtual characters in learning environments (as Squeak eToys) or distributed 3D spaces (as Open Croquet).

Different studies demonstrated that humans interact with affective agents as social actors. In some recent publications [70] affective agents promote emotional communication. Further authors examine the influence of gender-emotion stereotypes on user's message involvement and perceived social presence of affective agents. In experiments affective agents communicating emotional events exhibit greater social presence and higher user's message involvement.

Ubiquitous computing, as one of the key technical challenges, is closely related to human machine interaction (virtual reality, 3D interaction). Paper [71] concentrated on multi-agent technology and formalization of rational and emotional agents for human-machine interface. The model of concurrent game structure is improved. Mental BDI states of agents are represented in new multi-agent cooperation logics. Multi-subset semantics of individual intentions are given and extended, achieving the semantics of group intentions. Formal representation of emotion is added.

The identification of personalities or estimation of emotions in chat rooms has several advantages. It could match people of similar interests' or guard the chatters from conflicting personalities. The primary way of interaction in chat rooms is exchange of textual messages. Therefore, emotion estimation systems need to analyze textual phrases and newly introduced concept emoticons - special icons. Paper [72] presents an approach to predict the instant emotion of chatters using only textual content. The preliminary results, achieved in a pervasive manner using software agents, reflect more satisfied chatters.

Ambient systems, teams and their emotion dynamics, agent-based support model for group emotion are central components in research presented in [73]. An ambient agent analyzes the team's emotion level in different time points. When the team's emotion level is found to become deficient, the ambient agent provides support to the team by

proposing some actions to the team leader. The support model has been designed and simulation experiments have been performed within a dedicated software environment.

An automatic real-time system capable of creating expressive speech using a set of mathematical models is presented in [74]. This approach allows adding emotions in synthetic animated audio and video speech. A tracking system with a high-speed camera is used to collect the facial movement data. The proposed emotional model drives prosodic parameters to control the generation of synthetic audio, and muscle parameters to control the shape of the face. The authors tested model by developing an emotion-based chat system for creating synthetic emotional speech.

Usage of virtual agents with emotional expressions is seen as a natural way of utilizing interaction with the user [75]. Based on current technology limitations, virtual agents are often only able to produce facial expressions to convey emotional meaning. Authors place attention on effects of unimodal vs. multimodal expressions of emotions on the users' recognition of emotional state. Performed experiments showed that multimodal expressions of emotions obtain the highest recognition rates.

Facial displays represent an important communication channel and provide numerous functions in discourse and conversation. Humans are also very sensitive to the application of such displays in virtual interactive environments where main players are software entities - Embodied Conversational Agents (ECA). In paper [76] authors provide an extensive survey of facial gestures as special kinds of facial displays: eyebrow gestures and gaze, blinks, various nods and head movements. In comparison to verbal and emotional displays, the facial gestures are less tangible but offer more natural behavior of the face. Authors concluded that for an ECA it is extremely important to implement facial gestures in an appropriate way. It is not an easy job and existing ECA implementations usually concentrate only on some aspects of facial gestures. The paper offers a complete survey and taxonomy of facial gestures. It could be a useful guide for researchers to implement ECAs in more sensitive and higher-quality manner. Additional quality of the paper is a case study i.e. a practical system implementation of Autonomous Speaker Agent (ASA) that supports conversational signals, punctuators and manipulators.

3.6. Emotional Intelligence in Classification and Search

Paper [77] presents an affect-sensitive news agent (ASNA) that significantly differs from other similar ones. Main differences in comparison to other similar works are:

- The application of a cognitive theory of emotions (OCC model). The authors have integrated the approach to sense affective information from news-texts.
- The authors used common-sense and current-affairs as a knowledge base with a rule-based approach to assess each line of text by assigning a numerical valence.
- The use of natural language processing techniques to perform automated categorization of news stories on the basis of emotional affinity.

The authors have developed a news browser that categorizes the topics according to eight emotion types.

Emotions can play an important role in any purchasing process especially when it is done through the web. A fuzzy-logic based system aimed to generate emotions for a virtual seller or avatar is presented in [78]. The system, based on 3D avatar integrated

within an e-commerce portal, gives advice to the clients and assists them in the specification of constraints. The mood of the avatar depends on the products that the portal offers and also the recommendations that can be used to guide the customer when beginning a new search.

It would be nice if web browsers could provide customized recommendations for the users, rather than only suggestions based on browsing history. Generally, it is an interesting idea to provide suggestions or recommendations for the preferred websites based on the user's emotional behaviors. An efficient recommendation system based on emotional web browsing agent is presented in [79]. The system not only can take input from the environment accurately, but also provide efficient recommendations of the ranked websites. Experiments show that the proposed emotional web browsing agent can very efficiently recommend specific websites based on user's emotions.

An application of emotion identification in texts expressing user-contributed opinions about companies and e-business products and services is in the area of opinion mining and sentiment analysis. Intelligent software agents can use different methods to automatically extract opinions and sentiments of users. Paper [80] presents a sentiment classification method for the categorization of tourist reviews. Specific characteristics of the opinion holder, like for example his/her reputation, are related to the accuracy of the opinions expressed in his/her reviews. Such results are very useful for both individual users and tourism companies.

Having the presented relevant work and applications in mind, in the rest of the paper we will concentrate on determining our research efforts and propose several key steps for development and implementation of virtual agents as crucial parts of emotional interacting systems.

4. Usability of Emotional Intelligence: Necessary Research Activities

In today's world, users want to employ all their sensory organs, and require tactile, olfactory, and other modes of communications in interactive systems. An important trend is to build believable and trustable interactive systems that are closer to end-users. Consecutively, users want to provide information to the computer in different ways, using e.g. gestures, postures, languages, graphics and emotions. Research achievements presented in section III form valuable resources to direct and determine our research activities in the future. Based on previously presented wide range of research contributions in this domain, we are going here to propose specific research steps and directions.

It is extremely important for future intelligent systems development to consider how exactly emotions can be embedded in voice, gesture, posture and presentation styles.

Having complexity of such systems in mind, in the rest of the section we will suggest a systematic order of research activities which will lead us, in a straightforward manner, to the proposal of an adequate emotional framework for real-life applications. After systematic review of contemporary research we recognized and shaped the following research challenges and activities that need to be systematically performed in order to propose an emotional MAS:

- Analysis and evaluation of different emotional classification methods found in speech, expression, gesture, action, and electrophysiology information (e.g. pulse, blood pressure, ECG, EEG, etc.). In the domain of emotion recognition in human voice, it is justifiable to apply speech signal processing and pattern recognition techniques: cepstrum analysis, dynamic time warping, and hidden Markov modelling. It is necessary to propose new or modify existing techniques.
- To improve accuracy of emotional information pattern recognition, it is necessary to use a combination of multiple algorithms; to distinguish between and choose more appropriate parameters or combined features; to combine speech recognition with, for example, facial recognition; to use appropriate testing of emotional signals. To verify and test such approaches, it is necessary to obtain more adequate real-life data sets.
- Exploiting logical methods and design and implement agent-based systems, in which agents are capable of reasoning about and displaying different emotions.
- Identifying desirable features of emotion theories that make them ideal blueprints for agent models. Explore their application in concrete areas and services in tourism, education, recognition of infants' emotions.
- A consequence is to build and test a prototype MAS that is capable of: reasoning about emotions, predicting and understanding human emotions, and processing emotions during the interaction with a human user.

4.1. Research Directions

In this subsection we discuss research directions and the associated activities in the area of emotional MAS.

Agents with Emotional Intelligence. In the domain of employing emotional intelligence in interactive systems, significant attention needs to be given to MAS. Some researchers have been interested in developing logical frameworks for the formal specification of emotions [30-34], [40]. Their main concern is to provide a rigorous specification of how emotions should be implemented in an agent. The design of agent-based systems where agents are capable of reasoning about and displaying some kind of emotions can benefit from the accuracy of logical methods.

Computational models of emotions are useful in development of believable agents, video games, virtual environments, etc. Most of existing models are inspired by the appraisal theory and focus on the agent's cognitive behavior, for which they often generate emotions according to static rules or pre-determined domain knowledge. From this follows a description of the elements that are theoretically needed to construct a virtual agent with the ability to display human-like emotions.

The second important objective of these research efforts is to apply specific methods for dynamic data analysis and pattern mining/recognition in order to identify and discover new knowledge from available emotional information. The main focus and specific activities must be:

- Consider choosing the appropriate analysis methods for large amounts of dynamic and temporal data (collected from simulations and experiments) which can be used in explanations and modeling of human emotions.
- To explore possibilities of building logic that enables specification of complex emotions (e.g. regret, jealousy, envy, shame, guilt, pride, embarrassment). A logic of complex emotions should be sufficiently expressive not only to characterize different types of agents' mental attitudes (beliefs, desires, goals, intentions), but also to characterize concepts of responsibility, counterfactual thinking, norms and ideals. It is expected to be a combination of different existing approaches like: BDI logic of agents' mental attitudes, logic of norms and ideals, and logic of agency and multi-agent interaction.
- To perform experiments on numerous appropriate data sets. Recently we conducted first real-life experiments with several Serbian and Chinese colleagues. During extensive experiments brain signals are measured as reactions on Chinese short vocal sentences in different emotional states: happiness, jealousy, anger, sadness.
- Diverse software systems need to be tested to assist the user in this demanding task. We can suggest the usage of a system based on FAP - Framework for Analysis and Prediction [81]. FAP is a multifunctional library that implements the main techniques and methods for the analysis of time series and temporal data mining.
- Consequently, a prototype agent system needs to be developed. Such an agent system needs to be based on previously conducted extensive experiments and activities, and the encompassing achieved results.

Based on theoretical and empirical analysis, the proposed steps of our research efforts will provide insight into emotional information pattern recognition, modeling and implementation of intelligent emotional software agents applicable in different real-world applications: services of tourism, education, and recognition of infants' emotion.

Emotion Detection. Having in mind the above discussion, we specify concrete research topics to be focused on in the near future: emotion detection in human speech, as well as in online documents.

Emotion Detection in Human Speech - The voice characteristics and emotion expression of human speech are detectable in sound data. There is an emergent need for this kind of derived information in various aspects of telephone services. Telephone companies need to develop a "strong customer service sense," with the most important customer contact point being in the area of complaint handling. To improve customer experience, two major problems are faced: customer emotions which are delayed and hard to detect, and the lack of an effective problem-solving strategy for different cases of customer emotional response.

The first problem can be tackled with emotion detection techniques that operate on sound data. In order to detect emotions such as joy, trust, fear, surprise, sadness, disgust, anger, anticipation, as well as different gradients of each, classification models are built on top of various features extracted from sound data, belonging to various types: excitation source, vocal tract system, and prosodic features [82]. The first phase of our research will consist of acquisition and preparation of data in Chinese and English languages, determination of features suitable for the task, and development of a prototype system that can detect emotional content and intensity in recorded voice data.

The second problem of constructing a strategy for solving customers' problems based on emotional response lends itself to the application of techniques involving emotional agents. Such kind of agents can help in devising appropriate strategies through simulation of various scenarios of voice interaction, as well as the development of a "helper agent." The goal of this agent is to assist customers and service operators by dissipating emotional tension and providing hints toward a more constructive mode of interaction.

Emotion Detection in Online Documents - Agent technology will be employed to perform distributed emotion detection in online documents: blogs, discussion forums, social networks, news that report on emergency events, etc. Two types of agents will be developed: harvester and analyst. Harvester agents will be web crawlers. They will scan the web and search documents that meet the given criteria, and download and store them into a local database.

Analyst agents will perform text analysis in a distributed setting. Their functionality will be based on the state-of-the-art approaches for emotion detection. The process will be parallelized and run on a computer cluster [83]. To achieve it we need to apply specific methods for dynamic data analysis in order to identify and discover new knowledge from available emotional information, documents and other different resources and freely available data sets.

At this stage, the focus will be on English documents, with the goal of expanding it to other languages. We are going to apply specific methods for dynamic data analysis for emotion detection and discover rules and patterns that could help as in modeling highly functional analyst agent. Several freely available sentiment lexicons will be used.

4.2. Applications

Two applications of emotional MASs in the areas of computer-supported language education and sentimental analysis of social media content will be presented.

Emotional Intelligence System for Ubiquitous Smart Foreign Language Education. Another research direction, influenced by the above proposed specific research steps, is oriented towards the design of a system for Ubiquitous Smart Foreign Language Education [84]. The system is based on general architecture that could be adjusted for other application domains. In this part we will briefly present basic elements of such system.

Recently, ubiquitous learning (U-Learning) has become an excellent complement to classroom teaching but also an attractive way of foreign language learning. The learners can access online educational resources anytime, anywhere and through any multimedia terminal.

One of the major problems in this area is how to help learners search for and locate suitable learning resources on the Internet. One possible solution could be to use intelligent technology to recognize and analyze the learners' emotional reactions online [84]. It could help in providing an accurate, efficient resource organization model, retrieval technology and demand-based teaching strategies. We realized that the intelligent monitoring and automatic recognition of the learners' emotional information

in ubiquitous learning has to be considered firstly in the emotional intelligence system. We conduct a neural analysis of the learners' emotional characteristics in ubiquitous environment based on fMRI (functional Magnetic Resonance Imaging).

Intelligent monitoring of learner's emotions can be achieved through webpage analysis, speech information collection, and online data acquisition of mouse and keyboard actions. To fulfill these activities several different kinds of agents need to be developed. Webpage Information Analyzing Agent will be responsible for the retrieval and analysis of webpage information. The Voice Monitoring Agent will be responsible for the real-time monitoring and recording of learners' voices. The Webpage Event Monitoring Agent will capture the mouse and keyboard actions. Combined Analysis Agent will be responsible for analysis of all collected data supported by the Knowledge Base for Data Collection. The automatic recognition of emotions is also based on pattern recognition supported by multi agents, and it includes following steps: data preprocessing, feature extraction and emotion recognition.

Using mentioned mechanisms we propose an architecture for Emotional Intelligence System for Smart Education that includes three parts: system interface, functional components and resource components. The system interface offers the access and control to its users. Functional components are composed of five modules: Emotion Intelligent Monitoring, Emotion Automatic Recognition, Education Scheme Analysis, Smart Education Design, and Case Training and Feedback. This system provides intelligent monitoring and automatic recognition of foreign language learners' emotions. It adjusts online teaching according to the learners' emotional changes and supports case training and gives emotional feedback on teaching. The general structure of the framework of Emotional Intelligence System for Smart Education is presented in Figure 1.

Emotional Multi-agent System for Sentimental Analysis of Social Media Content. In this subsection we introduce an application of MAS for sentiment analysis and opinion mining in the areas of tourism, as well as climate and environment change.

The online space behaves as an amplifying mirror of the social impact of many real world facts and events, as concerning their perception and transmission as social pulses through online social media channels. For example, the social echo of climate and environment changes can significantly impact various industries including transport, tourism, health, finance, and commerce.

On the one hand, the continuous estimation of sentiments relative to a specific aspect of interest can reveal the position of the public opinion in relation to its occurrence and management. For example, the emergence of strong sentiments (positive or negative) can be temporally correlated with the occurrence of important facts and/or events. This approach can serve as providing alerts of important pending social events that can be thus anticipated.

Our proposed application combines the experiences and achievements in intelligent MASs, social context-aware computing, and sentiment analysis for online monitoring and analysis of sentiments, opinions and emotions expressed by users in social media content. As problem domains we considered tourism, and environment and climate changes.

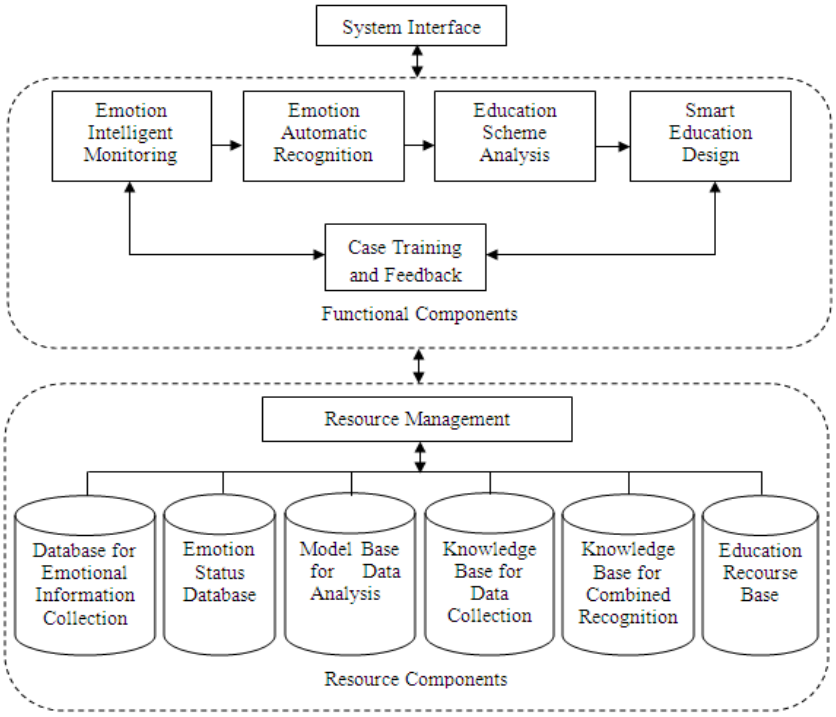

Fig. 1. Framework of the emotional intelligence system for smart education

The aim of the system is to quantify the dynamics of social pulses, as they are reflected by online social media, as well the monitoring of the dynamics after the detection of relevant facts and events, like for example opinion changes related to tourism attractions and destinations, climate and environment changes (pollution or extreme weather). Our solution combines emotional models and measures inspired from sociology and psychology with quantitative performance indicators borrowed from information retrieval.

The system integrates a number of cooperating agents that are specialized in realizing complex tasks of information retrieval and emotion analysis of online information resources. The goal of the system is to generate notes and recommendations that can be used by the decision makers of private and governmental institutions. The block diagram and the context of our system are presented in Figure 2.

The use of MAS offers a high degree of modularity of our system, enabling its facile extension by incorporating new agents specialized in the monitoring and analysis of various online information resources. The diversity of online resources requires the application of different text processing algorithms possibly using different natural languages, like for example English, Chinese, Serbian and Romanian. Using software agents, we can easily encapsulate heterogeneous processing algorithms as task-specific behavioral agent models. Finally, complex processing for sentiment analysis and opinion mining requires the combination of multiple algorithms. This is facilitated in our system by agent cooperation and interaction for the achievement of complex analysis and processing tasks.

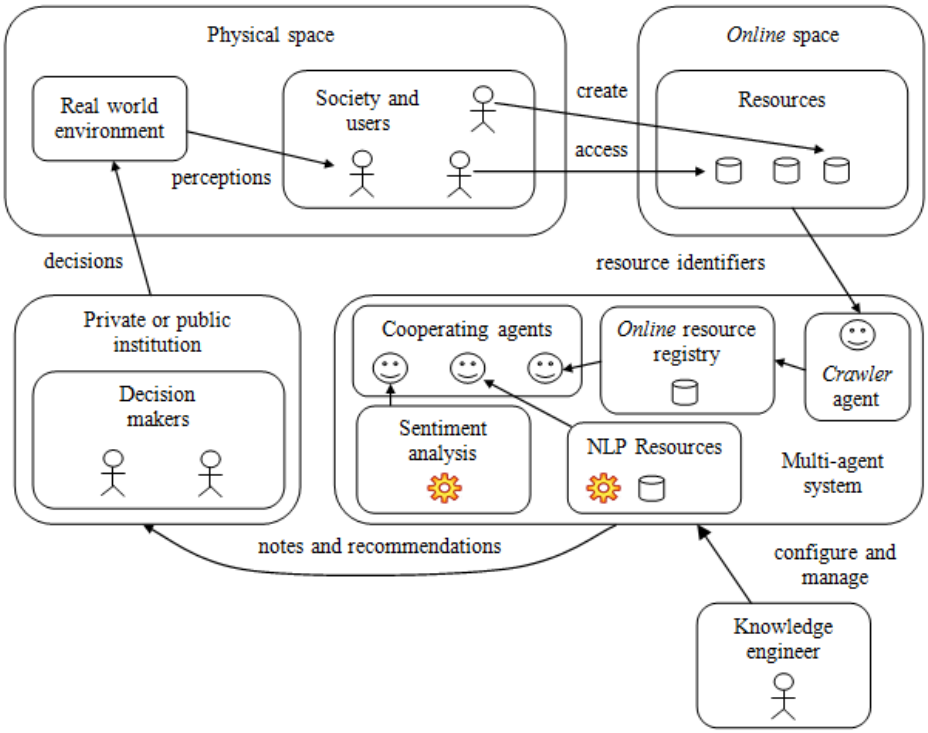

Fig. 2. Block diagram and context of a multi-agent system for sentiment

The agents are specialized for the following tasks:

a) Retrieve and index online information resources relevant for the problem domain. The agents use methods of Web search and information retrieval for discovering relevant information sources: blogs, forums, online reviews. The agents are semantically guided by problem specific lexicons related to tourism, climate and environment.

b) Preprocess and organize information extracted from online resources as XML-based corpus (the agents use resources and algorithms for natural language processing). The corpus elements are annotated with morphological and syntactic features, thus enabling their semantic processing.

c) Extract sentiments, emotions and opinions. We conceptualized an opinion as a quadruple (g, s, h, t), where g is the opinion target, s is the sentiment, h is the opinion owner, and t is the time moment when the opinion was expressed. Our sentiment analysis algorithms combine pattern-based and statistical approaches to identify opinions and sentiments related to climate and pollution events and sentiments expressed in tourist reviews [80].

d) Monitor the dynamics of sentiment polarity changes. The system is able to detect opinion changes in time, thus supporting two use cases: (i) detection and generation of new emergent events, and (ii) monitoring the dynamics of publicly recognized events, explicitly announced in online media. Each new or existing event is

represented using a set of attributes: time of occurrence/detection, the set of associated opinions, geographical location, and intensity.

5. Conclusions

Emotion modeling is expected to have an interesting and important role in the next generation man-machine interactive systems. It can be realized by modeling both input and output parameters. For instance, the visual expression of the input-user-interface, such as laughter, crying, speech [85] and other forms of facial manifestation [86] can directly be regarded as input to the computers. On the other hand, the emotional expression of a computer can be realized by synthesizing emotions.

In upcoming research efforts [87] it is important to exploit logical methods for specification and modeling of emotions suitable for implementation in agent-based systems. It is important to propose and develop a specific multi-agent architecture capable of reasoning about emotions, predicting and understanding human emotions, and processing emotions during the interaction with a human user [88]. For testing capabilities and effects of such an architecture it is unavoidable to evaluate it in several characteristic real environments, such as smart services in education, reception in exhibitions, recommendation in e-business, medicine etc. [89].

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